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Bio-oxidation of a high-sulfur and high-arsenic refractory gold concentrate using a two-stage process

Guohua Wang[a,*], Shuibo Xie[a], Xinxing Liu[b,c], Yonghong Wu[b,c], Yingjiu Liu[a], Taotao Zeng[a]

[a] Hunan Province Key Laboratory of Pollution Control and Resources Reuse Technology, University of South China, Hengyang 421001, China
[b] School of Minerals Processing and Bioengineering, Central South University, Changsha 410083, China
[c] Key Laboratory of Biohydrometallurgy of Ministry of Education, Central South University, Changsha 410083, China

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ABSTRACT

To improve the oxidation rate of high-sulfur and high-arsenic refractory gold concentrate (HGC), a two-stage chemical-biological oxidation approach, which contained a high-temperature chemical oxidation stage (ferric-leaching stage) and a subsequent biological oxidation stage with mesophiles, was used in this experiment. The surface analysis of pure arsenopyrite using scanning electron microscope (SEM), Energy Dispersive X-ray Spectroscopy (EDX) and X-ray photoelectron spectroscopy (XPS) indicated that the surface lattice structure was partly disrupted after chemical oxidation; as a result, the subsequent biological oxidation rate during the second stage improved significantly. The extraction levels of Fe, As and S were 49.8%, 50.4% and 51.0%, respectively, in the normal biological oxidation system, while the values increased to 63.3%, 64.2% and 63.3%, respectively, following the two-stage process. Accordingly, the recovery rate of gold increased by 16.8% using the two-stage process compared to that of the one-stage biological oxidation approach.

1. Introduction

According to geological surveys, resources of high-sulfur and high-arsenic gold concentrate (HGC) are abundant in many provinces of China (Gao et al., 2009; Li et al., 2009). On the one hand, HGC can become a source of acid mine drainage and induce an increase in heavy metal mobility when exposed to weathering, creating serious environmental problems. On the other hand, HGC contains a large number of precious metals and will become a viable source of gold in the future. As a result, highly efficient treatment of HGC can provide enormous economic and environmental benefits.

In HGC, gold is generally dispersed as submicroscopic particles and efficient recovery of this finely dispersed gold is extremely difficult using a direct cyanide leaching method without pretreatment (Hong et al., 2016; Mubarok et al., 2016). Pretreatment methods include a roasting process (La Brooy et al., 1994), pressure oxidation (Deng and Liao, 2002), chemical oxidation (Gao et al., 2009; Li et al., 2011, 2009) and bio-oxidation (Roberto, 2016; Xu et al., 2016). Bio-oxidation offers a great advantage compared to the other pretreatment methods, as reagent costs are low and the process is carried out under mild conditions which reduces the operational cost and environmental impact (Brierley and Brierley, 2013; Vera et al., 2013). However, the bio-oxidation process requires a long time for pretreatment (Rawlings et al., 2003), which limits its application.

To intensify the bio-oxidation process, a two-stage chemical-bacterial oxidation approach was proposed by Fomchenko et al. (2010). The two-stage process includes a high-temperature chemical oxidation stage and a subsequent biological oxidation. The physical separation of the chemical oxidation stage and the biological oxidation stage creates favourable conditions for both stages. Additionally, many articles have been published on ferric leaching of gold concentrate, and ferric sulfate is often available *in situ* in most bio-oxidation plants. However, the effect of the two-stage process on the oxidation efficiency of HGC has not been reported.

The purpose of this study is to investigate the potential application of a two-step pretreatment process of HGC and to determine how a two-step pretreatment leads to improved gold extraction using combined X-ray photoelectron spectroscopy (XPS) and Scanning Electron Microscope – Energy Dispersive X-ray Spectroscopy (SEM-EDX) observation.

2. Methods

2.1. Microorganisms and culture condition

The microorganisms used in this experiment were a mixed culture of

* Corresponding author.
E-mail address: wghcsu@163.com (G. Wang).

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Table 1
Iron and sulfur oxidizing microbes used in the experiment.

Species (strain)	Optimal temperature(°C)	Medium	pH value	Reference
At. ferrooxidans (F1)	30	9 K	2.0	Hu et al. (2006)
At. thiooxidans (A01)	30	9 K (without $FeSO_4$) + sulfur (10 g/L)	2.0	Liu et al. (2011a,b)
L. ferriphilum (YSK)	40	9 K	1.6	Gao et al. (2007)

9 K medium (g/L): $(NH_4)_2SO_4$ (3), KCl (0.1), K_2HPO_4 (0.5), $MgSO_4{\cdot}7H_2O$ (0.5), $Ca(NO_3)_2$ (0.01), $FeSO_4{\cdot}7H_2O$ (44.7).

