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The contribution of direct and indirect actions in bioleaching of pentlandite

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Abstract

The mechanisms of bioleaching of pentlandite by mesophilic *Acidithiobacillus ferrooxidans* and thermophilic MLY were investigated. The experimental results showed that the mechanisms were different when pentlandite was bioleached by the two bacteria. It was found that the direct action of the attached bacteria was more important than indirect action of the free cells in the solution during the *A. ferrooxidans* leaching of pentlandite, and that only the indirect action was significant during the MLY leaching of pentlandite.

Keywords: Pentlandite; Bioleaching; *Acidithiobacillus ferrooxidans*; Thermophilic MLY

1. Introduction

As an environmentally benign technology with wide application, biohydrometallurgical processing is characterized by low cost for recovering metals from low-grade ores. Biohydrometallurgy has received growing attention due to the increasingly stringent environmental protection regulations (Smith and Misra, 1993; Bartlett, 1996; Miller, 1997). The most extensively used bacterium in bioleaching of sulfide ores is *Acidithiobacillus ferrooxidans*, a strain of mesophilic bacteria. However, *A. ferrooxidans* cannot grow at higher temperatures (more than 40 °C), and this limits its efficiency in leaching. For this reason, great effort is currently devoted to finding more efficient bacteria to replace *A. ferrooxidans*. Thermophilic bacteria attract close attention due to the higher operating temperature (Methta and Murr, 1982; Boogerd et al., 1991; Brierley and Brierley, 1993).

Although bioleaching investigations have covered a lot of sulfide ores, studies on bioleaching mechanisms are focused on only a few minerals, such as pyrite (Boon and Heijnen, 1998; Boon et al., 1999) and chalcopyrite (Bhattacharya et al., 1990; Herrera et al., 1989; Blancarte-Zurita et al., 1986; Yasuhiro et al., 2001). The leaching mechanisms are relatively complex and often vary with the composition of the

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minerals. Though pentlandite is an important Ni-containing mineral, only a few studies have been devoted to the bioleaching of this mineral (Southwood, 1985; Miller, 1990; Nakazawa et al., 1993; Dew, 1999.). There are two main bioleaching mechanisms that lead to the dissolution of sulfides. For instance in *A. ferrooxidans* leaching of pyrite, the two mechanisms can be described briefly as follows (Shrihari et al., 1995).

The direct mechanism is

$$FeS_2 + \frac{7}{2}O_2 + H_2O \xrightarrow{\text{bacteria}} FeSO_4 + H_2SO_4 \quad (1)$$

And the indirect mechanism is

$$2FeSO_4 + H_2SO_4 + \frac{1}{2}O_2 \xrightarrow{\text{bacteria}} Fe_2(SO_4)_3 + H_2O \quad (2)$$

$$FeS_2 + Fe_2(SO_4)_3 \rightarrow 3FeSO_4 + 2S. \quad (3)$$

For the direct oxidation mechanism, the bacteria attach themselves onto the surface of the sulfide ores and directly solubilize the surface through hypothesized enzymatic oxidation reaction. Indirect oxidation occurs through microbial catalytic oxidation of aqueous ferrous to ferric ions and successive direct oxidation of sulfide by ferric ions. Some enzymatic effects are involved in the direct mechanism, but the indirect mechanism includes only chemical dissolution of sulfide due to ferric ions and sulfuric acid produced by the bacteria.

Quite diversified opinions about the mechanism of bioleaching of sulfides have been put forward. The effect of the adhered bacteria is to raise pH at the surface of ore particles so that the leaching rate is enhanced (Harvey and Crundwell, 1997; Fowler and Crundwell, 1998; Fowler et al., 1998). There are two indirect mechanisms in bioleaching, i.e. acid-insoluble metal sulfides such as FeS_2 are attacked by iron (III) only, generating thiosulfate; other metal sulfides can be attacked by both iron (III) and protons, resulting in the formation of elemental sulfur via polysulfides (Schippers and Sand, 1997). It has been postulated that there is no direct interaction between the bacterial membrane and the sulfide mineral in the enzymatic mechanism; the effect of attached bacteria is to condition surroundings of the sulfide to facilitate dissolution, which otherwise would not take place. Thus, the suggestion has been made that the "direct mechanism" should be renamed as "contact leaching" (Tributsch, 2001; Rojas-Chapana and Tributsch, 2000; Tributsch and Rojas-Chapana, 2000). Meanwhile, some researchers have suggested that the mass transfer of Fe(II), which is chemically produced at the pyrite surface, to the bulk solution determines the maximum observed chemical oxidation rate of pyrite and that this explains why the bacterial oxidation rate of pyrite is faster than the sterile pyrite oxidation (Boon, 2001).

In this study, pentlandite was bioleached by *A. ferrooxidans* and thermophilic bacteria MLY, and special designed experiments were conducted to shed light on the mechanisms of bioleaching. Pentlandite is the major ore phase containing Ni in Jinchuan Mine, the largest nickel-producing base in China. A pure sample of pentlandite was used in order to eliminate effects of impurity as completely as possible.

2. Materials and methods

2.1. Strains and growth conditions

The strains of *A. ferrooxidans* and thermophilic bacteria MLY were provided by Institute of Microbiology, Chinese Academy of Science. The strain of *A. ferrooxidans* was cultured in the Leathen medium containing 5% (wt/wt) pentlandite concentrate (the process line product) for a long time for being adapted to the pulp environment under the condition of 35 °C and 170 min^{-1}. The iron-free Leathen medium (Leathen et al., 1951), containing 0.15 g/L $(NH_4)_2SO_4$, 0.05 g/L KCl, 0.05 g/L K_2HPO_4, 0.5 g/L $MgSO_4 \cdot 7H_2O$, 0.01 g/L $Ca(NO_3)_2$, was used as the culture medium for both *A. ferrooxidans* and MLY. The unadapted strain of *A. ferrooxidans* was cultured in the Leathen medium containing 5 g $FeSO_4 \cdot 7H_2O$ per 100 mL.

The bacteria MLY is a thermophilic strain found from mine water. Its optimum temperature is between 45 and 55 °C and the most optimum temperature is about 50 °C (Li and He, 2001). MLY was also cultured in the Leathen medium containing 5 g $FeSO_4 \cdot 7H_2O$ per 100 mL, but 0.02 g yeast extract was added.