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Tank bioleaching of low-grade chalcopyrite concentrates using redox control

M. Gericke *, Y. Govender, A. Pinches

Biotechnology Division, Mintek, Private Bag X3015, Randburg, 2125, South Africa

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ABSTRACT

Bioleaching tests were carried out in bench-scale piloting facilities, comprising fully controlled multi-stage continuously operated reactor systems using moderate thermophile and thermophile consortia under both uncontrolled and controlled redox potential conditions to assess the effect of temperature and redox control on chalcopyrite leach kinetics. The bench-scale studies demonstrated that copper recoveries >95% could be achieved without redox control, using a thermophilic culture at 70 °C. Acceptable copper extractions could not be achieved under similar conditions at 45 °C. A significant increase in the copper leach kinetics and copper extractions was, however, achieved by controlling the redox potential in the 45 °C system at 420 mV. Final copper extractions increased from 64% at high redox potential to 97% under controlled redox conditions and as a result of the improvement in the Cu leach performance there is potential to reduce the overall residence time of the process. A key advantage of the process is that the bioleaching process costs are minimized, since the pyrite was not oxidized.

1. Introduction

Over the past two decades, the optimization of bioleaching processes for the treatment of chalcopyrite ores and concentrates has been the subject of numerous research programmes. Many papers have dealt with the issue of slow kinetics of chalcopyrite bioleaching and its passivation. Various theories have been proposed to account for this phenomenon, mostly involving passivation of the mineral by ferric precipitates and/or sulfur, though there is no consensus on the exact mechanistic reason for the recalcitrance of chalcopyrite to leaching (Stott et al., 2000; Sandstrom et al., 2005; Parker et al., 2003; Muñoz et al., 1979; Klauber, 2008; Hackl et al., 1995).

Advances in understanding the requirements for successful bioleaching of chalcopyrite concentrates have led to a number of experimental campaigns to show that high copper recoveries are achievable. Process options suggested include the use of high temperatures and thermophilic archaea, which have been successfully used in continuously operated bioleaching systems to overcome the slow and incomplete extraction of copper from chalcopyrite (Gericke et al., 2001; d'Hugues et al., 2002). It has also been shown that the incomplete extraction of copper from chalcopyrite can be overcome by operating at controlled redox levels (Third et al., 2002; van der Merwe et al., 1998), through the addition of catalysts such as silver (Cancho et al., 2007) and by fine grinding of the concentrate (Rhodes et al., 1998).

During recent years, the use of moderate thermophiles in bioleaching processes has received increased attention, since their optimal growth temperature of 45–52 °C represents a kinetic advantage over mesophilic conditions; they can grow at higher pulp densities than thermophiles (Nemati et al., 2000) and can tolerate higher concentrations of catalysts such as silver (Gómez et al., 1999).

The first commercial utilization of moderate thermophiles was by Bactech (Australia) Ltd for the bio-oxidation of a refractory gold concentrate in Western Australia. The plant at the Youanmi mine was operated at 45–47 °C, resulting in 90–97% gold recovery (Brierley, 2008).

In 2001, Mintek and its partners, Industrias Penoles S.A. de C.V. of Mexico and BacTech, successfully demonstrated the bioleaching of chalcopyrite using moderate thermophiles at an operating temperature of 45 °C in an integrated demonstration plant that was commissioned and operated in Monterrey, Mexico. The complex polymetallic concentrate, in which the main copper mineral was chalcopyrite, contained high levels of silver, which acted as a catalyst, resulting in copper recoveries of 95% at a concentrate feed rate of 2.7 t/day, provided the concentrate was milled to 100% <30 µm (van Staden, 1998).

Table 1
Chemical composition of the concentrate.

Element	Mass %
Cu	14.5
Fe	32.5
S°	0.3
S^{2-}	32.8
Si	2.5

* Corresponding author. Tel.: +27 11 709 4442; fax: +27 11 709 4579.
E-mail address: Mariekieg@mintek.co.za (M. Gericke).

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Table 2
Mineralogical composition of the concentrate based on SEM-analysis.

Mineral	Mass %
Chalcopyrite	48.0
Pyrite	35.4
Cu-sulfides[a]	0.1
Quartz	6.3
Chlorite	4.2
Mica	3.2
Feldspar	1.8
Fe-oxides	0.9
Gypsum	<0.1

[a] Mainly covellite, includes chalcocite.

Table 3
Summary of bioleach amenability results obtained during steady state conditions while operating at 45 and 70 °C (10% feed solids, 6-day residence time).