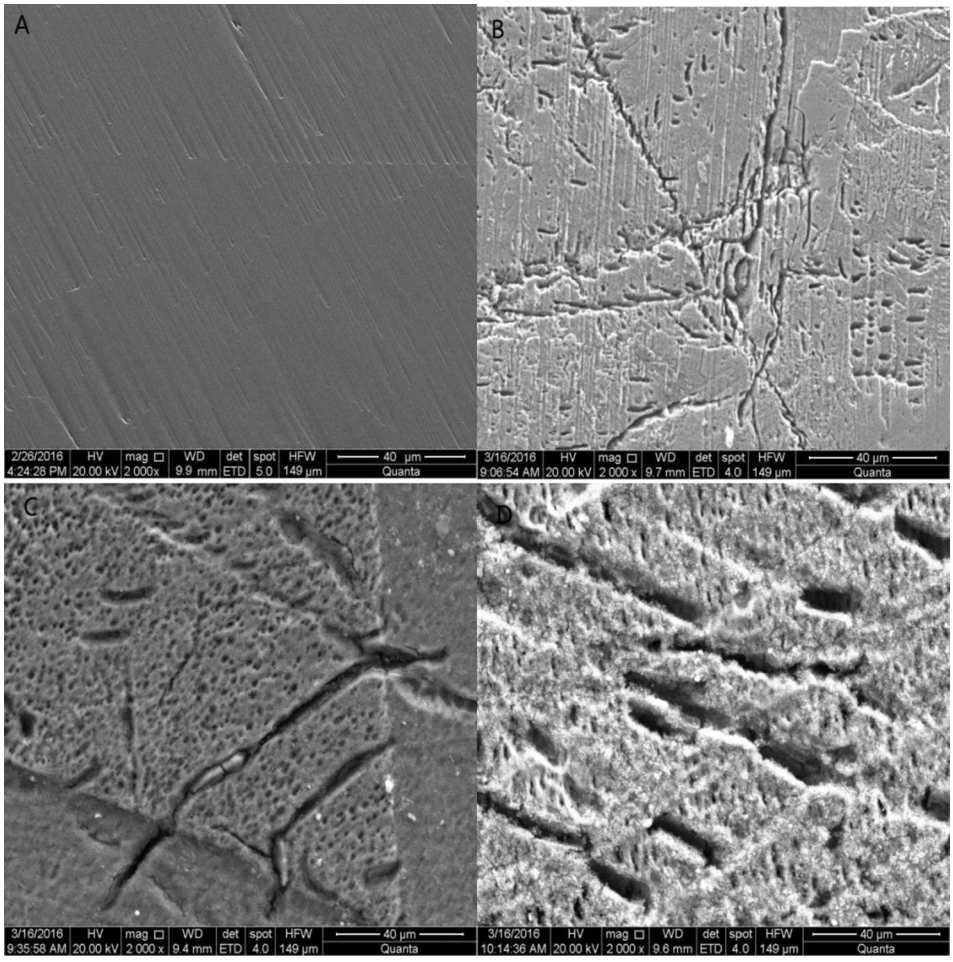

Fig. 1. The surface of pure arsenopyrite at different processing stages. A: Untreated; B: Chemical oxidation; C: Biological oxidation; D: Two-step process.

Table 2
The mole percent of each element on the surface of pure arsenopyrite using the different processes.

Sample	Mole percent of each element (%)				
	Si	Fe	As	S	O
Untreated	0.1	33.2	34.3	32.43	–
Chemical oxidation	–	28.53	32.23	30.43	7.33
Biological oxidation	0.3	14.5	12.1	42.6	29.7
Two stage process	0.3	13.5	9.6	38.9	36.39

mesophilic microbes. The mesophilic mixed culture was prepared from pure strains of equal proportion. The composition of the mixed culture is listed in Table 1. The mixed culture was adapted to the HGC by serially culturing the microorganisms to the solid particles of the concentrate with a gradient of increased pulp densities from 2% to 10% w/v replacing the energy source. The mixed culture was cultured at 30 °C. The adaptation procedure was carried out in 100 mL of 9-K medium in 250-mL flasks on a rotary shaker (170 rpm). The solution pH was adjusted to 2.0 using 10 N H_2SO_4.

2.2. Characterization of mineral samples and materials

The high-arsenic gold concentrate and pure arsenopyrite were purchased from Hunan Central South Gold Smelting Company Limited. The results of elemental analysis of the gold concentrate were as follows: 32.9% Fe, 22.8% As, 31% S, 8.4% SiO_2, 1.7% MgO, 1.3% Al_2O_3 and 33.0 g/t Au. The initial surface mean particle size of high-arsenic gold concentrate was 17.5 μm. Furthermore, the mineral composition was as follows: 50.2% arsenopyrite, 20.3% pyrite, 15.5% pyrrhotite, 6.4% quartz, 7.6% silicate and carbonate minerals. The mole percent of each element in pure arsenopyrite for the mechanism research of two-step approach was Fe 33.2%, As 34.3%, S 32.4% and Si 0.1%.

The ferric sulfate solution was collected from reactors of the Axi Gold Factory in Xinjiang Autonomous Region of China. The concentration of ferric ion in the solution was 20 g/L and the solution pH was 1.3. It was used in the following chemical oxidation process.