Available online at www.sciencedirect.com

SCIENCE DIRECT

Hydrometallurgy 82 (2006) 75–82

hydrometallurgy

www.elsevier.com/locate/hydromet

Bioleaching of low-grade sphalerite using a column reactor

S.M. Mousavi [a,b,*], A. Jafari [b], S. Yaghmaei [a], M. Vossoughi [a], R. Roostaazad [a]

[a] *Department of Chemical and Petroleum Engineering, Sharif University of Technology, Tehran, Iran*
[b] *Department of Energy and Environmental Engineering, Lappeenranta University of Technology, Lappeenranta, Finland*

Received 23 January 2006; received in revised form 28 February 2006; accepted 7 March 2006
Available online 11 May 2006

Abstract

The effects of several variables on zinc recovery in column bioleaching have been investigated. The ore contained sphalerite and pyrite as the main sulfide minerals and chalcopyrite and galena as minor minerals. Tests were carried out using a bench-scale column leach reactor which was inoculated with mesophilic (*Acidithiobacillus ferrooxidans*) and thermophilic (*Sulfobacillus*) iron oxidizing bacteria; initially isolated from the Sarcheshmeh chalcopyrite concentrate (Kerman, Iran) and Kooshk sphalerite concentrate (Yazd, Iran), respectively. In the inoculated column, jarosite and elemental sulfur were formed. The leaching rate of sphalerite tended to increase with dissolved ferric ion concentration. Microscopic counts of bacteria in the solution tended to be higher at lower pH ranges. Furthermore, the effect of a decreasing particle size on the rate of zinc leaching was enhanced at low pH values. Results show that the maximum zinc recovery was achieved using a thermophilic culture. Zinc dissolution reached 72% and 85% for the mesophilic and thermophilic strains, respectively, after 120 days at column temperatures ranging from 28 to 42 °C.

Keywords: Bioleaching; Zinc; Sulfide ore; Column reactor; Sulfobacillus; Acidithiobacillus

1. Introduction

Bacterial leaching or bioleaching of base metal sulfides is in use commercially and offers many cost advantages over other techniques such as pressure oxidation. Bioleaching involves the use of iron and sulfur-oxidizing micro-organisms to catalyze the dissolution of valuable metal species; such as zinc, copper, nickel or cobalt from sulfide ores or flotation concentrates. Base metal bioleaching is concurrent with the recovery of the metals from a bleed solution stream by conventional downstream processes such as solvent extraction and electrowinning. The principal bioleaching techniques in use for the treatment of sulfide minerals include stirred tank leaching, heap and dump leaching, and concentrate heap leaching. Heap leaching provides both operating and capital cost advantages. However, the use of heap leaching is limited to cases in which the temperature can be maintained within the heap at a suitable temperature without external heating. (Sampson et al., 2005).

A wide range of sulfide minerals can be oxidized by the common bacteria that are found in bioleaching environments. These include; pyrite (FeS_2), chalcopyrite ($CuFeS_2$), arsenopyrite (FeAsS), sphalerite (ZnS), pentlandite ($(FeNi)_9S_8$) and pyrrhotite (FeS). Bioleaching of sulfide minerals is based on the exploitation of the ability of the acidophilic bacteria to oxidize ferrous iron (Eq. (1)) and/or oxidize elemental sulfur (Eq. (2)). The actual role of bacteria in the bioleaching process has not

* Corresponding author. Department of Chemical and Petroleum Engineering, Sharif University of Technology, Tehran, Iran. Tel.: +98 21 66165494; fax: +98 21 66005417.
E-mail address: mousavi@mehr.sharif.edu (S.M. Mousavi).

0304-386X/$ - see front matter
doi:10.1016/j.hydromet.2006.03.001

been completely resolved (Lizama and Suzuki, 1989; Suzuki, 2001; Tributsch, 2001). However, recent findings (Fowler and Crundwell, 1999; Sand et al., 2001) suggest that the oxidation of sulfide minerals occurs mainly via the chemical attack by ferric iron and/or acid (Eqs. (3) and (4)) (Boon et al., 1998) which are generated by bacteria:

$$2FeSO_4 + H_2SO_4 + 1/2\ O_2 \overset{\text{bacteria}}{\rightarrow} Fe_2(SO_4)_3 + H_2O \quad (1)$$

$$S^0 + H_2O + 3/2\ O_2 \overset{\text{bacteria}}{\rightarrow} H_2SO_4 \quad (2)$$

