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A comparison of bioleaching ability of mesophilic and moderately thermophilic culture on copper bioleaching from flotation concentrate and smelter dust

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ABSTRACT

This study evaluates bioleaching treatments of chalcopyrite concentrate and smelter dust using mesophilic and moderately thermophilic bacterial cultures. Effects of some variable parameters such as solids concentration, temperature (type of bacteria) and inoculation on the bioleaching of the materials obtained from Sarcheshmeh copper complex were investigated. Bioleaching experiments were carried out in shaking incubator using mixed mesophilic and moderately thermoacidophilic bacteria. The results indicate that the efficiency of copper extraction is dependent on all the variables studied for both microorganisms. Maximum copper recovery from concentrate and dust was achieved using a moderately thermophilic culture.
Under optimum conditions, copper dissolution from concentrate reached 87.52% with moderately thermophilic, and 34.55% with mesophilic culture, after 25 days. Also, overall copper extraction calculated for dust bioleaching were 92.00% with moderately thermophilic bacteria and 73.27% with mesophilic bacteria.

1. Introduction

Bioleaching of copper and other heavy metals remains a promising technology as compared to other conventional technologies due to its relative simplicity, mild operation conditions, low capital costs, low energy input and relatively unskilled labor and its friendship towards the environment (Acevedo, 2000).

Two reverberatory and converter furnaces in the Sarcheshmeh copper complex (south-east of Iran) produce nearly 50 tpd copper dust with about 30% copper content. At present, the dust is recycled to the furnaces which resulted in the reduction of their efficiencies and increase the required energy for their smelting; furthermore, it damages the refractory bricks and imposes a circular load on the furnaces (Bakhtiari et al., 2008a, 2008b). Also, in this copper complex about 1500 tpd chalcopyrite concentrate is produced with about 27% copper content.

The flue dusts of Sarcheshmeh Copper Complex which mainly consisted of secondary sulphide minerals (Massinaie et al., 2006) were much more reactive in bioleaching media than chalcopyrite (Weston et al., 1995; Rawlings, 2002). According to Rear et al. (1994), the rate of chalcocite leaching was about five times the rate of chalcopyrite leaching.

According to Bakhtiari et al., 2008a, 2008b, bioleaching of dust is feasible at stirred tank and airlift bioreactors up to 7% pulp density, and maximum recovery can be about 90% using mesophilic bacteria. Also, at the agitated bioreactor with 5% pulp density, maximum recovery of dust achieved was nearly 91% using mesophilic bacteria (Massinaie et al., 2006).

Copper bioleaching from Sarcheshmeh chalcopyrite concentrate in stirred tank reactor conditions (pulp density 10% w/v) results in maximum copper recovery of around 37% or 65% after 22 days in the presence of mesophilic or moderately thermophilic cultures (Ahmadi et al, 2010).

The surface passivity by elemental sulphur, ferric precipitates or intermediate copper polysulphides at the high solution potentials (>600 mV vs. Ag/AgCl) are the most important problems of chalcopyrite bioleaching using mesophiles (Hiroyoshi et al., 2001a; Third et al, 2002; Petersen and Dixon, 2002a, 2002b).

To overcome these problems, chalcopyrite bioleaching must be conducted with thermophiles which greatly improve the reaction kinetics, additionally, avoid excessive chalcopyrite passivation which hinders the durative bioleaching (Zhou et al, 2009).

Mixed thermophilic cultures have shown higher ability for chalcopyrite bioleaching than mesophiles (Ahmadi et al., 2010). Also, because moderate thermophilic microorganisms are more resistant to higher pulp densities and higher heavy metal concentrations than extreme thermophiles, these microorganisms are being preferred (Rodriguez et al, 2003; Olson and Clark, 2004).

Comparatively studies on bioleaching ability of mesophilic and thermophilic bacteria indicated that thermophilic bacteria have higher ability for treatment of several types of materials (Romano et al, 2001; Wang et al, 2008).

The aim of the present work was to determine the efficacy of copper bioleaching from chalcopyrite concentrate and smelter dust using mixed cultures of mesophilic and moderate thermophilic bacteria,

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and to compare the characteristics of mesophilic and moderate thermophilic bioleaching of the materials.

2. Materials and methods

2.1. Flotation concentrate

A representative copper sulfide flotation concentrate, obtained from Sarcheshmeh Copper Mine (Kerman, Iran) was used in all experiments. X-ray fluorescence (XRF) and X-ray diffraction (XRD) analyses of the sample showed 27.32% Cu, 26.87% Fe, 30.54% S, 0.99% Zn and chalcopyrite ($CuFeS_2$) as the major mineral and pyrite (FeS_2) as the minor one together with small amounts of other sulfides and oxides. The particle size analysis of the samples by sieving and cyclosizer resulted to a d_{80} of about 40 μm.

2.2. Smelter dust

For one month, several samples were taken from the dust collectors of reverberatory and converter furnaces. The samples were mixed according to their production ratio, three parts of reverberatory and two parts of converter furnaces dust. Representative dust sample was sent to X-ray fluorescence (XRF), X-ray diffraction (XRD) analyses, mineralogy and assaying laboratory. The analysis results showed that the major copper sulfide minerals present in the pre-leached dust were chalcocite 24.3%, bornite 8.6%, and chalcopyrite 5.5%. Also, there were fairly amounts of arsenic 1.25% and lead 2.13%. The density of the pre-leached dust was 4570 kg/m^3. The particle size analysis of the samples by sieving and cyclosizer resulted to a d_{80} of about 60 μm.

