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Bio-oxidation of Arsenopyritic and Pyritic Containing Gold Ore from Tianli Gold Mine and Process

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Abstract

Being the most common sulfide minerals, Arsenopyrite and pyrite under oxidizing conditions breaks down to release acids of As and S into the environment, leading to acid mine drainage with high concentrations of dissolved As. In this research, the dissolution of gold ore (with FeS_2 and FeAsS as the main sulfides) from Tianli gold mine, Liaoning province, China was investigated. The experiments were conducted in 500mL conical flasks containing 200mL of three different media, 3% pulp density and 1.6 initial pH. The results indicated that treatment with mix culture medium resulted in the dissolution of 99% of Arsenic and 99% of iron, which was higher as compared with when treated in the same culture medium after centrifugation for 20 minutes which in turn higher in comparison with when treated in acidic and pure sterile system. The oxidation potential, *Eh* of the mix culture medium reached 680mV (vs.SCE) within the first three days of the experiment where as that of centrifuged, acidic and sterile media reached 580, 450 and 445mV (vs.SCE) respectively. The pH tends to increase within the first three days which eventually decreased to nearly one toward ending, courtesy of pyrite which is believed to be net acid releasing sulfide. The dissolution is suggested to be a combined effect of enzymes, ferric iron ions and organic acids. It was observed that enzymes and ferric ions played an essential role in the dissolution process.

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Introduction

The innovation of steam engine back in the late 19 the century resulted in an enormous growth of industrial activities globally, which in turn resulted in an increase deterioration of the ecosystem because of the discharge of highly polluted effluents in the forms of solid, liquid, and gas. The efforts have been put forward toward developing eco-friendly and sustainable processes in order to avoid rapid degradation of the ecosystem. In the fields of mineral processing and extraction of metals joint efforts are put forward to developing environmentally friendly processes [1]. Owing to the gradual depletion of high-grade ores, attention are now being focused toward recovering metal from ores, complex and lean ores, which cannot economically be treated by conventional routes [2,3]. Bio-hydrometallurgy is a new concept that involves the use of various microorganisms to recover metals from their ores. It is also environmentally friendly unlike conventional hydro-metallurgical process [4]. Bio-hydrometallurgy technique applies to different types of materials, so far unusable resources, by which metals can be recovered and also generates minimum effluents and therefore is preferred as green technology. For last several decades bioleaching prioritize in application for metal recovery from ores/concentrates namely; pyrite arsenopyrite, chalcopyrite, calcite [5]. Among the major bacteria group that are promising in bioleaching process are chemolithotrophic acidophiles namely, Acidithiobacillus ferrooxidans, Acidithiobacillus thiooxidans, and Leptospirillum ferrooxidans and heterotrophs like Sulfolobus. Some of eukaryotic bioleaching microorganisms that applied in metal recovery include fungal species such as Aspergillus niger and Penicillium from industrial wastes [6]. The recovery of free milling gold by gravity and direct cyanidation proved to be straightforward and well established, refractory ores pose a very different challenge to producers. The first challenge is determining the reason for the poor recovery by direct cyanidation, which can be caused by one or more contributors. The oldest and best understood is gold locked in sulphide, and most frequently pyrite. The second contributor to refractory behaviour is arsenic, which causes high refractoriness even at low concentrations. The presence of carbon in the ore is also a frequent cause of poor recovery. In this paper, gold ore sample (with FeS_2 and FeAsS as the main sulfides) from Tianli gold mine, Liaoning province, China was treated in four different media.

Materials and Methods

Mineral samples preparation

The sample ore for this study was obtained from Tianli gold mine, China. Chemical analysis of the representative sample by AAS (atomic absorption spectroscopy) was conducted. The sample Ore was sieved to -0.075 mm before used for all leaching experiments. X-ray diffraction analysis of the sample showed pyrite (FeS_2) as the major phase and Chemical analyses also indicated that the sample contained arsenical pyrite or arsenopyrite (FeAsS). The particle size of the sample was 80% below 75 µm (Figure 1). X-ray fluorescence spectroscopic analysis of the sample was conducted and the result is shown in table 1.

