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THE INFLUENCE OF DIFFERENT FORMS OF MINERAL PROCESSING ON THE BIO-OXIDATION OF SULPHIDE MINERALS BEARING GOLD

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ABSTRACT – The presence of sulphide minerals, such as pyrite, chalcopyrite etc., can pose major challenges in the gold extraction processes, regardless of the downstream extraction route used, including cyanidation and the use of thiosulphate. These sulphides consume the reagents used in this above-mentioned extraction processes, leading to operational problems due to the ever-increasing ionic strength during the extraction processes, which impacts the solubility of the oxidizing agent, specifically dissolved oxygen, which is of paramount importance for extracting gold. This bio-oxidation process aims at solubilizing the aforementioned sulphide minerals, using indigenous autotrophic microorganisms, such as *Acidithiobacillus thiooxidans, Acidithiobacillus ferrooxidans* and *Leptospirillum ferrooxidans,* subsequently reducing the consumption of leaching agents used in gold extraction turning this process more efficient and cost-effective. In this study, different crushing operations were used, such as the use of jaw crusher, high pressure grinding rolls (HPGR) and high voltage pulse fragmentation (HVPF), aiming at determining the influence of these unit operations on the bio-oxidative process of the aforementioned sulphide minerals, as prior steps to the extraction of gold particles encapsulated in the matrices of the aforementioned sulphides, substantially reducing the consumption of gold leaching agents, thus avoiding the milling operation, which is the most expensive in extractive metallurgy.

Keywords: Bio-oxidation, Gold ore, Micro-organisms, Grinding operations.

INTRODUCTION

The extraction of metals from weathered ores or ores containing sulphide minerals initially involves a mineral processing stage, which includes crushing and grinding operations. This step is crucial for determining the most efficient method to obtain metals in their elemental form with high purity. For weathered ores, a common approach is sulphuric acid leaching, applied to the ore in heaps, typically composed of coarse particles derived from primary and secondary crushing operations. For sulphide-rich ores, techniques such as roasting or pressure leaching are widely employed, particularly for gold ores. The objective is to release gold particles often encapsulated within mineral matrices such as sulphides, silica, and other components. Once released, gold is solubilized with alkaline cyanide solutions, forming stable complexes such as $Au(CN)_2^-$

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and $Ag(CN)_2^-$. These precious metals can then be recovered through electrowinning or precipitation with zinc powder, as used in the Merrill-Crowe process [1].

Different mineral processing approaches result in variations in particle size and, depending on the adopted method, can induce microfractures in the material. This phenomenon may facilitate the action of autotrophic microorganisms involved in the oxidation of sulphide minerals, as well as oxidizing agents such as ferric ions, which are generated during the oxidation of sulphides present in minerals such as pyrite, arsenopyrite, bornite, and chalcopyrite [2].

This study aimed at conducting comparative tests to evaluate the efficiency of gold extraction from ore samples subjected to three different crushing methods: conventional crushing in a jaw crusher, high-pressure grinding rolls (HPGR), and electrodynamic fragmentation, known as high-voltage pulse fragmentation [3].

Among the copper minerals commonly found in gold ores, chalcocite (Cu_2S) and cuprite (Cu_2O) exhibit high solubility in cyanide solutions, whereas chalcopyrite ($CuFeS_2$) has lower solubility. Both chalcocite and cuprite, besides consuming cyanide and oxygen during their chemical reactions, can generate by-products that negatively impact process efficiency by promoting undesired precipitation reactions. Therefore, pretreatment methods such as pre-aeration, pressure leaching, and roasting are beneficial for reducing cyanide and oxygen consumption [4]. Studies indicate that the pre-oxidation of pyrite-containing gold ores can increase gold recovery from 20% to 70%, while simultaneously reducing cyanide consumption from 2.5 kg/t to 1.5 kg/t of ore. However, excessive ore grinding can increase cyanide consumption without necessarily improving gold recovery.

