LEACHING GOLD BY LOW
CONCENTRATION THIOSULFATE SOLUTION①

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ABSTRACT

The effects of the concentrations of thiosulfate, copper and ammonia on the extraction of gold from sulfide gold concentrate have been studied. The results show that it is possible to reduce thiosulfate concentration. More than 95% of the gold could be extracted by a 0.2 mol / L thiosulfate leaching solution in two hours under suitable conditions. Therefore, the process of washing the residue was simplified, and the consumption and loss of thiosulfate carried by the washing residue were reduced.

Key words: gold extraction   thiosulfate   sulfide ore

1 INTRODUCTION

A growing interest has emerged in leaching gold with thiosulfate solution, instead of cyanide-dependent methods yielding high gold recoveries, without toxicity and at a fast leaching rate. Particulary, for sulfide gold ores ammoniacal thiosulfate method has some advantages of its own.

Over the past few years the investigations have been quite active at home and abroad. Umetsu et al [1] indicated that the presence of cupricamine complex is necessary for gold dissolution using metal gold as the leach specimen in ammoniacal thiosulfate solution and discussed the stability of $Cu(NH_3)_4^{2+}$. Zipperian et al [2] treated an ore sample containing gold at 3 g / t. They determined the effect of copper on gold leaching in a wide range of copper concentration and discussed the possible reactions in the ammoniacal thiosulfate leaching system thermodynamically using the relevant Eh–pH diagrams.

In China, Tian et al [3] reported the effect of copper on gold recovery from sulfide gold concentrate. Gold extraction was 79% in the absence of copper and 97% in the presence of copper. Gong et al [4] tried to improve the leaching conditions proposed by Kerley [5] and Perez [6]. Sulfate was used by them in the ammoniacal thiosulfate leaching to replace the less stable sulfide greatly reducing reagent consumption [4]. However, the thiosulfate concentrations were still rather high in the above leaching system. Using lower concentrations of thiosulfate in the leaching solution would probably be an effective means of further reducing reagent consumption.

2 MATERIALS AND METHODS

The ore sample used in the leaching test was a sulfide gold concentrate, containing copper, obtained by floatation. 90 % of the ore was ground to 200 mesh and used in all the leach tests. The mineral components of the material were pyrite, chalcopyrite, chacocite, bornite, azurite, malachite and limonite. The gangue were mainly quartz and calcite. Most of

the gold in the ore was found to be associated with pyrite, chalcopyrite and bornite. The results of the analysis of the ore are shown in Table 1.

Table 1　Components of the gold ore

Element	Au	Ag	Cu	S	SiO₂	Al₂O₃	Fe₂O₃	CaO
wt.-%	62 g/t	60g/t	3.19	20.6	38.0	5.8	28.9	0.39

Element	Mg	C	Co	Pb	Zn	MnO₂	Na₂O
wt.-%	0.28	0.42	0.04	<0.03	0.1	0.048	0.32

The leaching tests were conducted in a threeneck, 500ml round bottom flask. The stirring was accomplished using a D.C. motor kept at a constant speed of 850 r/min⁻¹ for all the tests. The flask was immersed in a water bath thermostat at the desired temperature with an error of ± 1 K. The air was pre-saturated by passing it through a solution with the same NH₃ levels through out the experiments.

All leaching solutions were prepared from chemicals of A. R. or C. P. grade. The pH value in the leachiing solution was around 10～10.5. Leach tests were generally run for 2 h with a 6:1 or 3:1 liquid: solid ratio on 50 g batches of ore. Gold extraction was calculated according to the gold levels of the head and the tail by an atomic absorption spectrophotometer. The levels of thiosulfate and sulfide in the leaching solution were determined every thirty minutes during the leaching process in order to determine their variation.

3　RESULTS AND DISCUSSION

3.1　*Gold Leaching in Cu—NH₃ System Without S₂O₃²⁻*

The Eh—pH diagram for the gold-thiosulfafte-ammonia-water system (Fig. 1) shows there is a small range of pH, between 9.5～10.5, Eh between 0.1～0.2 V, where the $Au(NH_3)_2^{+2}$ species are stable.

