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Improving high voltage pulse selective breakage for ore pre-concentration using a multiple-particle treatment method

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ABSTRACT

High Voltage Pulse (HVP) comminution has the potential to be used in ore pre-concentration. Mineralisation after HVP breakage is concentrated into the finer sizes and size separation can then be used to produce high and low grade ore streams. Previous work on this technique has been performed using a single particle (SP) testing method where HVP energy is applied to every single particle. This paper presents an improved method where HVP is applied to multiple particles (MP). The MP method gives HVP the "freedom" to differentiate between particles and selectively only break those containing mineralisation. The MP method is shown to result in better mineralisation deportment into the finer sizes, at a lower specific energy, than the SP method of HVP application. This enables higher metal recovery and waste rejection rates during ore pre-concentration. HVP MP breakage consumes more energy but generates a better ore pre-concentration result than mechanical breakage. The ways to further enhance HVP selective breakage using the MP method are discussed.

1. Introduction

Falling ore head grades, soaring energy costs, coupled with shrinking access to resources are making it increasingly expensive to produce metal from ore using conventional methods (Lessard et al., 2014). The hard rock mining operations, in particular, are now performed on low profit margins and some may be forced to shut down in the near future. It has, therefore, become strategically imperative for mineral engineers and researchers to develop new beneficiation methods which reduce energy use, increase throughput and improve mineral separability to lower costs and improve revenue. Ore pre-concentration has the potential to make a step change in terms of operating costs and product output by separating valuable mineral from gangue-waste minerals prior to conventional processing (Bearman, 2013; Burns and Grimes, 1986; Lessard et al., 2015; Napier-Munn, 2015; Salter and Wyatt, 1991; Sivamohan and Forssberg, 1991; Wyman, 1985). This pre-concentration separation is achieved by exploiting differences in the physical and chemical properties of minerals such as size, gravity, magnetic susceptibility, radioactivity, thermal reactivity, conductivity, optical properties and solubility.

While a variety of ore pre-concentration methods have been explored over the years, the application of high voltage pulses (HVP) as an identification technique to discriminate particles was only recently discovered and studied at the Julius Kruttschnitt Mineral Research Centre (JKMRC). The technique involves applying a controlled pulse energy to an ore sample to induce mineral selective breakage, followed by size-based screening to separate an ore into high grade and low grade components (Shi et al., 2015; Zuo et al., 2015). It was postulated that a critical energy can be found which is just enough to detect the existence of metalliferous grains inside a particle and disintegrate the particle by the metalliferous grain-induced breakdown channel. If the particle is a barren rock containing no metalliferous grains, the particle is unlikely to be broken subjected to the same pulse energy. In this regard, the electrical pulses treated particles will exhibit a difference in product size, and a size based separation method can then be implemented to separate the particles by grade.

The initial studies of ore pre-concentration using HVP were performed by breaking particles one at a time, which in this paper will be referred to as a single particle (SP), single pulse method. This method was originally developed for HVP pre-weakening of ores (Shi et al., 2013). Using the SP method, the pulse energy is equally delivered to every single particle, thus maximising the overall weakening result. It is argued, however, that HVP pre-concentration may be more efficiently applied when multiple particles are present. In this mode, the pulse energy should be attracted and preferentially go to the particles that contain high conductivity/permittivity minerals and leave the barren particles unbroken, thus resulting in better concentration of mineralisation into the finer sizes and an improved energy efficiency of the

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process. This article presents results of detailed investigations that were undertaken to investigate the efficiency of HVP selective disintegration for ore pre-concentration when multiple particles (MP) are present during HVP treatment. Results of these experiments are compared to that of the single particle (SP) HVP tests as well as conventional breakage tests to evaluate the degree of pre-concentration that is achieved with the different breakage methods. In addition, the overall energy transfer efficiency is also investigated for the MP and SP methods.

2. Experimental

2.1. Material

Four ore samples were tested in this study. Ores 1–3 were collected from a copper-gold mine operation in Australia. The minerals were predominantly veined, but in some particles both veined and disseminated minerals coexisted. The major valuable minerals comprised native gold, pyrite, chalcopyrite and bornite. The three ore samples were collected from different locations on different dates. Ore 1 was a ROM ore sample collected before the stockpile, Ore 2 was the SAG mill feed from one of the two underground mines, and Ore 3 was SAG mill pebbles collected from the milling circuit. Ore 4 was collected from an iron oxide-copper deposit from South American. The dominant sulphides were chalcopyrite with subsidiary siegenite and millerite and minor pyrrhotite and pyrite, and they were predominantly hosted by intrusive vein-like structures. It should be noted that the sample also contains a significant amount of magnetite.

All four samples are highly resistant to mechanical breakage as is evident by their very low A × b values (32.8, 33.3, 31.0 and 39.3 for the four ore samples respectively) measured in JK rotary breakage tests (JKRBT, Shi et al., 2009). Note that the smaller the A × b values, the more competent the ore and the more resistant to breakage (Napier-Munn et al., 1996). The inherently low A × b values make the samples "perfect candidates" for HVP treatment as they will be associated with high energy consumption when being processed by conventional mechanical crushing and grinding methods.

