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THIOUREA LEACHING OF GOLD FROM A CALCINE OF GOLD-BEARING ARSENICAL PYRITE CONCENTRATE①

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ABSTRACT The thiourea leaching of gold from the calcine of gold-bearing arsenical pyrite concentrate of Kangjiawan mine was studied. The effects of the leaching time, the concentrations of thiourea, hydrochloric acid and initial ferric ion on the leaching recovery of gold were investigated, and a regressive model has been established, which showed that the concentrations of thiourea and hydrochloric acid were the most important factors, leaching time the second, and concentration of the initial ferric ion the least. Under the optimal conditions, that is, temperature 50 ℃, the ratio of liquid to solid 4 : 1, thiourea 12 g/L, hydrochloric acid 1 mol/L, and initial ferric ion 1 g/L, the leaching recoveries of gold and silver were more than 81% and 73%, respectively. The increase of silver recovery and the reduction of thiourea consumption could be attained when sodium sulphite was added.

Key words gold-bearing arsenical pyrite concentrate calcine thiourea leaching of gold

1 INTRODUCTION

Kangjiawan Mine of Shuikoushan Mining Bureau, Hunan province, is one of the mines in China with the largest lead, zinc and gold deposit. Its reserve of gold is approximate to 50 t. The gold in the ore is disseminated in the arsenic and gold-bearing pyrite and recovered from a flotation concentrate which contains S 37. 09%, Fe 32. 70%, As 2. 09%, Pb 0. 27%, Zn 1. 06%, SiO_2 18. 31%, CaO 0. 55%, Al_2O_3 1. 13%, Au 7. 5 g/t and Ag 60 g/t. Examination of the gold mineralogy showed that free gold accounted for only 10. 7%, and the rest was submicroscopically encapsulated in host minerals. Therefore, the concentrate is classified as refractory one, and should be pretreated for extraction of gold. A few approaches, for instance, fluosolids roasting-cyanidation[1, 2], SKS smelting process[3] have been tested on the concentrate since 1987. This paper described the thiourea leaching process of the calcine produced by fluosolid roasting of the concentrate.

2 EXPERIMENTAL

2.1 *Materials and Analysis Method*

The sample was a calcine of the fluosolids roasting of Kangjiawan arsenic-bearing sulfide concentrate[1], which was reground to 90% minus 325 mesh. Its chemical composition and phases are presented in Tables 1 and 2, respectively. The refractory characteristics of the calcine shown in Table 2 will result in its lower gold extraction rate.

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Table 1 Main chemical composition of calcine

Components	S	Fe	As	Au	Ag
Distribution/%	0. 93	51. 53	0. 36	9. 2*	77. 5*
Components	SiO_2	CaO	Al_2O_3	Pb	Zn
Distribution/%	25. 41	0. 66	1. 56	—	—

Note: * —g/t

Table 2 Chemical phases of gold in calcine

Gold types	Content /$g\cdot t^{-1}$	Distribution /%
free	0. 19	2. 09
partially exposed	3. 40	37. 40
encapsulated in oxides	3. 60	39. 61
encapsulated in sulfides	0. 95	10. 45
encapsulated in silicates	0. 95	10. 45
Total	9. 09	100. 00

Analytically pure chemicals and distilled water were used in all experiments. Pyrogenic process and atomic absorption spectrophotometry were used for the analyses of gold and silver, respectively.

2. 2 *Experimental Design*

Conditional experiments were arranged according to quadrature table ($L_9(3^4)$); and fixed parameters were as follows: calcine 50 g, the ratio of liquid to solid (L/S) 4∶1, the leaching temperature 50 ℃. The relations between affecting factors and their variables are established in Table 3.

Table 3 The relations between affecting factors and their variables

Factors	C (Tu)* /$g\cdot L^{-1}$	C (HCl) /$mol\cdot L^{-1}$	C (Fe^{3+}) /$g\cdot L^{-1}$	t /h
Zero level	12	0. 6	2	5
Variables(Δ)	8	0. 4	1	3

Note: C (Tu)—thiourea concentration

3 RESULTS AND DISCUSSION

The results of conditional tests are presented in Table 4.

