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Gold leaching with elemental sulfur in alkaline solutions under oxygen pressure^①

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Abstract: A gold leaching process by using oxidation products of elemental sulfur in alkaline solutions was proposed and investigated. A gold concentrate and a residue from an arsenic refractory gold concentrate by acidic oxidation leaching were tested. The residue contains 16.3% elemental sulfur and no more elemental sulfur was added in tests. For the concentrate elemental sulfur was added before leaching tests. The leaching ratio of gold depends mainly on the initial equivalent ratio of elemental sulfur to hydroxyl ions, the consumption of oxygen and the reaction temperature in the process. Analysis of the experimental results shows that thiosulfate is the majority complexing reagent for gold in the process. Over 90% gold was leached from the residue and 82% - 87% from the concentrate by using this process.

Key words: gold leaching; elemental sulfur; alkaline solution; oxygen pressure; and thiosulfate

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1 INTRODUCTION

Cyanidation process, characterized by effectiveness and low operating cost, as a conventional technology for gold extraction from ores, has been used in industry for over 100 years. However the cyanide is a highly toxic chemical, and commercial cyanidation process is limited in the area sensitive to environment condition. Therefore considerable effort has been expended on attempts to develop new gold extractive process by using non-cyanide chemicals. Among them some sulfuric compounds is a commonly interesting and widely investigated^[1].

Some sulfuric compounds or polysulfides, such as HS^- , S_x^{2-} ($x = 2 \sim 5$), HSO_3^{2-} , $\text{S}_2\text{O}_3^{2-}$, are able to complex with auric ions and used to extract gold. The thiosulfate is an outstanding non-cyanide lixiviant, and a lot of fundamental studies has been contributed to its leaching kinetics and mechanism, gold solubility in the lixiviant solution, chemical reactions in the process, evaluation about the environmental influence and so on^[1-6]. Moreover thiosulfate shows excellent complexing ability to the auric ions in a weak alkalis and/or nearly neutral solutions, and then leaching with thiosulfate will produce a leachate containing a little basic metals^[1-6] and make sequences simplify. Up-date thiosulfate leaching has been commercially used to refine gold from high-grade materials. As for ores, this technology appears a little high operating cost due to its high consumption of chemicals. Processes to produce thiosulfate from elemental sulfur on the spot and to leach gold ores are therefore interested. A number of investigations on this

area, for example, the gold leaching process by products from disproportionate of elemental sulphur in ammonia media^[7, 8] and LSSS method^[9, 10], were reported.

A gold leaching process by using of thiosulfate-like lixiviates produced from oxidation reactions of elemental sulfur in alkaline solutions under oxygen pressure is proposed here. Main effective factors on the gold leaching are investigated and discussed. The final sulfuric product from the process is sulfate, and has no pollution on environment.

2 EXPERIMENTAL

A gold concentrate produced from sulfide flotation and a residue resulted from pretreatment of an arsenic refractory gold concentrate by using of oxygenated leaching in dilute sulfate and nitrate solutions are used as test samples. The gold in the materials is mineralogically presented as metals and free particles in micron sizes. The chemical analysis results of the samples are listed in Table 1 and Table 2 respectively.

The leaching ratio of gold by cyanidation is listed in Table 3.

Table 1 Chemical analysis of gold concentrate

Elemental	Fe	S	SiO ₂	Al ₂ O ₃	CaO	MgO	Au	Ag
w / %	30.68	31.64	24.38	4.22	1.20	1.63	44.97*	57.2*

* —g/t

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Table 2 Chemical analysis of residue

Element	Cu	Co	Pb	Zn	Sb	Fe
w / %	0.10	0.05	11.75	0.067	4.51	4.00
Element	C	S	S ⁰	As	Au	
w / %	0.97	19.60	16.3	4.32	254.3*	

* —g/t

Table 3 Results of cyanidation for both samples

Sample	NaCN consumption vs ore/ (kg·t ⁻¹)	Leaching ratio of Au/ %
Concentrate	5	92.1
Residue	5	68.9

All of the leaching experiments were carried out in an autoclave with 2 L effective volume. For the concentrate a required quantity of elemental sulfur was added, and the mixture was milled for 30 min in a bar mill. The mixture was then transferred into the autoclave, and a certain quantity of Ca(OH)₂ and 1 L water were added. The leached Au was calculated from the gold grade in residues. The consumption of oxygen was calculated from the cumulative drop of pressures during the test.

3 RESULTS

Preparatory tests show that the main factors affecting gold leaching is the initial equivalent ratio of elemental sulfur to hydroxyl ions added, the oxygen consumption and the reaction temperature. The following tests were performed with varying a single factor and keeping other factors unchanged.

3.1 Effect of ratio of S⁰ to OH⁻

The experimental results under various initial equivalent ratio of S⁰ to OH⁻ at 85 °C are shown in Fig. 1.

