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Gold Loading on Ion Exchange Resins in Non-Ammoniacal Resin-Solution Systems

Abrar Muslim[1,2]
[1] Chemical Engineering Department, Curtin University of Technology, Australia
[2]Chemical Engineering Department, Engineering Faculty, Syiah Kuala University, Indonesia
E-mail: abr_muslim@yahoo.com

Abstract

The loading of gold using strong base anion exchange resin in non-ammoniac resin-solution (NARS) systems has been studied. The loading of gold onto ion exchange resins is affected by polythionate concentration, and trithionate can be used as the baseline in the system. The results also show that resin capacity on gold loading increases due to the increase in the equilibrium thiosulfate concentration in the NARS system. Gold loading performances show the need of optimization the equilibrium concentrations of thiosulfate in the NARS system.

Keywords: equilibrium, gold loading, resin capacity, thiosulfate, trithionate

1. Introduction

Cyanide process that relies on the fact that gold dissolves in aerated cyanide solution to produce the gold cyanide complex (MacArthur, 1988), has significantly being used as a leach reagent at gold mines due to its high efficiency and has been the most important extraction process for the extraction of gold and silver for over 100 years (MacArthur, 1988; Marsden and House, 1992; Logsdon, Hagelstein *et al*., 1999; Young, 2001). However, its use is becoming undesirable from an environmental perspective owing to the acute toxicity of cyanide (Korte and Coulston, 1995; Moran, 1998; Miller and Pritsos, 2001). Dealing with the problems and improving the process, additional treatments are incorporated into the process (Koslides and Ciminelli, 1992; La Brooy *et al*., 1994; Mosher and Figueroa, 1996; Linge and Welham, 1997). Among alternative replacements for cyanide (Hilson and Monhemius, 2006), thiosulfate is the most capable because it is environmentally friendly and relatively cheap reagent (Muir and Aylmore, 2004).

There have been a number of extensive studies on the leaching of gold with thiosulafte ($S_2O_3^{2-}$), and the presence of ammonia and copper ions with copper(II) as oxidant (Hu *et al*., 1993; Abbruzzese *et al*., 1995; Jeffrey, 2001; Breuer and Jeffrey, 2002). The leach system with oxygen as the oxidant in the oxidation of copper ion (Inui *et al*., 1981; Lei *et al*., 1992; Miller *et al*., 1995; Breuer and Jeffrey, 2003), consumes thiosulfate leading to the generation of polythionates including tetrathionate (Wan, 1997). It affects polythionates analysis and the gold recovery using ion exchange resins (Nicol and O'Malley, 2002). Interestingly, a reliable method was proposed to deal with the analysis of thiosulfate and polythionate in gold thiosulfate solution with the presence of ammonia and copper ions (Jeffrey and Brunt, 2007).

The presence of ammonia, copper and dissolved oxygen may change the reaction kinetics, mechanism and products of the leaching of gold with thiosulfate. There are limited studies on the leaching of gold using ion exchange resins with the absence of ammonia and copper. Therefore the aim of this work is to investigate the loading of gold on ion exchange resins at equilibrium for the resin-solution system in the absence of ammonia.

2. Methodology

2.1 Apparatus

For the polythioates and thiosulfate and analysis of all samples, a Waters 2695 HPLC separation module was used with the separation being effected using a Dionex IonPac AS16 ion exchange column equipped with an IonPac AG16 guard column. The species analyses were conducted using Ion Chromatography (IC) with ultraviolet (UV) detection by means of a Waters 2996 Photodiode Array Detector. A pump with the flow rate of 1 mL min^{-1} was used, and the column temperature was 25°C. Empower software was used for the calculation of peak areas. The wavelength of peak UV adsorption, and the peak retention time, and lower detection limit measured for the species and gold thiosulfate is described in the available literature (Jeffrey and Brunt 2007). For the gold analysis, an inductively coupled plasma-optical emission spec-trometry (ICP-OES) method had been used.

