

Application of the BIOX Process to the Pretreatment of Refractory Sulphide Gold Ores and Concentrates in Order to Increase Au and Ag Recovery Rate in Hydrometallurgical Extraction Process

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Abstract: The key of the BIOX process is the exploitation of a naturally occurring mixed bacterial population consisting of: *Acidithiobacillus ferrooxidans*, *Acidithiobacillus thiooxidans* (oxidises sulphur compounds only) and *Leptospirillum ferrooxidans* (oxidizes iron substrates only). These bacteria are able to oxidize gold-bearing sulphide ores and concentrates under controlled conditions. Thus, they offer an alternative to conventional roasting or pressure techniques developed in hydrometallurgy in order to recovery Au and Ag from refractory sulphide gold ores and concentrates. Using the BIOX process as a pretreatment procedure of refractory sulphide gold ores and concentrates, Au and Ag recovery yields after cyanidation increased up to 78 % for Au and to 83 % for Ag.

Keywords: BIOX, Au, Ag recovery, gold ore

1. Introduction

BIOX is a biohydrometallurgical process for the pre-cyanidation treatment of refractory gold ores. This process offers an alternative to conventional roasting or pressure oxidation techniques.

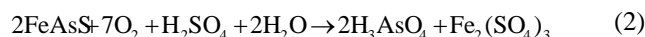
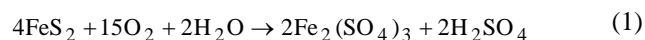
The nucleus of the BIOX process is the exploitation of a naturally occurring mixed bacterial population consisting of: *Acidithiobacillus ferrooxidans*, *Acidithiobacillus thiooxidans* (oxidises sulphur compounds only) and *Leptospirillum ferrooxidans* (oxidizes iron substrates only). Due to the possession of a chemolithotrophic mode of metabolism, these bacteria are able to oxidize gold-bearing sulphide ores and concentrates under controlled conditions. Inorganic substrates such as sulphides, elemental sulphur and ferrous iron are oxidized by the bacteria to provide chemical energy. This is enzymatically converted, by oxidative phosphorylation, to ATP, a form of metabolic energy used by the bacteria for various cellular functions. The carbon requirements of the bacteria for biosynthesis of cellular biomass are met by CO₂ in the atmosphere or from dissolution of carbonate minerals in the ore.

2. Bacterial oxidation mechanism

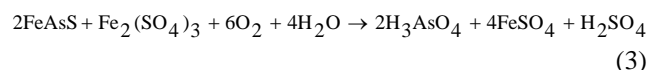
A wide range of metal sulphide minerals can be oxidized by the mixed bacterial population. These include pyrite, arsenopyrite, pyrrothite, chalcopyrite, chalcocite, covellite, stibnite, pentlandite and galena.

The mechanism of sulphide breakdown is usually a combination of direct enzymatic attack and indirect

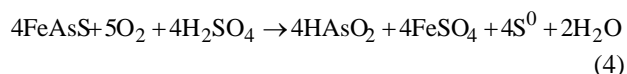
chemical activity of metabolic by-products of the bacteria. For direct enzymatic oxidation, attachment of the bacteria to the sulphide mineral is essential. Bacterial oxidation of pyrite and arsenopyrite are illustrated by the equations 1, 2:



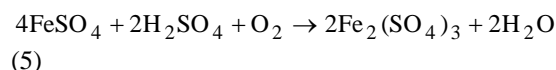
The ferric sulphate produced may contribute to further sulphide breakdown by indirect chemical attack:



Partial arsenopyrite oxidation may also occur by acid attack:



The ferrous sulphate and elemental sulphur are then bacterially re-oxidised to ferric sulphate and sulphuric acid, respectively equations 5, 6:



The arsenic acid produced from the oxidation of arsenopyrite is efficiently neutralized with limestone and/or lime to form non-polluting ferric arsenate precipitates. These precipitates are stable provided the Fe:As molar ratio in the BIOX liquor is greater than 3:1.

3. Material and methods

3.1. Microorganisms and culture media

The microorganisms, used in the amenability tests, consist in bacterial cultures isolated from the gold arsenopyrite concentrate. Isolation of chemolithotrophic iron- and sulf- oxidizing bacteria is performed by inoculating the liquid nutrient media with appropriate samples of studied ore.

In order to obtain iron-oxidizing cultures enrichment of *Acidithiobacillus ferrooxidans* (Fig. 1) and *Leptospirillum ferrooxidans* the nutrient MACKINTOSH(1978) medium based on ferrous sulphate (pH = 1.8) is recommended. Isolation of sulf-oxidizing *Acidithiobacillus thiooxidans* bacteria was performed by using the HUTCHINSON (1965) medium (which contains sulfur) at pH = 4.5.

