Hydrometallurgy 105 (2010) 47–53

Contents lists available at ScienceDirect

Hydrometallurgy

journal homepage: www.elsevier.com/locate/hydromet

The effect of flotation reagents on cyanidation, loading capacity and sorption kinetics of gold onto activated carbon

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ARTICLE INFO

Article history:
Received 15 March 2010
Received in revised form 24 May 2010
Accepted 20 July 2010
Available online 25 July 2010

Keywords:
Flotation reagents
Organic fouling
Cyanidation
Gold sorption kinetics
Gold loading capacity

ABSTRACT

In the current study, the effect of flotation and dewatering reagents on cyanidation process, loading capacity and adsorption kinetics of gold onto activated carbon has been evaluated through a developed experimental program.

The experimental results showed that the flotation reagents have a detrimental effect on the cyanidation process and this effect increases with increasing their concentrations. It was also clearly revealed that the occurrence of organic fouling influences the gold sorption kinetics onto activated carbon but not the loading capacity.

By applying a reagent scheme, in which the dosage of flotation reagents is very high, the gold sorption kinetics onto an activated carbon severely decreased and the kinetic constant of gold sorption (k value) fell below 50 h^{-1}. This problem was overcome by applying the optimized reagent scheme in which the dosage of flotation reagents is set to a minimum required amount for the optimum recovery of Mouteh gold bearing sulfides. By using this reagent scheme, the fouling effect of flotation and dewatering reagents was negligible and the gold sorption kinetics was slightly decreased in comparison with the non-fouled carbons.

1. Introduction

In gold processing plants, when gold occurs as finely disseminated particles in sulfides or in a solid solution, flotation is commonly used as a pre-concentration step to allow one of the more expensive pretreatment process including fine grinding, roasting, bacterial or pressure oxidations to be carried out on a smaller and concentrated fraction of materials (Marsden and House, 2006; Thomas and Cole, 2005; Miller and Brown, 2005; Thomas, 2005). In the flotation circuit, several reagents such as collector, frother, modifier, activator and depressant are used to maximize the recovery of all the gold bearing sulfide minerals (Marsden and House, 2006; Dunne, 2005). The pretreated concentrates and in some cases along with the flotation tailing, are transferred to the carbon in pulp (CIP) or carbon in leach (CIL) processes where gold is dissolved and adsorbed onto the activated carbon (Marsden and House, 2006; Staunton, 2005). The gold sorption efficiency onto the activated carbon is affected by a number of physical and chemical factors including carbon type and size, mixing efficiency, gold and cyanide concentration, presence of other metal ions and complexes in leach solution, solution pH and temperature, ionic strength and carbon fouling (Marsden and House, 2006). The carbon fouling is defined as the adsorption or accumulation of unwanted organic and inorganic species on the surface or within the pores of the activated carbon (Marsden and House, 2006; Dunn and Fisher, 2001). Many inorganic fouling agents can be removed from the activated carbons by a downstream process of acid washing, whereas organic fouling agents cause a great concern in the gold processing plants (Dunn and Fisher, 2001).

The effect of collectors, frothing agents, flocculants, oils and grinding aids as the main organic foulants present in the leach solution on the kinetic activity of gold sorption has been investigated by La Brooy et al. (1986). Their experimental program consisted of aging the activated carbon in a 500 mL distilled water together with a fouling agent and 200 ppm sodium cyanide for 24 h and then placing the carbon in a gold solution. They found that the flotation reagents such as xanthate type collectors and frothing agents are responsible for the most serious deactivation of the activated carbon and very large molecules such as grinding aids and flocculants have negligible effects on the kinetic activity of the activated carbon for gold sorption (La Brooy et al., 1986).

Fisher and Dunn (2000) identified organic foulants on the activated carbon by using thermal analysis techniques. The activated carbons had been taken from two commercial gold processing plants which both have a flotation circuit. They reported that the carbon fouling had occurred in one plant by xanthates and in other plant by both frothing agents and xanthates.

Salarirad and Behnamfard (2010) studied the kinetics of gold adsorption onto the activated carbons which have been fouled by flotation and dewatering reagents of different concentrations. A significant decrease of gold sorption kinetics was observed even at low concentrations (i.e., less than 15 mg/L) of xanthates including potassium isobutyl xanthate (PIBX) and potassium ethyl xanthate (PEX). At higher concentrations, deactivation by xanthates was found to

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doi:10.1016/j.hydromet.2010.07.009

be more pronounced. They observed that the presence of methyl isobutyl carbinol (MIBC) in the solution at low concentrations (i.e., up to 15 mg/L) causes a negligible decrease of gold sorption kinetics, but it is significant at higher concentrations. The fouling effect of the flocculant was found to be negligible.

In this study, two reagent schemes corresponding to the initial and optimized flotation reagent schemes of Mouteh gold processing plant in Iran were employed. The initial scheme represents the preliminary design of the plant in which roasting was chosen as an oxidative pretreatment process for the flotation concentrate and a high dosage of flotation reagents was determined to ensure that all of the sulfide and partially oxidized sulfide minerals to be floated (BHP engineers, 1989). In the final design of the plant, due to the regional environmental regulations and nature of gold occurrence in the sulfide ores, ultrafine grinding was employed as a replacement for the roasting process, but the initial reagent scheme was used in the flotation circuit. If roasting was employed, the flotation reagents are most likely oxidatively decomposed to gaseous products whereas by using ultrafine grinding, the majority of the flotation reagents proceed to the CIL tanks and lead to the occurrence of carbon fouling. Due to the high dosages of flotation reagents, the organic carbon fouling occurred to a great extent and the plant was closed after 1 month operation. Behnamfard (2009) carried out a series of flotation experiments and determine a new flotation reagent scheme. In this reagent scheme, the dosages of flotation reagents were set based on the minimum required amounts for the optimum recovery of sulfide minerals in the flotation circuit. The details of the initial and optimized reagent schemes are given in Table 1.