Harvest of culture medium

A mixed culture medium (HQ 2011) was used, the studies, which utilized ferrous ion or elemental sulphur as energy source. Cultivated by Northeastern University and mainly contain *Acidithiobacillus ferrooxidans, Ferroplasma acidiphilum, Leptospirillum ferriphilum* etc. The cells were incubated at 180 rpm and 37°C in sterile 9K basic salt medium containing different energy substrates [7] After incubation for three days, some portion of the cells was harvested by centrifugation at 10,000 rpm for 10 min.

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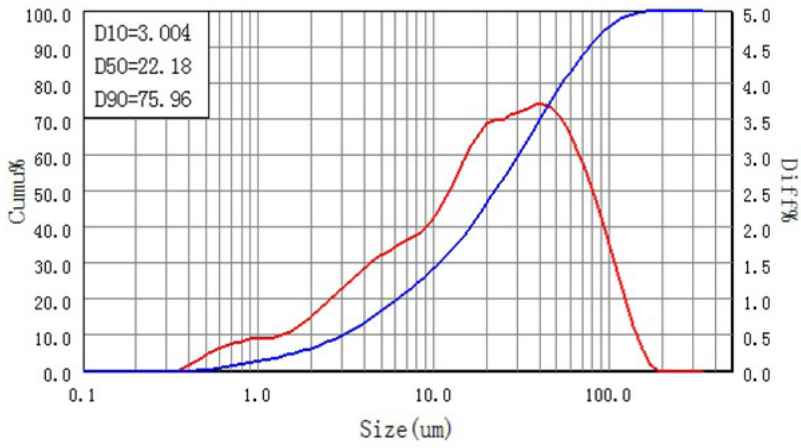

粒径μm	含量%
0.500	0.37
1.000	2.79
2.000	6.37
5.000	16.64
10.00	28.44
20.00	46.66
45.00	73.87
75.00	89.66
100.0	95.82
200.0	100.00

Figure 1: particle size of the sample ore.

No:	components	wt%	No:	components	wt%
1.	SiO_2	34.4098	11.	MnO	0.2559
2.	SO_3	25.1818	12.	P_2O_5	0.0924
3.	Fe_2O_3	17.3137	13.	PbO	0.0600
4.	Al_2O_3	9.3921	14.	Br	0.0466
5.	CaO	3.7806	15.	CuO	0.0396
6.	As_2O_3	3.0945	16.	Cr_2O_3	0.0355
7.	K_2O	2.8253	17.	NiO	0.0171
8.	MgO	2.6939	18.	ZrO_2	0.0110
9.	TiO_2	0.4043	19.	SrO	0.0088
10.	ZnO	0.3372			

Table 1: Chemical analysis of the sample ore by X-ray fluorescence (XRF).

Bioleaching experiments

The experiments were conducted in 500mL conical flasks containing 200mL of four different media, mix bacterial medium, mix centrifuged bacterial culture medium, in acidic medium and in a sterile medium. The pulp density was 3%. Sample of the ore mineral was added into media without Fe^{2+},[9] added with culture medium (inoculated amount of 10%), and pH was adjusted to 1.6 with H_2SO_4 and then placed into a constant-temperature incubator (175 r/p) for days.

Chemical analysis

Measurements of pH and potential were performed every day. Samples were aseptically withdrawn from the flasks every two to three days for chemical analysis. The samples were separated by centrifugation at 5000 rpm for 10 min. the dissolve Arsenic and total iron and were measured.