$$ZnS + 1/2\ O_2 + H_2SO4 \rightarrow ZnSO_4 + S^0 + H_2O \quad (3)$$

$$ZnS + Fe_2(SO_4)_3 \rightarrow ZnSO_4 + S^0 + 2FeSO_4 \quad (4)$$

$$4FeS_2 + 15O_2 + 2H_2O \rightarrow 2Fe_2(SO_4)_3 + 2H_2SO_4 \quad (5)$$

$$PbS + Fe_2(SO_4)_3 \rightarrow PbSO_{4(s)} + 2FeSO_4 + S^0 \quad (6)$$

The oxidation of galena (Eq. (6)) leads to the formation of lead sulfate, which is ‘‘insoluble’’ (0.045 g/L at 25 °C; Forward and Peters, 1985) under bioleaching conditions and reports to the residues. This raises the possibility of the selective extraction of metals such as zinc from complex ores/concentrates.

There are several important factors such as the temperature, pH, availability of nutrients, sulfide minerals, O_2 and CO_2, solid ratio, metal toxicity, etc., that affect the growth of bacteria and hence the dissolution process (Mousavi et al., 2005). The presence of some ions such as K^+, Na^+, and SO_4^{2-} in bioleaching environments could promote the formation of solid products such as ferric precipitates (e.g., potassium jarosite) which is controlled by pH (Tuovinen and Bhatti, 1999). The limited extraction of metals has often been attributed to the formation of these secondary phases during bioleaching (Ahonen and Tuovinen, 1995; Gomez et al., 1999; Hiroyoshi et al., 1999).

In the bacterial leaching of sulfide minerals, ferric iron is an important oxidizing agent. Soluble iron species are the main determinants of redox potential, with active iron oxidizing bacteria (*Acidithiobacillus ferrooxidans, Leptospirillum ferrooxidans*) contributing to high Fe^{3+}/Fe^{2+} ratios. Precipitation of iron oxide and jarosite phases in the leaching system may suppress the metal solubilization by preventing the contact between the leaching agent and the mineral. The solubility of iron is defined by the solution redox potential and pH.

The bacterial leaching process requires acidic conditions, the acidity often being autonomously produced by the oxidation of pyrite and hydrolysis of ferric ion. The acid may be neutralized in various acid-consuming reactions; for example, the leaching of carbonate minerals and some silicate minerals. As in all biochemical and chemical processes, the rates of leaching reactions are also temperature dependent. Therefore, evaluation of the temperature effects on the bacterial leaching is considered to be particularly important (Ahonen and Tuovinen, 1992).

Leaching in columns, with or without the recirculation of the leaching liquid, simulates percolation leaching because the conditions are very similar to those in the heap. Since results obtained in the laboratory can be extrapolated, with slight correction, to the real situation they will help show whether bacterial leaching is possible under acceptable conditions. In this sense, we might consider the columns as the heart of the heap, with the same degree of access for the leaching solution and the circulating gases. In other words, a column experiment simulates the flow or one of the possible paths of a liquid percolating through a mass of material by gravity.

This paper describes the bioleaching of Iranian low-grade sphalerite ore by *A. ferrooxidans* and *Sulfobacillus* in a column bioreactor. The results are discussed in terms of some investigations on the sulfide leachability by two indigenous micro-organisms: the mesophilic *A. ferrooxidans* and the thermophilic *Sulfobacillus*.

2. Material and methods

2.1. Minerals and micro-organisms

The sphalerite used throughout this study was the natural mineral obtained from the Kooshk Lead–Zinc Mine, (Yazd, Iran). The natural mineral was ground to obtain a sample in the size range of 5–30 mm. The elemental composition of ore samples is based on the averaged results obtained by X-ray fluorescence spectrometry (XRF). The chemical composition of the mineral sample was 8.9% Zn; 2.9% Pb; 8% Fe; 22.8% S; 9.32% Si; 2.3% CaO and less than 0.2% Cu. X-ray diffraction (XRD) analysis of the ore showed sphalerite (ZnS) (13%); pyrite (FeS_2)(14%), and quartz (SiO_2) (18%) as the major components and calcite ($CaCO_3$) (5%) and galena (PbS) as the minor ones. Chalcopyrite ($CuFeS_2$) was present in trace amounts.

The mesophilic and thermophilic iron oxidizing bacteria used in this work were isolated from the Sarcheshmeh chalcopyrite concentrate (Kerman, Iran) and the Kooshk sphalerite concentrate (Yazd, Iran). Mesophilic