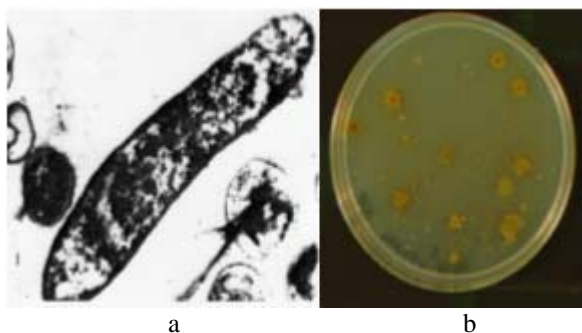


Figure 1. Thiobacillus bacteria (a - cells shape; b – colonies grown on agar medium)

The concentrated biomass used in oxidation process from laboratory tests was performed by inoculating the MACKINTOSH medium (30 g/L $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$) with bacteria cultures isolated from the pyrite concentrate.

3.2. Arsenopyrite concentrate characterisation

The experiments were performed using four types of gold arsenopyrite concentrates, as follows: P₁, P₂, P₃ – concentrates from Suior site; P₄ – Certej concentrate.

Chemical characteristics of the four samples are presented in Table 1 and the mineralogical content is presented in Table 2.

The samples also contain low concentrations of minor elements: 0.5 – 1.27 % CaO, 0.05 – 0.12 % MgO, 0.02 % Mn, 0.04 – 0.08 % Sb, 0.002 % Cd, 0.003 % Se, 6-16.00 % SiO₂.

The concentrate contains mainly pyrite (>80%), with less amount of arsenopyrite (≈10%) and traces of galena, chalcopyrite and calcite. The sulphides are generally very well liberated, although pyrite-arsenopyrite and pyrite-sphalerite were occasionally intergrown.

TABLE 1 Chemical composition of concentrate samples

Element	P-1	P-2	P-3	P-4
Au, g/t	11.30	12.6	11.03	9.02
Ag, g/t	39	39.8	42.6	141.7
S, %	38.8	48.3	45.9	47.24
Fe, %	30.5	39.6	31.5	41.18
As, %	2.57	2.97	1.52	0.59
Pb, %	0.77	0.76	0.70	1.67

TABLE 2. Mineralogical composition of the concentrates

Mineral	Symbol	Content, %	
		P1-P3	P4
Gold	Au	9.02 g/t	11.5 g/t
Silver	Ag	158.98 g/t	42.6 g/t
Pyrite	FeS ₂	83.05	80
Arsenopyrite	FeAsS	0.65	10
Blende	ZnS	7.17	8
Galena	PbS	1.93	2
Chalcopyrite	CuFeS ₂	0.36	1
Calcite	CaCO ₃	<1	<1

Using the mineralogical analyse, Au was untraceable. Mass Analyse by means of electron probe revealed the gold enclosure in sulphides (arsenopyrite, pyrite and galena); this was the reason why the docimazic analyse was performed. In order to this is need to pretreat the pyrite for sulphides destruction and release the Au, Ag particles. Gold distribution: native gold occurs as applicable grains having 5 - 20μ sizes, enclosed in pyrite, arsenopyrite and galena particles.

3.3. The BIOX flow sheet of gold pyrite concentrates

According to laboratory tests the BIOX flow sheet was proposed, see Fig. 2.

4. Experimental results

According to pilot flux, the main parameters were determined:

- auto reproduction of acidophilic bacteria in pulp;
- pH of feeding solution (maintaining at optimal values);
- optimal processing temperature;
- pulp density (L/S ratio);
- solid bacterial treatment period;

The BIOX process was carried out in two versions under pre-definite conditions:

Version I: S/L ratio = 1/10; leaching period = 5 days; temperature range = 28 – 33 °C; agitation rate = 500 rpm; acidophilic biomass (iron, sulphur and thiosulphat oxidative) obtained in laboratory.

Version II: S/L ratio = 1/10; leaching period = 10 days; temperature range = 28 – 33 °C; agitation rate = 500 rpm; acidophilic biomass.