2.2. Experimental apparatus

2.2.1. HVP experiments performed using a selFrag Lab unit

The fragmentation of ore samples by electrical discharge was carried out using a selFrag Lab installed at the JKMRC. The unit was manufactured by SELFRAG AG, Switzerland. The major components of this unit include a high voltage (HV) power supply, HV pulse generator, discharge electrode and a portable processing vessel (see Fig. 1). The processing vessel includes an interchangeable sieve bottom, which also serves as the ground electrode (cathode). The sieve can be closed (without aperture), or with various apertures. In this study, both the SP and the MP tests are carried out using the selFrag unit with different types of sieve in the processing vessel. Detailed descriptions about the two methods are described in the following sections.

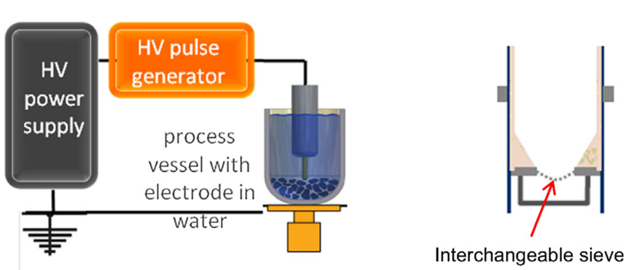

Fig. 1. Schematic illustration of the three major components of selFrag Lab unit (Shi et al., 2012) and the processing vessel with interchangeable sieve bottom (Wang et al., 2011).

2.2.2. The SP test method

The closed configuration which utilises a solid closed bottom electrode in the processing vessel was employed in the SP tests. Each test involved placing a single particle in the processing vessel such that it was centred below the top electrode. Then, a single pulse was delivered to the particle. After that, whole progenies from the HVP treatment were removed from the vessel and later sized and assayed. For each single particle tested, fresh deionised water was used. The specific energy input for the SP tests was changed by adjusting the applied pulse voltage. The actual spark energy used can be recorded and displayed in the control panel of the selFrag unit. The procedures to treat one particle at a time were repeated until the required number of particles were completed, typically more than 30 particles per test.

The objective of the SP tests is to deliver the similar amount of energy into every single particle. The water gap between the electrode and the particle has been shown experimentally to play a vital role on the percentage of energy transferred to a particle during HVP application (Araki et al., 2009). Because the particles in a same size fraction vary in height from one to another due to particle shape variation, the energy delivered to each particle in the same size fraction may be different in SP tests with a fixed gap between the anodic and cathodic electrodes. This was substantiated by measuring the smallest axis of over 360 particles from four size fractions. Taking particles from 37.5 to 45 mm for example, 86 particles were chosen, and the length of the smallest axis measured for each particle is presented in Fig. 2 in a histogram form.

The spread in this measurement was considered significant and therefore there would be a varying water gap between the particle and the top electrode if a fixed gap between the top and bottom electrodes was employed. A large water gap would cause the pulsed energy lost in water to create shockwave (a mechanism called the electrohydraulic breakage, which is not as energy efficient as the electrodynamic breakage that takes place when the water gap is minimal). To deliver a similar pulse energy to every single particle, all SP tests in this study were conducted by setting the electrode gap to be close to the length of the short particle axis. Note that in this circumstance the SP tests were assumed to be conducted at an optimal condition that can reduce the pulse energy loss in water gap.

2.2.3. The MP test method

In contrast to the SP tests, a processing vessel with an aperture of 8 mm (round holes) sieve bottom was employed (Fig. 1) so that fine fragments would fall through the apertures and leave the pulse treatment zone. These fine fragments often contain high conductivity/permittivity minerals that would preferentially attract the pulse energy in the subsequent pulse discharge used for the multiple particles, multiple pulses tests. This was different to the SP test in which only one pulse

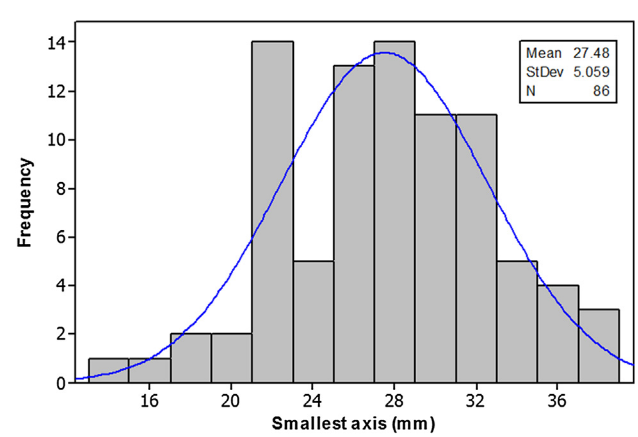

Fig. 2. Histogram of the length of the smallest axis for 86 particles in the 37.5–45 mm size fraction.