BIOOXIDATION OF MOUTEH REFRACTORY GOLD-BEARING CONCENTRATE BY AN ADAPTED *THIOBACILLUS FERROOXIDANS*

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Abstract

The Mouteh refractory pyrite concentrates at pulp densities of 1.5%, 3%, 4.5% and 6% were treated, using *Thiobacillus ferrooxidans* DSM 581 and the same bacteria adapted on the Mouteh pyritic concentrate. Compared with a non-adapted culture, use of an adapted inoculum of *T. ferrooxidans* increased bioleaching rate of iron by a factor of 1.940, 2.011, 1.859 and 1.559 for pulp densities 1.5%, 3%, 4.5% and 6%, respectively. Lag phase time for growth of adapted cells decreased to less than 24 hours. Ore samples were analysed for gold recovery by cyanide extraction before and after biooxidation in 4L and 20L bioreactors. When 55% of the sulphides were oxidised, as a result the gold recovery-upon subsequent cyanide extraction improved more than 95%. Mathematical analysis of bioleaching data showed that the X^3 variable equation satisfactorily predicts the gold recovery in relation to the oxidation degree of pyrite concentrate.

Introduction

Mouteh plant, located in Isfahan province, is the unique gold processing unit in Iran, commissioned in 1993. The plant has been designed to produce 450 KGs of gold annually from the oxidised ore by Carbon in leach (CIL) method. But the oxidised ore is being exhausted and the sulphidic ore should be mined and put into use. The mineralogical investigations showed that gold occurs in the form of blebs in pyrite [1]. Therefore, low recovery should be expected for gold extraction by cyanidation. The sulphide gold bearing reserves are estimated about 3-4 times of the oxide ores.

Anyhow, a considerable proportions of Mouteh reserves are in the refractory state that is inappropriate to conventional cyanidation methods [1,2]. A key step in gold extraction is conversion of the solid metal into a soluble cyanide complex:

$$2Au + 4NaCN + O_2 + 2H_2O \rightarrow 2NaAu(CN)_2 + 2NaOH + 2H_2O_2$$

Some parts of gold are refractory which means they

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are not easily available for cyanidation because (a) gold particles are finely disseminated in the host materials, (b) presence in chemically inert compounds, or (c) contain contaminants, which consume cyanide, making the process uneconomical [3,4].

Principally, gold is embedded in pyrite, arsenopyrite, and pyrrhotite. Straight cyanidation of the gold ores or flotation concentrate usually yields poor recoveries, rarely more than 80%. Consequently, in order to increase gold particle exposure, preliminary treatment of the concentrates is necessary [5,6].

Oxidation roasting and aqueous pressure oxidation are two processes that have found widespread industrial application for the treatment of refractory sulphide gold ores [3,7]. Bacterial oxidation is an interesting, low capital cost method alternative method with high potential for the liberation of finely dispersed gold from pyrite and arsenopyrite concentrates. The bacteria gradually breakdown the sulphides and release gold. Another major use of biooxidation is the leaching of copper and uranium from resources [8,9,10].

The aim of the research discussed herein has been the development of a biological process for increasing the recovery of gold from Mouteh ore.

Materials and Methods

Bacterial Culture

The culture of iron-sulphur oxidizing *Thiobacillus ferrooxidans* (DSM 581), used in this study was adapted for one year to the Mouteh pyritic concentrate and was maintained at 4°C. Bacterial adaptation on the sulphide concentrate was carried out using HP medium [11] (pH=1.9) with a pulp density of 3% at 30°C. During the adaptation, the bacterial solution was successively transferred to a fresh medium every two weeks. Before transferring, the cells were released from substrate particles by addition 0.1% w/v Triton X-100 [12], and isolated from the solution by using a membrane filter of 0.2 μm pore diameter.

The Ore

The main composition of the concentrate [1], consisting of pyrite, quartz and chlorite is given in Table 1. FeS_2 content was calculated from the corresponding elemental composition (pyritic iron 36.10%, pyritic sulphur 41.4%). The concentrate was ground to minus 45 μm and stored for bioleaching tests.

Table 1. Composition of Mouteh pyritic ore concentrate

% SiO_2	% Al_2O_3	% FeS_2	% Na_2O	% K_2O
13.98	2.99	78	0.99	0.27

Bioleaching tests

Shaking flask. Preliminary leaching experiments were carried out in 500 cm^3 shaking flasks containing 100 ml HP medium [11] including 1.5-, 3-, 4.5- and 6g of the concentrate (Particle Size (P.S.) < 45μm). The flasks were inoculated with 10 ml of adapted or non-adapted *T. ferrooxidans* (2×10^8/ml). The flasks were incubated at 30° C on a rotary shaker at 150 rpm. The bioleaching rates of iron (dx/dy) were determined from the slopes of curves plotting total iron versus time from a minimum of three inoculated flasks (unpublished data) and were reported as milligrams of iron per litre per hour. The slopes were determined during the linear portion of the leaching at a constant rate. The lengths of the exponential phases were measured and the percentage of leached pyrite was estimated six days after inoculation.

