Leaching and Recovery of an Oxide Gold Concentrate Using Ammoniacal Thiosulfate Solutions

Zhonglin Dong, Tao Jiang, Bin Xu, Yongbin Yang and Qian Li

Abstract Thiosulfate leaching-resin adsorption recovery, an environmentally friendly process, has been developed to efficiently extract gold from an oxide gold concentrate. 80.5% of gold extraction could be achieved by thiosulfate leaching under the conditions of $(NH_4)_2S_2O_3$ 0.2 mol/L, $CuSO_4$ 0.025 mol/L, NH_3 1.5 mol/L and leaching time 8 h, and the thiosulfate consumption was 53.6 kg/t-concentrate. IRA-400 anion exchange resin was used to recover gold from the leach solution, and an adsorption efficiency of 99.3% gold and 39.4% copper was attained. Two-step elution process, including pre-elution of copper with 0.5 mol/L $(NH_4)_2S_2O_3$ followed by gold elution with 2 mol/L NaCl + 0.5 mol/L Na_2SO_3 was adopted, and 98.6% of copper and 99.1% of gold could be successfully eluted from the resin.

Keywords Gold · Thiosulfate leaching · Recovery · Ion-exchange resin

Introduction

For the past century, cyanidation has been the predominant method for gold leaching from ores owing to its simple process and low cost [1]. However, there has been increasing public concern over the use of cyanide due to its strong toxicity. In addition, cyanide leaching shows unsatisfactory performance on refractory gold ores especially for those containing copper or "preg-robbing" carbon [2]. Thus, considerable attention has been paid to the alternative lixiviants, the most promising of which is thiosulfate. Compared with conventional cyanidation, thiosulfate leaching has the advantages of lower toxicity, lower reagent costs and faster leaching rate, particularly for some refractory ores, e.g. some carbonaceous gold ores [3].

Z. Dong · T. Jiang · B. Xu (✉) · Y. Yang · Q. Li
School of Minerals Processing and Bioengineering, Central South University, Changsha 410083, China
e-mail: xubincsu@csu.edu.cn

However, the successful commercial application of thiosulfate leaching is still rare, except for the development of an ammonia-free thiosulfate leaching process by Barrick Gold Corporation to treat a carbon-bearing sulfide gold ore pretreated with acidic or alkaline pressure oxidation [4]. Most of the past researches have concentrated on the gold leaching from its ores using thiosulfate solutions over the past several decades [5–11]. However, limited studies on gold recovery from the leach solutions have been conducted and there is a lack of a suitable recovery process. Past studies have pointed that it is difficult to recover gold from thiosulfate solutions using the common techniques of activated carbon adsorption, cementation, electrowinning, and solvent extraction. This can be attributed to the weak affinity of activated carbon for $[Au(S_2O_3)_2]^{3-}$ complex or the presence of large amount of undesirable anions particularly copper (I) thiosulfate complexes and sulfur-oxygen anions. In comparison, resin adsorption technique is more suitable because of its fast adsorption speed, high loading capacity, low requirements on the clarity of solutions, simultaneous elution and regeneration at ambient temperature through the elaborate choice of eluent. In addition, ion-exchange resins can be custom-made to selectively extract gold because the functional groups can be designed to have high affinity for objective ions in the solution [1, 2].

In this paper, a detailed study on the factors affecting the thiosulfate leaching of gold was carried out. Afterwards, the adsorption of gold and copper on the resin and their elution from the loaded resin were investigated. Based on these studies, the environmentally friendly process consisting of thiosulfate leaching-resin adsorption recovery was developed to efficiently extract gold from an oxide gold concentrate.

