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Column Bioleaching of Refractory Gold Ores

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Abstract. Refractory sulfide ores are ubiquitous resources of gold around the world. It was demonstrated that biooxidation pretreatment of refractory whole ores could be conducted in heaps. The effectiveness of column biooxidation of off-balance gold ores from Bakyrchik and Bolshevik deposits (northeast Kazakhstan) containing pyrite and arsenopyrite was examined in the laboratory. Bakyrchick ore contained 1.5% of pyrite, 3% of arsenopyrite and 4.5 g/t of gold. Bolshevik ore contained 1% of pyrite, 1% of arsenopyrite and 10.7 g/t of gold. The recovery rates of gold from the Bakyrchik and Bolshevik ores by direct cyanidation were 4.5% and 8.2%, respectively. Representative samples of each ore were processed in air-lift percolators. A bioleaching experiment was performed in duplicate. The enrichment culture was obtained from the pyrite flotation wastes and used as an inoculum. Bioleaching was conducted for 60 days at ambient temperature (20-25°C). The recovery rates of gold from the bioleaching residues of Bakyrchik and Bolshevik ores by cyanidation were 21.0% and 48.5%, respectively. The results obtained in the present work may be used to estimate perspectives of heap bio-oxidation for the recovery of gold from these sulfide ores.

Introduction

Biomining is commercially applied using three different methods: dump, heap, and stirred tank bioleaching/biooxidation. It has considerable potential for collecting a wide range of base and noble metals. Dump and heap bioleaching is an established technology for the recovery of metals from low-grade sulfide ores [1]. Nowadays, dump and heap bioleaching is widely applied commercially for the treatment of copper and uranium ores. This technology was also used to recover nickel, cobalt, copper, and zinc from Talvivaara deposit [2]. Minerals biooxidation/bioleaching in stirred tank reactors is usually applied to sulfidic-refractory gold concentrates because of reasonable capital and operating costs associated with this technology. Stirred-tank biooxidation of sulfidic-refractory gold concentrates has been practiced for more than 20 years [1]. Heap biooxidation of sulfide gold ores as a pretreatment process has experienced only limited application on a commercial scale [3]. Newmont Gold company has successfully demonstrated that heap biooxidation of sulfide gold ores can be applied when the ore is low-grade and the mineralogy is such that the refractory sulfides cannot be concentrated. Heap biooxidation for about 150 days increased gold recovery by

cyanidation from the refractory pyrite and arsenopyrite gold ore from approximately 30% to approximately 95% (BIOPRO™ technology) [4]. The aim of this work was to investigate the efficiency of biooxidation as a pretreatment process for gold recovery from off-balance gold ores from Bakyrchik and Bolshevik deposits (northeast Kazakhstan) in air-lift percolators.

Materials and methods

The samples of gold ores from Bakyrchik and Bolshevik deposits were provided by "Bakyrchik GOK" company. Chemical and mineralogical compositions of the ores are presented in Tables 1 and 2. The P_{95} was –0.074 mm.

Table 1. Mineralogical composition of the ores.

Deposit	Content [wt.%]					
	Pyrite (FeS_2)	Arsenopyrite (FeAsS)	Silicate minerals	Carbonate minerals	Gypsum ($CaSO_4 \cdot 2H_2O$)	Rutile (TiO_2)
Bakyrchik	1.5	3	84.5	4	1	1
Bolshevik	1	1	87	4	not detected	1

Table 2. Chemical composition of the ores.

Deposit	Content [wt.%]					Content [g t^{-1}]
	Fe_{tot}	Fe_S	As_{tot}	As_S	S_S	Au
Bakyrchik	3.14	1.58	0.63	0.585	1.45	4.5
Bolshevik	3.81	2.00	0.84	0.812	1.80	10.7

Representative samples of ores (200 g) were processed in air-lift percolators (4 cm in diameter and 40 cm in height). Each percolator received 200 mL of a liquid medium containing basal nutrient salts (g L^{-1}): 1.0 $MgSO_4 \cdot 7H_2O$, 0.75 $(NH_4)_2SO_4$, 0.08 KCl, 0.15 NaCl, 0.1 $K_2HPO_4 \cdot 3H_2O$, 1.0 Fe^{2+} adjusted to pH1.5. Bioleaching experiments were carried out in duplicate (two percolators for each ore were used). The enrichment culture obtained from pyrite flotation wastes containing strains of *Acidithiobacillus ferrooxidans*, *A. caldus*, *Leptospirillum ferriphilum*, *Ferroplasma acidiphilum*, *Acidiplasma* spp. was used as an inoculum. Bioleaching was conducted for 60 days at ambient temperature (20-25°C). pH and Eh were measured with a pH-150MA pH meter–millivoltmeter. The pH was continuously monitored, and H_2SO_4 was added when necessary to maintain the pH value in the range from 1.4 to 1.6. The redox potential was measured using a platinum electrode relative to a silver chloride electrode; the values were recalculated relative to a normal hydrogen electrode. The concentrations of the Fe^{3+} and Fe^{2+} ions in the liquid phase were determined by reacting a

sample from the liquid phase with potassium thiocyanate and measured the resultant reaction spectrophotometrically at a wavelength of λ=475 nm. The concentrations of arsenic in the liquid phase were determined using a Perkin Elmer 3100 flame atomic absorption spectrometer (USA). The iron, arsenic, and sulfur concentrations in the solid phase were measured using a phase method [5]. The gold content in the solid phase was measured using a fire assay. Gold recovery was estimated by carbon-in-pulp cyanidation.