Thermodynamically it would appear that the most stable gold species is the $Au(NH_3)_2^-$ complex under the leaching conditions (pH 10,

Eh 0.2V). However, which species, $Au(NH_3)_2^+$ or $Au(S_2O_3)_2^{3-}$, is the more stable complex under the real leaching conditions for gold extraction by the ammoniacal thiosulfate system? If it is the $Au(NH_3)_2^-$ complex, the Cu—NH₃ system without S₂O₃²⁻ can be used to leach gold, thus the thiosulfate consumptions could be markedly droped. Therefore the normal experiments were carried out with a leaching solution containing NH₄OH. (NH₄)₂SO₄ and Cu²⁺. The factor-levels table is shown in Table 2. The $L_9(3^4)$ tests plan and results were shown in Table 3.
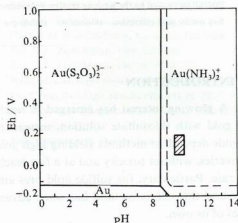

Fig. 1　Eh—pH diagram for the gold, thiosulfate, ammonia system

conditions: 5 mg/kg Au; 1mol/L S₂O₃²⁻; 1 mol/L NH₃/NH₄⁺; 3 mol/L NH₄⁺

Table 2　Factor and level table

Factor	NH₄OH / mol·L⁻¹	(NH₄)₂SO₄ / mol·L⁻¹	Cu²⁺ / g·L⁻¹	T/K
level 1	2	0.2	3	333
level 2	3	0.5	4	343
level 3	4	0.8	5	353

The results indicate that the gold extraction was very low with the best results around 20 % extraction in the absence of thiosulfate. That means only a little of the gold in the ore was dissolved into the solution in the form of $Au(NH_3)_2^+$. The low gold recovery can probably be ascribed to the low stability of the

Au(NH$_3$)$_2^+$ complex.

Other methods were tried to improve gold extraction, such as adding a reagent which was supposed to promote the dissolution of gold into the Cu–NH$_3$ system without thiosulfate. It was found that the addition of silver or MnO$_2$ increased gold extraction to around 37 %. However, in the presence of thiosulfate, the addition of bromine could not improve gold extraction.

3. 2 *Effect of Thiosulfate*

An analysis was conducted every 30 min to determine whether thiosulfate and / or sulfide were formed in the leaching process in the Cu–NH$_3$ system without S$_2$O$_3^{2-}$, as shown in Table 3. There was little, if any, S$_2$O$_3^{2-}$ and SO$_3^{2-}$ in the leaching solution. This denotes that it is not feasible to use the thiosulfate formed from ores during the leaching process to recover gold.

Table 3 L$_9$(3^4) experimental results

No	NH$_4$OH / mol · L^{-1}		(NH$_4$)$_2$SO$_4$ / mol · L^{-1}		Cu^{2+} / g · L^{-1}	T / K	Au Extn / %
	A		B	C	D		
1	1(2)		1(0.2)	3(5)	2(343)		14.0
2	2(3)		1	+(3)	1(333)		20.3
3	3(4)		1	2(4)	3(353)		15.9
4	1		2(0.5)	2	1		13.9
5	2		2,	3	3		20.1
6	3		2	1	2		16.0
7	1		3(0.8)	1	3		21.5
8	2		3	2	2		22.9
9	3		3	3	1		22.6
level 1	49.4		50.2	57.8	56.8		
level 2	63.5		50.0	52.7	52.9		
level 3	54.5		67.0	56.7	57.5		
R*	13.9		17.0	5.1	4.6		

* R: level difference

Common Conditions: pH 10.2, air of 1 L / min, stirring 850 r / min, L : S = 3 : 1, 3 h.

