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Bioleaching of a low grade sphalerite concentrate produced from tailings flotation

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ABSTRACT

In this research, the zinc extraction from a low grade zinc concentrate produced from the accumulated flotation tailings was investigated using the bioleaching process. Zinc content was initially upgraded to 11.97% through flotation process. Bioleaching experiments were designed and carried out by a mixed culture of *Acidithiobacillus ferrooxidans*, *Acidithiobacillus thiooxidans*, *Leptospirilium ferrooxidans*, as well as a mixed moderate thermophile bacteria in the shake flasks. The effect of two bacteria types, the indigenous bacteria accompanied by concentrate sample and added mixture of bacteria, were evaluated. The term of indigenous bacteria refers to the bacteria which initially exists in the natural concentrate sample. The results showed that more than 87% and 94% of Zn was dissolved in the bioleaching condition of mesophile and moderate thermophile bacteria, respectively. Comparing the bioleaching and leaching tests indicate that mesophile bacteria improves the Zn extraction by 36%, in which the contribution of concentrate indigenous bacteria (test condition of non-inoculation) and added mesophile mixed bacteria were equal to 34% and 66%, respectively. In addition, moderate thermophile bacteria improves the sphalerite leaching up to 38% in which contribution of the concentrate indigenous bacteria and added moderate thermophile bacteria were about 50% separately.

Keywords: *Bioleaching; Pyrite; Tailing; Sphalerite concentrate*

1. Introduction

The Kooshk lead-zinc tailing dam located in Yazd province of Iran contains approximately 5 million tons of sphalerite tailings with a grade of 3.67% zinc, 0.97% lead, 24.18% iron, and 2.2% of organic carbon. The tailings contain high amount of pyrite, organic carbon and fine particles. Because of the presence of high amount of fine pyrite particles, it was difficult to carry out selective flotation and continue the process in the cleaning stages [1]. Therefore, the bioleaching method was applied in order to investigate the Zn extraction from the tailings. The results indicate that more than 90% of sphalerite was dissolved during 14 days [2]. In recent years, the bioleaching processes have gained importance for the extraction of metals particularly from the difficult-to-treat and low grade ores or concentrates. Bioleaching is essentially a dissolution process based on the exploitation of acidophilic bacteria which have the ability to derive the energy required for their growth and other metabolic functions from the oxidation of ferrous iron and/or elemental or reduced sulphur compounds [3-5]. In terms of the processing of low-grade overburden and waste sulfide minerals from traditional mining operations, the bacterial leaching technology has attracted considerable interest. This is due to its low-cost and relatively more environment friendly discipline [6-8].

Several researchers have investigated the feasibility of applying the GEOCOAT process to the leaching process in order to recover zinc from a low-grade sphalerite concentrate produced from accumulated flotation tailings at the Kumbas Rosh Pinah zinc mine in Namibia [9-10].

Laboratory experiments in percolators have demonstrated effective bioleaching of copper and zinc, as well as recovery of precious metals from flotation tailings of the Svyatogor concentrator [11]. Bacterial tank leaching of zinc from flotation tailings was investigated by Panni et al., 2003. Zinc was leached under continuous conditions at 28-30°C in agitated tanks with a pulp density of 16.7, 28.6 and 40.0% of solids in weight [12].

Following the bioleaching experiments on the Kooshk tailings and considering the economical points [2], in this research, tailings were enriched through the flotation process to obtain a low grade sphalerite concentrate. Then the main objective of this research was founded on

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the zinc extraction from the prepared low grade sphalerite concentrate using the bioleaching process. The mixture of three mesophile bacteria and the mixture of four moderate thermophile bacteria were applied in the bioleaching process. The effect of pulp density, indigenous bacteria accompanying the concentrate, initial addition/inoculating of mesophile and moderate thermophile bacteria, and 9K medium on the sphalerite dissolution from the prepared concentrate was investigated over the leaching time.