From Table 4, the regressive model was established according to quadrature polynomial

Table 4 The results of conditional tests and extreme difference analyses

№.	C (Tu) /$g\cdot L^{-1}$	t /h	C (HCl) /$mol\cdot L^{-1}$	C (Fe^{3+}) /$g\cdot L^{-1}$	Gold extraction rate η_{Au} /%
1	4	2	0. 2	1	52. 28
2	4	5	0. 6	2	62. 27
3	4	8	1. 0	3	73. 04
4	12	2	0. 6	3	60. 07
5	12	5	1. 0	1	80. 37
6	12	8	0. 2	2	67. 58
7	20	2	1. 0	2	81. 91
8	20	5	0. 2	3	72. 06
9	20	8	0. 6	1	81. 04
K_{1j}	187. 59	194. 26	191. 92	213. 69	
K_{2j}	208. 02	214. 70	203. 38	211. 76	
K_{3j}	235. 01	221. 66	235. 32	205. 17	
$k_{1j}=K_{1j}/3$	62. 53	64. 75	63. 97	71. 23	
$k_{2j}=K_{2j}/3$	69. 34	71. 57	67. 79	70. 59	
$k_{3j}=K_{3j}/3$	78. 34	73. 89	78. 44	68. 39	
R	15. 81	9. 14	14. 47	2. 84	

Notes: leaching conditions: 50 ℃, L/S=4∶1; order of effects of factors on leaching efficiency of gold: C (Tu) > C (HCl) > t > C (Fe^{3+}); optimal leaching conditions: $C(\mathrm{Tu})_3C(\mathrm{HCl})_3t_3C(\mathrm{Fe}^{3+})_1$; $K_{i,j}$ is the sum of gold leaching efficiency of j factor at i level; $k_{i,j}$ is the arithmetic mean of $K_{i,j}$; $i = 1, 2, 3$; $j = 1, 2, 3, 4$; $R = \max|k_{i-1,j} - k_{i,j}|$

regression, namely:

$$\eta_{\mathrm{Au}} = 69.291 + 7.093\left(\frac{C(\mathrm{Tu}) - 12}{8}\right) + 4.567\left(\frac{t-5}{3}\right) - 2.247\left(\frac{t-5}{3}\right)^2 + 7.233\left(\frac{C(\mathrm{HCl}) - 0.6}{0.4}\right) + 3.414\left(\frac{C(\mathrm{HCl}) - 0.6}{0.4}\right)^2 - 1.42(C(\mathrm{Fe}^{3+}) - 2)$$

The surplus square deviation of the model is 1.34%, and the model can quantitatively describe the relations between gold leaching efficiency by thiourea and each affecting factor (see Figs. 1~4).

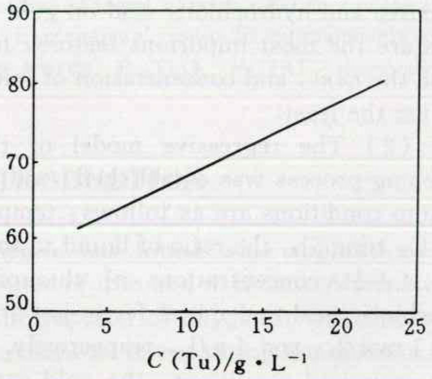

Fig. 1 The relation between gold leaching efficiency and concentration of thiourea
(θ = 50 ℃; t = 5 h, C (Fe^{3+}) = 2 g/L; C (HCl) = 0.6 mol/L; L/S = 4:1)

Fig. 1 shows that the higher the concentration of added thiourea, the more the extracted gold, but too high concentration of thiourea is not economical because it will cause hydrolysis or degradation of thiourea, etc[4, 5]. Fig. 2 illustrates that longer leaching time, for example, 5 h, is necessary for higher gold leaching efficiency.

Fig. 3 indicates that acid-washing pretreatment increased gold extraction because hydrochloric acid dissolved a part of iron oxides and made gold encapsulated dissolve in the thiourea solution. In general, the increase of hydrochloric acid concentration can increase the gold extraction. However, it would be better for the concentration of hydrochloric acid to be limited to 1.0 mol/L in consideration of economy. Because acid-washing pretreatment produced a lot of ferric ions, the influence of initial ferric ions on gold extraction was very weak. Fig. 4 illustrates that too many ferric ions are harmful to the leaching of gold, because they would enhance the redox potential of the leaching system and cause too much oxidation of thiourea.

