



A review of the effects of grinding media and chemical conditions on the flotation of pyrite in refractory gold operations



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ABSTRACT

Flotation performance of gold-bearing pyrite in refractory gold ores depend upon the interplay among process water chemistry, grinding chemistry, and ore mineralogy. The nature of pyrite itself (finely disseminated reactive pyrite vs. low reactivity) also plays a role in its surface reactivity. This paper reviews the experimental studies examining the interactions between grinding media, gold bearing pyrites and process water occurring during grinding of refractory gold ores and the effect of these interactions on flotation response of pyrite. The literature review reveals that the interactions are highly convoluted. It appears that the galvanic interactions between forged steel media and sulfide minerals ores are particularly significant after grinding of massive sulfide ores. Process water chemistry can also have an amplifying effect, as the process water becomes more laden with cyanide species and other ionic species. This paper should contribute an improved understanding of electrochemical and chemical processes occurring during the grinding of refractory gold ores, which is essential to improve flotation performance of pyrite. Judgement is reserved with regards to the overall economics associated with the use of various grinding media. Media consumption due to wear will have to be balanced against flotation recovery of gold bearing sulfides and whole circuit behaviour where gold in tailing may also be further recovered through leach processes.

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1. Introduction

Selection of grinding media is very important since the consumption of grinding media is one of the major operating costs in mineral processing industry, which can be up to 50% of the overall grinding expenditure (Aldrich, 2013). The consumption of grinding media can be caused by abrasion, impact, and corrosion wear mechanisms. While, abrasion and impact occur due to the mechanical forces, corrosion takes place in wet grinding environments, and depends on many factors such as oxygen content, hardness, chloride and cupric ions, galvanic interactions, and sulfur and sulfate content (Fontana, 1987). It should also be noted that the daughter products generated by these wear mechanisms can contribute to corrosive wear significantly due to their greater surface area.

Apart from the influence on the grinding cost, the choice of grinding media is essential to optimize the flotation response of valuable sulfide minerals. For example, the comprehensive review of the influence of different types of grinding media on flotation of copper sulfide minerals was published by Bruckard et al. (2011). However, in the case of refractory gold ores (i.e. ores in which the gold is hosted mainly in pyrite and/or arsenopyrite), the detailed analysis based on the literature data has not yet been performed. In this context, the main focus of this paper is to review past research concerning with the influence of grinding media on flotation response of pyrite from refractory gold ores.

Although the selection of grinding media is very influential to maximize flotation performance, other factors such as flotation reagents and dosages, aeration, gas dispersion, machine properties, and the use of nitrogen gas during grinding (e.g. as used in the N2Tech technology (Dunne et al., 2009; Simmons et al., 1999)) affect the achieved redox state and the flotation recovery of valuable minerals. The grinding media, ore mineralogy, and process water chemistry is therefore expected to play an important part in flotation recovery. It should be noted that the flotation recovery of valuable minerals can still be manipulated by a range of other factors as well, as discussed below.

As already mentioned above, the scope of this paper covers refractory gold ores which are located in Western Australia (e.g. Wiluna and Granny Smith gold mine), Nevada (e.g. Twin Creeks mine), and South Africa (e.g. Fairview mine). Refractory gold ores are classified as if a cyanidation process cannot recover more than 80% of gold even though fine grinding is used (Guay, 1981). The reason for the refractoriness of gold ores is either because gold is hosted in solid solution, or as colloidal particles, in pyrite and/or arsenopyrite. Therefore, the treatment of refractory gold ores is very complex, and involves numerous unit operations (e.g. gravity and flotation separation, roasting, oxidative leaching, bacterial leaching, neutralization) to render the gold amenable to cyanidation (Iglesias and Carranza, 1994).

The following section reviews the influence of galvanic interactions, which occur during the grinding of particularly refractory

Table 2

Rest potentials (vs. SHE) of mild steel (M.S.), austenitic stainless steel (A.S.S.), and martensitic stainless steels (M.S.S.) (Adam et al., 1984).

Electrolyte	pH	E _{A.S.S.} (V)	E _{M.S.S.} (V)	E _{M.S.} (V)
0.5 M NaCl (air exposed)	6.7	0.088	-0.056	-0.396
Distilled water (N ₂ bubbling)	6.8	0.118	-0.298	-0.516
Distilled water (air exposed)	4.0	0.150	-0.106	-0.374
	6.8	0.206	0.098	-0.336
	10.0	0.010	-0.088	-0.242
Distilled water (O ₂ exposed)	6.6	0.027	0.066	-0.176

gold ores on pulp chemistry and froth stability. This is followed by a review of the effect of flotation reagents and nitrogen gas added during the grinding. Last, the influence of high chrome white iron grinding media and their effect on flotation performance are also briefly reviewed.

2. Effect of ore type and galvanic interactions

Galvanic interactions, occurring between different materials, strongly depend on electrochemical activity of the materials (Rao, 2004). The measure of electrochemical activity of the material is the rest potential which represents the difference between the potential of the selected material and the potential of the reference electrode when the oxidation and reduction current are equal (Rao, 2004). Tables 1 and 2 present the rest potential of various sulfide minerals at pH 4 and a range of steels in a number of aqueous environments, respectively.

When the difference between the rest potential of the sulfide mineral and that of the grinding media is high, the galvanic interactions are more pronounced during the grinding stage due to the large galvanic current. In other words, electrons are transferred from the anode (i.e. grinding media, less cathodic mineral) to the cathode (i.e. cathodic mineral), causing the change of the potential of both materials from their rest potential to the mixed potential due to the tendency to achieve the equilibrium potential (Adam et al., 1984; Martin et al., 1991). As a result, the corrosion of the less cathodic material (low rest potential) increases and the corrosion of the more cathodic material (high rest potential) decreases (Fontana, 1987). Given that pyrite has the highest rest potential, and thus it is the least electrochemically active sulfide mineral, grinding with forged steel grinding media causes the significant galvanic interactions due to the large difference between the rest potential of pyrite and that of the forged steel grinding media (see Tables 1 and 2).

Fig. 1 shows the schematic representation of the galvanic interaction model for the following systems:

- forged steel media-cathodic mineral,
- forged steel media-anodic mineral-cathodic mineral,
- forged steel media-cathodic mineral-cathodic mineral.

The electrochemical reactions which might occur during the galvanic interactions are explained in Section 2.1. It should be noted that a sulfide mineral with a moderate rest potential can act as a cathode or an anode depending on the thermodynamic and kinetic properties of two sulfide minerals and forged steel media, (Pozzo et al., 1988).

However, the understanding of galvanic interactions only tells the small part of the story. When these minerals are considered, it is also important to note that, particularly for gold ores, the mineralogical association, particle grain morphology and the texture of gold ores influence the gold recovery. In most cases gold is associated with or hosted in pyrite. When the aim is gold recovery, either via direct exposure for leaching, liberation for gravity recovery, or

Table 1
Rest potential (vs. SHE) of sulfide minerals at pH 4 (Rao, 2004).

Minerals	E (V)
Molybdenite, MoS ₂	0.11
Stibnite, Sb ₂ S ₃	0.12
Argentite, Ag ₂ S	0.28
Galena, PbS	0.40
Bornite, Cu ₅ FeS ₄	0.42
Covelite, CuS	0.45
Sphalerite, ZnS	0.46
Chalcopyrite, CuFeS ₂	0.56 (anomalous)
Marcasite, (Zn,Fe)S	0.63
Pyrite, FeS ₂	0.66

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