Cyanidation generally requires preliminary treatment stages, such as roasting, pressure leaching, or bio-oxidation, which primarily function to minimize the effect of cyanicides—compounds that promote excessive cyanide consumption. The gold dissolution process can be hindered by the low solubility of oxygen in pure water, approximately 8 mg/L at 25°C. Any factor reducing oxygen solubility can negatively impact process efficiency. In this context, bio-oxidation was selected as the pre-treatment method for this study. Additionally, the ore was ground using modern processing techniques that increase surface area and consequently enhance the efficiency of sulphide minerals solubilization during pre-treatment, thereby improving gold extraction efficiency [5]. The use of unit operations in mineral processing enables the generation of microfractures in ore particles, promoting more effective contact between leaching agents and the mineral species carrying the metals of interest, whether in oxidized form (e.g., oxides, carbonates, silicates, sulphates) or as sulphides. This effect can enhance microbial activity in bio-oxidation processes, improving efficiency. Thus, this study aimed at comparatively evaluating the effectiveness of the gold extraction process in ore samples subjected to three different comminution methods: conventional jaw crushing, high-pressure grinding roll (HPGR), and electrodynamic fragmentation (Lightning Machines Limited – High Voltage Pulse Fragmentation).

EXPERIMENTAL

A mineral sample from EURO METAL BRASIL was homogenized, dried at 40°C, and divided to be processed by different crushing methods: jaw crushing, high-pressure grinding rolls (HPGR), and electrodynamic fragmentation. The initial crushing was conducted using a jaw crusher, followed by size classification with Tyler sieves. Samples were then processed at VALE (HPGR) and Lightning Machines (electrodynamic fragmentation). Additional size reduction (3–6 mm) was performed at CETEM for bio-oxidation experiments. At VALE, crushing was optimized to minimize fine generation, using a roll pressure of 2N/mm² with a 10 mm machine opening. The material was then sieved at CETEM to obtain particles from 3 to 6 mm, ensuring complete removal of fines by air jet. This preparation aimed at standardizing surface area conditions across different processing methods.

Bio-oxidation tests were conducted in acrylic columns (10 cm × 60 cm), each loaded with 3.5 kg of ore and layers of quartz for stability. A solution of MKM medium containing inorganic salts as nutrient source: 0.4 g.L^{-1} of ammonium sulphate; 0.4 g.L^{-1} of magnesium sulphate heptahydrate; 0.04 g.L^{-1} of monopotassium phosphate; $FeSO_4.7H_2O$ (33.3 g.L^{-1}) and S^o (10 g.L^{-1}) bearing *Acidithiobacillus ferrooxidans, Acidithiobacillus thiooxidan*s, and *Leptospirillum ferrooxidans* (10^7 cells/mL) was circulated at a rate of 10 L/m², with humidified air supplied at 0.5 L/min. The system was maintained at 30°C, and the acidic leachate was continuously renewed to enhance oxidation. For microorganism adaptation, mixed cultures of *A. ferrooxidans, A. thiooxidans*, and *L. ferrooxidans* were tested in MKM medium with $FeSO_4$ and gold ore, incubated at 30°C with agitation. Cell viability was monitored over 28 days through microscopic counting and spectrophotometry for Fe^{2+} analysis. Adjustments with 5M H_2SO_4 ensured controlled pH conditions.

Iron speciation was analysed weekly using spectrophotometry (HACH DR 6000) and atomic absorption spectrometry (AAS) for Cu and Ni quantification. The final bio-oxidized material was subjected to cyanidation in a glass reactor (5 L) under varying cyanide concentrations (3–10 g/L). The gold extraction efficiency was determined via atomic absorption spectrometry.

RESULTS AND DISCUSSION

The graphs in Figures 1 and 2 illustrate the effectiveness of different crushing methods—jaw crusher (BM), high-voltage pulse fragmentation (HVPF), and high-pressure grinding rolls (HPGR)—in extracting copper (Cu) and nickel (Ni) over a 30-day bio-oxidation period. Notable trends were identified during the analysis of these results.

During bio-oxidation tests on a semi-pilot scale, HVPF demonstrated superior performance, significantly increasing Cu and Ni concentrations in the leachate. This highlights its effectiveness in bio-extraction compared to the other crushing methods. HVPF efficiently fragmented the ore, generating internal microfractures that enhanced mineral exposure to microbial action. Nickel extraction was highest with HVPF, followed by jaw crusher processing, while HPGR exhibited the lowest solubilization rates (Figure 1 and 2).

