

BIOOXIDATION OF TWO ARSENICAL REFRACTORY GOLD CONCENTRATES AND GOLD CYANIDATION^①

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ABSTRACT

The influence of pulp density, ferric ion concentration and particle size on the tank bioleaching of two kinds of refractory gold concentrates are discussed. The chemistry and mechanism of bioleaching process are also presented. The relationship between oxidation of sulfides, liberation of enclosed gold and gold cyanidation are discussed. The consumption of NaCN could be reduced by alkaline pretreatment of bioleached residues prior to cyanidation.

Key words: gold bacterial leaching refractory gold ores

1 INTRODUCTION

It was well known that gold is finely disseminated in sulfides such as pyrite and arsenopyrite of refractory gold ores/concentrates^{1, 2}. It was also found that the typomorphic element arsenic is highly correlated with gold grade in many deposits. The relation between metallogenicity and mineralogy of refractory gold ores was discussed³. Bioleaching and pressure oxidation appeared to be the most attractive methods available for the preferential oxidation of arsenical refractory gold ores/concentrates.

Almost fourteen kinds of simple arsenical, antimony bearing, copper bearing and carbonaceous refractory gold ores/concentrates have been bioleached with the bacteria of *T. ferrooxidans* since 1980 in China⁴. However, a high gold liberation or extraction is obtained in the leaching cases of simple arsenical refractory gold ores/concentrates. The selection of pretreatment processes for the metallurgy of Chinese refractory gold ores was discussed according to their mineralogy⁵. Moreover, the influences of various factors such as ions, sulfides, temperature and pH etc on the growth and

bacterial activity, the electrochemical reaction mechanisms of sulfides and the bioleaching process chemistry were discussed^{1, 5}. Biooxidation and cyanidation of two kinds of arsenical sulfide refractory gold concentrates respectively from Banbishan Mine of Hebei province and Baogutu Mine of Xinjiang Province are described.

2 EXPERIMENTAL

2.1 Samples

The chemical compositions of two samples are summarized in Table 1. The analysis of minerals pyrite (Py) and arsenopyrite (Ar) in the concentrates is listed in Table 2. Gold occurrence and gold distribution among minerals are presented in Table 3.

2.2 Bacterial Adaptation and Culture of Bioleaching Solution

A sample of *T. ferrooxidans* strain T-3 has been adapted on arsenical concentrate since 1972.

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This culture develops at pH as low as 1.3 and with up to 15g/L As and 65g/L Fe in the solution. The culture of bioleaching solution was carried out in 500 mL flasks at the initial pH 2.0, each contained 180 mL ferrous ion solution and 20 mL of adapted solution. The flasks were inoculated on a gyratory shaker 180 r/min at 30 °C in the dark for 72 h. The biomass content of inoculated ferric ion solution was assayed as 5×10^6 cell/mL by measuring the protein content using Peterson's technique.

Table 1 The chemical compositions (%) of two kinds of arsenical refractory gold concentrates from Banbishan Mine(A) and Baogutu Mine(B)

Composition	Fe	As	S	SiO ₂
Sample A	15.20	4.63	9.48	49.78
Sample B	31.0	3.20	31.6	6.50

Composition	CaO	MgO	Al ₂ O ₃	calcite
Sample A	2.15	1.49	6.39	
Sample B				3.50

Table 2 The phase composition of elements Fe, As and S in minerals Py and Ar of concentrates

Sample	A	B
Phase composition Ar/Py	8.90/3.05	6.82/29.06
Total Fe	15.20	31.40
Fe distributed in Ar/Py	1.40/1.42	1.08/13.52
Total As	4.63	3.20
Fe distributed in Ar/Py	4.09/0.20	3.14/0.10
Total S	9.48	31.6
S distributed in Ar/Py	0.80/1.63	0.62/15.5

Table 3 Gold occurrence and gold distribution among minerals

Gold grade g/t	Gold occurrence and distribution (%)			Direct cyanidation extraction (%)	
	recoverable free gold	enclosed gold in Py-Ar	others		
Sample A	36.62	51.78	25.70/7.08	15.11	57.0
Sample B	31.09	46.16	21.83/3.77	25.21	55.7

2.3 Batch Bioleaching Test Procedure

For most tests, pulps of 10% solids were prepared from -320 mesh samples A or B and the above inoculated bioleaching solution. Then 200

mL 10% solids pulp was added to a 500 mL Erlenmeyer flask which was inoculated on a gyratory shaker 200 r/min at the initial pH 2.0 and 30 °C in the dark. Distilled water was added to the flask to compensate for the losses of sampling and evaporation. Bioleachate and residue were respectively analyzed to calculate the apparent extraction E' (%) of Fe and As. The actual extraction E (%) of Fe and As was calculated upon the bioleached residue which was washed by dilute HCl solution to remove the precipitates jarosite and arsenate.

