



A new concept of the biohydrometallurgical technology for gold recovery from refractory sulfide concentrates



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ABSTRACT

A new concept of a biohydrometallurgical technology for gold recovery from refractory sulfide concentrates was proposed and substantiated. The technology implies a two-step process for oxidation of gold-bearing sulfide concentrates. The first step is leaching with biogenic ferric iron at elevated temperature using the ferric iron-containing solution produced during the second step. The second step is biooxidation of the products of the first step by acidophilic chemolithotrophic microorganisms. A flotation concentrate, which contained pyrrhotite, arsenopyrite, pyrite, and antimonite, was used in the study. Effect of temperature on leaching of the concentrate with biogenic ferric was studied. Maximal rates of ferric and ferrous iron concentration change were observed at 80 °C and were 44.3 and 32.2 g L⁻¹ h⁻¹ within the first 40 min of the first cycle of the leaching. The level of oxidation after two cycles of pre-leaching with biogenic ferric iron (100 min) at 80 °C was 64.3, 31.1, and 45.4% for iron, arsenic, and sulfur of all sulfide minerals, respectively. Comparison of the two-step and traditional (one-step) technologies was carried out and the flow sheet for the new process was proposed. Gold recovery from the sulfide concentrate by carbon-in-pulp cyanidation was 67.8% in the one-step process and 93.0% in the two-step process at 4 days of biooxidation, while it reached 82.4% and 94.1% in the one-step and two-step processes at 8 days of biooxidation, respectively. Introduction of the pre-leaching of the concentrate with biogenic ferric step was shown to result in decreased duration required for subsequent biooxidation, thus enhancing the economical efficiency of gold recovery.

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1. Introduction

Biooxidation with subsequent gold dissolution in cyanide solutions (a biohydrometallurgical process) is a traditional procedure for gold recovery from sulfide ores. Mineral biooxidation of concentrates, in which the gold is occluded within sulfide minerals, is practiced in a number of mining operations around the world today; nevertheless, mineral biooxidation represents only about 5% of the world's total gold production (Brierley and Brierley, 2013). Biomining is a much more environmentally benign approach than roasting, as it was able to fix the arsenic in the ore in a stable precipitate that could be discharged to the tailings dam. There are new approaches to decrease environmental pollution during gold recovery using cyanidation processes. For example, an ASTER™ process that employs a complex consortium of microorganisms is used to bioremediate cyanide- (CN⁻) and thiocyanate- (SCN⁻) containing waste water (van Buuren et al., 2011; Huddy et al., 2015). Nowadays, new biological approaches are studied to recover gold from refractory sulfide raw materials. Kaksonen et al. (2014a) have reported a new biooxidation concept including leaching with

biological ferric iron followed by biooxidation of pyrite in column for gold extraction from low-grade ore. In general, low-cost heap bioleaching could be attractive technology for gold to recovery from low-grade ores or mining wastes, but this is not industrial practice at this stage (Petersen, 2016; Watling, 2015; Logan et al., 2007; Kondrat'eva et al., 2012; Brierley, 2003). Outotec (BIOX®) and Bactech-Mintek (Bacox™) are presently the most widespread biohydrometallurgical reactor technologies for industrial gold recovery, with 14 installations worldwide (Gericke, 2015; Kaksonen et al., 2014b). In 2009, the total estimated gold production using the BIOX® technology exceeded 47 t. The total volume of concentrates processed using the BIOX® technology was 4500 t/day in 2009, while an increase to 6500 t/day and more was planned in 2012 (van Niekerk, 2009).

The technological parameters of some industries processing gold-bearing sulfide concentrates are listed in Table 1 (Rawlings et al., 2003). The flow sheet for biooxidation of gold-bearing arsenopyrite-pyrite concentrates in BIOX® reactors is presented on Fig. 1 (Kaksonen et al., 2014b). It applies biooxidation in the primary, and secondary reactors. The leach solution from the last bioreactor, which contains considerable amounts of ferric sulfate (up to 30 g/L) and possesses high oxidation potential against sulfide minerals, is wasted rather than utilized.

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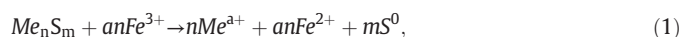
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Table 1
Technological parameters of some industries recovering gold from sulfide concentrates using biooxidation.

Plant (years in operation)	Production			Content, %			Biooxidation time, days
	t/day	m ³ /t	Total bioreactor volume, m ³	Arsenopyrite	Pyrite	Pyrrhotite	
Fairview, South Africa (1986–present)	55	25.7	1415	10	28	–	4
Harbour Lights, Australia (1992–1994)	40	24.5	980	18	28	–	4
Tamboraque (Coricancha), Peru (1998–present)	60	26.1	1570	5.7	35	–	4
Wiluna, Australia (1993–present)	154	27.5	4230	22	37	–	5
Ashanti-Sansu, Ghana (1994–present)	960	22.5	21,600	17	6.5	14	5
Youanmi, Australia (1994–1998)	120	25.0	3000	5	43	–	6
Laizhou, China (2001–present)	100	40.5	4050	7–15	25–49	–	6
Beaconsfield, Australia (2000–present)	68	34.0	2310	7–12	48–59	–	6

Since the time required for biooxidation of refractory sulfide concentrates using the traditional technology is four to six days (Rawlings et al., 2003), its efficiency is limited. Analysis of the mechanism of biooxidation of sulfide minerals is required for development of a concept of the process for intensified biooxidation.

