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The effect of non-sulphide gangue minerals on the flotation of sulphide minerals from Carlin-type gold ores

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ABSTRACT

Flotation pre-concentration of sulphide and gold values from certain Carlin-type deposits characterised as double-refractory gold ores is quite challenging. Numerous studies conducted on these ores in many laboratories globally (including the present study) under a variety of chemical and physical conditions have merely confirmed low recovery (and poor concentrate grades) for sulphide minerals and gold, and poor separation between sulphide minerals and carbonaceous matter, even when the valuable minerals are adequately liberated. None of the traditional reasons based on liberation or the choice of chemical and physical conditions and separation strategies could provide satisfactory explanation for the observed poor separation.

In this study, the focus was on the role of non-sulphide gangue (NSG) minerals. It was hypothesised that specific NSG minerals have a detrimental effect on flotation recovery of gold bearing minerals and their separation selectivity. In order to test this hypothesis and delineate the effect of the various gangue minerals, a new approach was taken. This involved first isolating the various mineral components of a double-refractory gold ore from one of the Carlin-type deposits using a gravity separation technique. Then flotation experiments were performed using a mixture design on various mixtures of these isolated components under controlled conditions. The results of these mixture experiments supported the hypothesis and demonstrated, for the first time for these types of ores, that even small amounts of NSG minerals, especially carbonaceous matter and clays, had a large adverse effect on the flotation of sulphides and selectivity of separation. While it is tempting to attribute the observed effects solely to slime coating, there is no basis to do so at this stage; it is more reasonable to propose that multiple contributions exist. The results of this study provide the much-needed context and direction for further fundamental studies and for developing processing strategies.

1. Introduction

With the depletion of high-grade deposits, the minerals industry faces a significant challenge in the efficient processing of low-grade deposits with complex mineralogy. Some Carlin-type deposits present such a challenge. The recovery of gold from these deposits is quite difficult and unsatisfactory. Gold in some of these Carlin-type deposits is characterised as double-refractory gold (Hausen and Bucknam, 1985; Zhou and Cabri, 2004). Two forms of refractoriness exist: (a) much of the gold values, often sub-microscopic, is locked in sulphide minerals (e.g. pyrite, arsenopyrite, and arsenian pyrite) and, therefore, are not amenable to direct leaching with cyanide; pre-concentration of sulphide minerals by flotation followed by either roasting or pressure oxidation is necessary; and (b) the ores contain varying amounts of carbonaceous matter which are known to cause “preg-robbing” in the cyanidation stage and must be removed before cyanidation or rendered innocuous. Numerous flotation pre-concentration studies conducted (Kappes et al., 2009, 2010; Orlich et al., 2009) in many laboratories globally (under a variety of chemical and physical conditions) have indicated low recovery (and poor concentrate grades) for sulphide minerals and gold,

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and poor separation between sulphide minerals and carbonaceous matter, even when the value minerals are adequately liberated. There is currently no satisfactory scientific explanation for the poor recovery and selectivity of separation.

Extensive mineralogical and flotation studies were conducted (Tabatabaei, 2012) on a known double-refractory ore type with the aim of developing an understanding of the root cause of the problem and to evaluate processing options. However, the results indicated that none of the traditional reasons based on liberation or the choice of chemical and physical conditions and separation strategies provided an adequate explanation for the observed poor separation. Several alternative hypotheses were then postulated, and many of them were ruled out based on existing mineralogical data and ore flotation results. One of the hypotheses, hitherto untested, was focused on the potential adverse role of non-sulphide gangue minerals in selective separation and recovery of sulphide minerals. In order to test such a hypothesis, a typical approach (which is practiced widely in mineral processing research) is to conduct fundamental studies with single minerals (e.g. a value sulphide mineral and a gangue mineral assumed to be the source of the problem) using measurement of electrophoretic mobility (and estimate zeta potentials) or contact angles, microflotation, and a variety of spectroscopic techniques. Several studies have been conducted in the past on potential problem gangue minerals such as clays, serpentines and so on (Edwards et al., 1980; Firth and Nicol, 1981; Warren, 1984; Arnold and Aplan, 1986a, 1986b; Bremmell et al., 2005). The single minerals selected for the studies are samples obtained from mineral suppliers from a variety of geographic locations rather than the indigenous sample from the ore itself. In such studies, conducted under idealised conditions and minerals in isolation, the important complex interactions between the various indigenous components of the ore and their effects on metallurgical performance are missing. Often, there is no rational basis to identify (or label) one or more gangue minerals to be responsible for the adverse effect (in other words, the selection is often arbitrary).