2.2 Experiments

Solutions prepared from either analytical grade or synthesized reagents and Millipore water were used in the all experiments. Sodium trithionate, sodium tetrathionate, and synthesized polythionates were prepared using the methods outlined in the literature (Kelly and Wood 1994). Loading solution was prepared in a conical flask by mixing 0.124 mg of gold thiosulfate with 210 mL of 5 mM sodium thiosulfate and 5 mM sodium trithionate, and to make initial gold concentration of 0.2 mg/L in a non-ammoniacal resin-solution (NARS) system with 0.5 g Purolite A500/2788 strong base anion exchange resin. 10 mL sample of loading solution at t = 0 h was taken for the gold analysis using an inductively coupled plasma-optical emission spectrometry (ICP-OES) method followed by taking 1 mL sample of the loading solution for HPLC. After 5 h loading, 10 mL sample and 1 ml sample were taken for ICP-OES and HPLC, respectively as the equilibrium condition samples.

The resins of loading system were decanted and washed 4 times into large vial using DI water. Suck remain the water, add 50 mL sodium perchlorate (0.5 M) and shack it (150 U/min) using Jubalo SW-20C for 30 minutes at the room temperature (25 ^{0}C) for the 1st strip. The 2nd stripping was done as well as the 1st stripping. Then, the resins were washed 4 times, put in a vial and dried for about 17 h. It was weighted to measure the dried resin. Samples of 10 and 1 ml were taken for ICP-OES and HPLC, respectively after the 1st striping and the 2nd stripping. All the samples with gold were added with 0.5 CN+OH solution to its stability. For the matrices, 10 mL loading solution without addition of gold was prepared for ICP-OES. The experiment was repeated for various initial gold concentration of 0.2-9.5 mg/l.

3. Results and Discussion

In general, the loading of gold onto ion exchange resins is affected by polythionate concentration. As defined by the six experiments in Table 1, the concentrations of thiosulfate, trithionate, and tetrathionate are fairly consistent, and gold concentration is varied from 0.262 mg/l to 10.476 mg/l. The concentration of polythionate and gold after 5 h loading in the experiments can be calculated using related species and gold in Tables 2 where the average concentration change of thiosulfate, trithionate, tetrathionate and gold are approximately 1.8, 45.3, 56.9 and 86.4%, respectively. From these, the amount of thiosulfate loaded on the resins is very small compared to the trithionate concentration, which is at the concentration of 20.754-25.144 mM based on the loading (see Table 3) and 14.317-39.284 mM based on the stripping solution volume.

Table 1. The initial concentrations of gold and species in loading solutions without resins.

Exp.	Concentrations			
	Gold (mg/l)	$S_2O_3^{2-}$ (mM)	$S_3O_6^{2-}$ (mM)	$S_4O_6^{2-}$ (mM)
1	0.262	5.322	5.153	0.018
2	0.480	5.300	5.156	0.015
3	0.713	5.268	5.168	0.018
4	2.025	5.127	4.911	0.020
5	5.109	5.164	4.960	0.015
6	10.476	5.172	4.913	0.016

Table 2. The concentrations of gold and species in loading solutions with resins.

Exp.	Concentrations			
	Gold (mg/L)	$S_2O_3^{2-}$ (mM)	$S_3O_6^{2-}$ (mM)	$S_4O_6^{2-}$ (mM)
1	0.044	5.269	2.751	0.006
2	0.064	5.227	2.774	0.008
3	0.093	5.188	2.712	0.006
4	0.258	4.981	2.732	0.008
5	0.645	5.068	2.805	0.008
6	1.362	5.044	2.768	0.007

Table 3. The measured speciation of the six loading solutions at equilibrium with resins.

