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Silver-catalyzed bioleaching of copper, molybdenum and rhenium from a chalcopyrite–molybdenite concentrate

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ABSTRACT

This study evaluated silver-catalyzed bioleaching to solubilize copper from a chalcopyrite-bearing molybdenite concentrate with mesophilic (32 °C) and moderately thermophilic (45 °C) microbial consortia. The Cu content of the concentrate was 0.987 (wt/wt) with chalcopyrite as the major Cu bearing mineral. The molybdenite phase (53.81 Mo) also contained 0.055 % rhenium. The addition of Ag⁺ as silver nitrate greatly enhanced copper dissolution under bioleaching conditions. Overall, >99% Cu was leached in the bioleaching experiments involving the addition of up to 200 mg l⁻¹ Ag, compared by 53% Cu solubilization in the absence of silver. The highest relative yields (>99%) were obtained under moderately thermophilic condition. Different pH conditions (1.0–9.0) and initial pH values (1.5–1.9) were also tested in the bioleaching experiments. These effects were masked by the effect of silver leaching due to silver catalysis. The results indicated the ability to change the bioleaching conditions to increase the leaching rate, suggesting that Ag was located in the molybdenite matrix. The relative dissolution was <13 Mo and <88 Re, and only a minor enhancement of their dissolution was observed upon Ag addition. Compared with the bioleaching with mesophiles at 32 °C, the dissolution of Mo and Re was lower in the 45 °C experiments with moderate thermophiles. Because the corresponding yields of Cu dissolution increased with the temperature, this difference suggested early passivation of molybdenite. Mo precipitation or a suppression of molybdenite oxidation capacity of the moderately thermophilic culture at the higher temperature.

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1. Introduction

Cu- and Fe-sulfides are typical impurities in molybdenite (MoS₂) concentrates and are difficult to remove adequately by conventional physical and chemical separation techniques. In principle, Cu- and Fe-sulfide minerals can be oxidized in bioleaching processes but concurrent solubilization of molybdenite may also occur. The leaching of mixed sulfide minerals involves galvanic interactions. In the electrochemical series of semiconductive sulfide minerals, molybdenite has a higher electrode potential than chalcopyrite (CuFeS₂). If only controlled by galvanic coupling,

molybdenite in contact with chalcopyrite acts as a cathode and is protected from oxidative leaching while chalcopyrite is anodically dissolved. However, many other factors interplay in the bioleaching process. The bioleaching of sulfide minerals involves oxidants such as Fe³⁺ and iron- and sulfur-oxidizing, acidophilic prokaryotes. Bioleaching of molybdenite in acid solutions leads to the formation of the molybdate ion (*Hansen et al., 2000a,b,c*).



The bioleaching of molybdenite is mediated by ferric iron. The role of acidophilic prokaryotes in this process is to oxidize ferrous iron and sulfur compounds and help maintain high redox potential in favor of molybdenite oxidation as determined by the Fe³⁺/Fe²⁺ ratio. Mesophilic bioleaching of molybdenite was tested already in the mid-1950's with undefined iron- and pyrite-

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Bioremediation of Organic Waste Sites: A Critical Review of Microbiological Aspects

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An overview is presented of the potential for bioremediation of a range of contaminated sites. Most of the compounds being groups are widespread and are generally present in soil. Although attention has been focused on abiotic processes of degradation, there is a growing interest in microbial degradation, largely input from petroleum, organic chemicals and microbiologists. It is emphasized that a protocol must be available for evaluating the success of the remediation of a local site. Attention is directed to several types of partial degradation, formation of metabolites and evaluation of specific enzymes in complex mixtures. An attempt is made to discuss the basic aspects of the biodegradation of compounds specific to the various sites. The discussion is limited to environments that are common in laboratory-based pilot-scale or full-scale field operations, that discussion is given of some less commonly perceived contaminants that may be present simultaneously. © 1997 Elsevier Science Limited

INTRODUCTION

Orientation

There is increasing concern over the increasing volume of solid waste both industrial and domestic. There are several reasons for this:

- (1) Some sites occupy valuable land in urban areas and it is therefore imperative that its reuse for commercial or domestic buildings must be insured against present or future health risks.
- (2) There is environmental concern over long-term effects of landfills used for industrial waste on account of hazard from the transformation of the components and discharge of leachate into water courses.
- (3) The volume of domestic waste is large, although its heterogeneity will be diminished with the adoption of source-separation by households.