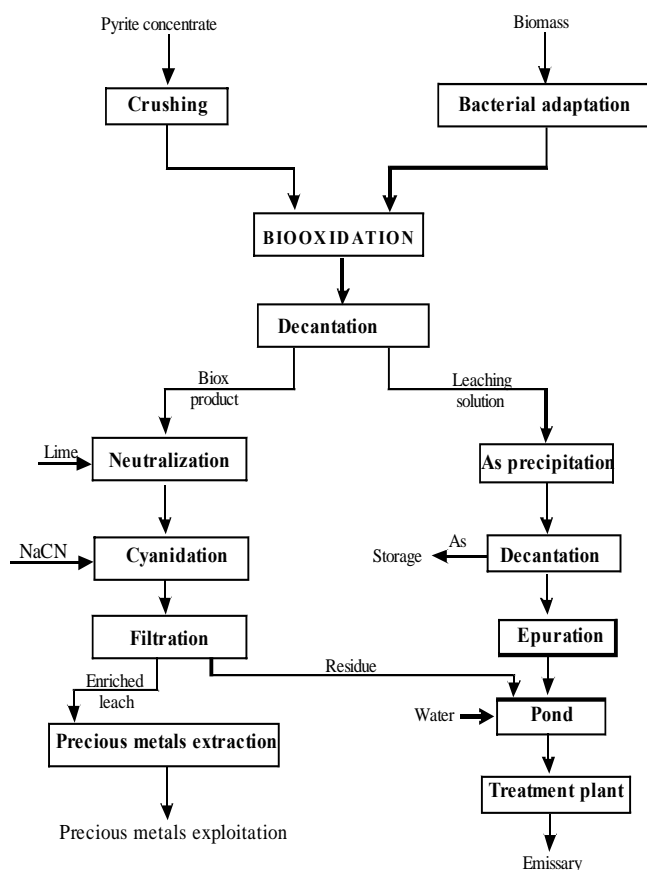


Figure 2. The flow chart for Au and Ag recovery from pyrite concentrate by BIOX process

The results of biooxidation tests are shown in Fig. 3 and 4. Experimental results showed the pyrite solubilization. The solubilization rates of pyrite components were as follows: 48.2% Fe; 68.4% Cu; 65% Zn; 48.4% As (version I) and 22.4% Fe; 57.2% Cu; 52.5% Zn; 33.8% As (version II).

As a result of solubilization, BIOX product has the following characteristics: modification of major elements and its granulometry; loss of weight compared to feeding pyrite; increasing of metal content insoluble in sulphuric acid (Au, Ag and Pb); decreasing of As content up to 48 – 65 %.

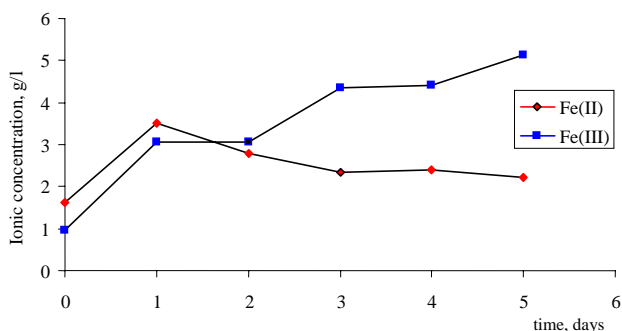


Figure 3. Variation of ferric content under version I conditions

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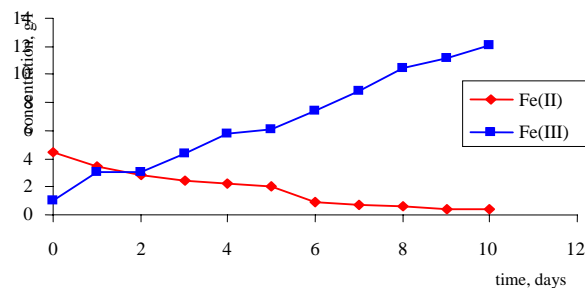


Figure 4. Variation of ferric content under version II conditions

The experiments showed that the BIOX process need to be carried out in 1.8 – 2 range of pH in order to avoid jarosit precipitation that could dilute the biooxidised pyrite mass. The BIOX parameters also could be optimized as follows: S/L ratio = 1/10; biooxidation time = 5 days; pH = 1.8; temperature range = 28 – 33 °C. The Au and Ag recovery yields obtained after cyanidation of previously biooxidised pyrite concentrate were up to 78% for Au and to 83 % for Ag. Cyanidation tests were carried out in two versions : direct cyanidation of gold concentrate and concentrate cyanidation after biooxidation, Fig. 5.

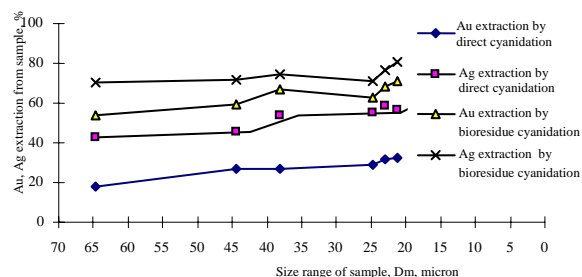


Figure 5. Au and Ag extraction obtained by different leaching S/L ratios of bacterial solubilization

5. Conclusions

Application of BIOX process to pretreat pyrite concentrate for gold recovery is a successful pathway to improve the recovery yields of precious metals. Thus, performing this process, dissolution yields of 80% for Au and 85% for Ag are obtained. The bacteria cultures employed in BIOX process are isolated from arsenopyrite concentrate because no supplementary costs are need for acquisition.

Bacteria growth involves minimal requirements such as: temperature maintenance in 28 – 30 °C interval and aeration of the pulp. Chemical mechanisms that take place during the process provide sufficient amounts of acid for maintaining pH value in 1.8 – 2 range..

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