2. Materials and methods

2.1. Tailings and produced concentrate characteristics

A representative sample was obtained from the Kooshk (Iran) tailing dam. The D_{80} of particles was 90µm. Chemical analysis and mineralogical compositions of the sample is presented in Table1. The tailing contains 3.64% zinc, 0.97% lead, 24.18% iron, 2.2% organic carbon and 28.6% sulfur. Analysis Show that pyrite is the dominant mineral in the tailing with a grade of 62.2%. Mineralogical studies indicate that sphalerite exist in free grains enclosed into pyrite and in some cases pyrite is in sphalerite matrix [2].

Flotation process was applied to produce a sphalerite concentrate from tailings. The tailings were conditioned in a pulp with a pH of 5.3, 600g/t $CuSO_4$, 400g/t $FeSO_4$ and 10g/l frother (MIBC). About 45% of sphalerite was floated in the flotation stage. Chemical analysis and mineralogical compositions of the concentrate is presented in Table 1. The prepared concentrate contains 11.97% zinc, 1.22% Pb, and 23.17% Fe.

Table 1. Chemical and mineralogical composition of tailings and the prepared concentrate.

Elements/minerals	Tailing (%)	Flotation Concentrate (%)
Zn	3.67	11.97
Fe	24.18	23.17
Pb	0.97	1.22
S	28.6	-
C_o (Organic carbon)	2.2	
C_T (Total Carbon)	2.8	
Pyrite	62.2	61.4
Sphalerite	5.3	18.9
Galena	2.1	2.8
Quartz	6.3	5.8
Montmorillonite	5.8	-
Pyrophyllite	5.8	-
Talc	5.8	-
Gypsum	4.3	6.9
Albite	2.2	2.1

2.2. Medium and microorganisms

In this study we used a mixed strain of mesophile bacteria of *A. ferrooxidans*, *A. thiooxidans* and *L. ferrooxidans,* isolated from the acidic water drainage of the Sarcheshmeh copper mine, located in Kerman Province, Iran. The bacteria were subcultured in laboratory using 9K medium (3 g/l $(NH_4)_2SO_4$, 0.5 g/l $MgSO_4\,7H_2O$, 0.5 g/l K_2HPO_4, 0.1 g/l KCl, and 43 g/l $FeSO_4$ at pH=1.85). The bacteria were then cultured by inoculating 10 ml of the bacterial cells into 90 ml of the medium. Potassium nitrate was used to maintain the ionic strength. The cells were incubated at 30 °C in a rotary shaker at the rate of 150 rpm.

A moderately thermophile culture (at 45°C) obtained from Sarcheshmeh, copper mine bioleaching center. The moderate thermophile culture contained *Acidithiobacillus caldus*, *Leptospirillum ferriphilum, Sulfobacillus spp. and Ferroplasma acidophilum*. The bacteria were subcultured in laboratory using 9K medium as well.

2.3. Bacterial adaptation and Bioleaching experiments

The bacterial adaptation process started by adding 1g of sphalerite concentrate to 90ml of fresh medium and 10ml of cell culture. In each adaptation stage, the adapted cells from the previous stage were transferred to the next stage and the process continued up to 20g of concentrate in 100ml solution.

All experiments were carried out in 250ml of Erlenmeyer flasks containing 100ml solution. The experiments were conducted with 10% inoculum in a rotary shaker at the rate of 150rpm and 30°C and 45°C. In order to compare the effect of bacterial leaching and chemical leaching, about 2% v/v Formaldehyde was added to control the tests to remove and inactive the bacteria from solution.

Ferric iron concentration in the solution was measured by 5 Sulfo-Salicylic acid spectrophotometric methods using a UV–VIS spectrophotometer [13].

3. Results and discussion

Bioleaching experiments were designed and carried out using pulps with different densities and in presence and absence of 9K medium. Experiments were performed in two temperatures of 30 and 45 ℃ using mesophile and moderate thermophile bacteria, respectively.

3.1. Bioleaching experiments using mesophile bacteria

3.1.1. Effect of pulp density and 9K medium

Figure 1 presents the Zn extraction from concentrate over the time, in three pulp densities of 10, 15 and 20% w/v. It indicates that in the presence of 9K, about 89% Zn was extracted within 15 days of leaching in the pulp densities of 10% and 15%, and a significant difference was not observed. Although a considerable difference was clear between the pulp density of 20% and the two other densities, in this condition only 58% of zinc was dissolved.