Results and Discussion

pH

At 37°C, 10% Inoculum, 175 r/p, 3% pulp density and 36 days the leaching time. The effect of pH on the sample ore bio-oxidation was studied. The results are presented in Figure 3. The pH of the centrifuge and mixed bacterial media during the dissolution of the sample showed almost similar characteristics. Within the first 3 day of the experiment, the percentage of the total Fe ion were 86% and 87 for the sample with mixed and centrifuge bacterial culture medium (Figure 4), this clearly indicates that the oxidation rate of the sample is higher at the initial stage, so the increase in pH is apparent. Furthermore, the increase in concentration of total iron (the Fe^{3+} ion) which partake in the oxidation process resulted in the subsequent decrease of pH (eq. (1)), [8] to nearly 1.1 on the 36th day. On the other hand the percentage of the dissolved total Fe ion in acidic and pure sterile media were 16% and 15% respectively, indicating that the oxidation rate is lower in the initial stage. It is believed that the decrease in the pH resulted from the dissolution of pyrite being net acid releasing sulfide and arsenopyrite presents in the ore sample.

$$Fe + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \qquad (1)$$

Oxidation potential

The variations in the redox potential (Eh) with time is given in Figure 5. It can be seen that after the first day, the redox potential of the samples with mix and centrifuge bacterial medium were increased reaching the values of about 640 and 465 mV after 3 day of the experiment. On the sixth day the redox potential of the sample with mix bacterial medium reached its peak value (680 mV) which indicates that microorganisms of the mix culture medium were more active at pH of about 1.5 to 1.6, whereas that of the centrifuge bacterial medium reached it maximum value (650 mV) on the 18th day of the

experiment. The higher dissolution of arsenic and total Fe could be attributed to the higher redox potential of the solution. On the other hand the oxidation potentials of pure sterile and acidic media were 310mV and 340mV indicating that the dissolution of the sulphide was much lower.

Percentages of dissolved arsenic and total Fe

It was observed that the dissolution of the arsenic and total iron for the sample with mix and centrifuge bacterial medium increases with the gradual decrease in the pH, initially the dissolution of arsenic were 73% and 34% (Figure 6) and the dissolved total Fe (Figure 4) were 87% and 86% within the first three day of the experiment and continue to rise during the process reaching up 99% both while the dissolution of the arsenic for the sample in acidic and pure sterile medium were 28% and 18% whereas those of the total Fe were 16% and 15% within the first three day of the experiment which appear to be low at the initial pH. The oxidation potential of the sample with mix bacterial and centrifuge bacterial medium is low but continue to rise during the whole process, which indicates that the bacteria are difficult to survive at the pH of 2 or above though could be alive but less active [8].

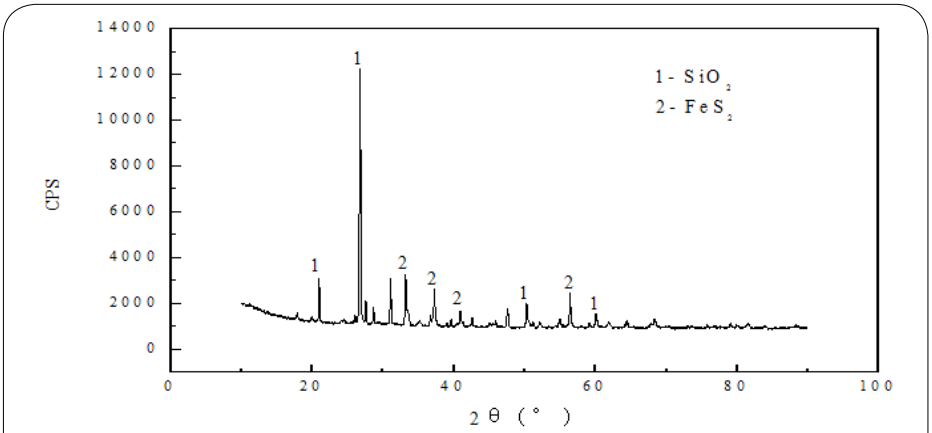

Figure 2: X-ray diffraction analyses of the sample ore.

