THE INFLUENCE OF BIO-OXIDATION OF A FLOTATION CONCENTRATE AS A PRE-OXIDATIVE STEP FOR THE CYANIDATION OF PRECIOUS METALS

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ABSTRACT

The sulphide minerals bearing precious metals impose a real drawback for extracting them using the cyanidation process as they have to be oxidized in the first place, by the joint action of cyanide, the complex agent, and oxygen, the oxidizing agent, which consume cyanide before start dissolving the precious metals. One has also to consider that while dissolving the aforementioned sulphide minerals the ionic strength gradually increases turning the PGMs cyanidation process less efficient as the solubility of oxygen decreases as such. Therefore, this technical contribution aimed at using the bio-oxidation pre-treatment process to overcome such inconvenient making the precious metals extraction process more cost-effective.

Keywords: Sulphide minerals. Bio-oxidation. Cyanidation. Precious metals.

1 INTRODUCTION

Biohydrometallurgy is a high-value field of study in the metal extraction industry, emerging as a viable option with conventional extraction methods. This process uses microorganisms to obtain and recover metals from minerals and mineral resources. Considering the metabolic activities of these microorganisms, biohydrometallurgy can minimize environmental damage, operational costs and harmful emissions related to adverse techniques, such as pyrometallurgy. In this context, bio-oxidation, a biohydrometallurgical process, is characterized as being a pre-treatment of minerals concentrates, where microorganisms are used acting oxidizing sulphide minerals and, thus, releasing the gold, encapsulated in their structure, for being further recovered by chemical and electrolytic processes[1]. Numerous species of microorganisms, with the ability to oxidizing Fe^{2+}, have been identified taxonomically, such as the bacteria *Acidithiobacillus ferrooxidans, Leptospirillum ferrooxidans* and *Acidithiobacillus thiooxidans* etc., which are frequently used on biotechnological extractive processes[2,3,4,5,6]. In the bio-oxidation process of metals, the microorganisms are only in charge of generating the oxidizing agent in the reaction system (*i.e.*, the Fe^{3+} ions) from the oxidation of ferrous ions (*i.e.*, Fe^{2+}) that can be added to the system either as soluble ($FeSO_4.7H_2O$) or insoluble (FeS_2) species.

Based on the studies of Darvanjoobhi and collaborators[7], bio-oxidation, together with bioleaching, present benefits when applied in contrast to other pyrometallurgical or hydrometallurgical processes, such as roasting and pressure leaching, respectively. The investment in reagents is reduced and the process occurs under atmospheric pressure and mild temperature conditions, between 30° and 50°C. These characteristics contribute to reach required goals with lower environmental impact and operational cost. However, the kinetics of these processes are slow, requiring longer residence times compared to previous pre- treatments. In the bio-oxidation process of iron bearing sulphides, for example in pentlandite ($(Fe, Ni)_9S_8$), two events occur simultaneously: (i) the dissolution of this sulphide releasing Fe and Ni into solution, in addition to the formation of sulphate (SO_4^{2-}), and (ii) the precipitation of secondary phases containing these elements. The literature frequently mentions the formation of jarosite. In bio- oxidation systems, the precipitation of ferric compounds is strongly affected by pH, temperature, and concentration of ferric ions[8]. An increase in temperature or pH favours the formation of these precipitates. Therefore, these parameters that affect the bio-oxidative process are monitored regularly[9]. This study aimed at accomplishing a bio-oxidation study of sulphide minerals bearing gold and platinum-group metals, PGMs (*i.e.*, Pd, Pt and Rh), for pre-oxidizing such minerals for subsequent extracting gold and PGMs by chemical and electrolytic processes.