Oxidation of some sulfide minerals (Me_nS_m) by ferric ions is known to be more rapid than microbial oxidation (Fomchenko et al., 2010; Fomchenko and Muravyov, 2014). Sulfide oxidation by ferric ions is described by the following reaction:



where Me is a metal, a is its valency in the sulfide mineral, and n and m are stoichiometric coefficients.

In this process the role of microorganisms is limited to oxidation of ferrous ions and elemental sulfur according to the following reactions:



According to the traditional technology of biooxidation, all reactions are carried out in the same unit process (Fig. 1). Efficiency of this one-step process is limited by such factors as pulp density, concentration of dissolved components, and temperature.

The optimal conditions for chemical reactions and microbial activity are different. Thus, the rate of chemical reactions increases with temperature and pulp density (concentration of solids) (Levenspiel, 1999), while biological processes are characterized by an optimum

depending on the microbial culture used. The optimal temperature is 20–40 °C for mesophilic cultures (*Acidithiobacillus ferrooxidans*, *Leptospirillum ferrooxidans*), 40–60 °C for moderate thermophiles (*Sulfobacillus* spp., *Acidithiobacillus caldus*) and above 60 °C for thermophiles (*Sulfolobus* spp., *Metallosphaera* spp., *Acidianus* spp.) (Johnson, 2014). Microbial activity is inhibited by the oxidation product (ferric iron), which acts as a reagent for chemical oxidation of sulfide minerals. Microbial activity is also limited by pulp density, which usually should not exceed 20%.

The new concept of two-step oxidation of gold-bearing sulfide concentrates implies separation of the chemical and biological steps of oxidation (Fomchenko et al., 2010; Muravyov et al., 2015). During the chemical step, the temperature and pulp density are maintained at the highest possible level, and ferric sulfate solution produced during the biological step is used as an oxidizer. Ferric leaching of the concentrates results in the degradation of the crystalline structure of sulfide minerals. During the biological step, all the products formed during the first step are oxidized by microorganisms. The leach solution, which contains Fe^{3+} ions and sulfuric acid, possesses a high oxidizing ability.

The mechanism of sulfide minerals biooxidation was previously investigated using thermodynamic and X-ray diffraction approaches (Fomchenko and Muravyov, 2014). Prior to microbial oxidation of sulfur, its crystalline structure was found to be altered, irrespective of the oxidized mineral. The resultant product was identified as a rare variety of elemental sulfur reproducing the β -modification of selenium. These results indicated that during the initial stage of sulfide minerals biooxidation, elemental sulfur with the crystalline structure different from the rhombic one was accumulated on the surface of the mineral particles. Analysis of arsenopyrite surface revealed its more intense

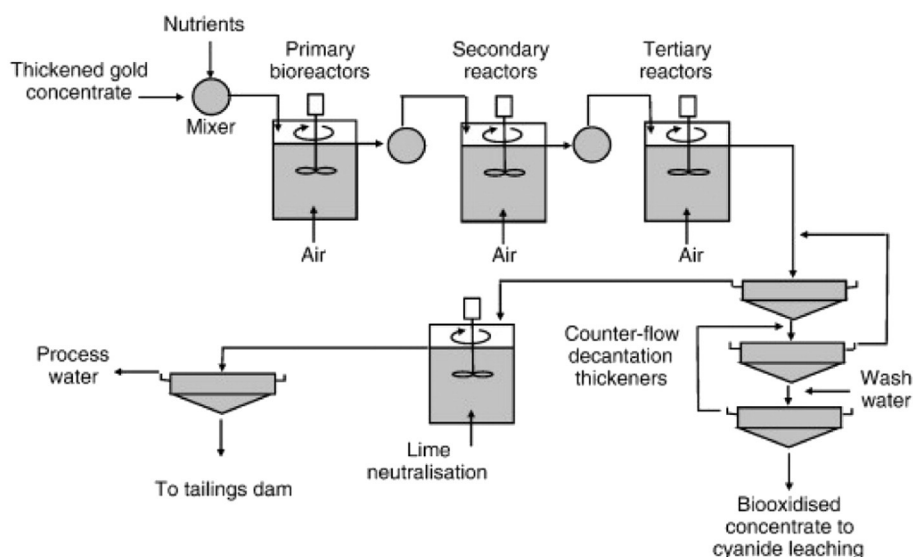


Fig. 1. Processing of gold-bearing sulfide concentrates in BIOX® reactors (Kaksonen et al., 2014b).

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