



Influence of grinding media and water quality on flotation performance of gold bearing pyrite



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ABSTRACT

Flotation performance is strongly dependent on the surface properties of the constituent mineral particles, and may therefore serve as a diagnostic tool to evaluate grinding chemistry interactions. The surface properties can be altered by numerous factors such as the type of grinding media used in the preparation of the flotation feed, the presence of chemical species in the process water, and the characteristics of flotation reagents added. This paper investigates the influence of grinding media (forged steel, 18% chromium and ceramic) and water quality (tap water and synthetic process water) on floatability of gold bearing pyrite using XPS and EDTA extraction technique. The grinding of pyrite ore was performed in a Magotteaux Mill® which allowed better simulation of plant chemical conditions by controlling pH and pulp potential during the grinding. Cupric ions were added as an activator prior to the grinding. This work demonstrated that there is no significant effect of water quality on flotation performance of pyrite. The results also showed that the pyrite recovery was slightly higher when the grinding was performed with the forged steel media rather than with the chromium media or the ceramic media. XPS and EDTA extraction technique demonstrated that the forged steel media produced more iron hydroxide species than the 18% chromium or the ceramic media, indicating the high corrosion rate of the forged media. XPS technique failed to explain the influence of different grinding media on the floatability of pyrite from its ore probably due to the insensitivity of XPS technique to detect the presence of a low amount of copper species on the surface of the particles collected by flotation. The results obtained from this study confirmed that the selection of grinding media may be important to maximize pyrite recovery by flotation. The conclusions should be limited to ores low (< 2%) in pyrite content, and where there are no reactive sulfides present other than pyrite. From an economic perspective, the marginal impacts on flotation should be balanced against grinding media wear.

1. Introduction

Flotation is used to recover gold-bearing pyrite, and is based on the differences between the surface properties of pyrite and non-sulfide minerals. The surface properties of pyrite strongly depend on the grinding environment which might improve, aggravate or have no effect on pyrite floatability (Rabieh et al., 2016).

The grinding environment can be changed by the presence of some chemical species in the process water. For example, in the gold mining industry, free cyanide is added during leaching to dissolve gold locked in pyrite. Although a significant amount of free cyanide (and its metal complexes and derivatives) might be destroyed following the leaching process (Adams, 2013), the recycled process water commonly contains some residual cyanide, cyanide derivatives such as cyanate and thiocyanate and metal cyanide complexes such as copper and iron cyanocomplexes, which are known to depress pyrite flotation. Additionally, if

a small amount of free cyanide is present in the process water, floatability of liberated gold is reduced due to the formation of the stable and soluble ion $\text{Au}(\text{CN})_2^-$ (Rees and Van Deventer, 1999; Yin et al., 2011).

Apart from chemical species dissolved in the process water, the grinding media might also affect the grinding environment and thus the floatability of pyrite. The selection of media for grinding of pyrite ores may be dependent on whether or not Cu^{2+} (activator) is added prior to the grinding stage (Peng and Grano, 2010; Chen et al., 2013). Peng and Grano (2010) found that if Cu^{2+} was not added during grinding of pure pyrite, the floatability of this mineral was enhanced when the grinding was conducted with the high chromium media compared to that with the mild steel media. This was probably due to the contamination of pyrite surfaces with hydrophilic iron hydroxide species during the grinding with the mild steel media, which prevented the adsorption of collector on the pyrite surface, rendering this mineral less floatable.

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Greet et al. (2004) also found a beneficial effect of chromium media on the floatability of pyrite from its ores when the grinding was performed in the absence of Cu^{2+} ion.

On the other hand, if Cu^{2+} was added before the grinding of pure pyrite, the floatability of this mineral was higher when the grinding was performed with the mild steel media than with the chromium media (Peng and Grano, 2010; Chen et al., 2013). The reason for this behaviour can be attributed to the less oxidizing environment (200 mV (SHE)) produced during the grinding with the mild steel media, which provides an environment for the activation of the pyrite surfaces through the reduction of Cu^{2+} to Cu^+ . This observation was experimentally confirmed using conventional XPS (Peng et al., 2003). More precisely, it was found that the percentage of adsorbed Cu^+ on pyrite surfaces was 1.5 times higher when grinding of this mineral was performed with the mild steel media than that with the 18% chromium media. In the case of grinding of pure pyrite with the chromium media, Richardson et al. (1996) showed that the oxidising environment (330 mV (SHE)) produced during grinding with this media diminished the adsorption of copper ions on pyrite surfaces and thus significantly reduced the floatability of pyrite.