2 EXPERIMENTAL

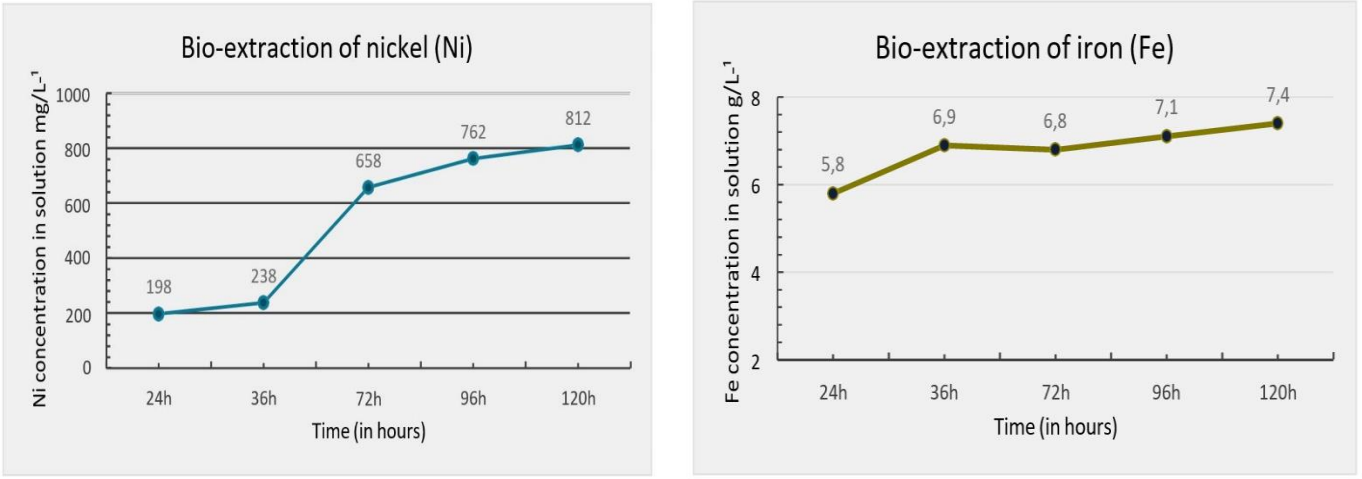
The bio-oxidation tests were carried out in two replicates using Erlenmeyer flasks. Each flask contained: i) inorganic salts as a nutrient source, specifically: $(NH_4)_2SO_4$ 80.0mg.L^{-1}; $MgSO_4.7H_2O$ 80.0mg.L^{-1}; K_2HPO_4 8.0mg.L^{-1}, pH 1.8; ii) previously acclimatized cultures of acidophilic mesophiles of *Leptospirillum ferrooxidans*-LR strain , *Acidithiobacillus ferrooxidans* ATCC 53992 and *Acidithiobacillus thiooxidans* FG01; and iii) flotation concentrate. The microorganisms were acclimatized to the concentrate by contacting them to an ever-increasing amount of the aforementioned flotation concentrate until reaching the solid:liquid ratio of 10%, bearing in mind that the microorganisms population density being at least 10^7 microorganism per milliliter of solution. The flasks were incubated at a temperature of 30ºC and orbital shaking at 150 rpm. Throughout the 120- hour process, an aliquot was collected every 24 hours for monitoring Fe and Ni concentrations. The redox potential was monitored, and the pH was recorded daily and, when necessary, adjusted with 5M H_2SO_4, also recordind the final pH.

The number of drops of H_2SO_4 5M used to adjust the pH in each Erlenmeyer flask was recorded to assess the acid consumption. After finishing the bio-oxidation process, the supernatant was filtered, washed, and submitted to cyanidation tests.

For the gold and PGMs extraction processes, the solid phase remaining after the bio-oxidation tests was placed in a one litre (1000mL) glass reactor full of aerated cyanide solution, at different concentrations of free cyanide (*i.e.,* this concentration can vary depending on the mass of gold ore to be treated and the content of these precious metals present, normally ranging from 3 to 10 $g.L^{-1}$, at pH 11). Once finishing the cyanidation process, the leachate was analysed by ICP-EOS to evaluate the extraction of gold, palladium, platinum, and rhodium. A direct cyanidation test was carried out with the ore without being previously bio-oxidized.

3 RESULTS & DISCUSSION

By carrying out bio-oxidation as a pre-treatment of the flotation concentrate, which was further submitted to cyanidation, as an attempt to reduce the sulphide content so as to make the process more cost-effective. Figures 1 and 2 show that nickel and iron extraction increased over time during the bio-oxidation process.