Results and discussion

Liquid phase parameters for biooxidation are presented in Fig. 1. pH adjustment with sulfuric acid was required throughout the experiment (Fig. 1 A). Sulfuric acid consumptions were (kg t^{-1}) 11 for Bakyrchik ore and 8 for Bolshevik ore. At the beginning of the experiments iron concentration fluctuated due to precipitation caused by fluctuations in pH. Subsequently, dissolved ferric and total iron concentrations gradually increased as ferrous iron concentration decreased as a result of microbial oxidation. No dissolved ferrous iron was detected in any of the percolators after 30 days. The redox potential increased in response to a change in Fe^{3+}/Fe^{2+} ratio. Concentrations of arsenic increased from 0 to 0.8 g L^{-1} in all percolators.

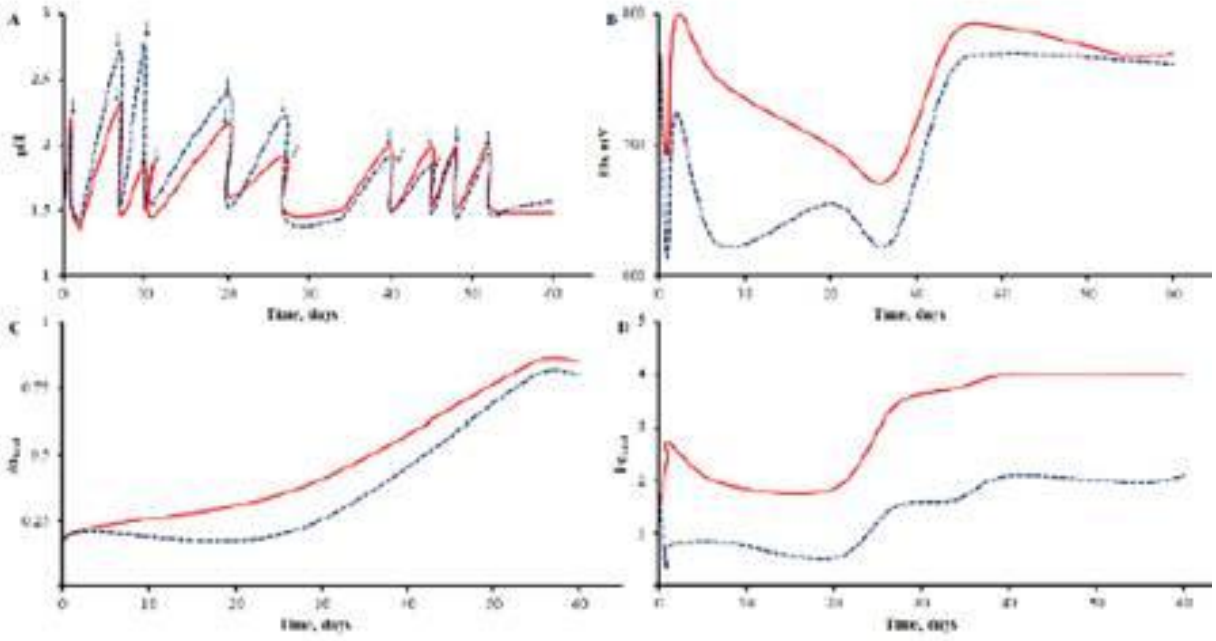

Figure 1. Liquid phase parameters for biooxidation. A – pH; B – Eh, mV; C – As_{total} (g L^{-1}); D – Fe_{total} (g L^{-1}). – – – Bakyrchik; ——— Bolshevik, ↓ – addition of sulfuric acid.

After 60 days of biooxidation solid residues were washed and dried, chemical composition of the solid residues was determined, and the extent of oxidation of the sulfide minerals was determined. The residues yields were 95% of the ore. The extent of oxidation of the pyrite and arsenopyrite in the Bakyrchik ore was 37 and 35%, respectively, and in the Bolshevik

ore, 17 and 51%, respectively. Biooxidation efficiency was calculated from the gold recovery from the biooxidized residues measured by carbon-in-pulp cyanidation (Table 3).

Table 3. Gold recovery by the cyanidation of the ores and biooxidized solid residues.

Deposit	Au recovery [wt.%]	
	Ore	Solid residue
Bakyrchik	4.5	21.0
Bolshevik	8.2	48.5

The gold recoveries from the unoxidized Bakyrchik ore and bioleach solid residue were very low (4.5% and 21.0%), whereas recoveries from the unoxidized Bolshevik ore and bioleach solid residue were visibly higher (8.2% and 48.5%). Thus, biooxidation in percolators for 60 days resulted in a five-fold increase in gold recovery from both ores. At the same time, gold recovery from Bakyrchik ore was very low after biooxidation.

Conclusions

Laboratory-scale experiments provided a demonstration of the key process performance parameters of biooxidation of off-balance gold ores from Bakyrchik and Bolshevik deposits. Obtained results suggest heap biooxidation can be a promising strategy for pretreatment of this type of ore owing to low capital and operational costs and high efficiency. Biooxidation in percolators resulted in a five-fold increase of gold recovery by cyanidation in a relatively short time. At the same time, the results demonstrated that the efficiency of biooxidation depended on the nature of the ores. This fact should be taken into consideration when planning of pilot scale experiments.

Acknowledgments

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