Exp.	Solution concentrations			
	Gold (mg/L)	$S_2O_3^{2-}$ (mM)	$S_3O_6^{2-}$ (mM)	$S_4O_6^{2-}$ (mM)
1	0.219	22.251	629.452	6.097
2	0.415	21.893	617.020	5.485
3	0.621	20.754	619.235	6.015
4	1.767	20.804	615.535	5.798
5	4.463	24.171	606.851	5.083
6	9.115	25.144	606.276	5.007

Table 4. The measured speciation of the resin in equilibrium with loading solution.

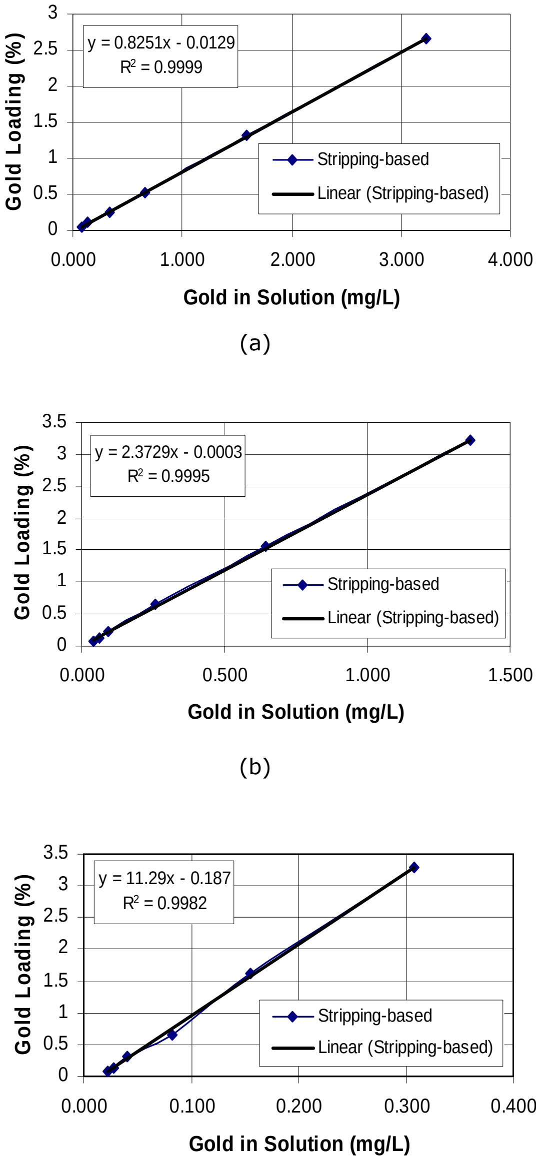
Exp.	Resin concentrations			
	Gold (mg/L)	$S_2O_3^{2-}$ (mM)	$S_3O_6^{2-}$ (mM)	$S_4O_6^{2-}$ (mM)
1	77.357	14.317	644.596	3.226
2	150.778	19.762	649.759	1.934
3	237.688	21.638	665.122	3.213
4	714.625	39.284	589.815	3.301
5	1695.136	25.923	586.519	1.899
6	3510.550	34.921	586.932	2.452

Interestingly, the tetrathionate concentration change (73.8%) is much larger than trithioante concentration (13.4%), as revealed in Table 4. However, with the very small initial concentration of tetrathionate, the amount of tetrathionate loaded on the resins is also very small which is varied at the concentration of 1.899-3.301 mM based on the stripping. Meanwhile, the trithionate concentration is from 586.519 mM to 665.122 mM based on the stripping.

It is also important to note that thiosulfate degradation in the previous studies (Wan, 1997; Nicol and O'Malley, 2002; Jeffrey and Brunt, 2007) with tetrathionate as the one of the principle product in ammoniacal thiosulfate solution, might not occur in the NARS system, since there is very small decrease in thiosulfate concentration during 5 h loading. It could be because of the loading of thiosulfate on the resins, not due to its degradation to form tetrathionate. In addition, there is no significant decrease in the stripping-based thiosulfate concentration compared to the loading-based concentration.