It is clear that the leaching ratio of gold depends intensively on the ratio. There is a favorable range of the ratio for the concentrate or the residue although it is a

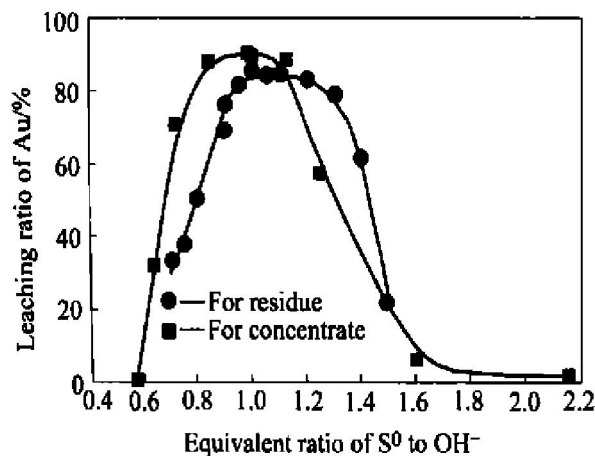


Fig. 1 Effect of initial equivalent ratio of S⁰ to OH⁻ on leaching ratio of gold

little different. For the concentrate leaching the favorable ratio is from 1.0 to 1.3, for the residue from 0.9 to 1.2. This difference may mainly come from the others in mineral composition of both samples. In addition, inaccurate assay of elemental sulfur in the residues might be the other reason. The elemental sulfur is measured by the procedure that dissolve the residue in CCl₄ at first and measure the mass of the residue after evaporation of CCl₄. In this way, the measured quantity of elemental sulfur may lower than the actual value.

3.2 Effect of oxygen consumption

Experiments show that the leaching ratio of Au is correlated to the oxygen consumption, as shown in Fig. 2. The complex agent for auric ions is produced by oxidation of sulfur and is also exhausted by further oxidation, as discussed below. Therefore it is very important to control the quantity of oxygen consumption during the leaching process. The experimental results indicate that the favorable range of oxygen consumption vs S⁰ is 0.45 to 0.63 L/g for the residue and from 0.42 to 0.60 L/g for the concentrate.

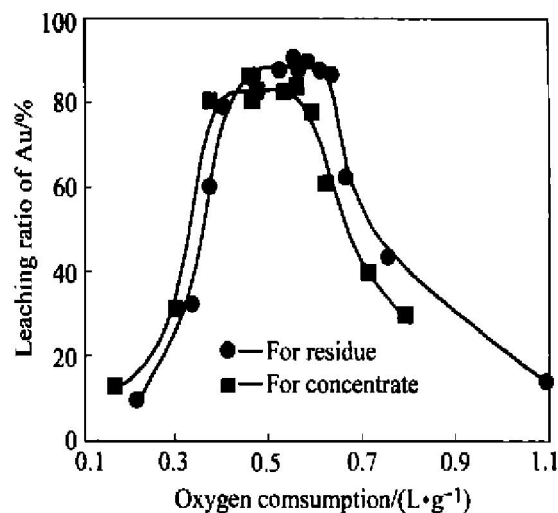


Fig. 2 Correlation of leached Au with oxygen consumption

On the other hand, it is found that the leaching ratio of Au in the process is correlated to the final pH in leachates, as shown in Fig. 3. The final pH value in leachates mainly depends on both initial ratio of S⁰/OH⁻ and the consumption of oxygen. It is indicated that the favorable range of the final pH in leachates for the residue defers from that of the concentrate. The reason for this is not very clear. It may be affected by the ions in the residue, such as Co²⁺, Sb²⁺, Cu²⁺ and AsO₃²⁺. These ions may change the kinetics of sulfur oxidation or the stability of the intermediates, which are able to complex the gold ions.

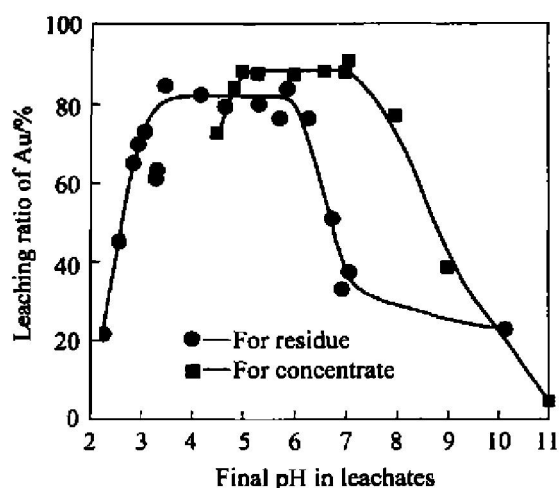


Fig. 3 Correlation between leached Au and final pH value in leachates

3.3 Effect of leaching temperature

The leaching ratio of Au in nearly equal quantity of oxygen consumption at various temperatures is listed in Table 4. It indicates that the favorable leaching temperature is 85 °C.

