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# Evaluation of the replacement of NaCN with *Acidithiobacillus ferrooxidans* in the flotation of high-pyrite, low-grade lead–zinc ore

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ABSTRACT

We investigated the replacement of NaCN with *Acidithiobacillus ferrooxidans,* in the flotation of a low-grade lead–zinc ore containing high amounts of pyrite. *A. ferrooxidans* were adapted to original ore, and its growth curves were monitored before and after adaptation. Because of its characteristics, the addition of original ore caused the bacterial cell count to increase in the culture medium and growth improved. The effect of the bacteria and their capability to depress pyrite were investigated in galena and sphalerite concentrates. Two models were then fitted to the sphalerite and pyrite recoveries. The results indicated that pyrite was significantly depressed in the both galena and sphalerite concentrates, using *A. ferrooxidans* like NaCN depressant.



## 1. Introduction

Flotation is often used in mineral processing and to achieve selective separation of minerals and associated gangues. It utilizes the hydrophobic (aerophilic) nature of mineral surfaces and their tendency to attach to rising air bubbles in a water–ore pulp. In flotation processes, a number of chemicals (“reagents”) is used. Each of these reagents has a serious impact on the environment, some greater, some lesser. Certain reagents used in the mineral flotation of non-ferrous metals (cyanides, xanthates, etc.) are strong poisons or carcinogens, and their decay creates harmful substances.

Pyrite (Py) is an undesirable mineral that is often associated with other valuable metal sulfides such as chalcopyrite, arsenopyrite, galena (Ga), sphalerite (Sp) etc. Economical extraction of these valuable metals demands selective depression of Py from the associated metallic sulfides within the froth flotation. In most flotation plants, cyanide is used to depress Py and it accordingly has a key role in the extraction of gold and other metals such as copper, lead and zinc. Cyanide is highly toxic, and this is related to its physicochemical characterization. The free cyanide form of HCN, $CN^-$, is classified as the most toxic group, due to its high potential for metabolic inhibition [1–4].

In excessive quantities, cyanide can be poisonous to humans and animals, because it binds to the iron-carrying enzymes required for oxygen transport. In cases of cyanide poisoning, the body rapidly exhibits symptoms of oxygen starvation and suffocation.

During the process of lead and zinc flotation, concentration is normally carried out in such a way as to avoid the dispersion of gaseous cyanide, and it is deposited in tailings dump where it has the potential to leach into the surrounding water sources. Exposure to cyanide in solution through the consumption of surface water is the main exposure route for most animals affected by cyanide poisoning, but exposure through inhalation and skin absorption may also occur. Because of increasing cyanide consumption concerns and other environmental concerns, the development of an alternative, environmentally benign process is imperative.

Bioflotation is a relatively new method for processing ores and is defined as the selective separation of commercial gangue ores, through interactions with microorganisms [5]. Many investigations have suggested that certain types of bacterium such as *A. ferrooxidans* may prevent the flotation of certain minerals, such as Py [6–10].

*A. ferrooxidans*, a commonly implicated autotrophic, acidophilic, mesophilic microorganism, uses sulfur, thiosulfate and iron as energy sources. They are Gram negative, small rods of 0.5 by 1–3 μm,

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occurring singly or occasionally in pairs. These bacteria have been extensively used in mineral bioprocessing [11–14].

In the present research, we evaluated the replacement of NaCN with *A. ferrooxidans* in the flotation of a primary Pb–Zn ore on a laboratory scale. Moreover, using statistical design and fitting models, we optimized the flotation process to consume the least amount of chemical reagents. In the most previous micro-scale bioflotation research, pure minerals were used [7–10]; while this study was based on lead–zinc ore flotation.

## 2. Materials and methods

### 2.1. Ore characteristics

A low-grade Pb–Zn ore sample containing 31% Py and assaying as 2.34% Pb, 6.91% Zn and 15.36% Fe, was used as the primary ore in flotation and bioflotation experiments. The mineralogical and elemental compositions of the ore were studied using semi-quantitative X-ray diffraction (SQXRD) and atomic absorption spectroscopy (AAS), respectively.

### 2.2. Bacterial culture

A pure strain of *A. ferrooxidans*, which was isolated from the acidic water drainage of the Sarcheshmeh copper mine (located in Kerman Province, Iran) was used in this study. The bacteria were subcultured in the laboratory using 9 K medium (3 g/l $(NH_4)_2SO_4$, 0.5 g/l $MgSO_4$ $7H_2O$, 0.5 g/l $K_2HPO_4$, and 0.1 g/l KCl at pH 1.85). The bacteria were cultured by inoculating 10 ml of a pure strain of the bacterial cells to the medium. Potassium nitrate was used to maintain the ionic strength. The cells were incubated at 32 °C in a rotary shaker maintained at 160 rpm.