2.3. Apparatus and bacterial cultures

Two types of mixed cultures were used in the bioleaching tests. The first one contained strains of *Acidithiobacillus ferrooxidans*, *Acidithiobacillus thiooxidans*, and *Leptospirillum ferrooxidans*. This culture was previously isolated from the Sarcheshmeh Copper Mine (Iran). The second culture consisted of moderately thermophilic, acidophilic iron and sulfur oxidizing bacteria and was originally obtained from the Mintek Company (South Africa).

The mixed cultures were used in adaptation experiments in which the bacteria gradually acclimatized themselves to different concentrate and pre-leached dust concentrations as sole energy source. The isolates were adapted and grown with gradually increased concentrations of concentrate and pre-leached dust up to 10% (w/v) and 7% (w/v), respectively, in 500 mL Erlenmeyer flasks containing 200 mL of nutrients and bacteria (mesophilic and moderately thermophilic).

The materials (concentrate and dust) were added to 500 ml Erlenmeyer flasks containing 200 ml of the 9 K basal salts and inoculum and the pH was adjusted with sulfuric acid on 1.5. Cultures were incubated at 35 °C (mesophilic) and 50 °C (moderately thermophilic) in a temperature-controlled orbital shaker (Innova 4200 model, New Brunswick scientific company, USA) at 150 r/min and examined by measuring pH (MP120 model, Mettler Toledo Company, Switzerland) and growth was monitored by measuring oxidation reduction potential (ORP) using a pH/Eh meter (826 pH mobile model, Metrohm Company, Switzerland) for ferrous iron and sulfur oxidation ability.

2.4. Shake flask experiments

Mesophilic bioleaching tests were carried out in 500-ml flasks incubated in a Kohner shaking incubator at 35 °C with an agitation rate of 150 rpm as well as moderately thermophilic bacteria at 50 °C and 130 rpm. Periodically redox potential and pH of the pulp were controlled on 1.5, and adjusted using sulphuric acid when its value was higher than 1.5. Samples (1 ml) were removed from the flasks and analyzed for Cu. Loss of water and taken sample from the system was compensated by distilled and nutrient medium, respectively. In control tests (inoculation = 0%), media were inoculated with 5% (v/v) of methanol solution containing 2 g/l thymole to inhibit bacterial growth. The progress of the bacterial leaching was monitored by daily measurement of ORP values, as well as copper analyses of solutions and final leached residues.

3. Results and discussion

Fig. 1 shows XRD patterns of "as received" chalcopyrite concentrate. The main minerals at the powder contain chalcopyrite, pyrite and quartz.

Having been leached considerable amount of acid soluble copper (13% w/w) of dust in a stirred vessel, the solid residue was used for bioleaching tests. In turn, the as-received dust analysis by XRD indicated that $CaSO_4$, PbS, CuO were responsible for absolute acid consuming during chemical leaching.

XRD pattern of dust after chemical leaching is shown in Fig. 2. The main compounds in the dust were magnetite, gypsum, and galena, anglesite, hematite, copper oxide, and bornite. There were not significant peak of secondary copper sulphids in XRD pattern. However, the photomicrograph and mineralogical analysis of the dust apparently exhibits the presence of a high amount of secondary copper sulphides such as Cu_2S, CuS whose peak breadths in XRD analysis were completely wide that indicate their likely deformed crystalline structure due to smelting process.

Rates of copper solubilization from chalcopyrite concentrate and smelter dust processed at 35 °C and 50 °C using mesophilic and moderately thermophilic bacteria, respectively, are shown in Fig. 3. These results show that at low pulp densities (3% and 5% w/v), the copper extraction was higher than the high pulp densities (7% and 10% w/v). The main reason for inefficient bioleaching at high pulp density is that the rate of oxygen demand outstrips the oxygen supply which is limited by gas–liquid mass transfer rates. For this reason, 7% (w/v) of pulp density was selected as the best level for both concentrate and dust.

The experimental results indicated that the leaching rates of the two types of copper sulphides significantly decreased from dust to concentrate and finally to the bioleaching under the same conditions with the two types of bacteria, mesophilic and moderately thermophilic bacteria. The effect of the base bacterial inoculation values shown in Fig. 4, also, displayed that the leaching rate of copper sulphides increased proportionally with the increase of bacteria inoculation.

Effect of bacteria inoculation on their growth and activity to ore, pH, Eh, and extraction of copper was studied with mesophilic and moderately thermophilic consortium as inoculum. Furthermore, the results compared with chemical leaching (inoculation = 0% (v/v)). The increase of the potential is directly related to the bacterial activity in the

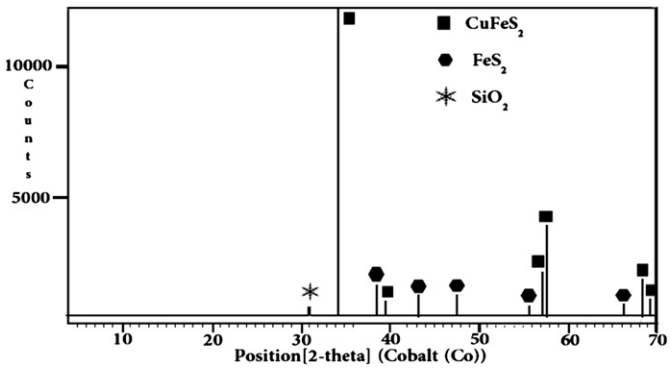

Fig. 1. XRD patterns of "as received" chalcopyrite concentrate.