According to the results, in one part of experiments, the bacterial 9K medium was removed. Figure 1(B) indicates that 87% of zinc was dissolved in the absence of 9K medium, in the pulp density of 10%. Although there is a slight difference between pulp densities of 10% and 15%, in some days of leaching, Zn extraction rate in the absence of medium was identical to the test condition of 9K medium. Comparing the Zn extraction in the absence and presence of 9K medium in the pulp density of 15% indicated that there was no significant difference between most leaching days. In other words, 9K addition for bacterial growth was not a considerable and necessary factor. This effect can be referred to bacterial activity and population in the solutions. Mesophile bacterial population counting during the bioleaching tests (pulp density of 15% w/v) indicated that there was no significant difference in the bacterial population with and without 9K during 15 days of bioleaching (Figure 2).

3.1.2. Effect of added mesophile bacteria and concentrate indigenous bacteria

In one test, the bacteria were not added to the solution; however some bacteria were detected through direct counting into a Thoma chamber with a depth of 0.1 mm and an area of 0.0025mm^2 using an optical microscope (×1000). The detected bacteria were indigenous bacteria in concentrate sample which grew during the leaching and dissolution of sphalerite. Figure 3 presents the Zn extraction using mesophile and indigenous bacteria, and their cell number over the time. Based on Figure 3(A), more than 61% of sphalerite was dissolved in the presence of indigenous bacteria. Addition of a mixed culture mesophile bacteria to the experiments (10% inoculum) showed a Zn extraction of 85.97%. Figure 3 also shows that in the control condition (without any bacteria) about 49% Zn was chemically leached, while concentrate indigenous bacteria improved Zn dissolution by about 12% and reached to 61.6%. Figure 3(B) presents the number of bacteria with and without addition of bacterial culture. It is noticed from Figure 3 that the number of free cells in the test condition, which was inoculated with mesophile bacteria, was twice the experimental condition of non-inoculation. Totally, the indigenous and added mesophile bacteria improved Zn extraction by 36%, of which the contribution were 34% and 66%,

respectively for each bacteria.

3.2. Bioleaching experiments using moderate thermophile bacteria

3.2.1. Effect of pulp density and 9K medium

Bioleaching experiments using moderate thermophile bacteria were designed and carried out in the presence and absence of 9K medium in different pulp densities. Figure 4 reveals that when 9K was used as a bacterial medium in the pulp densities of 10%, 15% and 20%, more than 95%, 94% and 82% of Zn was dissolved within 15 days of leaching, respectively. In the same condition and in the absence of 9K medium 94.30%, 85.87% and 58.57% of Zn was extracted in the pulp densities of 10%, 15% and 20%, respectively. The results show that as the pulp densities increase, sphalerite dissolution rate decreases and the rate of reduction was more tangible in the test condition that 9K medium was not applied as a bacterial medium. In other words, in the pulp density of 20%, when the 9K was applied in the bioleaching test, more than 82% of Zn was extracted while in the absence of the 9K, it was only 58.57%.

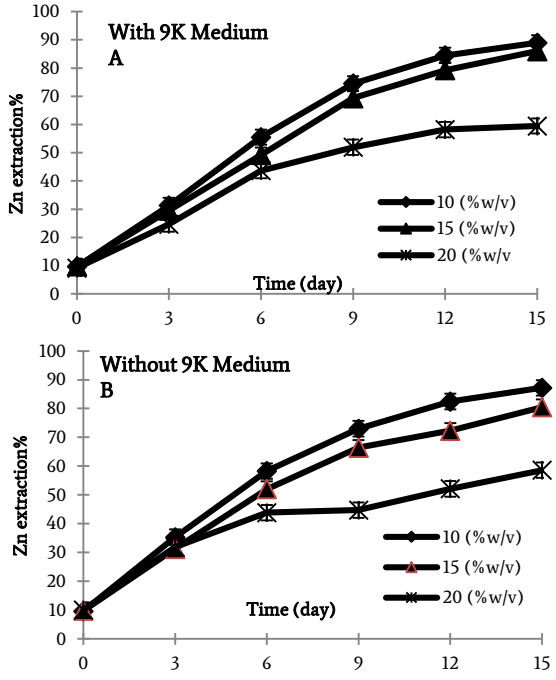

Figure 1. Zn extraction of mesophile bacteria over the time in different pulp densities. A) In presence of 9K medium. B) In absence of 9K medium.