In general, more than 0.7 mol / L S$_2$O$_3^{2-}$ is needed in the leaching solution for about 95 % gold extraction. Deducing the thiosulfate concentration is unfavorable to gold extraction

but beneficial to reduction of reagent consumption and the loss of thiosulfate carried by washing tails.

The tests were conducted with low concentrations of thiosulfate. The test results are shown in Fig. 2.
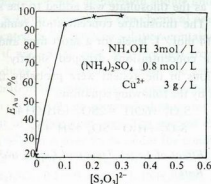
Fig. 2 Effect of thiosulfate concentration
L : S = 6 : 1, stirring 850 r / min, 333 K, 2 h,
pH 10.2, air of 1 L / min

In the absence of thiosulfate, gold extraction was very low. As only 0.2 mol / L thiosulfate was added, the gold extraction increased rapidly to an optimal results of about 97 %. This remarkable effect demonstrated that most of gold in the leaching solution was present mainly as the Au(S$_2$O$_3$)$_2^{3-}$ complex. Although it seems that the Au(NH$_3$)$_2^+$ complex is more stable as indicated by Fig. 1, it is believed that the Au(S$_2$O$_3$)$_2^{3-}$ complex is probably much more stable than the Au(NH$_3$)$_2^+$ complex under the leaching conditions. On the other hand, the experimental results indicated that the gold extraction was extremely low, only 0~4 %, in a leaching solution containing sufficient thiosulfate and copper, and even ammonium, but without ammonia. It was inferred that the Au(NH$_3$)$_2^+$ complex, which is an easy-to-form but less stable complex, was formed first, then most of it was conversed into the more stable Au(S$_2$O$_3$)$_2^{3-}$ complex.

In a test conducted on the Cu–NH$_3$–

$S_2O_3^{2-}$ system with a gold extraction of 97.7 %, the concentrations of thiosulfate and sulfite were determined every 30 min during the leaching process. The results are shown in Table 4.

A certain amount of sulfite was formed as soon as the thiosulfate was added to the solution. The thiosulfate concentration remained at 0.14 mol / L levels for a short time and the sulfite concentrations dropped slightly. The reactions in the system were probably those given by the following equations:

$$S_2O_3^{2-} + 6OH^- = 2SO_3^{2-} + 3H_2O + 4e \quad (1)$$
$$S_2O_3^{2-} + H_2O = SO_4^{2-} + 2H^+ + 2e \quad (2)$$
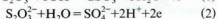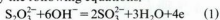
3. 3　Effect of Leach Time and Liquid to Solid Ratio

Table 5 shows the degree of gold extraction in ammoniacal thiosulfate solutions for different leaching times.

Table 4　The levels of $S_2O_3^{2-}$ and SO_3^{2-}

leach time / min	concentrations / mol · L^{-1}	
	$S_2O_3^{2-}$	SO_3^{2-}
0*	0.14	0.08
30	0.13	0.07
60	0.13	0.07
90	0.14	0.06
120	0.11	0.05

* Time "0" means the time when the ores had not been added to the leaching solutions

Conditions　NH_4OH— 4 mol / L, $(NH_4)_2SO_4$—0.3 mol / L, Cu^{2+}—3 g / L, L : S = 2 : 1, stirring 850 r / min, 333 K, air of 1 L / min, pH 10.2

Table 5　Effect of leach time

No	L : S	T / K	T / h	Au Extn / %
G1	3 : 1	333	1.0	97.4
G2	3 : 1	333	1.5	96.7
E2	3 : 1	333	2.0	94.4
G3	3 : 1	333	3.0	93.5
D4	6 : 1	303	2.0	51.9
D5	6 : 1	303	4	21.8

Conditions, NH_4OH—3 mol / L, $(NH_4)_2SO_4$—0.8 mol / L, Cu^{2+}—3g / L, air of 1 L / min, pH 10.2, stirring 850 r / min

Tests G1, G2, E2 and G3 were carried out at 333 K. The optimal gold extraction was ob-

tained within 1 h. Tests D4 and D5 were conducted at 303 K with gold extractions only around 20 ~ 50 %. One of the reasons was probably the decomposition of thiosulfate.