The presence of key microorganisms, including *Acidithiobacillus ferrooxidans, Leptospirillum ferrooxidans,* and *Acidithiobacillus thiooxidans,* was critical for bio-oxidation efficiency. Their acidic exopolymeric substances influenced mineral solubility and redox kinetics. The crushing method selection directly impacted bio-oxidation efficiency, with HVPF yielding the best Cu and Ni extraction rates, emphasizing the need to optimize crushing parameters based on ore properties (Figure 3).

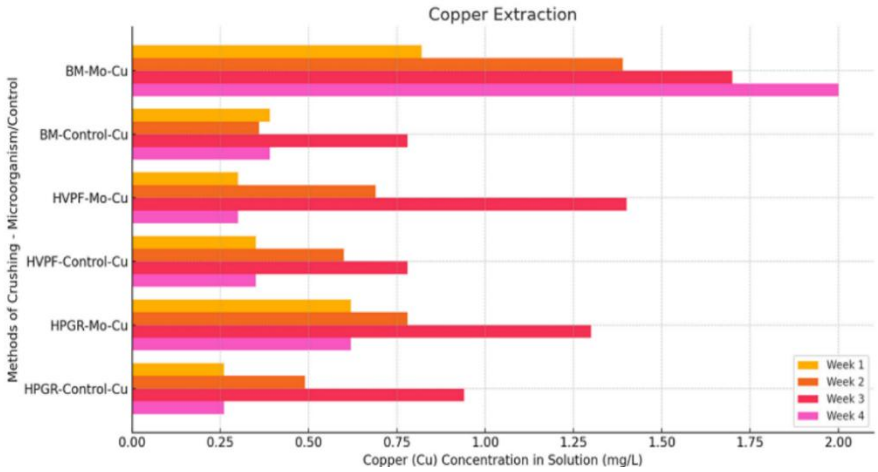

Figure 1 Copper extraction from gold ore using different mineral processing operations (HPGR-control-Cu; HVPF-control-Cu, BM-control-Cu: tests without the addition of microorganisms (*i.e.*, negative control); HPGR-Mo-Cu, HVPF-Mo-Cu, BM-Mo-Cu: tests with the action of microorganisms (*i.e.*, bio-oxidation)).

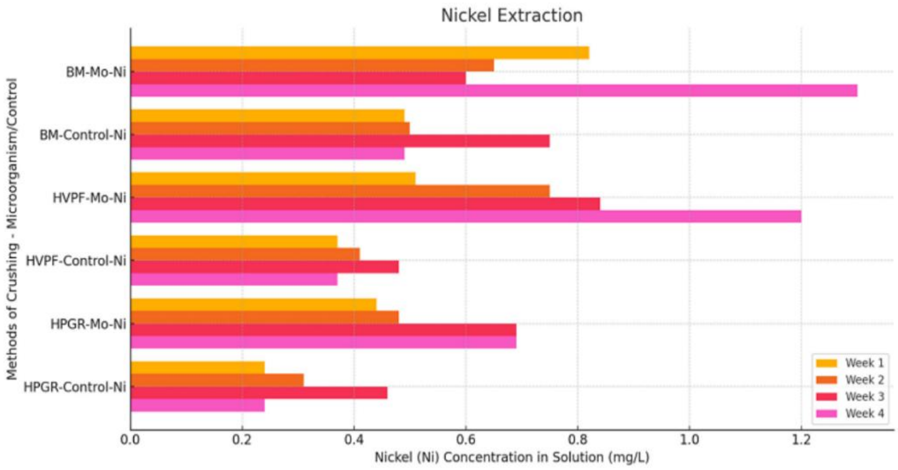

Figure 2 Nickel extraction from gold ore using different mineral processing operations (HPGR-control-Ni; HVPF-control-Ni, BM-control-Ni: tests without the addition of microorganisms (*i.e.*, negative control); HPGR-Mo-Ni, HVPF-Mo-Ni, BM-Mo-Ni: tests with the action of microorganisms (*i.e.*, bio-oxidation)). The inconsistency observed in HPGR performance may be attributed to factors such as equipment setup, particle size distribution, or intra-particle pH increases, which could have led to metal ion hydrolysis and the formation of insoluble hydroxides, restricting microbial access to minerals.

