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Studies on Bio-oxidation of Galena

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ABSTRACT
Bio-oxidation is the process of oxidation of metal sulfide using variety of microorganisms for leaching the metal. The aim of the present study was to assess the capacity of *Acidithiobacillus ferrooxidans*, on the bioleaching of lead from galena concentrate. While the process carried out under the sulfur concentration about 6%, the results showed that the maximum of 79.8% Pb was leached from the galena.

Introduction

Bio-oxidation is the process of leaching of metals from solid ore materials using variety of microorganisms including mesophiles, moderate thermophiles, and extreme thermopiles. This process is based on the following principles: (1) the conversion of organic or inorganic acids (protons); (2) oxidation and reduction reactions; and (3) the exudation of complexing agents [1].

The use of microbes for the extraction of metals from low-grade ores and metal concentrates has developed into a successful area in biohydrometallurgy and it represents an eco-friendly technology in metal separation from its ore. This method is inexpensive and requires only less capital cost when compared with other conventional methods [2]. The raw and complex ores of lead-zinc sulphide are not economically processed by existing smelters. Even it is technically possible to process sulphide ores, difficulties are encountered including the emission of toxic gases and fumes of SO_2 into the environment during the roasting and smelting operations [3]. The bioleaching of base metal sulfides is an alternative method to rectify the above said difficulties.

Microbial leaching is presently used in mining industries for the pretreatment of refractory gold-bearing sulfides and for the extraction of copper, uranium and cobalt [4]. Lead is one of the important metal which is widely used in construction materials, electric circuit boards as a part of solder, lead-acid batteries, fusible alloys, weights and as a radiation shield. Extraction of lead from its ores in mining is a hazardous task because of the toxic fumes released during the process. Bioleaching of lead reduces this hazard to people work in lead mines. Bioleaching involves the use of iron and sulfur-oxidizing microbes to catalyze the dissolution of the metal species from sulfide ores or concentrates [5].

Acidithiobacillus ferrooxidans and Acidithiobacillus thiooxidans are the most common bacteria used in bioleaching [6,7]. In recent years, one of the members of genus Acidithiobacillus , Acidithiobacillus ferrooxidans has been under investigation for the bioleaching of base metal sulphides, which shows maximum growth upon the temperature of 40-45°C and the pH of 1-2 while comparing to Acidithiobacillus thiooxidans. So, it was chosen as targeted bacterium for this study. A. ferrooxidans is chemoautotrophic iron oxidizing bacterium (IOB) and it obtains energy by the oxidation of Fe (II) ion to Fe (III) ion which is called as biological oxidation or bio-oxidation.

This conversion is catalyzed by a specific type of protein, which was proposed to be the Iro protein [8]. The activity of this protein plays an important role in iron based leaching. Thus, A. ferrooxidans can be successfully used in this study for lead bioleaching from galena concentrate through indirect mechanism (Both direct and indirect mechanism are responsible for microbial attack on sulphide ores). Indirect bioleaching is essentially a lead dissolution depending on ferric iron attack of sulphide minerals such as galena (Eq.1). The bacterium reproduces ferric iron, the oxidizing agent of mineral by oxidizing ferrous iron (Eq.2) [9 – 11]. It is often dominant at later stage of bioleaching processes [12 – 14]. A brine leaching with NaCl aids to extract the lead as soluble chloride (Eq.3) [3].

$$PbS + Fe_2(SO_4)_3 \rightarrow PbSO_4(s) + 2FeSO_4 + S^0(s) \quad (1)$$

$$4FeSO_4 + 2H_2SO_4 + O_2 \xrightarrow{bacteria} 2Fe_2(SO_4)_3 + 2H_2O \quad (2)$$

$$PbSO_4 + 2NaCl \rightarrow PbCl_2 + Na_2SO_4 \quad (3)$$

In this bioleaching process, sulfur is added as an energy source to the organism however, high amounts of sulfur concentration lead to substrate inhibition in the bioleaching. Thus, identification of the ideal optimum values of the effective parameters in bioleaching is considered as an important step to determine the maximum yield of the metal by this process.

Materials and Methods

Isolation and tolerance of microorganism

Pure strain of *A. ferrooxidans* was used for bioleaching of galena concentrate in this study. Initially, *A. ferrooxidans* species were obtained from mine drainage samples of the Chitradurga mine sector in Ingaldhal (Karnataka, India) by serial dilution method [27], which is mostly applied in the isolation of organisms using 9K medium.