It should also be emphasized that the sludge from industrial water treatment facilities may be sent to landfills which therefore may contain both undegraded and presumably more recalcitrant substrates and include terminal metabolites that may have been produced.

The range of compounds in non-domestic landfills is extremely wide and includes not only industrial waste from a variety of industries but also substantial volumes of ordinary waste containing a number of explosives and chemical warfare agents. It should also be noted that continuous atmospheric precipitation will have occurred, and therefore virtually any established atmospheric contaminant may also be present. Indeed, the atmospheric input into Lake Michigan has been found to exceed that from landfills (Hornbeck et al., 1995), so that important interphase partition should be taken into account. The range of relevant compounds to which attention should be directed is dependent on the availability of analytical procedures both for the original compounds and for their possible transformation products. An illustrative example is provided by the development of chromatographic procedures that have been applied to PAHs and coal tar and their use and the presence of PAHs with up to nine rings (Bengtzelius et al., 1994).

On account of the toxicity of most of the compounds that are discussed here, there is increasing demand for remediation of such sites that involves removal of the offending compounds. In this overview, the concept will be

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Abstract

Bacteria present in effluents from the process of iron ore flotation were isolated and identified as *Serratia marcescens* and *Escherichia coli*. The identification of *S. marcescens* was based on the toluidine blue test and the identification of the bacterial species *Serratia marcescens* in the microflora of the reverse flotation effluent. The identification of *E. coli* was based on the fact that the *lacZ* gene, which codes for β-galactosidase, was shown to be the biodegrading agent. Both *S. marcescens* and *E. coli* are Gram-negative, motile bacteria. The *lacZ* gene was inserted in the *lacZ* locus of *S. marcescens* and *E. coli*. After 5 days, around 34% of *S. marcescens* was already consumed increasing to 75% after 10 days; these data are similar to those obtained by *S. marcescens* grown in the presence of fatty amines. The results obtained when carried out with *E. coli* revealed the constant rate of temperature and concentration on the biodegradation of the reverse flotation DNA. For the concentration of 10 mg l⁻¹, amine biodegradation rate is very close to zero. The same results were obtained for 40 mg l⁻¹. This result will be better observed, mainly the concentrations of 40 and 60 mg l⁻¹. This result will be

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both quartz and hematite surfaces are positively charged and, therefore, can adsorb the amine despite its preferential attraction to the negatively charged surface. The amine adsorption is used as a deprecating agent (Hoover, 1983; Leja, 1983; Numela and

Auer, 1996). After amines are used in industrial flotation processes, such as reverse flotation, they are released into the environment. It is estimated that approximately 5000 tons of amine derivatives per year are used in flotation processes only in Brazil. With the ongoing increase in the use of reverse flotation, the amount of amine derivatives released into the environment will also increase. Environmental introduction of high levels of fatty amines has been reported to cause serious ecological problems (Schultz et al., 1991; Schultz et al., 1993). Aquatic toxicity to the bacteria *Pseudomonas aeruginosa* was evaluated by Garcia et al. (2000). The results showed that the bacterium was able to biodegrade the fatty amines. The fatty amines used were the cationic surfactants (LC₅₀ from 0.11 to 1 mg l⁻¹) than creatinine (LC₅₀ from 6.8 to 40 mg l⁻¹; Saifer (1996)), however, reports toxicity of fatty amines to *S. marcescens* and *E. coli* are not available. The LC₅₀ of 15–40 mg l⁻¹ for fish and 40–100 mg l⁻¹ for D. magna was reported (Hoover, 1983). The LC₅₀ of 10 mg l⁻¹ for *Pseudomonas aeruginosa* was reported (Yoshida et al., 1997). The authors studied the metabolism of several fatty amines by *Pseudomonas sp.*, measuring their biochemical

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