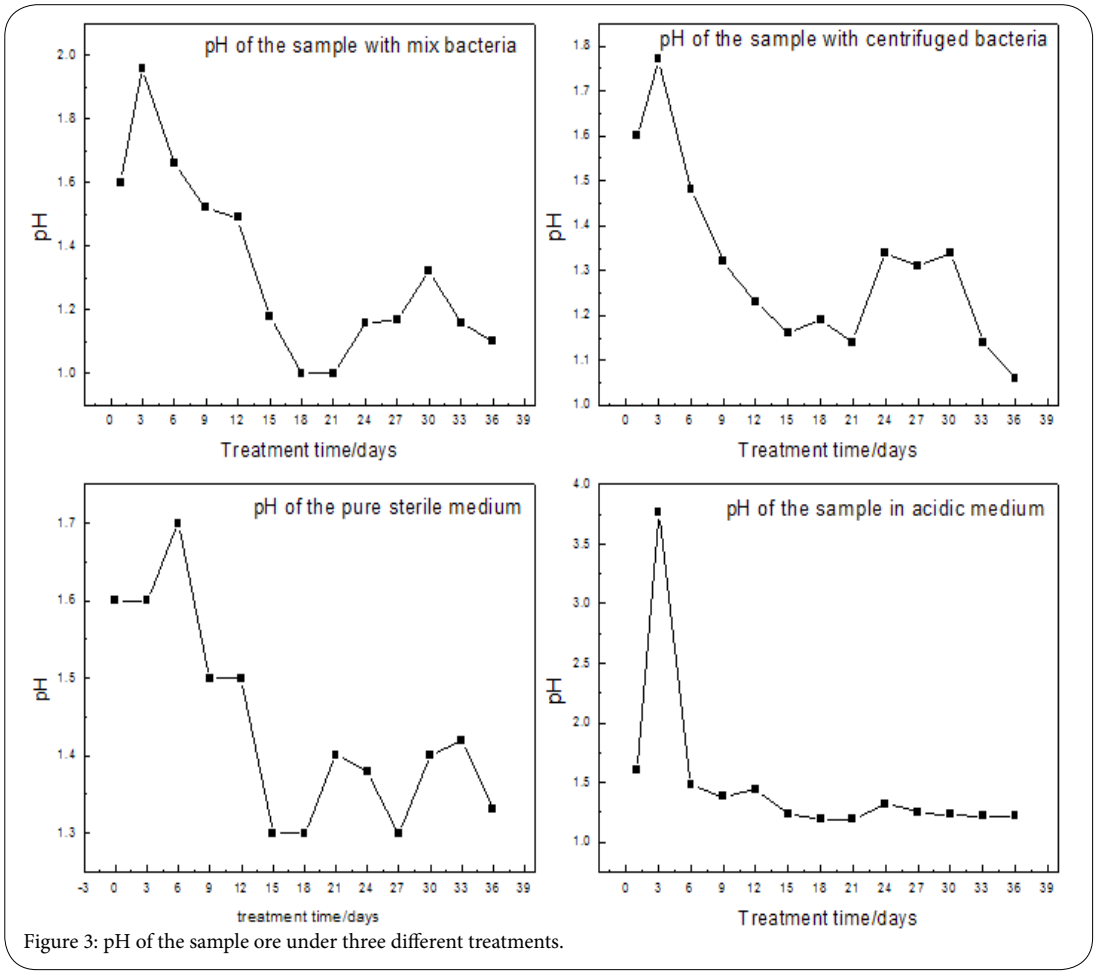

Figure 3: pH of the sample ore under three different treatments.