2.4 Cyanidation

The bioleached residue was collected, dried and weighted before cyanidation. Cyanidation tests were conducted with standard cyanidation technique. Pulps of 20% solids content were treated for 48 h at pH 10.5–11.5 with 0.10% NaCN. Gold extraction recovery was calculated on the fire assay of gold in the residue.

3 RESULTS AND DISCUSSION

3.1 The Influences of Various Factors on the Arsenic Oxidation

The influences of particle size and pulp density on the oxidation of arsenic are respectively illustrated in Fig. 1 and Fig. 2. Arsenic oxidation is inversely proportional to pulp density as the density increases to 20% solids. Considering the conditions in the practical production, the particle size and pulp density are chosen as 320 mesh and 10%.

The effect of $[\text{Fe}^{3+}]$ on arsenic oxidation is shown in Fig. 3. The oxidation of arsenic increases with the addition of $[\text{Fe}^{3+}]$ in the range $[\text{Fe}^{3+}] < 8 \text{ g/L}$. The reduction of arsenic oxidation probably results from the precipitation of arsenate when $[\text{Fe}^{3+}] > 8 \text{ g/L}$. The ferric ion concentration is chosen in a reasonable range 6–8 g/L. An experiment is conducted under the above reasonable conditions, as shown in Fig. 4.

The compositions of leached solutions and residues of samples A and B are listed in Table 4.

The distribution of precipitates jarosite and arsenate in bioleached residues is listed in Table 5.

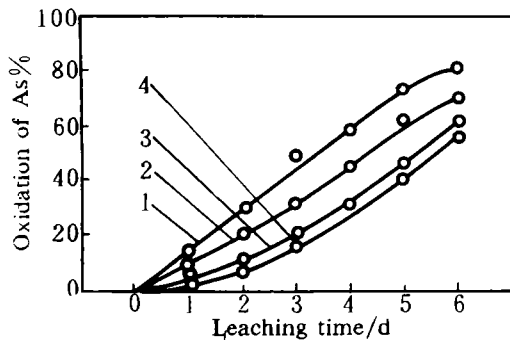


Fig. 1 The influences of particle sizes of Baogutu concentrate (B) on the arsenic oxidation (30 C, 10 g/L Fe³⁺, pH2.0)

Samples No	size (mesh)	pulp density (%)
1	320	10
2	200	10
3	320	20
4	200	20

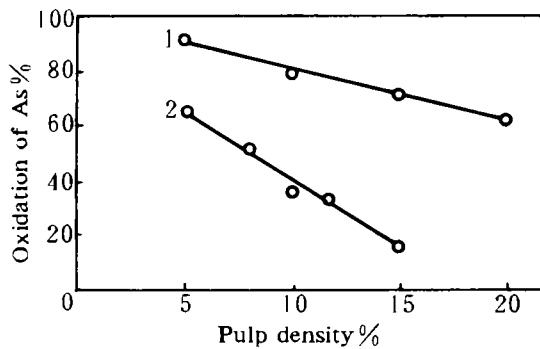


Fig. 2 The influence of pulp density on the arsenic oxidation

(10 g/L Fe³⁺, pH2.0, 30 C, 320 mesh)

1—Sample A, Residence time 6 days;

2—Sample B, 5 days

3.2 The Process Chemistry and Bioleaching Mechanism

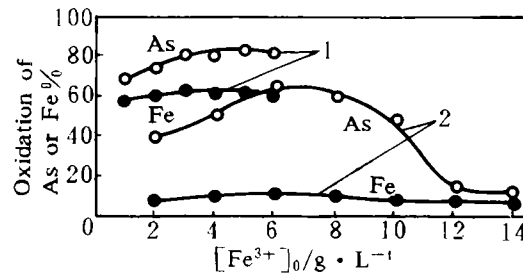


Fig. 3 The influence of [Fe³⁺] on the arsenic oxidation of Sample A (1) and Sample B (2) (pH2.0, 30 C, pulp density 10%, particle size 320 mesh, 6 days)