As predicted, trithionate which could be used as the baseline in the multiple component NARS system with gold is loaded on the resins very well together with gold. It could be true because the amount of trithionate loaded on resins is in certain proportion to the amount of resins in the solution. The reason is the amount of trithionate loaded on resins is almost constant even if there is small decrease; 619.235, 615.535, 606.851 and 606.276 mM (loading-based in Table 3); and 665.122, 589.815, 586.519 and 586.932 mM (stripping-based in Table 4), for the increased gold concentration in solution of 0.621, 1.767, 4.463 and 9.115 mg/l, and for the increased gold concentration in resins of 237.688, 714.625, 1695.136 and 3510.550 mg/l, respectively.

Figures 1 show the gold loading vs gold in solution in the systems with the equilibrium concentrations thiosulfate, thrithionate and tetrathionate being 1.46, 0.76 and 0.138 mM, respectively (Figure 1.a); with the equilibrium concentrations thiosulfate, thrithionate and tetrathionate being 5.04, 2.77 and 0.01 mM, respectively (Figure 1.b); and with the equilibrium concentrations thiosulfate only being 98.30 mM (Figure 1.c). As can be seen in Figures 1, the gold loading linearly increases with the increase in the gold concentration in solution. It is reasonable because small amount of gold in solution leads to the low loading of gold. But, something important to note that the change in the equilibrium thiosulfate concentration in the systems contributes to change in the gold loading per 1 mL gold in solution. As shown in Figures 1, the slope of gold loading curve is correspondently increased from about 0.83 to 2.37 for the increase in the equilibrium thiosulfate concentration from 1.46 to 5.04 mM. It becomes much higher which is 11.29 when the equilibrium thiosulfate concentration was 98.30 mM.



(a)

(b)

(c)

Figure 1. Gold loading vs gold in solution in the NARS systems without ammonia and copper based on stripping processes (a,b,c).

In terms of the gold loadings, the equilibrium thiosulfate concentration in the loading solution also affects the gold loading performance. The relationship within the gold loading and the equilibrium thiosulfate concentration in solution tends to be a first order system, shown in Figure 2. Therefore, the optimization of equilibrium thiosulfate concentration in the NARS system is badly needed to consider in minimizing the thiosulfate reagent in the recovery of gold.

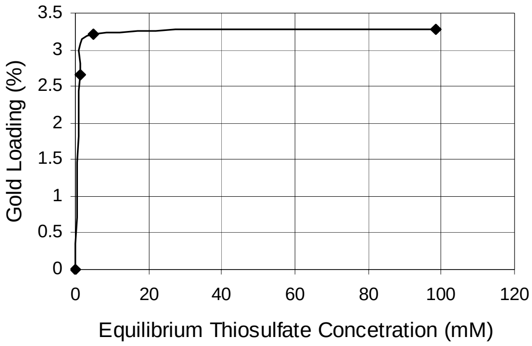


Figure 2. Gold loading vs equilibrium thiosulfate concentrations in the NARS system without ammonia and copper based on stripping processes.

4. Conclusion

Experiments on the loading of gold on using ion exchange resins at equilibrium in non-ammoniacal resin-solution (NARS) system has been conducted where IC with UV detection is used for the analysis of species and ICP-OES was used to measured gold loaded on resins. Isotherm for gold on resin versus gold in solution shows that the low gold loading results in linear relationship between the mass of gold per kg resin and gold in solution. Gold loading performances show the need of optimizing the equilibrium concentrations of in the recovery of gold.

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References

Abbruzzese, (1995) Thiosulphate leaching for gold hydrometallurgy, *Hydrometallurgy*, 39, 265-276.

Breuer, P. L., Jeffrey, M. I. (2002) An electrochemical study of gold leaching in thiosulfate solutions containing copper and ammonia, *Hydrometallurgy*, 65, 145-157.