Experimental Work

Materials and Reagents

The original gold concentrate used in this study had the particle size of 95% less than 0.074 mm, and its chemical composition is indicated in Table 1. The gold content was 3.3 g/t, whilst the total content of acid gangues including SiO_2 and Al_2O_3 was 72.16%. The mineralogical phases of the concentrate were determined by quantitative X-ray diffraction analysis, and the result showed that the main minerals were quartz and muscovite. Table 2 shows the result of chemical phase analysis of gold. As indicated, 90.9% of the gold was exposed, and the others were mainly encapsulated in oxides and sulfides

Table 1 Chemical composition of the oxide gold concentrate (%)

Constituent	Au[a]	SiO_2	Al_2O_3	CaO	MgO	Fe	S	C	Ti	Mn	Cr
Content	3.3	58.20	13.96	6.86	4.72	5.25	0.90	0.75	0.90	0.07	0.06

[a]Unit g/t

Table 2 The chemical phases of gold in the oxide gold concentrate

Phases	Exposed gold	Encapsulated in oxides	Encapsulated in sulfides	Encapsulated in silicates	Total
Content g/t	3.0	0.2	0.08	0.02	3.3
Distribution %	90.9	6.1	2.4	0.6	100.00

The reagents used in this study, such as ammonium thiosulfate, copper sulfate, ammonia, sodium chloride, sodium sulfite, sodium hydroxide and sulfuric acid were of analytically grade. Ultrapure water was used throughout all experiments.

Leaching and Recovery Tests

All thiosulfate leaching tests were performed in 1 L baffled PVC reactor using an overhead stirrer with a flat-bladed impeller, which was open to air through a sampling port. For each leaching test, 0.5 L of distilled water containing desired quantities of requisite reagents was firstly transferred into the reactor, and then a given mass of the gold concentrate was added and the formed pulp was simultaneously agitated at a constant speed of 300 rpm. All of these tests were performed at a liquid-to-solid ratio of 3. Pulp pH was adjusted to a preset value with the addition of NaOH (1 mol/L solution) and was kept steady by readjustment every half an hour. Pulp temperature was kept at 25 ± 0.5 °C with a water bath during leaching. When the reaction was completed, pulp was vacuum filtrated. The obtained solution samples were immediately subjected to thiosulfate concentration assays and gold recovery tests, and the residue samples were analyzed for gold content to calculate the gold extraction.

Strong-base anion exchange resin Amberlite IRA-400 was adopted to recover gold from the leach solutions. First, a certain amount of resin (wet base value) was added into 100 mL of leach solution, which was agitated in a 250 mL beaker at 200 rpm. A 1 mL of the sample, if necessary, was consecutively taken to observe the concentration changes of gold and copper. When the adsorption was finished, the leach solution was filtrated by a vacuum filter and the obtained resin was adequately rinsed with ultrapure water. Then, the gold-loaded resin was transferred to an ion-exchange column which was constructed with a 10 mL burette with small wool plugs both on the top and at the bottom of the resin bed. Finally, the eluants were pumped into the column through a rubber stopper on the top of the burette using a peristaltic. The flow rate of eluants was 3BV/h (bed volume per hour) in this experiment where 1 BV was the volume of the burette occupied by the resin bed. During the elution stage, consecutive 1 mL of eluate was collected from the tip at the bottom of the burette for gold and copper assays. The elution efficiencies of copper and gold were

calculated based on the content differences of these two metals on the loaded resin and in the eluate.

Analytical Methods

Sulfur and carbon contents in solid were determined using a high-frequency IR carbon and sulfur analyzer (HW2000B, Wuxi Yingzhicheng). The other elements in solid were analyzed using acid digestion and an atomic absorption spectrometer (AA-6800, SHIMADZU). Element concentrations in solution were all measured by an inductively coupled plasma-atomic emission spectrometer (PS-6, Baird). Thiosulfate concentration was determined by an iodometric method with the indicator Vitex, and certain amounts of EDTA-2Na and formaldehyde were added before the titration in order to eliminate the interferences of cupric tetra-amine complex and sulfite.

Mineralogical compositions of samples were obtained by an X-ray diffractometer (D/Max 2500, Rigaku). Chemical phase constitution analysis has been widely utilized in China to determine the distribution percentage of an element for its every phase in research sample, which is usually carried out by professionals in research institutes of mining and metallurgy. In this paper, the analysis procedure was as follows: At first, the phases of element were discovered using an optical microscope combined with an electron probe micro-analyzer. After that, selective dissolution was carried out to determine element contents in identified phases by appropriate process flow and chemical reagents.