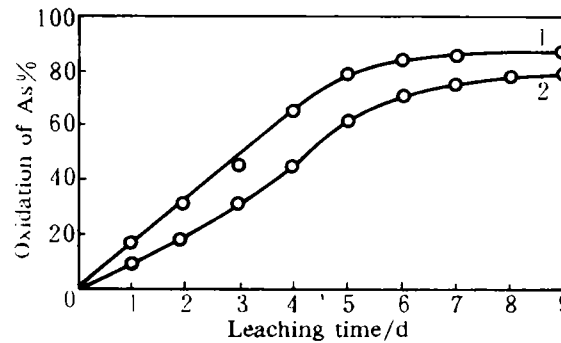


Fig. 4 Relationship between arsenic oxidation and time in the bioleaching processes of Sample A (1) and Sample B (2) under the reasonable conditions of 9.0 g/L Fe³⁺, pH2.0, 30 C, pulp density 10%, and particle size 320 mesh

According to Fig. 5 and Tables 4, 5 the process chemistry and leaching mechanism are proposed by the following reactions eqs. (1) to (8):

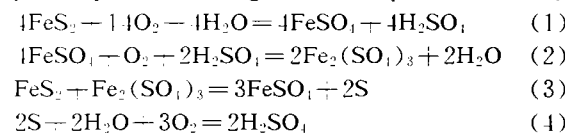


Table 4 The chemical compositions of bioleachate characteristics and residues of samples A and B after 7 days bioleaching at the optimum conditions (7 days; L:S, 10%; Fe³⁺, 9.0 g/L; pH 2.0)

	Leachate g·L ⁻¹							Residue ³⁰				Residue loss wt.-%
	Fe ²⁺	Fe ³⁺	As ³⁺	As ⁵⁺	SO ₄ ²⁻	pH	ψ mV	Fe	As	S	Au g·t ⁻¹	
A	2.84	11.24	0.43	2.41	32.5	1.5	550	9.60	0.78	7.58	42.0	18.0
B	6.15	11.36	0.57	1.42	36.2	1.4	535	29.3	1.60	28.2	34.2	9.5

Table 5 The proportions of precipitates jarosite and arsenate* in the bioleached residues of sample A (%)

	Fe	As
<i>E'</i> , Apparent oxidation calculated on leachate	49.0	83.0
<i>E</i> , Actual oxidation calculated on residue washed by HCl	62.0	93.0
<i>P</i> , Precipitation percentage(<i>E</i> - <i>E'</i>)	13.0	10.0
Proportions of	Jarosite = 13.0 - 10.0 = 3.0; Arsenate = P(As) = 10.0	

* jarosite and arsenate are considered as the soluble precipitate in HCl solution

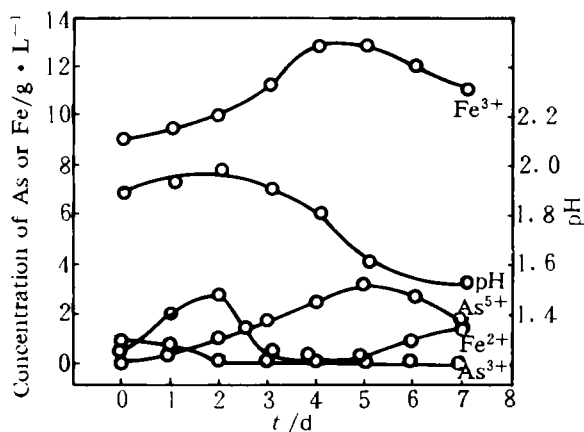
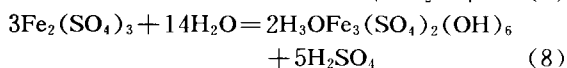
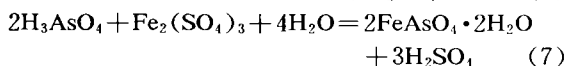
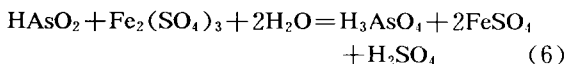
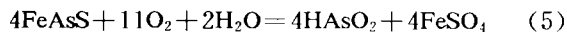


Fig. 5 The variation of pH, ionic states and concentration during the bioleaching process of sample A (Fe³⁺ 9 g/L, 30 C)

The above reactions explain the experimental behaviours;

(1) The slight increase of pH in the initial one day was a result of acid-consuming reactions of gangue minerals. After then the diminishing of solution pH from 2.0 to 1.5 may be attributed mainly to the oxidation of sulfides and the precipitation of jarosite and arsenate. As a result, the bacterial activity and ferric ion oxidation decrease in 5 or more days later.

(2) The ion As³⁺ is more easily oxidized than Fe²⁺ [$\varphi(\text{As}^{3+}/\text{As}^{5+}) = 0.559 \text{ V}$; $< \varphi(\text{Fe}^{2+}/\text{Fe}^{3+}) = 0.77 \text{ V vs SHE}$]. The ion As⁵⁺ is the dormi-

nant existing state in the leachate.

