PERGAMON

Minerals Engineering 15 (2002) 751–753

MINERALS ENGINEERING

This article is also available online at: www.elsevier.com/locate/mineng

Technical Note

Strategies for efficient start-up of continuous biooxidation process for refractory gold ores

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Received 6 February 2002; accepted 17 June 2002

Abstract

Strategies for efficient start-up of a continuous process for biooxidation of refractory gold ore and concentrate obtained from Hutti Gold Mines Limited (HGML), India are discussed in this work. The biooxidation of the concentrate at high pulp density (10%) with wild strain of *Thiobacillus ferrooxidans* isolated from HGML mines is characterized by significant lag phase (20 days) and incomplete oxidation (35%) even after prolonged operation (60 days). Two strategies, biooxidation with concentrate adapted cells and a step leaching strategy, in which the pulp density is progressively increased from 2% to 10% were considered and the latter resulted in efficient biooxidation of concentrate. Conversion of such a process from batch to continuous operation is shown to result in complete biooxidation of the concentrate and gold extraction efficiency in excess of 90%.

Keywords: Gold ores; Bacteria; Bioleaching; Biooxidation

1. Introduction

The Hutti Gold Mines Company Limited (HGML), India, has recently opened various new gold mining zones and preliminary reports indicate that gold is present in refractory ores in some of these zones. As against the conventional cyanidation process, the biotechnological route would prove to be more efficient, economically viable and environmentally acceptable technology for such refractory ores (Natarajan, 1998). Also earlier studies have shown that these deposits host a variety of microorganisms of relevance to gold extraction (Modak et al., 1995; Natarajan, 1996). This project was undertaken to study the feasibility of biooxidation as a pretreatment for enhancing gold and silver recovery.

Biooxidation was conducted in both batch and continuous mode and its effect on gold and silver recovery was studied. Biooxidation rate depends to a large extent on the efficiency of the bacterial strain used. This paper discusses the effect of pulp density on the biooxidation efficiency and brings about the start-up strategies required for optimum activity of the bacterial strain.

2. Experimental

2.1. Materials

An indigenous strain of *Thiobacillus ferrooxidans* cultured in sterile 9 K medium was used for biooxidation. The refractory sulphidic concentrate obtained from HGML was in finely ground form with an average particle diameter of 70 μm. The chemical composition was 31.95 wt.% Fe, 29.25 wt.% S, 3 kg/t silver and 22.5 g/t gold.

2.2. Biooxidation studies

Biooxidation experiments were done either in batch mode or in continuous mode in well agitated and aerated stirred tank bioreactors. The agitators were of pitched blade turbine design with four blades. Compressed air sparged at the rate of 0.5 V/V/min was supplemented with 1% (V/V) CO_2. Continuous mode operation was carried out by pulse feeding acid stabilized slurry from the feed tank at the rate of 1.5 l/day

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0892-6875/02/$ - see front matter
PII: S0892-6875(02)00129-2

giving 4 days residence time. Oxidation rate was estimated by monitoring the ferrous and ferric iron in solution using ASTM standard technique (ASTM E 394-94). Cell number was also periodically monitored by microscopic counting with Petroff–Hausser counter using a Leitz phase contrast microscope (Laborlux K Wild MPS12).

3. Results and discussion

The experimental result of the batch biooxidation at various starting pulp densities is portrayed in Fig. 1. From the figure it can be observed that the initial lag period increases with pulp density. Complete oxidation was considered to be achieved when the total iron in the solution reached the theoretical value estimated stoichiometrically, which is 2.92 g/l for 1% pd. In case of 2% pd, this took about 53 days and the leached iron was mainly in the ferric form indicating that the bacteria in the solution immediately converted the ferrous iron coming into the solution from the concentrate. Time for complete oxidation in case of 3% pd was about 60 days. Leaching in the case of 5% pd started only after a lag period of about 10 days and the percent iron oxidized at the end of 80 days was only 77%. The cell number in solution showed a gradual increase only after a lag period of 10 days. This effect is more clearly seen from the results obtained with 10% pd, where the leaching was very poor with just 35% oxidation of iron in 60 days. Also the iron in solution during the initial period was mainly in the ferrous form indicating that the bacteria in the solution were not active during this period.

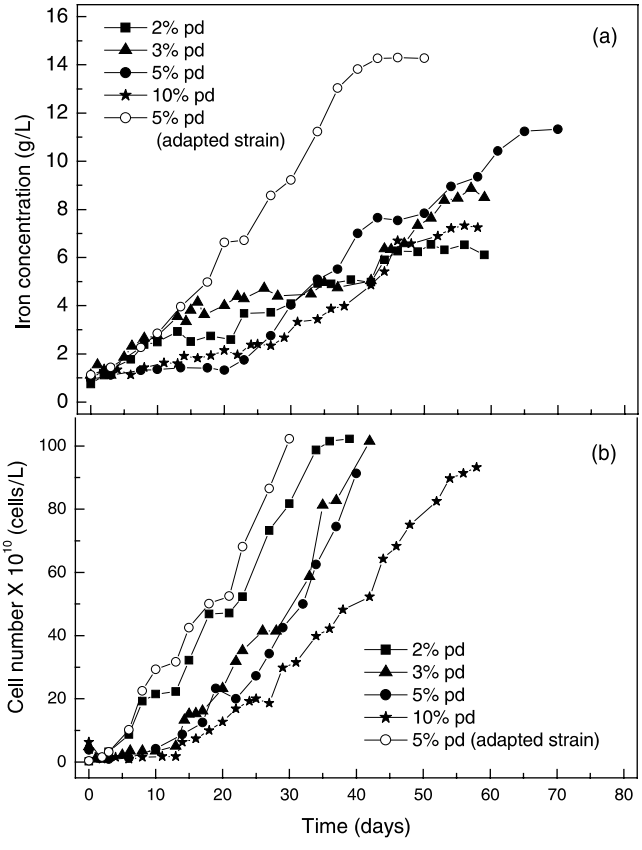

Fig. 1. Batch biooxidation with unadapted and adapted strain of *T. ferrooxidans* at different starting pulp density: (a) variation of iron concentration in solution and (b) variation of solution cell number.