Results and Discussion

Cupric-Ammonia Catalyzed Thiosulfate Leaching

Effect of Initial Thiosulfate Concentration

Figure 1 shows the effect of initial thiosulfate concentration on gold extraction and thiosulfate consumption. Only 44.2% of gold extraction was obtained when the thiosulfate concentration was 0.05 mol/L, the thiosulfate consumption was also only 21 kg/t-concentrate. Increasing the initial thiosulfate concentration from 0.05 to 0.15 mol/L evidently increased gold extraction as well as thiosulfate consumption. However, when the thiosulfate concentration increased to 0.25 mol/L, there was no evident increase in gold extraction, but thiosulfate consumption continued to increase to 52.3 kg/t-concentrate. Therefore, the optimum thiosulfate concentration is around 0.20 mol/L.

Fig. 1 Effect of initial
thiosulfate concentration on
gold extraction and
thiosulfate consumption
under the conditions: Cu^{2+}
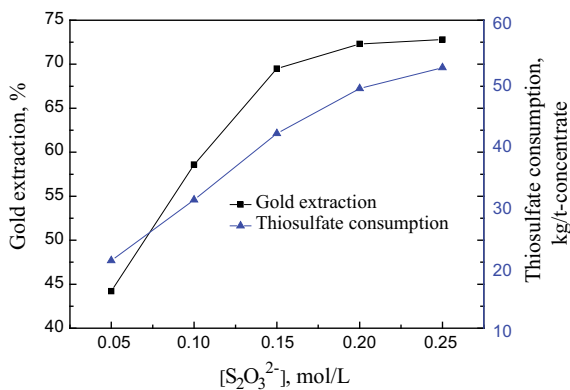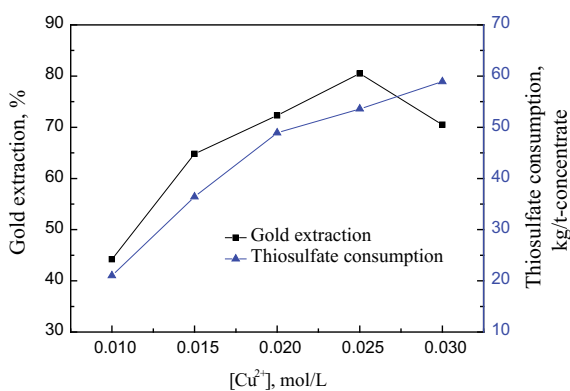0.02 M, NH_3 1.5 M and
leaching time 8 h

Fig. 2 Effect of initial
cupric concentration on gold
extraction and thiosulfate
consumption under the
conditions: $S_2O_3^{2-}$ 0.2 M,
NH_3 1.5 M and leaching
time 8 h

Effect of Initial Cupric Concentration

Figure 2 presents the effect of initial cupric concentration on gold extraction and
thiosulfate consumption. Gold extraction increased with the increase of initial cupric
concentration in the initial range of 0.01–0.025 mol/L. However, when the concen-
tration was beyond the range, gold extraction began to decrease. The possible reason
for this is that the high thiosulfate consumption led to the passivation of gold surface
[1]. Thiosulfate consumption increased as the concentration increased in the entire
abscissa range. Thus, the optimum cupric concentration is about 0.025 mol/L.

Effect of Initial Ammonia Concentration

Figure 3 shows the effect of initial ammonia concentration on gold extraction and
thiosulfate consumption. Gold extraction increased with increasing ammonia con-
centration until it reached maximum at 1.5 mol/L and then decreased gradually until

Fig. 3 Effect of initial
ammonia concentration on
gold extraction and
thiosulfate consumption
under the conditions: Cu^{2+}
0.025 M, $S_2O_3^{2-}$ 0.2 M and
leaching time 8 h
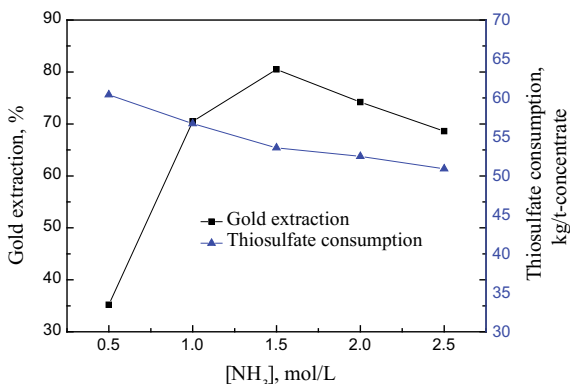
2.5 mol/L. The evident decline of gold extraction can be attributed to the formation of $(NH_4)_5Cu(S_2O_3)_3$ under high ammonia concentration. This not only lowered the activity of $Cu(NH_3)_4^{2+}$ complex but also inhibited the gold leaching due to the cover of the solid precipitate on the gold particle surface [12] Thiosulfate consumption was always decreasing in the whole range of ammonia concentration studied. Therefore, the optimum ammonia concentration is around 1.5 mol/L.

