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ENCHANCED BACTERIAL LEACHING OF LOW-GRADE CHALCOPYRITIC ORES IN COLUMNS BY USE OF ARTIFICIAL AERATION AND A MUTANT STRAIN OF THIOBACILLUS FERROXIDANS

A mutant strain of Thiobacillus ferrooxidans possessing a high ability to oxidize chalcopyrite efficiently leaches copper from low-grade chalcopyrite ores in shake-flasks and in percolation columns with artificial aeration. The activity of the strain during leaching of the ores in percolation columns without artificial aeration was limited by deficiency of air. The data from this study suggests that it could be possible to efficiently leach low-grade chalcopyritic ores under industrial conditions in well-aerated dumps and by using highly active strains of chemolithotropic bacteria.

1. Introduction

The bacterial leaching of copper from low-grade ores in dumps or in situ is widely practiced in several countries (Lundgren, Malouf, 1983; Torma, 1987). Copper is relatively easily leached from secondary sulphide minerals such as chalcocite, covellite, etc due to their rapid oxidation by the chemolithotropic bacteria which are the main leaching agents in such operations. Furthermore, the sulphuric acid formed as a result of bacterial oxidation of sulphide minerals dissolves copper from the oxide minerals which are present together with the sulphides in mixed ores. However, the most important copper-bearing mineral, chalcopyrite, is highly recalcitrant to leaching.

Mutant strains of Thiobacillus ferrooxidans possessing a high ability to oxidize chalcopyrite were obtained as a result of a gradual selection starting from a natural sample and changing them by different mutagens of wild strains of this bacterium (Groudeva, 1978.; Groudeva,

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Groudev, 1980). These mutant strains when combined with mechanical stirring and artificial aeration efficiently leach chalcopyrite concentrates (Groudev, 1986). The possibility of using such strains for leaching of chalcopyritic ores in dumps or in situ is of a great interest.

In this study three different low-grade chalcopyritic ores were leached in percolation columns. Leaching under such conditions is the closest possible simulation to dump leaching. A mutant strain of T. ferrooxidans possessing a high oxidizing towards chalcopyrite was used. The results obtained in these experiments have been compared with those obtained in experiments using mixed cultures of acidophilic chemolithotropic bacteria. In some experiments the leaching was carried out without any artificial aeration but in others air was injected into the columns containing ores.

2. Materials and methods

The three low-grade chalcopyritic ores used in this study contained 0.23%, 0.21% and 0.18% of copper, respectively. The chalcopyrite was the only copper-bearing mineral and there were only slight traces of secondary copper sulphides and oxides in the ores.

Mixed enrichment cultures of acidophilic chemolithotropic bacteria were obtained by inoculation of an iron-free 9K nutrient medium (Silverman, Lundgren, 1959) containing a defined ore as an energy source with samples from acid mine drainage waters containing natural populations of such bacteria. The cultures were adapted to the relevant ore by consecutive transformations in media containing ore suspensions with increasing pulp densities.

The mutant strain of T. ferrooxidans was obtained as a result of a gradual selection based on the combined use of different mutagens (UV rays, ethylamine, nitrosoguanidine). This strain oxidized different chalcopyrite specimens at high rates. Batch cultures of the strain were adapted to the different ores by using the procedure mentioned above.

Ore samples finely ground to - 400 mesh (- 37 μm) were used for leaching in shake-flasks. The experiments were carried out in 300 ml Erlenmeyer flasks containing 95 ml of an iron-free 9K nutrient medium, 20 g of ore and 5 ml of an active late-log-phase culture, previously adapted to the ore being leached and containing 2×10^8 cells/ml. In the sterile control flasks, 5 ml of a methanol solution containing 2% of thymol were added instead of the inoculum. The initial pH of the ore suspensions was adjusted to 2.3. The flasks were incubated on a rotary shaker at 225 rpm at 35°C for 28 days, in the dark. The water losses due to evaporation were compensated for by the addition of distilled water, and pH was readjusted with 1N sulphuric acid or 1N sodium hydroxide.

PVC columns with 2200 mm effective length and 105 mm internal diameter were used. Each column was charged with 30 kg of ore crushed to minus 10 mm. After an initial neutralization of the acid-consuming components in the host rocks, the ores were irrigated for 1 to 2 days per week with a leach solution applied at a rate of 2 - 4 l per day for a period of 10 months. The leaching solution contained between 3.0 and 3.5 g/l iron ions (Eh was in the range of 480 - 510 mV), ammonium and phosphate ions at concentrations of 50 and 20 mg/l, respectively, and chemolithotropic bacteria at a concentration of approximately 10^8 cells/ml. The pH was in the range of 2.1 - 2.3. The leaching solution of the control experiments contained 50 mg/l panacide (2,2'-methylenebis (4-chlorophenol)). The oxygen and carbon dioxide concentrations in the porous space of the ores were measured by using the method described by Harries and Ritchie (Harries, Ritchie, 1985). Gas sampling ports were installed in each column at depths of 0.6, 1.2 and 1.8 m.

Air was injected into some columns through their false bottoms during the rest periods at a rate of 120 ml/min.

The copper extractions were determined by periodically removing a 1 ml sample from the leach solution and analysing its copper content with an atomic absorption spectrophotometer.

All microbiological procedures used in this study have been described elsewhere (Groudev, 1974, Groudev, Genchev, 1978).

3. Results and discussion

The mutant strain of T. ferrooxidans leached copper from the ores under shake-flask leaching conditions much more efficiently than the mixed cultures of acidophilic chemolithotropic bacteria (Table 1). In these mixed cultures T. ferrooxidans was the prevalent microorganism and T. thiooxidans, Leptospirillum ferrooxidans and some acidophilic heterotrophs were also presented.

