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Characterization of the industrial flotation process based on size-liberation relationships

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ABSTRACT

A methodology to characterize the mineral feed to the flotation process by liberation and particle size was proposed. This methodology considers a modification of the classical Gaudin liberation model, incorporating a grain size distribution for the mineral in the ore deposit. The results from a previous study were analyzed to test and validate the new methodology. The characterization of the mineral was successfully reproduced by liberation and particle size.

At an industrial scale, a mineral in the rougher circuit feed of a copper flotation concentrator was characterized by liberation and particle size, applying the proposed methodology. From the above results, along with the overall recovery and top of froth (TOF) grade profiles, the characterization of the collection rate along the rougher circuit was performed. The rate constants and maximum recoveries were estimated by liberation and particle size. The results allowed the estimation of the mineral recovery profiles along the rougher flotation bank both by liberation and particle size classes.

1. Introduction

The mineral liberation is a critical factor that drives the particle-bubble aggregate formation and mineral collection during the flotation process. The degree of liberation, as defined by Gaudin (1939), represents the fraction of pure mineral particles that have been physically separated after the grinding process.

To estimate the degree of mineral liberation, Gaudin (1939) developed a practical model based on the cubic fracture of an ore matrix consisting of homogeneous cubic grains of two randomly distributed minerals. This approach allowed the identification of a single liberation coefficient per particle size class after grinding.

The standard size classes used to characterize the particle size distribution (e.g., Taylor mesh) allow a wide range of particle sizes per size class, where the upper particle volume can be 2.8 times larger than the lower particle volume (Kelly and Spottiswood, 1982). Experimentally, it has been found that the mineral liberation in each size class is not unique but is also a distribution function (Welsby et al., 2010). For this reason, the characterization of the mineral feed in terms of size-by-liberation becomes relevant, to understand the flotation process along the industrial flotation rows.

Another relevant aspect is the link between the flotation feed liberation after grinding and the ore properties, particularly the grain size of the valuable mineral from different geological units in the ore. In this paper, to relate the ore characteristics and the flotation feed after grinding, in terms of size-by-liberation, a modified (generalized) Gaudin's model that considers an expected grain size distribution of valuable mineral in the ore will be considered, which is a simple and more realistic representation.

It is also important to notice that the particle-bubble aggregate formation does not require that particles be fully liberated. In a practical sense, a large number of particles consisting of associated minerals, where even a small fraction of the surface belongs to a floatable mineral, can be recovered by flotation. In this case, the fraction of the particle surface with exposed floatable minerals represents the percentage of mineral liberation (e.g., in two dimensions) for each particle size class.

It has been reported in the literature that coarse and multiphase particles (850 × 500 μm) with more than a 1.5% exposed grain surface area were collected by true flotation in a fluidized bed flotation with low energy dissipation without the presence of strong turbulence caused by a rotor (Miller et al., 2016). In this experimental work, the average grain surface area exposed was approximately 19%. Sutherland (1989) reported that the rate of flotation increased with the degree of liberation, but flotation was significant even at very low levels of liberation ($< 10\%$). The work consisted of an experimental

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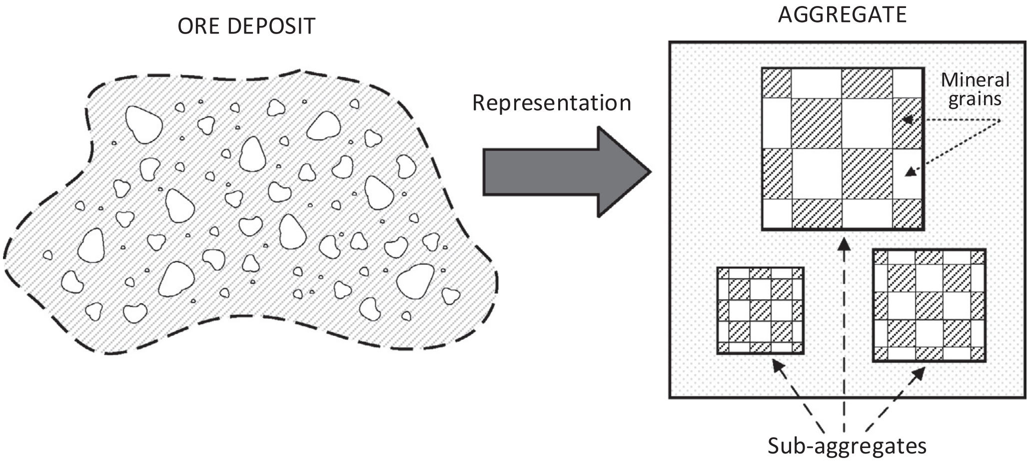