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The medium had the following chemical composition: $FeSO_4.7H_2O$ (40 g/L), $(NH_4)_2SO_4$ (2 g/L), $MgSO_4.7H_2O$ (500 mg/L), K_2HPO_4 (25mg/L) and ddH_2O at initial pH of 2.5 using 1N H_2SO_4. The target bacterium, pure strain of *A. ferrooxidans* was developed by numerous sub-cultures from serial dilutions.

In order to increase the tolerance of the microbe, *A. ferrooxidans* bacterium was made adapted to mixed ore mineral by sub-culturing (10% v/v) using the medium containing components as given in 9K medium provided with 1% (w/v) of galena concentrate. The cultivation conditions of temperature 37 ^oC, initial pH 1.5 and rotation speed of 150 rpm were also maintained. The initial pH of the media was adjusted using 1N H_2SO_4. The resulting adapted culture of *A. ferrooxidans* was used as inoculums for bioleaching experiments.

2.2 Galena Concentrate Collection

The Galena concentrate was collected from the Agucha mine province in Bhilwara district of Rajasthan state of India. The sample was crushed using laboratory jaw crusher then ground by ball mill. The particle size fractionation was carried out using ASTM sieves. The particle size ranged from 100 to 1200 µm with an average particle size of 300 microns ground ore was used in the bioleaching experiments. The chemical analysis of the galena concentrate showed the composition mentioned in Table 1.

Table 1. Chemical composition of the mixed ore (Galena)

Compound	Percentage %
Pb	58.12
SiO_2	16.40
CaO	8.72
MgO	7.50
LOI	4.50
Al_2O_3	0.70
Na_2O	0.38
H_2O^-	0.25
K_2O	0.05
Fe_2O_3	0.03
TiO_2	0.05
P_2O_5	0.03

X-ray diffraction (XRD) was used to identify the mineralogical composition of raw ore sample. It revealed that the mineral composition of the sample and It contained 67.196 % Galena (PbS), 17.612 % Sphalerite (ZnS), 7.962 % "Quartz low" and 7.230 % SiO_2. The content of elements in the galena concentrate was examined by area analysis of EDX. The spectral pattern of the sample was shown in Fig. 1 and It revealed that the elemental composition of the sample. It was found to contain 26.35 % O, 5.67% Mg, 9.54% Si, 11.63% S, 11.47% Zn and 35.34% Pb.

Lead extraction and Analysis Method

After 144h, the residue samples were filtered through Whattman No 1 filter paper. The residue was taken in a 250 mL Erlenmeyer flask containing 0.5 mol/L of sodium chloride solution. The flasks were then kept in a thermostatted water bath at 60 ^oC and leached for 1h with the aid of electric stirrer at 200 rpm. The slurry obtained after the leaching was filtered immediately through Whattman No 1 filter paper. The amount of lead in the filtrate was estimated by atomic absorption spectrometer (Perkin Elmer, AA200 model) after appropriate dilution whenever necessary. Pb bioleaching efficiency, denoted by Pb(%), was calculated using the mathematical expression

$$Pb\% = \frac{M_{soln}}{M_{Pb}} * 100 \quad (4)$$

Where, M_{soln} is the lead concentration in aqueous phase at time 144h and M_{Pb} is the total lead concentration in the mixed ore.

Results and Discussion

Characteristics of Galena:

The characteristics of the ore revealed that the ore was found to be rich in Pb metal in nature. Phosphorus content in the ore was very low. The estimated levels of sodium, potassium and calcium were moderate. It was observed from the analysis that the heavy metal, Pb was abundantly present in the ore. The concentration of total Pb present in the sludge was found to be 58.12% by weight which poses highly toxic and hazardous to the environment.

Variation in pH during Bio-oxidation:

In the inoculated experiment changes in pH show significant changes whereas, no changes were observed in control without bacteria. This is due to the conversion of elemental sulfur to metal sulphuric acid by bacterial catalysis. It was observed that at 0, 2, 4, 6, and 8 % the pH values decreased from 3 to 2.6, 2.43, 2.4, 2.3, 2.02, and 2. 3, respectively. Among the experiments, 6 % showed a tremendous decrease in pH, thereby facilitating bacterial growth. The variation in pH during the bio-oxidation process is shown in Figure 2.