The factors that affect biooxidation at high solids concentration include oxygen and carbon dioxide availability, low cell-to-solid ratio, mechanical damage of bacteria, and buildup of toxic leach metabolites. There are several ways of overcoming this problem. Since ferric sulphate is a good lixiviant, metabolite of a fully grown culture can be used as the leaching medium. Our experiments with 5% pd showed 88% oxidation at the end of 48 days (data not shown).

Another alternative considered was to use concentrate (substrate) adapted strain. A strain of *T. ferrooxidans*, which was adapted to the solid substrate for about 6 weeks, was used for the experiment with 5% pd. No lag phase was observed both in leaching and cell growth in solution in case of adapted strain. There was 96% iron oxidation observed in just 40 days, as compared to just 77% in 80 days in case of unadapted strain.

Apart from the above, step leaching technique can be a better option for such situation since it combines the advantages of both ferric iron built up and adaptation in single stage. In this technique, the leaching is started with a low pulp density and when almost all the iron has been leached out, the pulp density is increased by the addition of fresh concentrate to the running bioreactor. By doing so, the sudden exposure of unadapted bacteria to high solids concentration is avoided and thereby the inhibition of its growth minimized. The result of such an experiment with a starting pulp density of 1% is plotted in Fig. 2. The pulp density was increased stepwise to 2%, 3%, 5% and finally to 10% pulp density. From the results it can be observed that there is no significant lag phase at any stage of leaching. During the initial stages of the experiment, low pulp density is maintained and no lag phase can be expected. As the leaching proceeds, the bacteria are getting adapted to the substrate and hence its leaching efficiency increases with time. The iron in the solution is mainly in ferric form indicating that the bacteria in solution are active. With such a technique it was possible to obtain almost complete oxidation of a 10% pulp density concentrate in just 40 days. The step leaching experiment was made continuous at the end of 38 days. The process reached steady state after about 8 days with the iron oxidation at steady state being 83%. The cyanidation results of the samples collected showed an average gold recovery of about 85% as against 38% obtained prior to biooxidation. Maximum recovery of gold was 91%. It is interesting to observe that, the silver

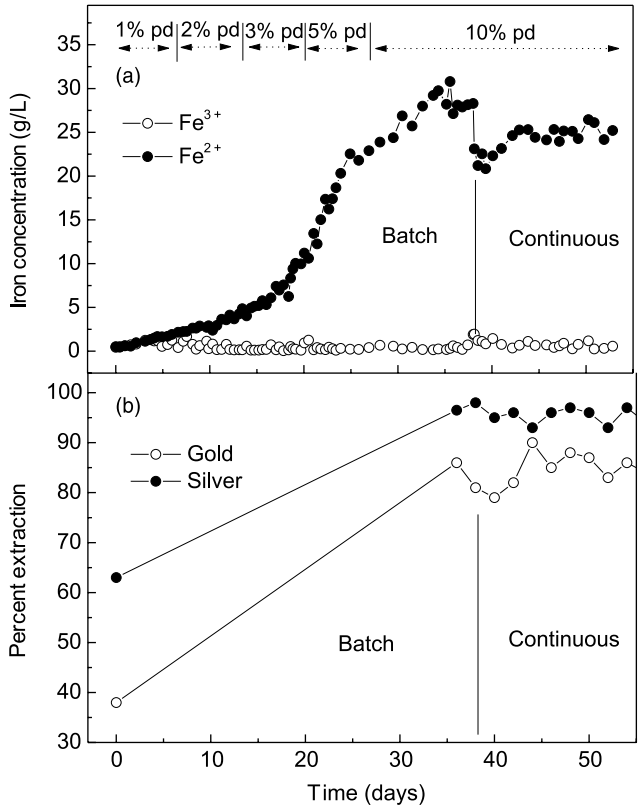

Fig. 2. Stepwise biooxidation (batch and continuous) with wild strain of *T. ferrooxidans* at 1% starting pulp density: (a) variation of iron concentration in solution and (b) percent gold and silver extracted at 10% pulp density (continuous operation).

recovery was also substantially increased from 63% to 98% due to biooxidation.

4. Conclusions

Step leaching technique with a low starting pulp density was found to be most efficient to obtain good leaching rates at high pulp densities. The cyanidation results of the biotreated samples at 10% pulp density continuous run showed about 85% gold recovery and 98% silver recovery, as against 38% and 63% obtained prior to treatment. The above results clearly demonstrate advantage of biooxidation as a pretreatment process prior to cyanidation for refractory gold containing sulphidic concentrates.

Acknowledgements

The authors gratefully acknowledge the financial assistance provided by Department of Biotechnology, Government of India and Hutti Gold Mines Company Limited.

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