Fig. 1. Representation of the original ore as an aggregate, which consists of a population of sub-aggregates.

characterization of the batch flotation process, where the flotation response was defined for each size fraction and liberation class. These results are in agreement with data reported from industrial mechanical cells on top of froth (TOF) grades along the rougher flotation banks (Yianatos et al., 2014). The TOF measurement is described elsewhere (Yianatos et al., 2016). where the minerals collected by true flotation in the last cell reach a maximum grade of approximately 3–4% Cu. Otherwise, a 10–12% mineral grade (mainly chalcopyrite) in a particle size range of 150–300 µm, can be attributed to an approximate 10–12% surface coverage (assuming entrainment was not significant). This surface coverage is slightly lower than the one observed in the fluidized bed flotation, which has no agitation (Jameson and Emer, 2017; Kohmuench et al., 2017). Recently, Farrokhpay and Fornasiero (2017) reported the experimental testing of an artificial mineral composite, consisting of quartz in a lead borate matrix. In this study, an evaluation of the size by liberation class effects as well as the hydrophobicity effects on the flotation of coarse particles was performed. The results showed that the flotation of composite particles decreases with increasing particle size and decreasing liberation class (quartz) or the degree of hydrophobicity of the floatable mineral. Additionally, they found that the probability of attachment between the hydrophobic phase and bubbles was enhanced as the size of the hydrophobic phase decreases for the same liberation class.

Note that despite the lower grade of the collected particles the collection process is still highly efficient in terms of selectivity. For example, the average feed grade to the last cell was 0.06% Cu, while the enrichment ratio was higher than 30, which is similar to the first cell.

Currently, various techniques are available for the mineral feed characterization by size class and liberation, particularly by two-dimensional analysis (exposed surface area grade). These methods include the quantitative electron mineralogical scanner, QEMSCAN, and the mineral liberation analyzer, MLA (Gu, 2003; Pascoe et al., 2007; Lastra, 2007). Additionally, three-dimensional analysis (X-ray microtomography) has been reported by Andrusievich et al. (2016); Miller et al., (2016) and Lin and Miller (2002).

2. Methodology

A methodology to characterize the minerals fed to the flotation process by liberation and particle size is proposed. This methodology allows the calculation of the mineral mass distribution in the feed to the flotation row. Then, from this approach, it is possible to characterize the collection recovery by particle size and liberation in flotation cells.

2.1. Characterization of the flotation feed by particle size and liberation

2.1.1. Modified Gaudin Liberation Model (MGL Model)

In this section, a new methodology for the mineral characterization of the flotation process feed based on particle size and liberation is proposed. The procedure consists of a modification of Gaudin's liberation model (Gaudin, 1939), where the assumption of uniform size mineral grains in the ore, as stated by the conventional Gaudin's model, was replaced by a grain size distribution.

When a uniform grain size and a constant mineral grade are considered for the original ore, the application of Gaudin's liberation model allows the identification of a single average liberation per particle size class. Otherwise, the mineral characterization by size class and liberation is not possible. However, assuming a grain size distribution and a constant mineral grade (overall) in the original ore, this characterization can be achieved. This new approach represents a better (more general) description than the assumption in Gaudin's model for the actual distribution that mineral grains exhibit in the ore.

Another assumption stated by Gaudin's model is that the mineral fracture occurs in parallel planes and always generates a uniform cubic particle size after grinding (Kelly and Spottiswood, 1982). Alternatively, the modified Gaudin's model considers that the comminution process generates a mineral particle size distribution, which is closer to the actual operating condition. In this sense, the modified Gaudin's model assumes the ore can be described by a population model, where each particle size class follows the assumptions of the conventional Gaudin's model.

To apply the proposed methodology, the following additional assumptions are also required:

- The valuable mineral consists of grains of different sizes, which are homogeneously distributed in the original ore, as shown in Fig. 1.
- The average mineral grade in the original ore considers all the grain sizes.
- The mineral grains are grouped by size classes inside the mineral aggregate (ore), thus forming sub-aggregates. The mineral aggregate is composed of a finite amount of sub-aggregates, equivalent to the amount of grain size classes in the original ore. This arrangement can be observed in Fig. 1.
- During the comminution process, each sub-aggregate is reduced until it reaches the same particle size distribution of the flotation feed, which is known data. This assumption considers that the minerals of each sub-aggregate has the same grinding properties (e.g.,