Bioreactors. The leaching experiments were performed in 4 and 20 dm^3 glass reactors, which charged, by 3- and 18 dm^3 HP medium, followed by adding pyrite concentrate as sole energy source. The initial pH (pH=1.9) was achieved by the addition of 2.0 M H_2SO4. As an inoculum, 100 ml of iron free cell suspension (3.6×10^9 cells/ml) was added to the pyritic concentrate to give an initial density of 1.2 x 10^7 cells/ml as determined by direct cell counting with improved Neubuer counting chamber. The reactors were mechanically stirred (400 rpm) and kept at 33° C. In the 20-dm^3 bioreactors, air enriched with 1% (v/v) CO_2, was injected at the bottom of the reactors [11,13].

Analytical methods. Solution samples were periodically withdrawn and analysed for total iron. During the leaching process, some portion of the released iron was precipitated. Therefore, total iron was measured after acid digestion with 6 N HCl for 30 min at 65°C [14]. The metal content was analysed by titrimetric method using 0.06N $K_2Cr_2O_7$ [15].

Cyanidation Tests. All Cyanidation tests were conducted in rolling bottles. The materials were added to the distilled water. After addition of the required calcium hydroxide and sodium cyanide, the bottles were rolled for 24 hours or more, when necessary. Gold content in this solution was measured using a Atomic Absorption Spectrophotometer (A.A.S.).

Results and Discussion

The purpose of this investigation was to assess the potential benefits of bioleaching process on Mouteh sulphide bulk flotation concentrate prior to cyanidation as an alternative method to the conventional roasting method.

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Shaking Flask Experiments

In order to examine the leaching behaviour of the concentrate, a series of experiments at different pulp densities were conducted and oxidation rate of the sulphide minerals was studied.

The bioleaching rates of iron with adapted or non-adapted *T. ferrooxidans* at different pulp densities are given in Table 2. Bioleaching rate obtained by the adapted cells is roughly twice the rate of non-adapted bacteria. Exponential phase of pyrite oxidation initiated 6 days after inoculation for non-adapted cells, whereas for adapted cells, the release of iron started within 1-4 days after inoculation.

Pyrite Oxidation by Adapted Cells in Bioreactor Systems

After adaptation of *T. ferrooxidans* (DSM 581), for improvement of bioleaching kinetic parameters, adapted strain was used for bioleaching of concentrate in bioreactors.

Biooxidation Tests in 4-dm^3 Bioreactor

Ore samples were analysed for gold recovery by cyanide extraction before and after the biooxidation. Conventional bottle-roll cyanide extraction was used for determining gold recovery after biooxidation. Figure 1 illustrates the effect of pulp density variations, ranging from 3-6% w/v, upon the extraction of iron in relation to leaching time. After 10 days of leaching, at 6% w/v pulp density, the degree of pyrite oxidation was 40%, while at 3% and 4.5% pulp densities were 52% and 44%, respectively. Figure 2 shows the gold recovery improvement as a function of extended biooxidation. When 55% of the sulphides were oxidized, the gold recovery-upon subsequent cyanide extraction improved to more than 95%. Gold extraction from roasted ore was nearly 100% [1], representing a gold recovery upper limit for this ore.

Table 2. The ratio of most important kinetic parameters obtained from bioleaching of samples of the Mouteh pyritic ore concentrate by two samples of *Thiobacillus ferrooxidans*

Pulp Density	1.5%	3%	4.5%	6%
Number of days[a]	6-10[b] 1-6[c]	6-16[b] 1-4[c]	6-16[b] 1-4[c]	6-16[b] 1-4[c]
The ratio of bioleaching rates by adapted cells/non-adapted cells	1.94	2.011	1.859	1.5588
The ratio of oxidation level by adapted cells/non-adapted cells	1.542	1.724	1.698	2.208

[a] The lengths of the exponential phase
[b] Non-adapted cells
[c] Adapted cells

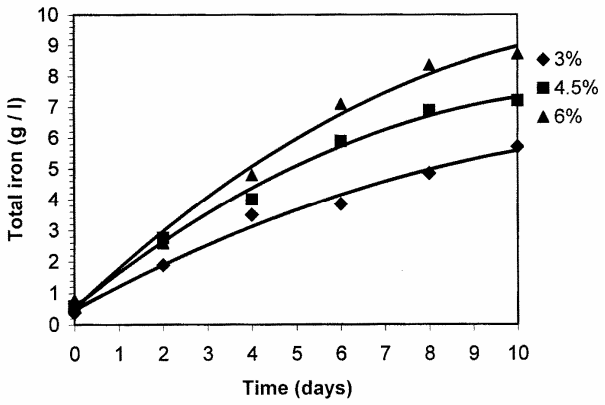

Figure 1. The bioleaching rates of refractory gold bearing concentrate at different pulp density in a 4L bioreactor.

