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A method to determine the minimum quantity of ore sample required for laboratory scale study of ore pre-concentration by high voltage pulses

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ABSTRACT

High voltage pulse (HVP) selective breakage followed by screen separation has been shown to have the potential to be used for ore pre-concentration. The effectiveness of HVP enhanced pre-concentration is determined by experimentation. It is important when performing these tests, that the minimum quantity of ore sample required to achieve a statistically consistent HVP pre-concentration result is used. In this study, multiple repeat HVP pre-concentration tests were carried out using three different Cu-Au samples and statistical analysis of datasets created by resampling of real data was then performed. The results demonstrate that the minimum sample size required to achieve a statistically consistent result is ore-dependent, and should be determined for every ore sample prior to HVP pre-concentration characterisation. To evaluate the sensitivity of HVP performance to the variation in sample size, a Sensitivity Index (***SI***) has been introduced and a mathematical description of the Sensitivity Index is presented in this paper.

1. Introduction

The feasibility of high voltage pulse (HVP) techniques for ore disintegration in the mineral industry has been intensively studied in the past 50 years. However, it has been noticed that the literature often reports HVP testing results using a small number of ore samples, due to the difficulty to process a large number of particles in a batch testing mode using a laboratory scale HVP device. Questions may arise regarding the representativity of the reported HVP experimental results. A literature search indicates that it lacks detailed study of the minimum ore sample required to obtain consistent HVP testing results.

Gy's sampling theory is well accepted for determining the minimum amount of sample required to generate a representative product. Barbery (1972) derived an expression of sampling for size analysis based on Gy's theory:

$$M = \frac{f \cdot \rho \cdot d^3}{\sigma_{FE}^2 \cdot P} \quad (1)$$

where M is a mass of sample required (g), f is shape factor for material ($0 < f < 1$), ρ is the density of the material (g/cm^3), d is mean particle size (cm), δ_{FE}^2 is the variance of the fundamental error, and P is the expected proportion of material in the size range of interest. Note that the maximal acceptable fundamental error for technical sampling and processing requires a relative standard deviation smaller than 5% (Pitard, 1993). Napier-Munn et al. (1996) present an example of sampling SAG mill trammel oversize stream to determine its size distribution using the Barbery's expression (Eq. (1)). For 10% lying in the screen size range of 25–50 mm, a sample mass 99 kg is required to be screened to ensure 90% confidence of determining this proportion to a relative precision of 20% (i.e. P = 10 ± 2%). It is emphasized that this sample mass is used only for size analysis.

For base metal or precious metal content determination such as Cu or Au grades, the required sample mass is amplified as the grade factor is also incorporated in the calculation (Pitard, 1993). The sample mass required to give a representative precious metal content is given by Eq. (2)

$$M = Cd^3 \quad (2)$$

where C is a function of gangue particle and precious metal properties (density, shape and grade). The form of C varies depending on the mineralogy of the precious metal (liberated, not liberated, associated with other minerals etc.). In general, a feed mass in the magnitude of one (1) ton will be needed for Cu content determination and even more for Au.

In HVP breakage, however, obtaining a representative feed is not only dependent on particle size, sample mass and head grade but also dependent on mechanical breakage properties and dielectric properties of particles. It is an established fact that even for nominally identical, or very similar particles, there exist wide variations in their fracture

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strength due to the differences in flaws and mineral texture (Kapur et al., 1997). Considering the current laboratory system fragmentation device can only process a few hundred grams of feed each time, it becomes clear that it is infeasible to process a large amount of feed and better methods need to be developed for determining the minimum quantity of ore sample required for laboratory scale study of ore pre-concentration by high voltage pulses.

The effect of ore properties on HVP testing result is compounded by the ways to utilise HVP energy to break the ore sample. In the previous studies, ore samples were repeatedly subjected to HVP discharge loading using approximately 100 kWh/t HVP specific energy to liberate minerals along the boundaries of minerals with different permittivity values (Andres et al., 2001). In this type of HVP liberation, the metal distributions by size were assumed to be relatively consistent, since all particles in the feed have been pulverised into a micron size range. Recently, research conducted by the Julius Kruttschnitt Mineral Research Centre (JKMRC) shows that HVP can use less than 10 kWh/t specific energy to selectively break mineralised particles from barren rocks. This selective breakage between particles would result in the high-grade minerals being broken into finer particle size fractions, whilst the low-grade particles retaining on coarse particle size fractions. Thus HVP selective breakage followed by size-based screening separation enables the feed ore to be split into high-grade and low-grade products (Shi et al., 2015; Zuo et al., 2015). In this type of HVP breakage, the product is much coarser than the aforementioned high energy HVP liberation, and the grade by size distribution is more sensitive to the feed particle representativity.