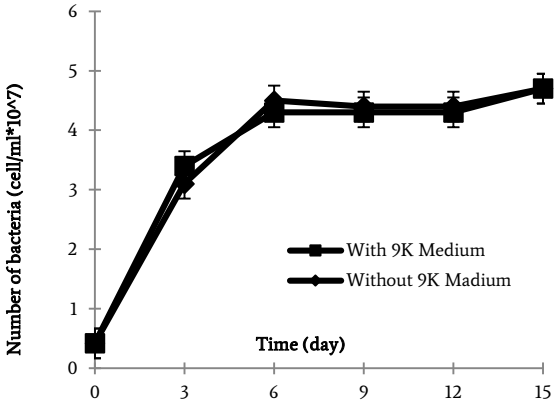

Figure 2. Number of mesophilic bacteria in the test conditions (with and without 9K Medium) in the pulp density of 15% w/v.

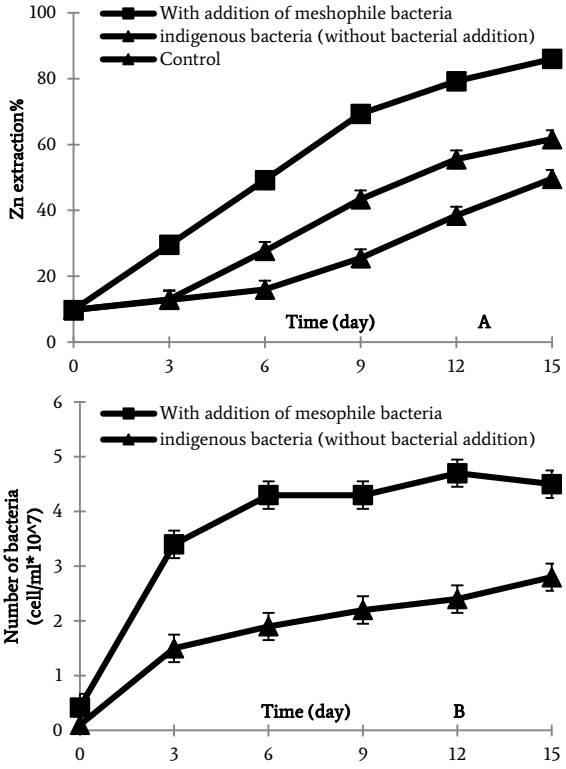

Figure 3. A: Effect of added mesophile bacteria and concentrate indigenous bacteria (without mesophile bacterial addition) on the zinc dissolution in the pulp density of 15% w/v. B: Number of bacteria in the test conditions of mesophile bacterial addition, and without mesophile bacterial addition (only concentrate indigenous bacteria).