The aim of this study is to investigate the effect of flotation and dewatering reagents at these two reagent schemes, on cyanidation process, loading capacity and adsorption kinetics of gold onto the activated carbon. For this purpose, a sequential experimental procedure as shown in Fig. 1, was developed.

2. Experiments and methods

2.1. The ore sample

A sample of gold bearing sulfide ore was taken from Mouteh gold mine in Iran. The chemical composition of the sample was 2.51 g/t Au, 2.68% S, 64.5% SiO_2, 10.0% Al_2O_3, 7.8% Fe_2O_3, 2.98% CaO, 2.37% MgO, 1.90% K_2O and 0.97% Na_2O. The major mineralogical constitutes of the ore are gold bearing pyrite as the valuable mineral and quartz and feldspar as the major gangue minerals.

2.2. Reagents

Analytical grade sodium cyanide (NaCN), sodium hydroxide (NaOH), and methyl isobutyl carbinol (MIBC) were supplied from Merck Co. and PEX and potassium PIBX were obtained from New Brunswick, USA. Anionic polyacrylamide with the trade mark of Nasfloc, Aero promoter 238 (AP238) and lime were of commercial grade. A size fraction of 2 to 2.36 mm of the industrial grade coconut shell granular activated carbon, produced through a steam activation process by Haycarb Company, Sri Lanka, was chosen for experiments.

Table 1
The initial and optimized reagent schemes of flotation and dewatering circuits of a gold processing plant.

Reagent scheme		Initial	Optimized
Collector	Type	Potassium isobutyl xanthate	Potassium ethyl xanthate
	Dosage (g/t)	200	20
Co-collector	Type	Aero promoter 238 (AP238)	–
	Dosage (g/t)	50	–
Frother	Type	Methyl isobutyl carbinol	Methyl isobutyl carbinol
	Dosage (g/t)	40	20
pH modifier	Type	Without pH adjusting	Without pH adjusting
	Dosage (g/t)	–	–
Activator	Type	Sodium sulfide	–
	Dosage (g/t)	100	–
Flocculant in thickeners	Type	Polyacrylamide	Polyacrylamide
	Dosage (g/t)	30	30

2.3. Preparations of sample

The ore sample was crushed and thoroughly passed through a 2 mm size screen and then split using a riffle splitter to obtain 1.5 kg subsamples. Three subsamples were separately ground at 60% solids in a Denver laboratory rod mill to obtain a P_{80} of 63 μm. The slurries were thoroughly mixed together and filtered in a pressure filter.

2.4. Preparation of the stock gold solution

For the preparation of the gold stock solution, accurately weighted gold slices, cut from a pure gold plaque provided from Pamp S.A. Switzerland, were added to 1000 mL double distilled water containing 1000 mg/L NaCN. The pH of the solution was pre-adjusted to 10. The solution was agitated in glass flask using an orbital shaker (IKA-Werke) at room temperature. Enough shaking was performed to ensure that all the gold slices have been dissolved. Finally, the gold concentration of stock solution was determined 700 mg/L by using Unicam 939 Atomic Absorption spectrometer (AAS) at a wavelength of 242.795 nm.

2.7. Experimental procedure

As shown in Fig. 1, the experimental procedure was implemented in three successive stages, i.e., (1) CIL testing and (2 and 3) two stages kinetic tests. The detail of the experimental procedure is given as follows.

2.7.1. Stage 1 (CIL testing)

The prepared filter cake was divided into three equal parts and each of them was added into a 4 L stainless steel cell. The pulp density was set to 40% solids and the pulp pH was adjusted to 10.5 with lime. By adding 2.25 g sodium cyanide into each cell, the cyanide concentration was adjusted at 1000 mg/L. As shown in Fig. 1, flotation and dewatering reagents were added into cells No. 2 and 3 according to the optimized and initial reagent schemes, respectively. After weighing 4.5 g portions of the activated carbon, they were washed with 1% hydrochloric acid solution, rinsed with distilled water and added to each cell. Continuous mixing for 24 h was provided during the experiments with a mechanical stirrer at a constant agitation speed of 250 rpm. After 24 h, the activated carbons were separated from the pulps through a screen with an opening of 1 mm and the pulps were filtered. The gold analysis of the filtrate was performed by solvent extraction into DIBK/Aliquat 336 and then direct aspiration of the loaded organic phase into AAS. The filter cake was washed, dried, homogenized, sampled and analyzed for gold by fire assay. The activated carbons immediately after separation from the pulps were washed with distilled water and directly used for subsequent experiments.

2.7.2. Stages 2 and 3 (kinetic tests)

Appropriate amounts of NaOH and NaCN solutions were added into three 1 L volumetric flasks and mixed thoroughly. A 25 mL aliquot of gold stock solution was transferred into each flask. The solution volumes were adjusted to the mark with distilled water to obtain 1 L solutions containing 250 mg/L NaCN and 17.5 mg/L Au at pH of 10. The contents of the flasks were transferred into 2.5 L glass bottles and then the activated carbons of the previous stage were added to achieve an adsorbent concentration of 4.5 g/L. The bottles were placed on a bottle roll apparatus and agitated at 100 rpm for 24 h