Table 4 Leaching ratio of Au at different temperatures

Temperature/ °C	Leaching of residue	
	Oxygen consumption vs ore/ (m ³ •t ⁻¹)	Leaching ratio of Au/ %
60	52.8	72.3
75	58.6	82.7
85	59.3	89.9
95	61.2	75.4

Temperature/ °C	Leaching of concentrate	
	Oxygen consumption vs S ⁰ / (L•g ⁻¹)	Leaching ratio of Au/ %
60	0.403	62.8
75	0.512	74.3
85	0.514	82.6
95	0.532	71.3

4 DISCUSSION

The φ -pH diagrams for the S-O-H₂O system are shown in Fig. 4. Fig. 4(a) demonstrates the preponderant regions of compounds in normal thermodynamic equilibrium. Fig. 4(b) indicates possible preponderant regions of some metastable compounds, based on the consideration of that the sulfate is not included as its low formation kinetics. It predicts that the thiosulfate may produce because of an intermediate of sulfur oxidation in the pH values from 4 to 6 at a certain range of the redox potentials although they would not be thermodynamically stable un-

der these conditions. As mentioned above, the favorable range of the final pH value in the leachates for concentrate leaching is from 4 to 6. Both of thermodynamical and experimental results support that thiosulfate is the major complex agent for auric ions produced in the oxidation process of elemental sulfur in the alkaline solution. The favorable pH range for leaching of the residue is a little difference however. From Fig. 3 it appears that the correlation curve between the final pH value and the leaching ratio of gold for the residue has a parallel shift from that for the concentrate. This may be caused from the affection of a certain ions on the kinetics of sulfur oxidation.

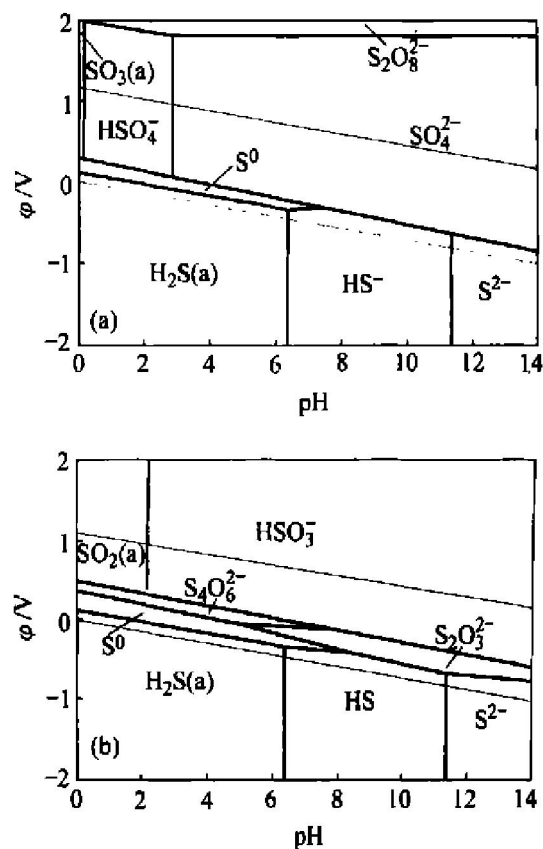
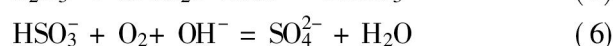
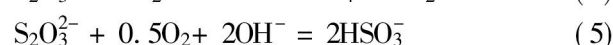
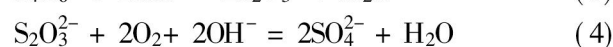
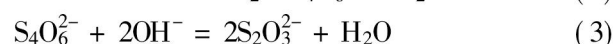
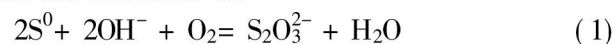


Fig. 4 φ -pH diagrams for S-O-H₂O system

So that possible reactions in the process of sulfur oxidation are considered as:



Based on reaction (1), (2) and (3), the theoretic oxygen consumption is calculated. In contrast with the theoretic value the actual consumption of oxygen is very close to that of the residue and is a little high for the concentrate. In addition, the initial favorable ratio of the elemental sulfur to the hydroxyl ions added is near 1. These

facts also support the point that thiosulfate is the major complex agent resulted from the oxidation reactions of elemental sulfur in an alkaline solution.

Thermodynamically, the thiosulfate is not a stable compound, and might be oxidized to sulfate at a higher redox potential, as shown in Fig. 4(a). In order to leach gold completely the thiosulfate should be produced continually. So the consumption of elemental sulfur in the gold leaching process by oxygen pressures is much greater than the required quantity for complexing auric ions.

5 SUMMARY

Experimental results indicate that gold can be leached by a complex agent, mainly thiosulfate, generated from oxidation reactions of elemental sulfur in an alkaline solution under oxygen pressures. The leached gold in the process depends mainly on the initial equivalent ratio of elemental sulfur to the hydroxyl ions, the consumption of oxygen and the reaction temperature. The favorable equivalent ratio nears to 1. The favorable consumption of oxygen nears to the theoretic value for generation of thiosulfate from elemental sulfur under pressure oxidation. The favorable leaching temperature is 85 °C.

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