Effect of Leaching Time

Figure 4 shows the effect of leaching time on gold extraction and thiosulfate consumption. Clearly, both gold extraction and thiosulfate consumption increased in the whole range of leaching time studied. From the above, the optimal leaching conditions were established as follows: $S_2O_3^{2-}$ 0.2 mol/L, Cu^{2+} 0.025 mol/L, NH_3 1.5 mol/L and leaching time 8 h. The gold extraction from the gold concentrate by thiosulfate leaching under these conditions was 80.5%, whilst the thiosulfate consumption reached up to 53.6 kg/t-concentrate.

Gold Recovery from the Leach Solution by the Ion-Exchange Resin

Adsorption of Gold and Copper on the Ion-Exchange Resin

The gold concentrate was first leached under the optimal conditions obtained from the above leaching experiment. Then, the pulp was filtrated, and the obtained solution sample was used for the following adsorption experiment. The concentrations of gold

Fig. 4 Effect of leaching time on gold extraction and thiosulfate consumption under the conditions: Cu^{2+} 0.025 M, NH_3 1.5 M and $S_2O_3^{2-}$ 0.2 M
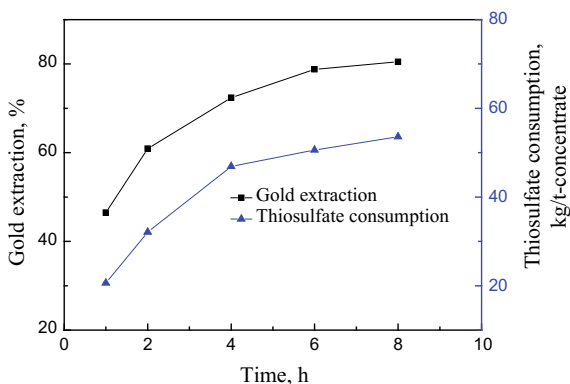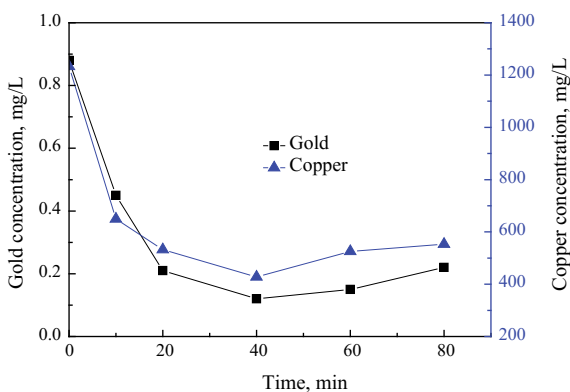
Fig. 5 Kinetic plots for the adsorption of gold and copper on IRA-400 anion exchange resin from the leach solution containing 0.88 mg/L gold and 1232.6 mg/L copper

and copper were separately 0.88 and 1232.6 mg/L after the solution was analysed. This indicates that parts of the copper precipitated and were transferred to the residue.

In this study, the adsorption behaviors of gold and copper on the resin were measured by adding 1 g of resin into 100 mL of the above leach solution, and the results are demonstrated in Fig. 5. As can be seen, the adsorption kinetics of gold and copper were fast, and both of their concentrations sharply decreased and simultaneously reached minimum at 40 min. It should be noticed that it's our goal to realize complete gold adsorption while minimizing copper adsorption. It can be seen, however, not all of the gold was adsorbed on the resin at this time. Furthermore, their concentrations increased again after a prolonged adsorption time, indicating that part of gold and copper were transferred from loaded resin into the leach solution. The potential reason is that high concentrations of polythionates mainly including trithionate ($S_3O_6^{2-}$) and tetrathionate ($S_4O_6^{2-}$) would be produced over an extended period due to the unwanted oxidation of thiosulfate in the leach solution. The two sulfur-oxygen anions could strongly adsorb on the resin and compete with the gold and copper thiosulfate complexes for ion-exchange sites [3]. Therefore, overlong adsorption time is not beneficial to the gold recovery.