A comprehensive literature review has identified the following knowledge gaps: (1) There is no study investigating the influence of the grinding environment on floatability of pyrite from its ores when Cu^{2+} is added during grinding; (2) The influence of water quality on flotation performance of pyrite from its ore is rarely available; (3) There is limited information about using of XPS analysis and EDTA extraction method to explain the flotation behaviour of valuable minerals from its ore. For that reason, the objective of this work was to investigate the effect of the type of grinding media (i.e. 18% chromium, ceramic and forged media) and water quality (tap water and synthetic process water) on floatability of gold bearing pyrite and gold recovery using XPS analysis and EDTA extraction technique. The gold ore used in this work was obtained from Kanowna Belle gold mine (Kalgoorlie, Western Australia). This plant has a flotation circuit to recover gold-bearing pyrite and a gravity circuit to recover free gold. In other words, the flotation feed contained gold locked in pyrite and free gold.

2. Materials and methods

2.1. Ore sample

The only valuable mineral was gold-bearing pyrite (2.0%), while major non-valuable minerals were quartz (29.6%), albite (22.9%), muscovite (22.5%), and dolomite (11.6%). The grade of gold in the ore was 5 g/t.

2.2. Water composition

The chemical analysis of the plant process water from the plant ball mill discharge is given in Table 1. High performance liquid chromatography (HPLC) analysis technique was used to determine the concentration of SCN^- , OCN^- and SO_4^{2-} ions while ICP-OES was used to measure the concentration of Ca^{2+} , Mg^{2+} and Cl^- ions. Based on the results of chemical analysis of the plant process water, the synthetic

Table 1
Chemical analysis of the process water from the ball mill discharge.

Species	Concentration (mg/L)
Ca^{2+}	2100
Mg^{2+}	2800
Cl^-	100000
SO_4^{2-}	4340
SCN^-	80
$\text{Fe}(\text{CN})_6^{4-}$	7.38

Table 2
Chemical analysis of the tap water.

Species	Concentration (mg/L)
Manganese	0.0013
Iron	0.0104
Chlorine	0.3
Fluoride	0.85
Total dissolved solids	187

* Total dissolved solids includes other ions such as Ca^{2+} , Na^+ , and Mg^{2+} .

process water was prepared. More precisely, the synthetic process water had 134 mg/l of KSCN, 15 mg/l of $\text{K}_4\text{Fe}(\text{CN})_6 \times 3\text{H}_2\text{O}$, 11,135 mg/l of $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, 665 mg/l of MgCl_2 , 5823 mg/l of CaCl_2 and 150,000 mg/l of NaCl. The experiments were performed using the synthetic process water and the tap water. The chemical analysis of the tap water is given in Table 2.

2.3. Grinding

The feed ore was prepared to obtain a P_{80} of 106 μm by wet grinding with 50% w/w solids in a highly instrumented ball mill, as manufactured by Magotteaux. This ball mill allows better control of Eh, pH, and DO (dissolved oxygen) content by regulating the duration of air and nitrogen purging during grinding of ores (Greet et al., 2004). Three different grinding media were used i.e. the forged media (cast high carbon low alloy steel with high iron content), the chromium media (18% chromium), and the ceramic media.

Given that grinding of ores in the plant ball mill is conducted with the chromium media in the presence of the plant process water and 60 g/t of CuSO_4 as an activator, the calibration of the Magotteaux mill was also performed with the same grinding media in the presence of synthetic process water and 60 g/t of CuSO_4 . The Magotteaux mill was calibrated to match pulp chemical variables of the plant ball mill discharge (pH = 8.0 ± 0.2 ; $E_{h_{\text{SHE}}} = -60 \pm 24$ mV; DO = 2.1 ± 0.5 ppm; Temp = 31°C) by adjusting the nitrogen and air purging times during the grinding. The time for nitrogen purging was 43.5 min while that for air purging was 5.2 min. The duration of nitrogen and air purging was kept constant in all experiments and 60 g/t of CuSO_4 was added prior to the grinding stage.

The pulp chemical measurements of the Magotteaux mill discharge are given in Table 3. As seen in Table 3, the changes from the forged steel media to the high chromium and ceramic media shifted the grinding conditions from strongly reducing to moderately oxidising. The drop in the pulp potential during the grinding with the forged media is ascribed to the galvanic interactions between the forged media and pyrite. Furthermore, the higher galvanic current is correlated to a higher redox reaction rate whereby dissolved oxygen (DO) is more rapidly reduced. For more details about galvanic interactions, the readers are referred to the relevant literature (Rabieh et al., 2016; Bruckard et al., 2011).

Table 3
Chemical measurements of mill discharge (SPW is the synthetic process water and TW is the tap water.)

Water	Media	Mill discharge			
		DO (ppm)	pH	Eh, SHE (mV)	Temp ($^\circ\text{C}$)
TW	Forged steel	0.10	9.10	-241	31.20
SPW	Forged steel	0.30	8.00	-310	32.00
TW	18% Chromium	0.50	9.00	187	32.00
SPW	18% Chromium	0.40	8.10	-70	31.60
TW	Ceramic	0.90	9.20	247	30.80
SPW	Ceramic	0.70	8.00	169	33.10

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