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The effect of breakage energies on the mineral liberation properties of ores

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ABSTRACT

A number of previous researchers have noticed that the degree of mineral liberation in a given size fraction is the same regardless of where in a comminution circuit a sample is collected. This behaviour has been observed for a range of ore types, and was found to be independent of the mode of breakage. This provides a useful heuristic for modelling the particle characteristics in mineral comminution and separation circuits. However, the published research does not explicitly consider the effect on the liberation behaviour of minerals of the amount of energy applied to break the ore. In this study, a gold-bearing pyrite ore and a copper sulphide ore were comminuted over a wide range of energy levels, using impact breakage. The liberation properties of the product particles were characterised using a Mineral Liberation Analyser (MLA). It was found that that the amount of impact energy applied did not significantly affect the degree of liberation of the minerals in a given size fraction, measured using particle sections. This provides sound experimental evidence to support the heuristic model.

1. Introduction

In an integrated mineral processing simulator, a mineral liberation model serves as a link between comminution and separation models by generating particle composition data for the comminution products, which is passed into the subsequent separation models. Various mineral liberation models for comminution have been developed over the years, starting with the early work of Gaudin (1939), but no standard model has been widely accepted because of the complexity of modelling how rock breaks and liberates during comminution. Many of the mineral liberation models for comminution described in the literature assume random breakage, which simplifies the mathematics considerably. However, it has been recognised that there is some degree of non-random breakage in ores (Laslett et al., 1990; King and Schneider, 1998; Evans et al., 2013; King 2012) which means that the usefulness of models based on random breakage is limited. Non-random breakage can occur through a number of mechanisms and a review of the definitions of random and non-random breakage in mineral liberation presented in the literature was conducted by Mariano et al. (2016).

On the other hand, observations have been made on liberation in comminution which can be helpful for modelling the particle characteristics in mineral comminution and separation circuits. Specifically, a number of researchers (Bérubé and Marchand, 1984; Manlapig et al., 1985; Wightman et al., 2008; Vizcarra, 2010) have observed that the degree of liberation in a given size fraction is the same regardless of where in the comminution circuit a sample is collected. This heuristic model (or 'rule of thumb') can be a useful alternative for modelling liberation in comminution while researchers continue to work on fundamental models.

Bérubé and Marchand (1984) noted that for particle sizes less than 210 µm, both the degree of liberation and the particle grade distributions in a given size fraction were constant for an ore subjected to different modes and degrees of crushing and grinding. This observation did not hold for particles coarser than 210 µm. The study was conducted with an iron ore sample from Newfoundland (Canada) containing hematite, magnetite and quartz subjected to different comminution processes (jaw crushing, roll crushing and ball milling). An areal image analyser was used to measure the degree of liberation observed in each product size fraction.

Similar results were obtained by Manlapig et al. (1985), who analysed samples from different grinding circuits in the Lead/Zinc Concentrator of Mount Isa Mines Limited. Samples from the primary and secondary circuits were measured using QEM*SEM to understand the liberation of the major minerals of the ore during comminution. It was found that the amount of liberation of galena in a specific size fraction (0.014–0.027 mm) was unchanged under different grinding conditions.

Wightman et al. (2008) observed that the particle composition distribution of a given size fraction in a comminution circuit was constant for the mineral, irrespective of whether the ore had been crushed, ground or subjected to impact or compressive breakage, and regardless of the overall size distribution of the comminution product. Three ore samples were used in the experiment: two copper porphyry ores, with

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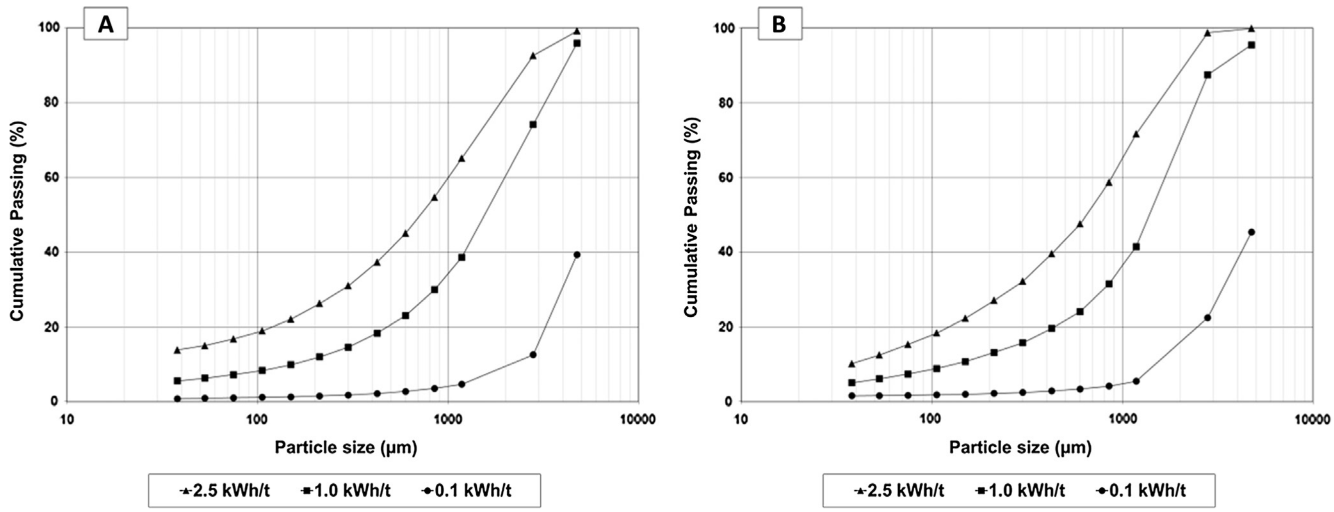