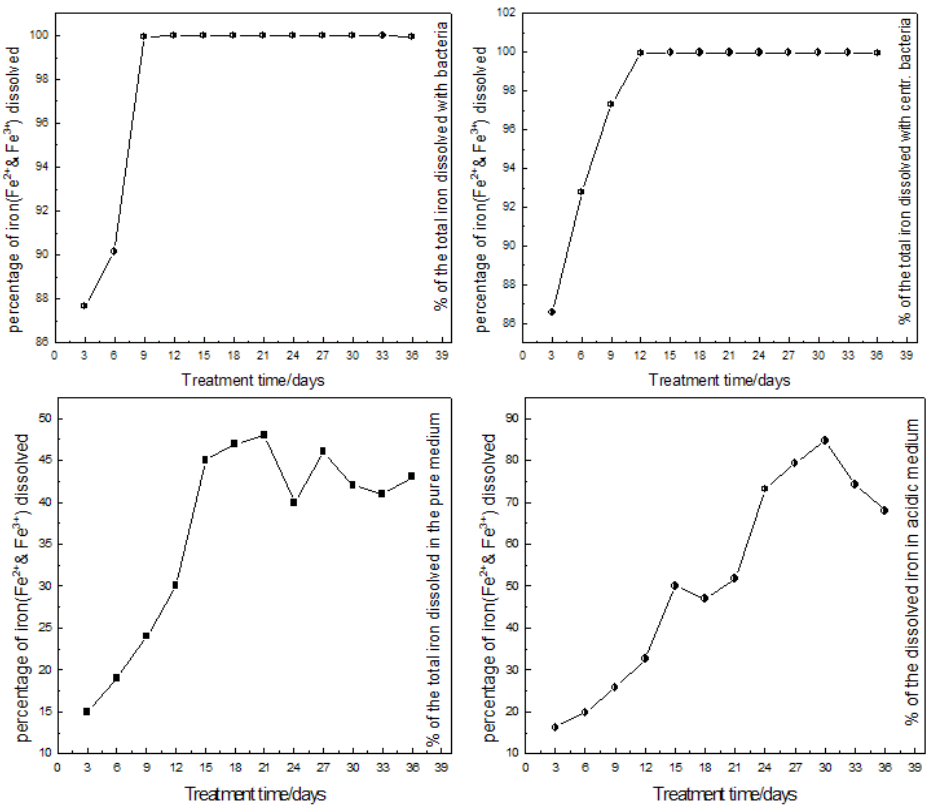

Figure 4: the percentage of the dissolve total iron of the sample treated under three different media.

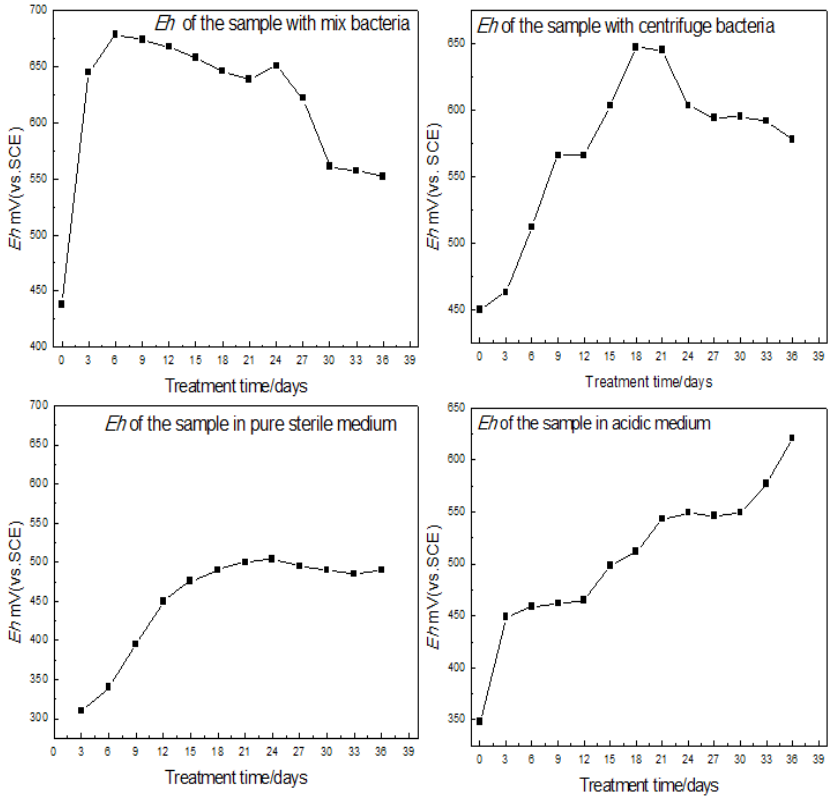

Figure 5: potential (Eh) of the samples under three different treatment.