(3) The decline in the soluble iron and arsenic ion and arsenic ion concentration with leaching time might be due to the precipitations of jarosite and arsenate after 5 days. The amount of precipitate arsenate is more than that of jarosite. Generally, jarosite is formed at the conditions of high temperature and ferrous ion concentration.

(4) The oxidation rate of arsenopyrite is greater than that of pyrite, so the oxidation of elements increases in the sequence of $E_s < E_{\text{Fe}} < E_{\text{As}}$.

(5) Sulfide minerals are oxidized with the direct and indirect attack mechanisms.

3.3 Cyanidation Process of Bioleached Residues

Gold cyanidation increases with the additions of bioleaching time and arsenic oxidation, as shown in Fig. 6. The relation between gold cyanidation (%) and arsenic oxidation is illustrated in Fig. 7. In spite of that, the direct cyanidation rate R(%) for both samples A and B is almost equal to each other, that is, the inclusional percentages of gold(1 - R) in both samples A and B are equal. However, the gold cyanidation of bioleached residues with the same arsenic oxidation is different. Thus, a new concept of activity of enclosed gold, β , is defined as follows:

$$E_{\text{Au}} = E^{\circ}_{\text{Au}} + \beta_{\text{As}} \pm \varepsilon \quad (9)$$

where ε represents the average error between the experimental results and the quasi-linear value.

So the more tight the enclosed gold, the lower the β value, the lower the gold extraction, as shown in Fig. 7. Furthermore, the linear relation between gold extraction and arsenic oxidation shows that gold is highly related with the element arsenic which is geologically as a typomorphic element. To diminish the consumption of NaCN, the

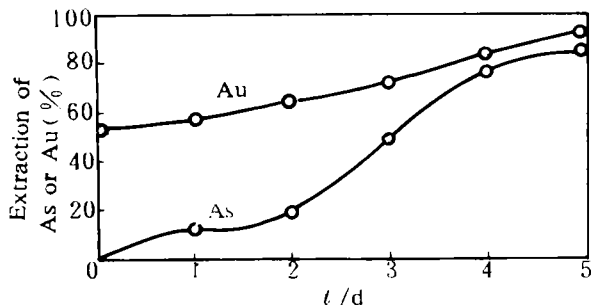


Fig. 6 Effects of leaching time on the arsenic oxidation and on the extraction recovery of gold cyanidation for sample A

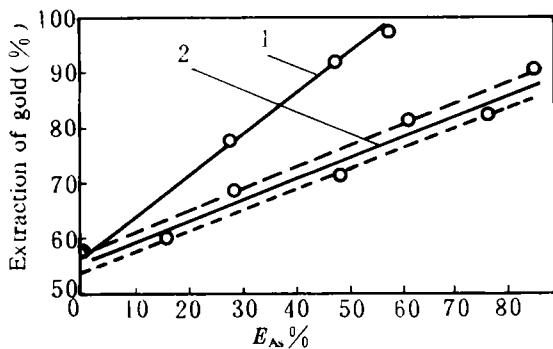


Fig. 7 Effect of arsenic oxidation (E_{As}) on gold cyanidation response (E_{Au})
 1—sample A, $\beta = 0.774$, $\varepsilon = 0.5\%$;
 2—sample B, $\beta = 0.388$, $\varepsilon = 2\%$

bioleached residues are pretreated in an alkaline solution prior to cyanidation process. The consumption of sodium cyanide decreases from 10.8 kg/t (untreated residue) to 5.7 kg/t (treated residue). In spite of that, the problem of high NaCN consumption needs to be solved further. At the same time, however, gold is lost by 7.1% due to the formation of soluble gold complexes with multi-sul-

fide ions, as shown by eqs. (10)–(11):



4 CONCLUSIONS

(1) The mechanism and process chemistry for the bioleaching process have been discussed.

(2) Selective bio-oxidation technique is suitable for the pre-treatment of simple arsenical refractory gold ores/concentrates. Batch leaching is reasonable under the optimum conditions of 80% particle size through 320 mesh, pulp density 10%, initial ferric ion concentrations 6–8 g/L, pH 1.8–2.0, temp. 30 °C and 7 days.

(3) Gold is highly related with the typomorphic element arsenic in some simple arsenical refractory gold ores. The linear relation $E_{Au} = E_{Au}^0 + \beta E_{As, S}$ is suitable for the determination of a reasonable oxidation time for different ores. The activity of enclosed gold is respectively as 0.774 and 0.388 for sample A and sample B.

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