Fig. 1. Particle size distributions for (A) gold-bearing pyrite ore and (B) copper sulphide ore comminuted using the JK-RBT at different breakage energies (i.e. 0.1, 1.0 and 2.5 kWh/t).

Table 1
Number of product particles measured in MLA for the gold-bearing pyrite ore, by size fraction.

Size fraction	Number of product particles measured			Number of polished blocks measured for each energy level
	2.5 kWh/t	1.0 kWh/t	0.1 kWh/t	
− 2.8 + 1.18 mm	804	603	642	6
− 1.18 mm + 850 µm	1482	1505	1244	4
− 850 + 600 µm	5966	4616	5360	4
− 600 + 425 µm	16,283	13,267	13,595	4
− 425 + 300 µm	13,745	16,894	14,309	2
− 300 + 212 µm	13,180	13,981	16,337	1
− 212 + 150 µm	24,114	17,926	16,086	1
− 150 + 106 µm	10,406	15,163	11,737	1
− 106 + 75 µm	13,004	14,015	13,196	1
− 75 + 53 µm	15,154	14,029	13,486	1
-53 + 38 µm	15,918	14,858	4893	1
− 38 µm	20,306	20,764	6347	1

Table 2
Number of product particles measured in MLA for the copper sulphide ore, by size fraction.

Size fraction	Number of product particles measured			Number of polished blocks measured for each energy level
	2.5 kWh/t	1.0 kWh/t	0.1 kWh/t	
− 2.8 + 1.18 mm	871	663	610	6
− 1.18 mm + 850 µm	1992	1284	1695	5
− 850 + 600 µm	4555	5053	2339	4
− 600 + 425 µm	8513	9803	3051	3
− 425 + 300 µm	12,774	18,784	5829	2
− 300 + 212 µm	11,634	19,897	7157	2
− 212 + 150 µm	17,847	17,504	17,446	2
− 150 + 106 µm	18,806	14,184	21,936	1
− 106 + 75 µm	12,782	15,481	21,376	1
− 75 + 53 µm	15,071	16,288	21,143	1
− 53 + 38 µm	21,446	17,003	20,820	1
− 38 µm	21,284	20,789	21,192	1

chalcopyrite and bornite as the dominant copper minerals, and a silver-lead-zinc ore. After the samples were crushed, further size reduction was conducted using the following laboratory scale comminution equipment: rod mill (impact and abrasive breakage), hammer mill (impact breakage), or piston-and-die (compressive breakage). The product particles were submitted for mineralogical analysis in polished sections using the JKMRC Mineral Liberation Analyser (MLA).

The most recent investigation in this area of research was conducted by Vizcarra (2010), who concluded that for both valuable and non-valuable mineral phases, the size-by-size liberation properties of particles were independent of the breakage method used to produce them. In addition, the degree to which a sample was comminuted was found to have no effect upon the size-by-size liberation properties of each mineral phase. These results were obtained using ores of different compositions and textures, from Northparkes, Ernest Henry and Century Mines, which were comminuted to various particle size distribution using both impact and compression breakage (particle bed breakage), in a hammer mill and piston-and-die compression unit, respectively. Size-by-size liberation measurements were conducted using an FEI MLA automated mineralogy system.

These investigations suggest that the degree of mineral liberation, or more specifically the particle composition distribution, in a given particle size fraction is the same anywhere in a comminution circuit, irrespective of the ore type and mode of breakage. The heuristic model appears to be robust and applicable to a wide range of cases, providing a useful link between comminution and separation models in mineral processing simulation. However, none of the previously published research considered separately and explicitly the effect of using different amounts of breakage energies on the liberation behaviour of minerals.

The research described here investigates the effect of different energy levels on the liberation behaviour of minerals in two ore samples, and tests the heuristic model described above. Impact breakage was used as it is one of the major modes of breakage in comminution devices.

2. Experimental

2.1. Sample preparation

The two ore samples used in this study were a gold-bearing pyrite ore and a copper sulphide ore. Both samples were obtained during full plant surveys from the conveyor belts feeding the respective SAG mills. The gold-bearing pyrite ore was stage crushed to 100% passing 6.7 mm, and the − 6.7 + 4.75 mm size fraction was taken to represent the