Effect of Sulfur on Pb Leaching:

Figure 3. shows the bioleaching of Pb from the bio-oxidation at different sulfur concentrations such as 0, 2, 4, 6, 8 %. The experimental results revealed that Pb bioleaching is greatly influenced by the sulfur concentration. Pb solubilization was reached the maximum in a relatively short period of time at 6 % S. After 30 days of treatment, the bioleaching efficiencies of Ni were 64.16%, 68.14%, 76.57%, 83.5% and 80.62% at the experiments at 0, 2, 4, 6, and 8 %S, respectively. It has been reported that the bioleaching behavior of metals strongly depends on their chemical forms in the original ore. The experimental data show that the removal efficiencies of heavy metal with respect to S concentration took place in the order of 6% > 4% > 2% >8% > 0% S. Therefore, the better heavy metal solubilization requires treatment preferably an optimum sulfur concentration of 6%.

Conclusion

The present study showed that the biooxidation using sulfur-oxidizing bacteria, *A. ferrooxidans* was effective in Pb from the galena ore. Pb solubilization efficiencies were observed for experiments carried out at different sulfur concentrations.

Maximum bioleaching efficiency of Pb was achieved to be 6% at 37 °C. This study clearly demonstrates the practicability and design strategy of bio-oxidation system for sulfide ore using bioleaching process, which thereby provides a solution to control the toxicity levels in the environment.

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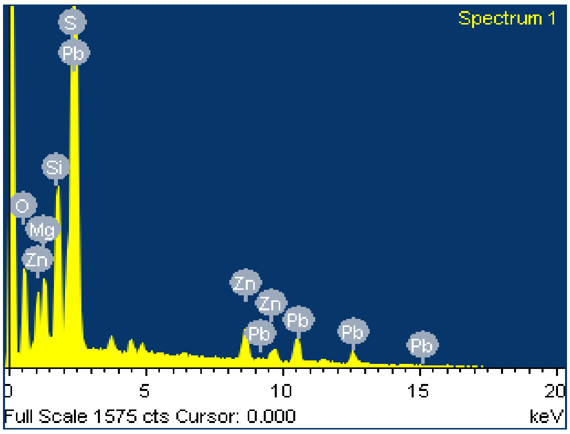

Figure 1. Spectrum of SEM-EDX on galena ore.

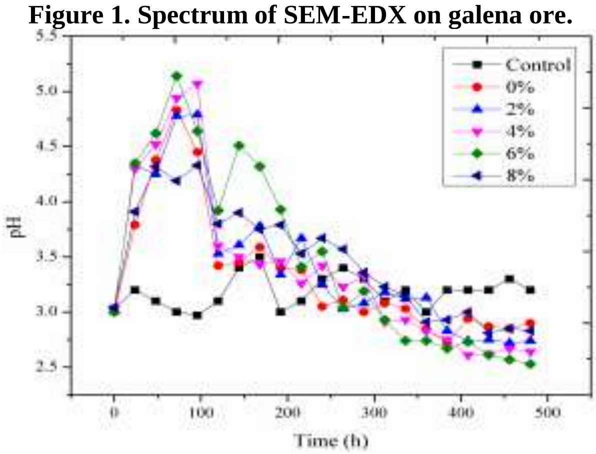

Figure 2. The variation in pH during bio-oxidation of galena

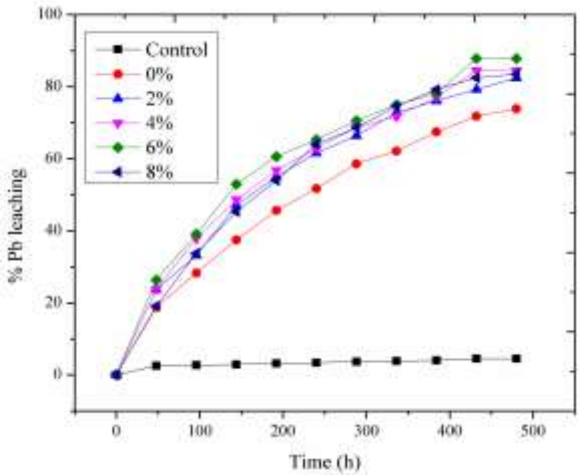

Figure 3. The profile of Pb leaching by galena ore bio-oxidation

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