### 2.3. Flotation and bioflotation experiments

Flotation and bioflotation experiments were performed in a 1.5-L Denver cell running at 850 rpm using 300 g ore samples (at 25% of pulp density) at the size of 95 μm ($d_{90}$). Both Potassium ethyl xanthate (PEX) and potassium amyl xanthate (PAX) (industrial grades) were implemented as Ga and Sp collectors, respectively. Zinc sulfate, copper sulfate and sodium hydroxide were used for the Sp depression, Sp activation and pH adjustment, respectively, and were of analytical grade. Four control factors and their levels used in the flotation and bioflotation experiments are presented in Table 1. Regarding the selection of low and high values of the factors, we note that some early research has been carried out in the Kooshk lead and zinc mine. Based on these studies, we chose concentration ranges suitable for the investigation of their effects on Sp — Py flotation selectivity, and these are presented in Table 1. Moreover, these reagent concentrations are in use in the Kooshk flotation plant. Since there are insufficient references regarding the bioflotation of lead–zinc ore, we conducted some primary bioflotation experiments using different ores. From these experiments, we determined that a desirable concentration of bacteria is approximately $3 \times 10^6$ cells/ml. We note that in this work, we chose cell concentrations in the range $1.5–3 \times 10^6$ cells/ml to investigate the effect of the presence and absence of bacteria on the flotation process.

In the Ga concentration stage, we altered only the concentration of NaCN and the number of cells (Table 1). In all experiments, we pre-floated organic materials in the ore using 120 g/t methyl isobutyl carbonyl (MIBC) and 250 g/t diesel oil. For this purpose, we conditioned the pulp for 2 min at pH 7–7.5 and then collected the froth for 4 min using an impeller speed of 850 rpm. The pH of the pulp was adjusted to 9.5 and 11 in the conditioning stage for Ga and Sp, respectively.

**Table 1**
Studied factors and their levels in flotation and bioflotation experiments.

| Level | A: PAX(g/t) | B: $CuSO_4$(g/t) | C: NaCN(g/t) | D: number of bacteria (cells/ml) × $10^6$ |
|---|---|---|---|---|
| Low | 140 | 700 | 0 | 0 |
| High | 280 | 1400 | 100 | 3 |
| Center | 210 | 1050 | 50 | 1.5 |

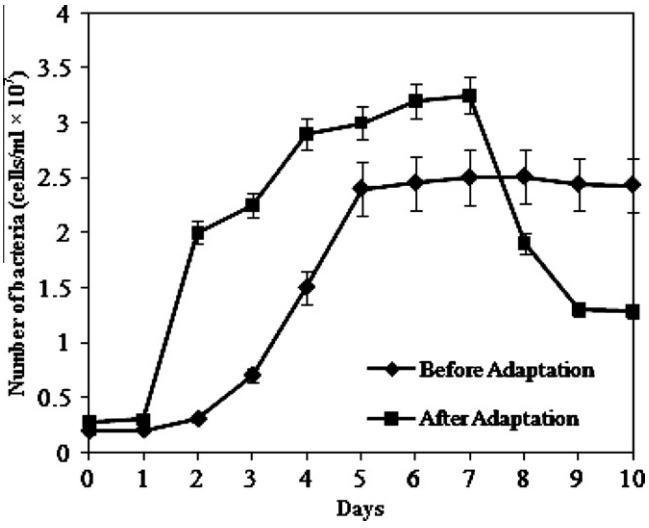


**Fig. 1.** The growth curve of *A. ferrooxidans*.

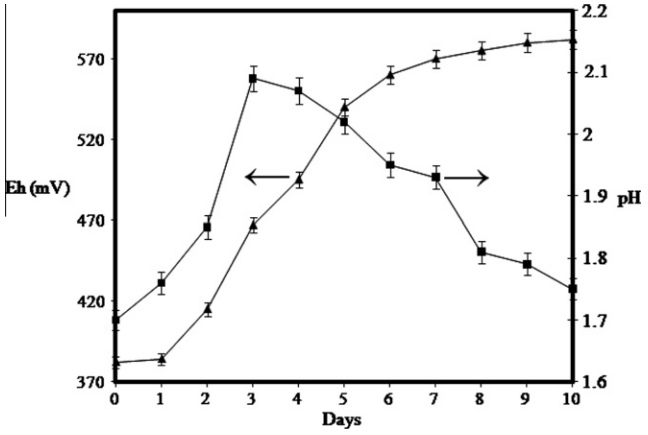


**Fig. 2.** pH and Eh changes during *A. ferrooxidans* growth.

The microorganisms were adapted to 50 g/L of original ore. *A. ferrooxidans* was grown on ferrous sulfate. Three-hundred milliliters culture with initial count of $3 \times 10^7$ cells was filtered through Whatman filter paper to remove the suspended solids. The cells were separated from this medium using biological filter paper (0.42 μm). The number of bacteria which were separated from the culture medium and remained on the filter surface was about $1.5 \times 10^7$ cells i.e. half of the initial count. Then these cells were washed using 300 ml distilled water and added to the volume of 1200 ml pulp, so the final count of bacteria in the pulp based on the chosen level in the experimental design was determined in