Fig. 3 shows the effect of liquid to solid ratios on the gold extraction.

The degree of extraction rose as the L : S ratio increased from 2:1 to 6 : 1. The optimal L : S ratio considering gold extraction, reagent consumption and washing loss appears to be 3 : 1.

3. 4　Effect of Temperature Effect on Gold Extraction

According to the normal experiments in Table 3, we know that the effect of temperature on the gold extraction was not remarkable from 333 K to 353 K. The results from 333 K to 343 K are shown in Fig. 4 .
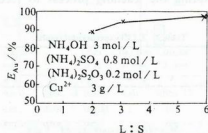
Fig. 3　Effect of liquid to solid ratio

Conditions, pH 10.2, stirring 850 r / min.
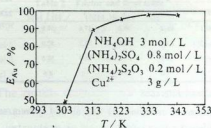
333 k, air of 1 L / min

Fig. 4　Effect of temperature on gold extraction

Conditions, stirring 850 r / min.

L : S = 6 : 1, 2h, pH 10.2, air of 1 L / min

The gold extraction was as low as about

52 % at 303 K, but it rapidly increased to about 89 % at 313 K and reached its peak result, above 97 % at 333 K.

The results of the above experiments indicate that a solution with a low concentration of thiosulfate can be used for leaching gold from sulfide ores instead of using higher concentrations of thiosulfate. Thus reagent consumption can be markedly reduced. The loss of thiosulfate was mainly caused by oxidation and decomposition of thiosulfate in the leaching process, loss in the washing tails. It was proved that the former was related to the air flow introduced into the system, the copper concentration and the liquid to solid ratio; the latter was related to the reagent concentrations in the leaching solution, the washing system for tails. The loss of thiosulfate was about 4.8 kg $(NH_4)_2S_2O_3$ per ton of ore using a three stage countercurrent washing tails system with a leaching solution containing 0.7 mol / L $(NH_4)_2S_2O_3$, but only 1.4 kg $\cdot$ t^{-1} $(NH_4)_2S_2O_3$ with 0.2 mol / L thiosulfate leaching solution. This fully demonstrated that the reduction of thiosulfate concentration is signficant for the reduction of reagent consumption and simplification of washing processes. However, the results of chemical analyses indicated reduction of the thiosulfate concentration has no ef-

fect on the dcomposition of thiosulfate during the leaching process.

4 CONCLUSIONS

Gold extraction was very low, with the best results only 20 %, in the solutions containing ammonia, ammonium sulfate and copper without thiosulfate.The chemical analyses indicated the leaching solution contained little, if any, $S_2O_3^{2-}$ and SO_4^{2-} formed from the ore during the leaching process. The low concentration thiosulfate leaching system reported here is probably an economical route for treatment of sulfide gold ores. The percent extraction of gold is over 95 % under the conditions of; $2\sim4$ mol / L $(NH_4)OH$, $0.5\sim0.8$ mol / L $(NH_4)_2SO_4$, $0.2\sim0.3$ mol / L $(NH_4)_2S_2O_3$, 3 g / L Cu^{2+}, 333 K, $1\sim2$ h, air aeration, L : S = 3 : 1.

REFERENCES

1 Umetsu. Y. *et al*. Tohoku Daigaku Senko Seiren Kenkyusho tho, 1972, 28(1), 97~104.

2 Zipperian. D. *et al*. Hydrometallurgy, 1988, 19, 361~371.

3 Tian, Yuchen *et al*. Gold, 1987, 2, 30~33.

4 Gong Qian *et al*. Engineering Chemistry & Metallurgy, 1990, 11(2), 145~151.

5 Kerley, B. J.. US Patent, 1981, 4, 269, 622; 1983, 4, 369, 061.

6 Perez, A. E.. US Patent, 1987, 4, 654, 078.