In order to verify the model and reduce the consumption of thiourea, another set of tests was carried out. The results are present-

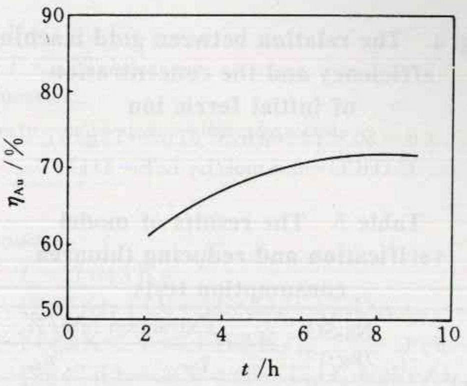

Fig. 2 The relation between gold leaching efficiency and leaching time
(θ = 50 ℃; C (Fe^{3+}) = 2 g/L; C (HCl) = 0.6 mol/L; L/S = 4:1; C (Tu) = 12 g/L)

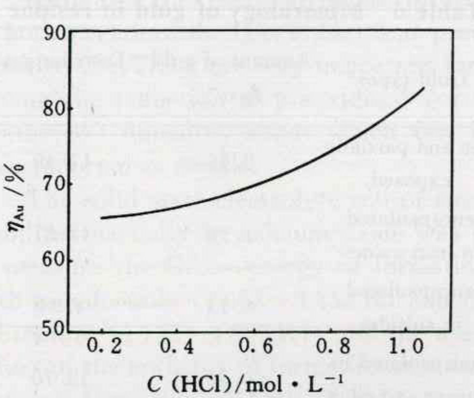

Fig. 3 The relation between gold leaching efficiency and concentration of hydrochloric acid
(θ = 50 ℃; t = 5 h; C (Fe^{3+}) = 2 g/L; C (Tu) = 12 g/L; L/S = 4:1)

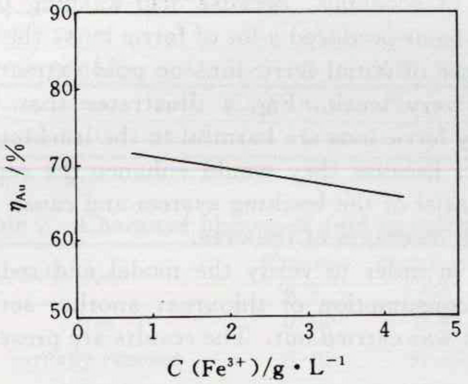

Fig. 4 The relation between gold leaching efficiency and the concentration of initial ferric ion

($\theta = 50$ ℃; $t = 5$ h, C (Tu) = 12 g/L; C (HCl) = 0.6 mol/L; L/S = 4∶1)

Table 5 The results of model verification and reducing thiourea consumption tests

№.	θ/℃	Na_2SO_3 /kg·t^{-1}	Extraction rate/%	
			η_{Au}	η_{Ag}
1	50	0	81.01	73.32
2	50	5	81.24	83.32
3	θ_r	0	75.36	—

Note: θ_r —room temperature; C (Tu) = 12 g/L; C (HCl) = 1.0 mol/L; C (Fe^{3+}) = 1 g/L; $t = 5$ h

Table 6 Mineralogy of gold in residue

Gold types	Amount of gold /g·t^{-1}	Distribution /%
free and partially exposed	0.46	17.49
encapsulated in iron oxides	1.18	44.87
encapsulated in sulfides	0.13	4.94
encapsulated in silicate and silica	0.86	32.70
Total	3.63	100.00

ed in Table 5. Table 5 demonstrates that the extraction rates of gold and silver can reach over 81%, and the addition of sodium sulphite is useful for the increase of silver recovery. In the meantime, the mineralogy of gold in the residue (see Table 6) shows that the increase of gold recovery is limited unless the concentration of hydrochloric acid is higher so as to dissolve more iron oxides encapsulating gold grains.

4 CONCLUSIONS

(1) In the thiourea leaching process of the calcine, the influences of concentrations of thiourea and hydrochloric acid on gold extraction are the most important factors, leaching time the next, and concentration of initial ferric ion the least.

(2) The regressive model of thiourea leaching process was established, and the optimum conditions are as follows: temperature 50 ℃, time 5 h, the ratio of liquid to solid (L/S) 4∶1, concentrations of thiourea, hydrochloric acid and initial ferric ion are 12 g/L, 1 mol/L, and 1 g/L, respectively. Under the optimized conditions, the gold extraction rate can reach above 81%.

(3) There is a limit to the extraction rates of gold and silver.

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