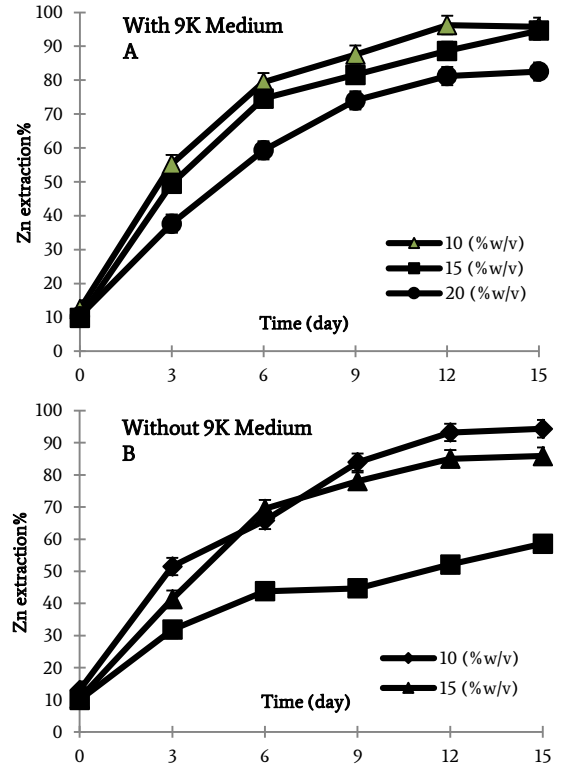

Figure 4. Zn extraction of moderate thermophile bacteria over the time in different pulp densities. A) In the presence of 9K medium. B) In the absence of 9K medium.

3.2.2. Effect of added moderate thermophile bacteria and concentrate indigenous bacteria

Figure 5 presents Zn dissolution in the bioleaching and leaching process. It indicates that around 95% of sphalerite was leached when the moderate thermophile bacteria were initially added to the experiments, while in the control test (without bacteria), only 57.2% of Zn was leached. In the test condition which initially was not inoculated with moderate thermophile bacteria, some indigenous bacteria were detected and counted. Figure 5(B) illustrates the number of bacterial cells in the test conditions of bacterial inoculation and non-inoculation. The number of concentrate indigenous bacteria (test condition of non-inoculation) in the solution was about half of the cell numbers in the inoculated solution. When no bacteria were added to the solution and only indigenous bacteria were presented in the solution, about 77% of Zn was dissolved. Comparison of results indicates that the bacteria improved sphalerite leaching up to 38% in overall, of which contribution of added moderate thermophile bacteria and concentrate indigenous bacteria were about 50% separately.

3.3. Comparing mesophile and moderate thermophile bacterial leaching

Figure 6 compares Zn and Fe extraction using mesophile and moderate thermophile bacteria. It indicates that Zn extraction using moderate bacteria is equal to 94.65%, and it is 10% more than that of mesophile bacteria in the same bioleaching time. About 24% and 21% of Fe was dissolved using moderate and mesophile bacteria, respectively. In other words, there was no significant difference in Fe extraction using the two bacteria. Figure 6 also shows Zn and Fe (III) concentration in the bioleaching solutions. Zinc concentration in moderate and mesophile bioleaching solution is 16.97 g/l and 15.42 g/l, respectively, and Fe (III) concentration was equal to 5.2 g/l and 5.9 g/l, respectively. Although the Fe (III) concentration of both types of bacterial leaching solutions are similar, Zn extraction and concentration in the moderate bacterial leaching were significantly higher than the other one. In fact, in the same Fe (III) concentration, Zn extraction was 10% more than that of mesophile, and it might be related to temperature effect on the bacteria.

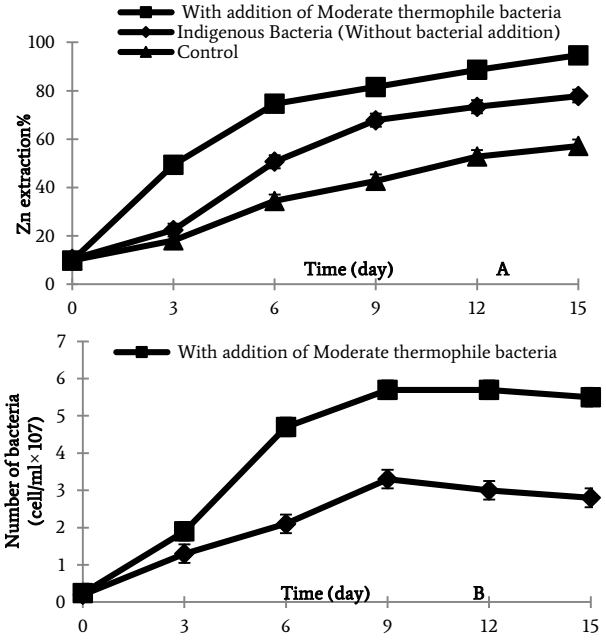

Figure 5. A: Effect of added moderate thermophile bacteria and concentrate indigenous bacteria (without moderate thermophile bacterial addition) on the zinc dissolution in the pulp density of 15% w/v. B: Number of bacteria in the test conditions of moderate thermophile bacterial addition and without moderate thermophile bacterial addition (only concentrate indigenous bacteria).