In the HVP pre-concentration experiment, the number of particles required for testing has been based purely on borrowed experimental procedures from mechanical rock breakage characterisation tests such as the Drop Weight Tester (DWT) and the Rotary Breakage Tester (JKRBT). For example, in a standard JKRBT test, 30 particles are customarily used per size-energy to determine t_{10} values. This was the number of particles used in the previous single-particle, single pulse (SP) pre-concentration tests presented by Zuo et al. (2015). In this work, HVP was shown to result in only surface breakage of barren rock whilst particles containing mineralisation exhibited extensive body breakage. Duplicate tests performed for one of the four ore types tested showed similar body breakage rates (61.4% and 60.9%), as well as similar Cu grade of the surface breakage product (0.109% and 0.104%) using the SP method. It was concluded that the use of 30 particles was sufficient to overcome variations in the mechanical and electrical properties of the particles in the ore sample and produce a consistent result (Shi et al., 2015; Zuo et al., 2015).

In subsequent multiple-particle, multiple-pulse (MP) tests performed by Huang and Shi (2018), 40 particles were tested to determine the ore pre-concentration result. Several repeated tests using the same number of particles (40) with exactly the same HVP conditions were conducted to estimate the experimental errors. It was found that significant variations in the ore pre-concentration results existed. Forty particles per test proved insufficient to generate a consistent result for this ore. This raised the question: What is the minimum quantity of ore required to achieve a statistically consistent HVP pre-concentration result? To answer this question a detailed study was carried out, and the major outcomes are presented in this paper.

2. Experimental

2.1. Materials

A total of three different ores from three different mines were used in this study. It is known from previous research that coarse waste rejection is not feasible for ore samples with high head grades. As a result, all three samples selected were of relatively low head grades, the primary commodities being all gold and copper, with the Cu content varying between 0.1 and 0.3%, and Au grades no more than a few ppm. Moreover, it was considered that an extremely low Au grade is apt to result in a much wider variation in the performance indices related to grade. In this regard, Cu was used as the valuable metal in this study.

All three samples received from the mines were assumed to be not homogeneous, and therefore the content of each individual drum was mixed, dried and screened using a Gilson screen. Each individual size fraction was then divided with an 8-segment rotary splitter to ensure homogenization of samples. Ore A and Ore B were collected from a Cu-Au mine operation in New South Wales, Australia. Ore A was SAG mill pebbles collected from a low-grade ore concentrator whereas Ore B was the SAG mill feed. The valuable minerals in both ore samples consisted of native gold, chalcopyrite and bornite, with some magnetite. These minerals were predominantly veined but were also disseminated. Ore C was a ROM sample collected from a Cu-Au operation located in New South Wales, Australia.

2.2. HVP breakage

The HVP breakage experiments were carried out using a selFrag Lab unit installed at the JKMRC. The machine configuration has been described elsewhere (Wang et al., 2011). A single layer of particles was placed in the processing chamber covering the ground electrode as this had previously been shown to provide the best pre-concentration results, presumably because it results in less unwanted damage of barren rocks.

Feed particles from a selected size fraction were randomly chosen for each experiment. Electrical gap and pulse rate were kept constant at 40 mm and one (1) Hz respectively. The selective fragmentation process was performed in batches, with each batch of particles subjected to a fixed number of pulses through a series of cycles. At the end of each cycle, the progeny particles were screened and only the screen oversize product returned to the processing chamber. The above process was then repeated. Particles in the processing chamber were immersed in de-mineralised water with the water refreshed prior to every new cycle. The experimental settings are summarised in Table 1.

2.3. Hand-held XRF assay

On completion of a HVP test, the product was sized and the size fractions pulverised. Copper content in the sized products was measured using a portable XRF Analyser (Model Thermo Scientific Niton™ XL3t GOLDD+, Fig. 1). This device contains an X-ray tube, which, when the device is operating, emits X-rays. During sample measurement, these X-rays are used as an external energy source to excite individual atoms within the sample, which then emit X-ray photons of a characteristic energy or wavelength. By counting the number of photons of each energy emitted from a sample, the elements present may be identified and quantified. At the beginning of each use, the XRF analyser was calibrated using the detector auto-calibration procedure.

The pulverised sample was placed in the XRF sample cup to perform the measurement. In order to compare and calibrate the hand-held XRF measurements, 36 samples were analysed using the hand-held XRF and then also submitted for chemical assays by a commercial laboratory, ALS. A comparison between the Cu grade measured by the hand-held XRF and that measured by ALS are given in Fig. 2.

Table 1
Experimental settings for HVP breakage tests.

Ore sample	Ore A	Ore B	Ore C
Feed size (mm)	22.4–26.5	22.4–26.5	22.4–26.5
Number of particles per batch	10 ± 1	10 ± 1	10 ± 1
Recycle screen size (mm)	16	19	19
Number of pulses per cycle	3	2	2
Number of cycles	4	4	4
Applied voltage (kV)	170	170	170