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Microbial oxidation of refractory gold sulfide concentrate by a native consortium

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Abstract: A defined mesophilic consortium including an iron oxidizing bacterium and a sulfur oxidizing bacterium was constructed to evaluate its ability for bioleaching a flotation concentrate from Andacollo mine in Neuquén, Argentina. Experiments were performed in shake flasks with a pulp density of 10% (w/v), using a basal salt medium containing ferrous iron at pH 1.8. The leaching solutions were analyzed for pH, redox potential (using specifics electrodes), ferrous iron (by UV-Vis spectrophotometry) and metal concentrations (by atomic absorption spectroscopy). The results showed that the consortium was able to reduce the refractory behavior of the concentrate, allowing 91.6% of gold recovery; at the same time, high dissolution of copper and zinc was reached. These dissolutions followed a shrinking core kinetic model. According to this model, the copper solubilization was controlled by diffusion through a product layer (mainly jarosite), while zinc dissolution did not show a defined control step. This designed consortium, composed of bacterial strains with specific physiological abilities, could be useful not only to optimize gold recovery but also to decrease the leachates metallic charge, which would be an environmental advantage.
Key words: biooxidation; refractory gold concentrate; native consortium; kinetic analysis

1 Introduction

Refractory gold-bearing ores are characterized by containing submicroscopic gold particles occluded in sulfide minerals such as pyrite and arsenopyrite. Under these conditions, gold cannot be recovered efficiently without an oxidative pretreatment such as roasting, chemical oxidation, or biooxidation. During these processes, the mineral structures which contain gold are destroyed and the precious metal is subsequently available to be solubilized by a conventional leaching technique like cyanidation [1,2].

Traditionally, roasting has been used to treat these ores despite the high energy consumption and production of pollutant gases that severely damage the environment. Furthermore, chemical oxidation is an expensive process requiring high temperature, high pressure and corrosion-resistant materials [3].

The increasing interest in using biooxidation as alternative technology is due to its numerous advantages as opposed to conventional techniques. This process takes place at atmospheric pressure and low temperatures; in addition, it is easy to operate, has low capital costs and is compatible with the environmental legislation [4,5].

The first experiences with microorganisms were carried out to recover gold from refractory sulfides in the 1980s. Nowadays, iron- and sulfur-oxidizing bacteria are widely used to oxidize sulfur-containing ores and flotation concentrates. Depending on the type of metal sulfides, dissolution of the mineral occurs by a combined action of ferric iron and protons. Microorganisms re-generate ferric iron and create acidic conditions in the systems.

The development of stirred tanks to treat flotation concentrates containing refractory gold was initially

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done by the Gencor Company [6]. The first commercial plant to use the BIOX process was Fairview Mine (in South Africa), installed by Gold Fields in 1986. The number of biooxidation projects in gold mining increased due to the successful application of this technology during the 1980s. At least 14 active gold projects with biooxidation can be identified in the commercial project databank of the Minerals Economic Group [7] as well as in other sources (BGR databanks) [8].

Leachable gold deposits occurring near the surface have been preferentially exploited in the past and are now due to be depleted. Gold production obtained from gold refractory or low grade ores will significantly increase in the future. Many of the new projects are deeply located and must be considered as refractory in mineralogical terms, since gold is occluded in sulfides [7]. This context leads to thinking about the need to include a pretreatment before leaching the minerals with cyanide, in order to improve the recovery of gold. Previous studies showed that biooxidation seems to be a promising alternative to process these sulfides.

Although the commercial application of biooxidation has increased over time worldwide, only a few regional ores have been studied in Argentina at laboratory scale. This work attempts to contribute to the knowledge of this technology applied to regional ores, using native microorganisms.

In the Andacollo mining district, gold is present as submicroscopic particles contained in a pyrite matrix. Previous studies have distinguished a highly refractory feature in this ore (about 50% of gold was recovered without pretreatment) [9]. Currently, CORMINE SEP and MAG S.A. are exploiting the natural resources of this area. The treatment plant processes 350 t/d. The products obtained are a high-grade sand (1000−3000 g/t Au and 5000−14000 g/t Ag) and a flotation concentrate (50−100 g/t Au and 4000−10000 g/t Ag) [10]. In this context, it is imperative to find some alternative environmentally-friendly technologies, which allow to increase Au and Ag recovery from this concentrate.

The aims of this work are to evaluate an alternative process to improve the recovery of gold contained in a flotation concentrate and to study copper and zinc dissolution as subproducts of this biooxidation process.

2 Experimental

2.1 Mineral sample

A flotation concentrate from Andacollo's treatment plant was used throughout this study. The concentrate consists of polymetallic sulfides and gold which is mainly occluded in pyrite. In addition, great amounts of zinc and copper are in a sulfide form. X-ray diffraction (XRD) was used to identify the phases present in the mineral sample, which were pyrite, sphalerite, covellite, galena, quartz and feldspar. In addition, the sample could contain remnants of froth flotation collectors like sodium isobutyl xanthate (SIBX), potassium amyl xanthate (PAX), AERO 208, AERO 404 and AERO 3477, since these organic compounds are regularly used in this processing plant. The sample chemical characterization was carried out by Inductively Couple Plasma/Optical Emission Spectrometry (ICP-OES) and the results are shown in Table 1.

Table 1 Main values of metals present in flotation concentrate determined by ICP-OES (mass fraction, %)

Au*	Ag*	S	Cu	Fe	Pb	Mo	Ni	Zn
36.23	3548	19.2	0.27	14.98	2.15	0.0096	0.0015	3.44

*: g/t

2.2 Microorganisms and culture media

The consortium used in these experiments was composed of mesophilic iron and sulfur oxidizing bacteria isolated from La Carolina mining district (Province of San Luis, Argentina). Two different isolates (called OxFe and OxS) were used to constitute the inoculum. OxFe presented iron oxidative capacity, and according to BLAST comparison, its 16S-rDNA gene sequence showed 99% similarity with many *Leptospirillum ferrooxidans* sequences. OxS was able to oxidize sulfur, and its 16S-rDNA gene sequence manifested similarities of 98%−99% to *Acidithiobacillus ferrooxidans* and *Acidithiobacillus ferrivorans,* although it has not shown any iron oxidative capacity up until now [11].

OxFe isolate was regularly grown in a 9K medium at pH 1.8, whereas OxS was cultivated in a 0K medium supplemented with elemental sulfur (10 g/L) at pH 3.0 [12]. After the bacteria reached the exponential growth phase, cultures were filtered using a blue ribbon filter paper (Whatman Schleicher and Schuell, Kent, England, 2 μm retention) to eliminate jarosite and sulfur from OxFe and OxS, respectively. Cells were harvested using a 0.2 μm membrane and then suspended again in an iron-lacking medium. A suspension containing about 5×10^8 cell/mL from each culture was used as inoculum.

2.3 Biooxidation experiments

Experiments were carried out in 1000 mL Erlenmeyer flasks with 400 mL of 1K medium (containing 1 g of ferrous iron per liter) at pH 1.8 and 40 g of flotation concentrate (10% (w/v) pulp density). Each flask was inoculated with cell suspension containing both microorganisms at 5% (v/v). Sterile controls were also run replacing the inoculum by an equal volume of 2% (w/v) thymol in methanol. The flasks were stirred at 200 r/min and incubated at 30 °C.