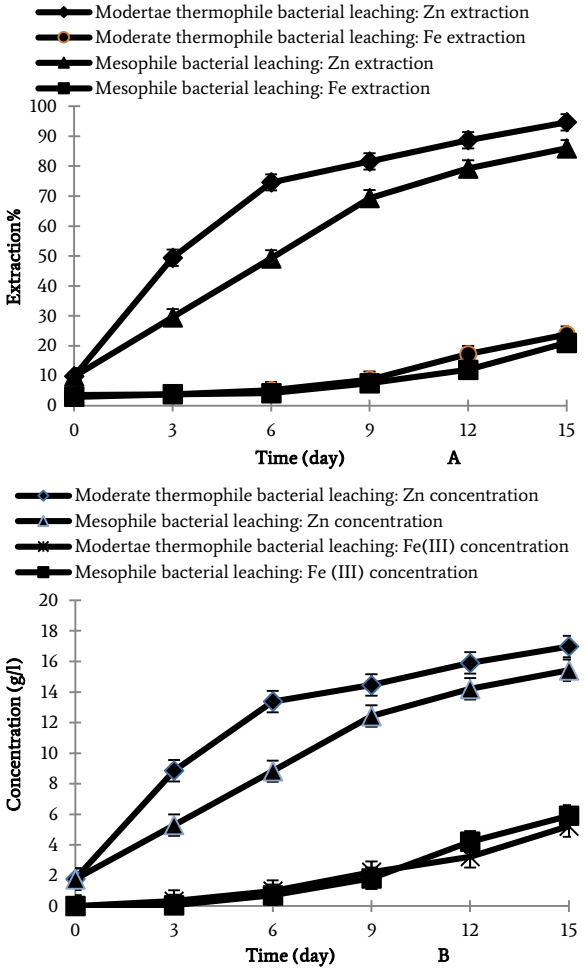

Figure 6. Comparison of mesophile and moderate thermophile bacterial leaching on A: Zn and Fe extraction, B: Zn and Fe (III) concentration.

4. Conclusions

The Kooshk tailing dam contains approximately 5 million tons of sphalerite tailings, grading 3.67% zinc, 0.97% lead and 24.18% iron. A low grade sphalerite concentrate produced from the tailings. About 45% of sphalerite was floated with a grade of 11.95% Zn, 23.17% Fe and 1.22% Pb. In order to evaluate the Zn extraction from the prepared concentrate, the bioleaching experiments were carried out using a mixture of three bacteria of *A. ferrooxidans*, *A. thiooxidans* and *L. ferrooxidans*, as well as moderate thermophile bacteria. According to the results of various experiments, the following conclusions were made:

Removing the bacterial medium (9K) from bioleaching experiments did not show a negative effect on biological dissolutions of sphalerite, in the low pulp densities.

More than 85% of sphalerite was dissolved in the bioleaching optimum test in presence of mesophile bacteria. The bacteria improved sphalerite dissolution about 36%, of which contribution of concentrate indigenous bacteria and added mesophile mixed bacteria were 34% and 66%, respectively.

More than 94% of sphalerite was dissolved in the bioleaching optimum test in presence of modertae bacteria. The bacteria improved sphalerite dissolution about 38%, of which contribution of concentrate indigenous bacteria and added moderate thermophile bacteria were about 50% separately.

Comparing Zn and Fe extraction, application of mesophile and moderate bacteria indicated that although the Fe (III) concentration in

both types of bacterial leaching solutions were identical, Zn extraction and concentration in the moderate thermophile bacterial leaching were significantly higher than the other one.

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