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Improved recovery of a low-grade refractory gold ore using flotation–preoxidation–cyanidation methods

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ABSTRACT

In this work, different flotation–preoxidation–cyanidation methods are considered for treating a low-grade refractory gold ore. On the one hand, the results of selective flotation show that 22% and 31.1% of total Sb and As, respectively, remained in the final tailings and only about 28% of the total Au remained for further cyanidation processes. On the other hand, in bulk method of flotation the maximum Au recovery of 90.6% achieved after 60 min of flotation at the grind size with K80 of 146 micron. In addition, the bulk flotation method resulted in the concentrate with low concentrations of Sb and As elements. To improve the recovery of low-grade refractory gold ores, flotation should be followed by roasting, biological, or pressure oxidation processes so that the gold could be liberated prior to cyanidation processes. It is also found that the pressure oxidation pre-treatment of the concentrates prior to cyanidation may yield high gold recoveries of over than 83%. In these processes, recoveries are controlled by the temperature and the oxygen partial pressure in the solvent. However, by utilizing the bio-oxidation technique, the oxidation of sulfur to sulfate cannot be completed and, consequently, the gold recovery may be limited to only 72.2%.

1. Introduction

In sulfidic refractory gold ores, fine gold particles may be highly disseminated and locked up in sulfide minerals such as pyrite and arsenopyrite. All the largely unoxidized ores exhibit very low gold recoveries (typically <20%) by direct cyanidation. This suggests that the primary ore, as a whole, is highly refractory in nature and will therefore have to be processed using an appropriate refractory method. Often, the gold bearing ores are refractory due to the gold grains and concentration by flotation is necessary, either followed by roasting, bacterial leaching, or pressure leaching in a way that the gold is liberated prior to cyanidation. Two basic initial approaches are available, either treating the whole ore or processing some form of concentrate into which a high proportion of the gold has been recovered. A moderately low grade of the bulk ore and the additional processing costs involved in whole ore treatment processes are most certainly not economically viable and therefore not being considered [1].

A significant proportion of the sulfidic refractory gold appears to be hosted by the arsenical pyrite, arsenopyrite and stibnite components of the ore. These minerals are amenable to recovery by flotation. Adequate recovery of these fine-grained components might be difficult to achieve, even if the grind size is relatively fine (e.g. d80 = 38 μm). Orpiment (As2S3) and realgar (AsS) are both naturally hydrophobic and will float readily, and will thereby contaminate any sulfide concentrate with excessive amounts of arsenic. A high proportion of these minerals is, however, present in the form of relatively coarse grained vein fillings. It is also believed that these minerals do not host significant amounts of refractory gold. Disposal of any arsenic-rich product of this nature might, however, cause significant problems. Stibnite (Sb2S3) is sporadically present in the ore and, at least in some cases, may also adhere some of the refractory gold components [1].

Montethe et al. examined hydrogen peroxide in the selective flotation of gold from pyrite with potassium amyl xanthatein (PAX) which showed a high selectivity for gold from pyrite at pH l0 and higher, but with a low increase of recovery [2]. In the ores which contain free gold, it may be beneficial to involve selective flotation of the free gold to improve the overall gold recovery [3]. Bulatovic showed that the results obtained with bulk flotation were superior to those obtained by selective flotation [4].

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Among pre-oxidation methods, acidic pressure oxidation is considered the most effective method. Typical operating conditions include temperatures from 170 to 225 °C and oxygen partial pressures from 350 to 700 kPa over retention times from 1 to 3 h [5]. An overview of the role of pressure oxidation in treating refractory gold ores was given and subsequent developments have been highlighted. Examples of pressure oxidation plants commissioned since the mid-1980's and a brief description of their operation can be found in the article by Marsden and House [2].

Bacterial oxidation technology can be applied to refractory sulfide ores and concentrates to break down the mineral matrix and release the precious and base metals [6]. During bio-oxidation refractory gold ores processes, mineral decomposition is believed to be mostly due to chemical attack by ferric iron, with the main role of the microorganisms being to re-oxidize the resultant ferrous iron back to ferric iron [7]. If the Fe, As and S of the arsenopyrite are effectively oxidized by pretreating with bio-oxidation, gold will be naked and its recovery will be increased [8].