In this study, a new approach was taken to test the hypothesis regarding the adverse effect of NSG on flotation of sulphide minerals. This involved conducting studies using mineral components isolated from the ore itself. Thus, sulphides and NSG minerals were isolated from the double-refractory gold ore using gravity separation (i.e. isolate minerals without the use of chemicals) and then conducting flotation experiments using mixture designs to investigate the effect of one of more of the NSG minerals on flotation of sulphide minerals (and gold values). Such an approach has the following important advantages: (a) allows working with the real ore system and using indigenous components of the ore (rather than high-grade single minerals purchased from other sources); (b) eliminates the need to arbitrarily assume a particular mechanism by which such adverse effects manifest or that a particular gangue mineral is responsible (i.e. there is no pre-conceived notion, conclusion, or bias); and (c) provides a rational basis and a context to conduct fundamental studies.

2. Experimental

2.1. Materials

A double-refractory gold ore from one of the Carlin-type deposits was used in the test work. To minimise oxidation effects, the ore sample (<30 cm, as received from the mine site) was stored in a freezer. Previous confidential reports and cursory mineralogical characterisation studies on this ore indicated that the gold occurred as sub-microscopic grains (i.e., solid solution and colloidal form) associated with fine-grained sulphide minerals (pyrite, arsenopyrite and arsenian pyrite[1]). These studies concluded that in order to maximise gold recovery from this ore, it was necessary to improve the recovery of the sulphide minerals. Extensive mineralogical studies were conducted as part of this study (Tabatabaei, 2012) in order to establish separation potential from this ore and to guide processing strategies.

Mineralogical characterisation of the ore using the Mineral Liberation Analyser (MLA) – a mineralogical characterisation system based on automated scanning electron microscopy – identified 20 different minerals in the ore, but to simplify data processing for discussion purposes the modal mineralogy was grouped as shown in Fig. 1. Also MLA analysis indicated that sulphide minerals in the ore were fine-grained, and to achieve an adequate degree of liberation the ore should be ground to a P80 of 20 μm.

Flotation reagents were supplied by Cytec Industries Inc. This included collector Cytec S-10294 and a frother blend containing 75% methyl isobutyl carbonyl (MIBC) and 25% Cytec X133 (both reagents were selected based on prior ore flotation work conducted by Cytec). Sulphuric acid was also used as pH modifier.

2.2. Methods

2.2.1. Preparation of the ore sample

The bulk ore sample was stage-crushed to 100% minus 2 mm. The crushed sample was mixed thoroughly, split into 1 kg samples using a rotary splitter, and stored in a freezer.

2.2.2. Fine grinding using a combination of conventional grinding and IsaMill™

For each test, 1 kg of ore was ground in a mild steel laboratory rod mill, with a charge of 20 kg, 26 mild steel rods, at a solids concentration of 60% by weight for 20 min to achieve a P80 of 150 μm.

A laboratory-scale M4 IsaMill™ (Xstrata Technology) was used for finer grinding to achieve a P80 of 20 μm. The product of the rod mill with a P80 of 150 μm was used as feed for the IsaMill™. The IsaMill™ was operated at slurry density of 30% solids by weight and speed of 1600 rpm. The grinding media were ceramic beads of 2.5 mm with a volume of 2.5 L (approximately 6 kg). Brisbane tap water was used in all stages.

2.2.3. Separating various mineral components from the ore using Mozley separator

Several techniques were evaluated in order to isolate the major mineral components from the ore. The laboratory-scale Mozley separator was found to be the best and the most efficient in terms of sharpness of separation and integrity of the minerals (no chemicals are used). In the Mozley separator, particles are separated based on their specific gravity. Given that the specific gravity of the sulphide minerals is quite different from that of carbonaceous matter and clays, they can be separated using this technique. Details can be found in Cordingley et al. (1994) and Wills and Napier-Munn (2006). In the present study, because the particle size was quite fine, only the flat deck profile was used. The flat profile oscillates horizontally to separate particles. An even film of water is provided over the entire tray surface by irrigation pipes around the circumference and the flow is controlled by the flow meter. In this separator, high density particles sink to the tray surface and are retained, and low density particles are carried down the tray by the flow of irrigation water to the discharge via the launder.

The flow sheet used for effective separation of mineral components of the ore is shown in Fig. 2. For each experiment, approximately 50–100 g of ore with a P80 of 20 μm was placed at the

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[1] Arsenic rich pyrite commonly referred to "arsenian pyrite" contains ppm to weight-percent amount of arsenic and smaller but important amount of gold (Huston et al., 1992; Reich et al., 2005).