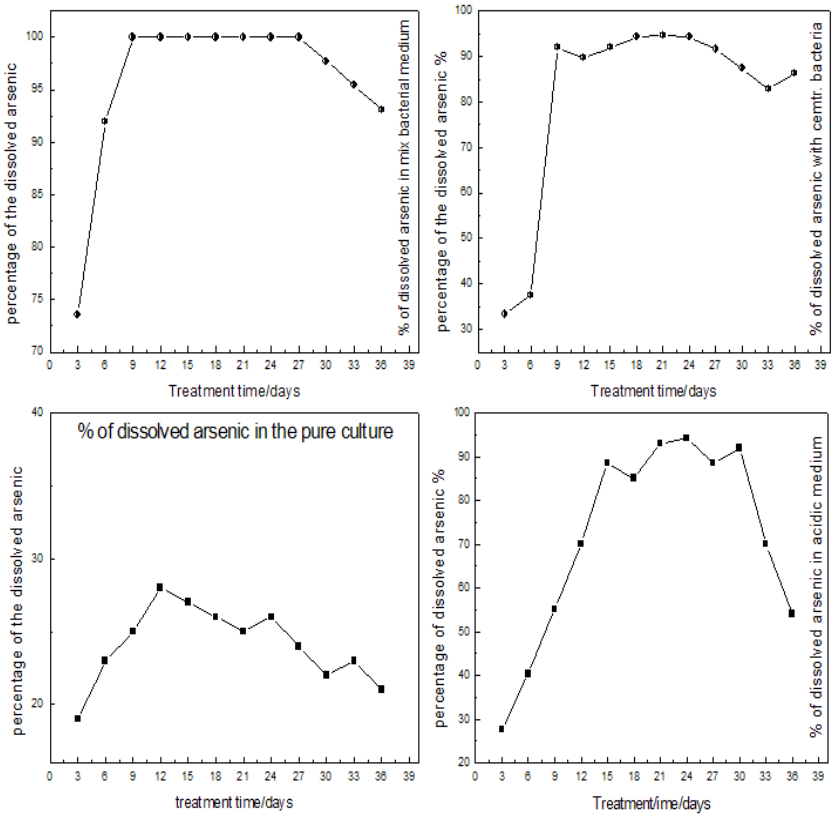

Figure 6: the percentage of the dissolved arsenic of the sample treated three under different media.

Conclusion

The bio-oxidation of arsenic-bearing gold ore from tianli gold mine was investigated by comparing the dissolution of the sample ore in four different media, in a mix bacterial medium, mix bacterial medium after centrifugation, acidic medium and in a pure sterile medium. The experimental results showed typical oxidation characteristics for the four different media. After the first day, the redox potential of the samples with mix and centrifuge bacterial medium were increased, reaching the values of about 640 and 465mV after 3 day of the experiment. On the sixth day the redox potential of the sample with mix bacterial medium reached its peak value (680 mV) which indicates that microorganisms of the mix culture medium were more active at pH of about 1.5 to 1.6, whereas that of the centrifuge bacterial medium reached it maximum value (650 mV) on the 18th day of the experiment. The higher dissolution of arsenic and total Fe could be attributed to the higher redox potential of the solution. On the other hand the oxidation potentials of pure sterile and acidic media were 310mV and 340mV indicating that the dissolution of the sulphide was much lower. It is believed that the decrease in the pH resulted from the dissolution of pyrite being net acid releasing sulfide.

Competing Interests

The authors declare that they have no competing interests.

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