Breuer, P. L., Jeffrey, M. I. (2003) Copper catalysed oxidation of thiosulfate by oxygen in gold leach solutions, *Minerals Engineering*, 16, 21-30.

Gong, Q. (1993) Kinetics of gold leaching from sulfide gold concentrates with thiosulfate solution, *Transactions of the Nonferrous Metals Society of China* 3, 30-36.

Hilson, G., Monhemius, A. J. (2006) Alternatives to cyanide in the gold mining industry: what prospects for the future?, *Journal of Cleaner Production*, 14, 1158-1167.

Jeffrey, M. I. (2001) Kinetic aspects of gold and silver leaching in ammonia-thiosulfate solutions, *Hydrometallurgy*, 60, 7-16.

Jeffrey, M. I., Brunt, S. D. (2007) The quantification of thiosulfate and polythionates in gold leach solutions and on anion exchange resins, *Hydrometallurgy*, 89, 52-60.

Kelly, D. P., Wood, A. P. (1994) Synthesis and determination of thiosulphate and polythionates, *Methods in Enzymology*, 243, 475-501.

Korte, F., Coulston, F. (1995) From single-substance evaluation to ecological process concept: the dilemma of processing gold with cyanide, *Ecotoxicology and Environmental Safety*, 32, 96-101.

Koslides, T., Ciminelli, V. S. T. (1992) Pressure oxidation of arsenopyrite and pyrite in alkaline solutions, *Hydrometallurgy*, 30, 87-106.

La Brooy, S. R. (1994) Review of gold extraction from ores, *Minerals Engineering*, 7, 1213-1241.

Langhans, J. W., Jr. (1992) Copper-catalyzed thiosulfate leaching of low-grade gold ores, *Hydrometallurgy*, 29, 191-203.

Li, J., (1995) The ammoniacal thio-sulphate system for precious metal recovery, *Metallurgy and Exploration*, 37-42.

Linge, H. G., Welham, N. H (1997) Gold recovery from a refractory arsenopyrite (Feass) concentrate by in-situ slurry oxidation, *Minerals Engineering*, 10, 557-566.

Logsdon, M. J. (1999) The management of cyanide in gold extraction, ICME Publications, Ontario, Canada.

MacArthur, J. S., Forrest, R. W., Forrest, W. (1988) Improvement in obtaining gold and silver from ores and other compounds, *British Patent* 14174.

Marsden, J., House, I. (1992) *The Chemistry of Gold Extraction*, Ellis Horwood Ltd., London.

Miller, G. C. and C. A. Pritsos (2001). *Unresolved problems with the use of cyanide in open pit precious metals mining, Cyanide*: social, industrial and economic aspects. New Orleans, USA.

Moran, R. (1998) *Cyanide Uncertainties: Observations on the Chemistry, Toxicity, and Analysis of Cyanide in Mining-Related Waters,* MPC., Mineral Policy Center, Washington.

Mosher, J. B., Figueroa, L. (1996) Biological oxidation of cyanide: A viable treatment option for the minerals processing industry, *Minerals Engineering*, 9, 573-581.

Muir, D. M., M. G. Aylmore (2004) Thiosulphate as an alternative to cyanide for gold-processing issues and impediments, *Mineral Processing and Extractive Metallurgy*, 113, 2-12.

Nicol, M. J., O'Malley, G. (2002) Recovering gold from thiosulfate leach pulps via ion exchange, *JOM*, 54, 44-46.

Tozawa, K. (1981) Dissolution of gold in ammoniacal thiosulfate solution, *Metallurgical Society AIME*, 12.

Wan, R. Y. (1997) Importance of solution chemistry for thiosulphate leaching of gold. Carlton, Vic, The Australasian Institute of Mining and Metallurgy: 159-162.

Young, C. A. (2001) Cyanide: social, industrial and economic aspects. New Orleans, Minerals and Materials Society.