	Stage 1	Stage 2	Stage 3
Test 1			
Temperature (°C)	70	70	70
Accumulative residence time (day)	3	4.5	6
pH	1.1	1.0	1.0
Redox potential (mV, Ag/AgCl)	560	630	670
Soluble Fe (g/L)	24.6	28.2	26.6
Soluble Cu (g/L)	16.1	16.5	16.9
Fe extraction (%)	72	77	77
Fe extraction–HCl (%)	89	93	93
Cu extraction (%)	88	95	97
Test 2			
Temperature (°C)	45	45	45
Accumulative residence time (day)	3	5	6
pH	1.0	0.9	0.9
Redox potential (mV, Ag/AgCl)	640	690	710
Soluble Fe (g/L)	20.7	23.5	25.2
Soluble Cu (g/L)	7.4	8.6	8.8
Fe extraction (%)	65	76	78
Fe extraction–HCl (%)	75	84	86
Cu extraction (%)	52	61	64

The work presented in this paper describes research carried out on a low-grade chalcopyrite concentrate in continuously operated mini-pilot plant facilities to assess the effect of temperature and redox potential on chalcopyrite leach kinetics and copper extractions. For the treatment of this concentrate, which did not contain silver, a number of processing requirements had to be achieved, namely, high Cu extractions from the chalcopyrite-containing concentrate, reduction of processing costs because of the low-grade of the concentrate and minimisation of the environmental impact from the waste products produced.

2. Materials and methods

2.1. Mineral characteristics

The test work was performed using Veliki Krivelj, a low-grade chalcopyrite concentrate provided by the Copper Institute Bor, Serbia. The concentrate was fine-milled in a stirred ball mill to a particle size of $d_{90} = 12\,\mu m$. The chemical composition of the concentrate is presented in Table 1.

The different proportions of each mineral phase in the feed concentrate and in the bioleach residues were determined by scanning electron microscopy (SEM) based image analysis. The concentrate was found to contain chalcopyrite and pyrite as the main mineral phases. Modal analysis of the feed is described in Table 2.

2.2. Inoculum

The study was performed with moderate thermophilic (45 °C) and thermophilic (70 °C) cultures, which have been maintained for several years at Mintek on chalcopyrite-containing concentrates. The moderate thermophile culture contains *Acidithiobacillus caldus*, *Leptospirillum ferriphilum*, *Sulfobacillus* sp. and *Ferroplasma* sp. (Okibe et al., 2003), while the thermophile culture is dominated by *Acidianus brierleyi*, with lower numbers of *Metallosphaera sedula* and *Sulfolobus* sp. present (Dinkla et al., 2009).

2.3. Continuously operated tests

Bioleach amenability test work performed at 70 °C was carried out in a fully controlled continuously operated 3-stage reactor system with a volume of 2 L in the first stage reactor and 1 L each in the consecutive reactors. The test work at 45 °C was performed in a larger-scale multi-stage continuously operated reactor system, consisting of a 30 L first stage reactor, followed by two secondary reactors of 20 and 10 L respectively. Both systems consisted of a feed pulp tank and three reactors in series with a container at the end for product collection. Nutrients were added to the feed tank at the following concentrations; 1 g/L $(NH_4)_2SO_4$, 0.5 g/L $MgSO_4.7H_2O$, 0.1 g/L KCl and 0.5 g/L K_2HPO_4. Feed slurry was fed to the first reactor from the feed tank via a peristaltic pump. For the 2 L system, peristaltic pumps were used to transfer pulp between reactors at the same flow rate as the feed slurry. Pulp transfer between the larger reactors was by means of gravity overflow.

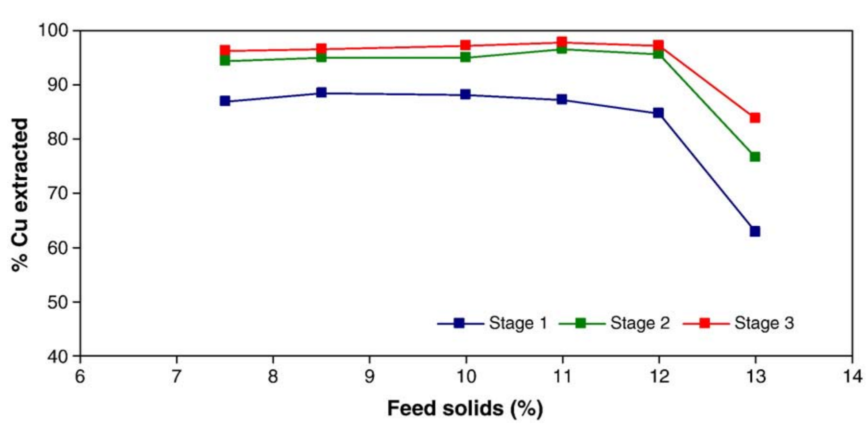

Fig. 1. The effect of feed solids concentration on Cu recoveries while operating at 70 °C.