It will be necessary to undertake a series of metallurgical scoping tests to determine the nature, composition, and gold content of potential concentrates that might be produced from the ore. Therefore, it is necessary to evaluate a series of initial bench-scale metallurgical scoping tests to determine if it is possible to recover adequate properties of the refractory gold by flotation. The concentrate (bulk or sequential) from flotation stage should be further processed using pre-oxidation methods to liberate the locked gold and recover it by cyanidation. Thus, one of the aims of this study was to evaluate selective and bulk flotation pre-concentration methods to find out which of these methods could produce better concentrates for further processing stages like cyanidation. Also, two pre-oxidation methods (pressure oxidation-bio-oxidation) in acidic media were compared and subsequent cyanide leaching of the pretreated ores was investigated.

2. Materials and methods

2.1. Sample characterization

A sulfidic refractory gold ore containing 2.7×10^{-6} Au was obtained and used for all the experiments. Optical mineralogy by using the polished and thin sections, semi-quantitative X-ray diffraction (SQXRD) and ICP techniques are applied for ore characterization. Results of ICP and SQXRD are shown in Table 1 and Fig. 1 [1].

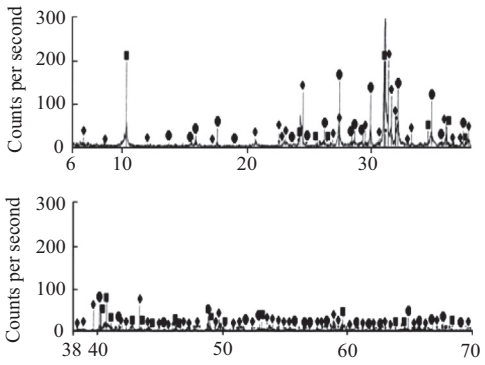

Fig. 1. XRD analysis of the ore sample.

A portion of the sample was submitted for mineralogical characterization. As indicated in Fig. 1 and Table 1, the sample was dominated by silicate minerals including quartz, potassium, feldspar, and mica. Sulfide minerals comprised 8% of the sample with pyrite accounting for most of the sulfide content. Other sulfide minerals identified as very minor components were arsenopyrite, galena, orpiment, realgar, sphalerite, chalcopyrite, Cu sulfat, and stibnite. The arsenic content of the pyrite determined the analysis to be in the range of 0–36% (by weight) by electron microprobe.

The mineralogical sub-samples were washed and wet-screened to recover the 106–500 μm size. Afterwards, these size fractions were subjected to heavy liquid separation using a Na-polytungstate solution with a density of 2.89 g/cm^3. The resultant heavy mineral concentrates were molded into epoxy resin and polished before examination using reflected light microscopy and SEM based techniques. Heavy liquid separation of the feed sample concentrated almost half of the gold in 1.9% (by weight), which was predominantly pyrite. The calculated gold grade was 94 g/t, but no visible gold was identified. Gold was also not identified in the overall head sample. The results suggest that the majority of the gold was present as a solid solution component in pyrite [1].

The bulk of the stibnite appears to be developed within transgressive late-stage veinlets where it is commonly intergrown with orpiment and/or quartz. The bulk of the stibnite is therefore also relatively coarse grained compared to the arsenical pyrite and arsenopyrite. The bulk of the stibnite should therefore be clearly librated during comminution and, if necessary, it should be possible to separate it from the arsenical pyrite–arsenopyrite–pyrite-rich concentrate by differential flotation.

Table 1
The results of ICP scan of the gold ore sample [1].

	ICP scan				
Element	Sample	Element (g/t)	Sample	Element (g/t)	Sample
Au (g/t)	2.700	Al	76,000	Mo	<20
Ag (g/t)	1.600	Ba	1500	Na	2000
S (%)	2.170	Be	2	Ni	23
S^{2-} (%)	1.720	Bi	<20	P	740
SO_4^{2-} (%)	<0.400	Ca	2100	Pb	420
As (%)	0.400	Cd	<5	Se	<100
Sb (%)	0.044	Co	12	Sn	<100
Fe (%)	3.310	Cr	16	Sr	100
Tl (%)	0.230	Cu	22	Ti	160
C(t) (%)	0.300	K	34,000	V	52
CO_3 (%)	1.360	Li	<10	Y	9
C(g) (%)	0.010	Mg	3800	Zn	120
TO (%) (Total organic)	<0.050	Mn	750	Tl	<100