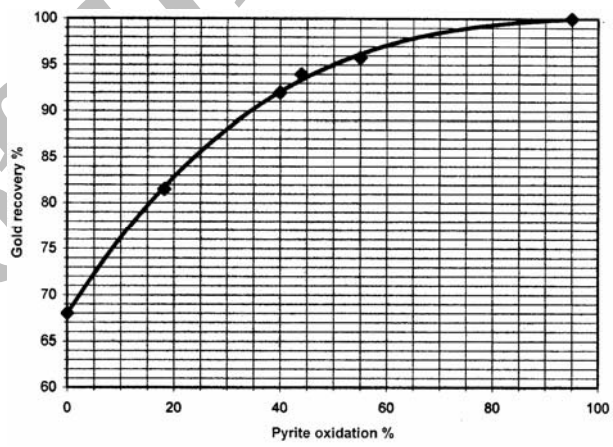

Figure 2. The gold recovery improvement as a function of the extension of biooxidation.

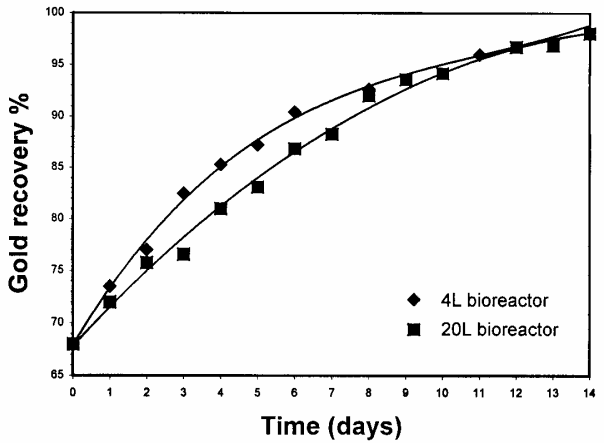

Figure 3. Evaluation of the effect of reactor scale on the bioleaching performance.

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Mathematical Analysis of Bioleaching Data

In order to predict the overall gold recovery in relation to the oxidation degrees of sulphide minerals, the X^2 and X^3 variable equations were examined. Taking into consideration the following assumptions the bioleaching data were analysed.

(1) The Mouteh pyritic concentrate consisted of 78% FeS_2 as can be seen from the chemical data presented in Table 1.

(2) The Au is widely dispersed in mineral phase.

The equations that may describe the recovery of gold after biooxidation and a subsequent cyanidation can be similarly written as follows:

1. $Y= 68.1852 + 0.7748 X – 0.00458 X^2$

2. $Y= 67.8083 + 0.8810 X – 0.0077 X^2 + 0.00002X^3$

Where X and Y represent different degrees of pyrite oxidation and the percent of gold recovery, respectively. Table 3 summarises the Au recoveries calculated from equations 1 and 2, as well as experimental values for comparison with two given oxidation level. It is observed from data presented in Table 3 that equation 2 satisfactorily predicts the gold recovery in relation to the oxidation degree of pyrite concentrate.

Bacterial Leaching of Pyrite

To evaluate the effect of reactor scale on the bioleaching performance, a batch test including the leach of Mouteh pyrite concentrate finer than 45µm was performed at scale 4- and 20 dm^3, while the 4- and 20 dm^3 vessels were configured as geometrically similar stirred glass tanks, at optimum conditions determined previously. Tests were performed at a pulp density of 4.5% (w/v), keeping the temperature at 33°C. The percentage of gold recovery was predicted through equation (2) by insertion of the degree of sulphide mineral oxidation, which calculated from total iron released during bioleaching. Similar gold liberation rates were found at two different scales of bioreactor operation. Figure 3 presents a group of gold recovery percentage versus time. Slightly different delayed rates were experienced between the scales of operations; this means that by increasing the scale, the bioleaching efficiency kept constant. In 20-dm^3 bioreactor the recovery percent of gold reached to 90% and 95%, 7 and 12 days after inoculation, respectively.

Table 3. Gold recoveries prediction by Equations 1 and 2

Oxidation Level %	Gold recovery % After CIL method	Gold recovery % Calculated by Eq. 1	Gold recovery % Calculated by Eq. 2
67	97	99.54	98.60
22	84	83.14	83.65

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