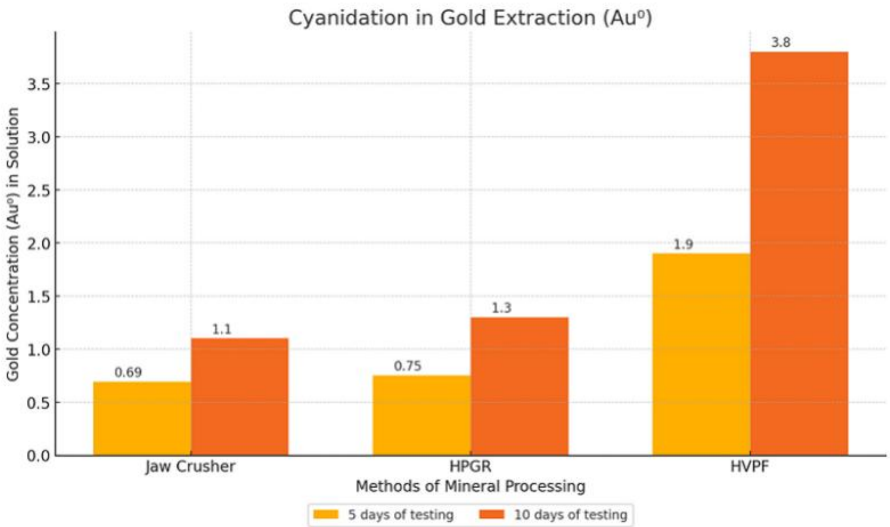

Figure 3 Result of the cyanidation process for gold from previously bio-oxidized mineral samples.

Cyanidation is widely used for extracting gold; however, the presence of sulphides increases cyanide consumption due to their cyanicide properties. To address this, bio-oxidation was performed prior to cyanidation. The results showed significant variations in cyanidation efficiency depending on the crushing method used before bio-oxidation. These findings suggest that HVPF is the most effective method for liberating gold particles, enhancing their exposure to cyanidation. The mineralogical species carrying gold underwent greater liberation, leading to improved bio-oxidation, which in turn facilitated gold dissolution during cyanidation (Figure 3). Additionally, HVPF fragmentation enabled better release of gold encapsulated in gangue materials such as silica and silicates, contributing to higher gold concentrations in the cyanide solution. Thus, the cyanidation results for solid residues from bio-oxidation demonstrate that HVPF outperforms conventional crushing methods, making it an optimal pre-treatment step for gold recovery. Its ability to create microfractures enhances the combined action of cyanide, oxygen, and complexing agents, improving overall gold extraction efficiency.

CONCLUSION

Based on the results achieved in terms of the bio-oxidation of the ore under study subjected to different mineral processing methods, we can affirm that it is possible to reduce the sulphur content in a differentiated manner depending on the processing operation used. This reduction in sulphur content aims at maximizing the liberation of gold particles through the extension of the bio-oxidative process and to minimize cyanide consumption in the gold extraction stage, as some mineral species consume cyanide. On the other hand, the removal of these cyanide-consuming species, particularly sulphide minerals, should be maximized to avoid an increase in ionic strength and thus greater solubilization of oxygen, the oxidizing agent in the cyanidation process. It is concluded that the High-Voltage Pulse Fragmentation (HVPF) operation stands out as the most efficient in both the bio-oxidation and cyanidation processes of gold ore, providing greater extraction of precious metals. These findings have significant implications for the optimization of mining and precious metal extraction processes from primary gold ores. The leachate resulting from the bio-oxidative process of sulphide minerals present in the gold ore under study contains iron ions (*i.e.*, Fe^{2+} and Fe^{3+}), Ni^{2+}, and Cu^{2+}, and requires treatment for the proper recovery of these metals, also preventing environmental contamination. The bio-oxidation of the gold ore sample processed in the HPGR showed greater variation in redox potential and a higher concentration of ferric ions, possibly due to the oxidation of Fe^{2+} to Fe^{3+} during the bio-oxidative process within the micro fissures, preventing the continuity of the reaction cycle.

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