In the column leaching experiments without artificial aeration the copper extractions obtained by the mutant strain and by the mixed cultures were similar (Table 2). It must be noted that in the column initially inoculated with the mutant strain, mixed microbial populations established themselves within short periods of time as a result of contamination with microorganisms other than the mutant. The microflora composition of these columns was similar to that of the columns initially inoculated with mixed cultures of acidophilic chemolithotrophic bacteria. However, the mutant was the prevalent microorganism in these mixed populations during the whole leaching period.

The content of oxygen in the porous space of the ores located at the middle and in the lower half of the columns (at depths of 1.2 and 1.8 m, respectively) was decreased from the 20.9% atmospheric value (at the

Tab. 1. Leaching of copper from low-grade chalcopyritic ores in shake-flasks

Ore	Mixed cultures of acidophilic chemolithotrophic bacteria	Mutant strain of Thiobacillus ferrooxidans	Sterile control (chemical leaching)
	Copper solubilized in 28 days, %		
No 1	21.7	68.6	2.8
No 2	28.2	69.3	3.5
No 3	17.8	53.0	2.3

Tab. 2. Leaching of copper from low-grade chalcopyric ores in columns without artificial aeration

Ore	Mixed cultures of acidophilic chemolithotrophic bacteria	Mutant strain of Thiobacillus ferrooxidans	Sterile control (chemical leaching)
	Copper solubilized in 10 months, %		
No 1	9.1	9.9	3.5
No 2	12.5	13.2	4.1
No 3	8.8	9.9	2.8

tops of the columns) to less than 10%. However the content of ...bon dioxide was higher than the atmospheric value. The source of this excess carbon dioxide was probably the action of sulphuric acid on the carbonates which were present in the ores.

These data were an indication that under such conditions the bacterial activity was limited by a shortage of oxygen.

In the column leaching experiments with artificial aeration the copper extractions were increased in the cases both the mutant strain and the mixed cultures. However, the increase was much higher (by 69 - 96% with the different ores) in the experiments with the mutant strain than in those with the mixed cultures as inocula (by 30 - 32% with the different ores) (Table 3). The content of oxygen in the porous space of the ores located at depths of 1.2 and 1.8 m in the columns was similar to the atmospheric value.

Tab. 3. Leaching of copper from low-grade chalcopyritic ores in columns with artificial aeration

Ore	Mixed cultures of acidophilic chemolithotrophic bacteria	Mutant strain of Thiobacillus ferrooxidans	Sterile control (chemical leaching)
	Copper dissolved in 10 months, %		
No 1	12.0	19.4	4.4
No 2	16.3	22.3	5.3
No 3	11.6	17.0	4.1

The number of chemolithotrophic bacteria in the aerated columns was higher than that in the nonaerated columns and even at depths of 1.2 and 1.8 m exceeded 10^8 cells/g ore, while in the nonaerated columns at the same depths was in the range of 10^5- 10^7 cells/g ore.

These data were an indication that in these well-aerated systems the main rate-limiting factor was the genetically determined ability of bacteria to oxidize chalcopyrite.

The results of this study suggest that the bacterial leaching of low-grade chalcopyritic ores in dumps or in situ can be accelerated by increasing the rate of ingress of oxygen to the oxidation sites. The introduction of bacteria possessing a higher oxidizing ability to the ore mass is also a promissing way to accelerate the oxidation, more especially in some particular systems of in situ leaching (Groudev, 1980).

4. References

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STRESZCZENIE

Groudev S.N., Groudeva V.I., 1988. Ługowanie bakteryjne niskoprocentowych rud chalkopirytowych z użyciem sztucznego napowietrzania i mutacyjnych szczepów Thiobacillus ferrooxidans. Fizykochemiczne Problemy Mineralurgii 20 ; 177-183.

Mutacyjny szczep Thiobacillus ferrooxidans, posiadający wysoką utleniającą aktywność, ługował efektywnie chalkopiryt z niskoprocentowych rud chalkopirytowych w wytrząsanych kolbach oraz w sztucznie napowietrzanych kolumnach. Aktywność tego szczepu podczas ługowania rud w kolumnie perkolacyjnej bez sztucznego napowietrzania była ograniczona z powodu braku powietrza. Z naszych badań wynika, że jest możliwe efektywne ługowanie niskoprocentowych rud chalkopirytowych w warunkach przemysłowych w dobrze napowietrzonych odpadach z użyciem wysokoatywnych szczepów chemolitotropowych bakterii.

СОДЕРЖАНИЕ

С.Н.Гроудев, В.И.Гроудева, 1988. Бактерийное выщелачивание низкопроцентных халькопиритовых руд с использованием искусственой аэрации и мутационных прививок **thiobacillus ferrooxidans** . Физикохимические вопросы обогащения, 20; 177-183.

Мутационная прививка **thiobacillus ferrooxidans** , обладающая **высокой окисляющей активностью, эффективно выщелачивала** халькопирит из

низкопроцентных халькопиритовых руд в вытряхиванных колбах, а также в искусственно аэрированных колонках.

Активность этой прививки во время выщелачивания руд в перколяционных колонках без искусственного аэрирования ограничивалась в связи с нехваткой воздуха. Из исследований следует, что возможным является эффективное выщелачивание халькопиритовых руд в промышленных условиях, в высоко фэрированных отходов с использованием высокоэффективных прививок хемолитотроповых бактерий.