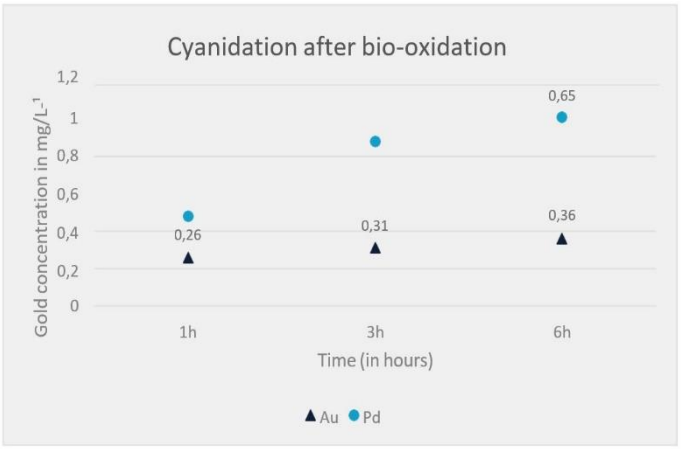


(A) **(B)**

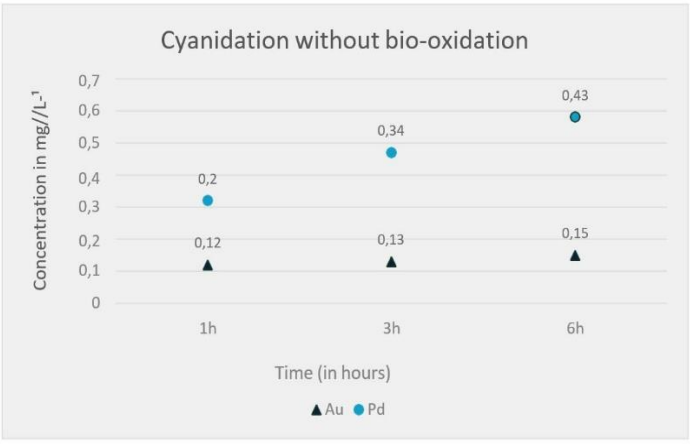
Figure 1 (A) Nickel extraction over test time**. (B)** Iron extraction over test time.

The results obtained (Figure 1A) in the bio-oxidation process show that the concentration of nickel increased significantly over test time. This consistent increase in the concentration of nickel extracted, from 198 mg/L after 24 hours to 812 mg/L after 120 hours, suggests that the efficiency of nickel extraction improved over time, considering a possible adaptation of the microorganisms to the increasing ionic strength. The results obtained for iron extraction (Figure 1B) during the bio-oxidation process also show a progressive increase over time. These data indicate that the amount of iron extracted increased from 5.8 g/L after 24 hours to 7.4 g/L after 120 hours. However, there was a drop in the concentration of extracted iron between 36 and 72 hours, before it increased again. This may be due to variations in the process conditions, such as pH or temperature, which may have affected the efficiency of bio-oxidation during this period.

However, the microorganisms used in the process, *Leptospirillum ferrooxidans, Acidithiobacillus ferrooxidans,* and *Acidithiobacillus thiooxidans,* were not adapted to increasing ionic strength during the bio-oxidative process. Adapting the microorganisms to these conditions could potentially increase the efficiency of nickel extraction, which suggests an area of improvement for future experiments. Figure 2A shows the cyanidation results, which indicate a significant improvement in the extraction efficiency of gold (Au) and palladium (Pd) when bio-oxidation is used as a pre-treatment before cyanidation. A progressive increase in gold recovery is observed over time, from 0.26 to 0.31 and finally to 0.36. This suggests that bio-oxidation makes the gold leaching easier. On the other hand, in direct cyanidation (Figure 2B), a modest increase in gold recovery was observed over time, from 0.12 to 0.13 and finally to 0.15. This suggests that direct cyanidation, without bio-oxidation pre-treatment, results in relatively low gold extraction efficiency. Palladium recovery increased from 0.2 to 0.34 in three hours and reached 0.43 in six hours. Although thereis an increase, the efficiency is significantly lower compared to cyanidation after bio-oxidation.



(A)



(B)

Figure 3 (A) Extraction of gold and palladium over the test time after bio-oxidation**. (B)** Extraction of gold and palladium over the test time before bio-oxidation.

The higher concentration in the results after bio-oxidation can be attributed to the ability of this process to solubilize complex sulphide minerals that encapsulate precious metals. In the absence of bio-oxidation, the sulphides remain, access to the precious metals is limited and the efficiency of cyanidation is reduced, as well as being less cost-effective when compared to cyanidation preceded by bio-oxidation. However, by incorporating a bio-oxidation stage, the situation changes significantly. The sulphides are oxidized, which exposes the precious metals. This, in turn, makes cyanidation highly effective in extracting gold (Au) and palladium (Pd) from the flotation concentrate. Therefore, bio-oxidation as a pre-treatment significantly improves the efficiency of precious metals extraction in industrial scale. This reinforces the importance of bio-oxidation as a pre-treatment step for the extraction of precious metals.

4 CONCLUSION

Bio-oxidation has proven to be a step to be discussed for the efficient extraction of precious metals. By solubilizing complex sulphide minerals, bio-oxidation exposes the precious metals, making them more accessible for subsequent extraction by cyanidation. The results indicate that the extraction efficiency of gold and palladium improved significantly when bio-oxidation was applied as a pre-treatment. In addition, the absence of bio-oxidation resulted in a relatively low extraction efficiency, as the sulphides were not solubilized at first, limiting access to the precious metals. This reinforces the importance of bio-oxidation in improving cyanidation efficiency. Therefore, incorporating a bio-oxidation stage can be an effective strategy for improving the efficiency of precious metal extraction in industrial processes.

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