Elution of Copper and Gold from the Gold-Loaded Resin

Based on the aforesaid adsorption tests of copper and gold on the resin, it was considered to use a larger amount of resin to realize the complete gold adsorption at a shorter adsorption time. Thus, the gold-loaded resin was prepared by adding 7 g of resin into 100 mL of the above leach solution, which was agitated at 200 rpm for 10 min. The assay results for the barren solution show that the concentrations of gold and copper were 0.006 and 747 mg/L, and therefore, the adsorption efficiency of them achieved 99.3 and 39.4%, respectively.

Elution was carried out in two stages: (1) pre-eluting copper with 0.5 M $(NH_4)_2S_2O_3$ solution for 12 BV, followed by (2) eluting gold with mixed solution of 2 M NaCl + 0.5 M Na_2SO_3 for 10 BV, and the results are shown in Fig. 6 and Table 3. It is clear that the elution profiles of copper and gold presented a sharp peak followed by a rapid decline, and the maximum concentration of them was separately 728 and 4.85 mg/L. As indicated in Table 3, the gold concentration in the copper eluate was only 0.001 mg/L, thus copper could be selectively eluted from the gold-loaded resin with negligible gold loss. The elution results show that the efficiencies of copper and gold could attain 98.6 and 99.1% after two-stage selective elution.
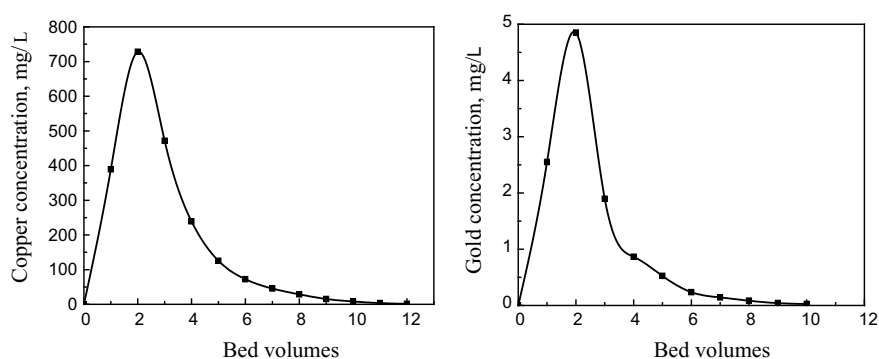

Fig. 6 Pre-elution of copper with 0.5 mol/L $(NH_4)_2S_2O_3$ followed by gold elution with 2 mol/L NaCl + 0.5 mol/L Na_2SO_3

Table 3 The elution results of copper and gold (the units of gold and copper concentrations are mg/L)

Copper eluate		Gold eluate		Copper elution efficiency, %	Gold elution efficiency, %
[Cu]	[Au]	[Au]	[Cu]	98.6	99.1
558.2	0.001	0.872	2.5		

Conclusions

The present work put forward a thiosulfate leaching-resin adsorption recovery process to extract gold from an oxide gold concentrate. 80.5% of gold in the concentrate was extracted by thiosulfate leaching under optimal conditions of $(NH_4)_2S_2O_3$ 0.2 mol/L, $CuSO_4$ 0.025 mol/L, NH_3 1.5 mol/L and time 8 h, whilst thiosulfate consumption was 53.6 kg/t-concentrate. An adsorption efficiency of 99.3% gold and 39.4% copper was achieved using 7 g of IRA-400 anion exchange resin to adsorb gold from 100 mL of the leach solution. Two-step elution process, consisting of pre-elution of copper with 0.5 mol/L $(NH_4)_2S_2O_3$ for 12 BV followed by gold elution with 2 mol/L $NaCl$ + 0.5 mol/L Na_2SO_3 for 10 BV, was adopted to recover copper and gold from the loaded resin, and an elution efficiency of 98.6% of copper and 99.1% of gold could be attained.

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