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Integration of a liberation model in a simulation framework for comminution circuits

E.M. Pérez-García[a,*], J. Bouchard[b], É. Poulin[c]

[a] Université Laval, Département de génie des mines, de la métallurgie et des matériaux, LOOP, Centre E4m, Pavillon Adrien-Pouliot, 1065 avenue de la médecine, Québec, Québec G1V 0A6, Canada

[b] Université Laval, Département de génie chimique, LOOP, Centre E4m, Pavillon Adrien-Pouliot, 1065 avenue de la médecine, Québec, Québec G1V 0A6, Canada

[c] Université Laval, Département de génie électrique et de génie informatique, LOOP, Centre E4m Pavillon Adrien-Pouliot, 1065 avenue de la médecine, Québec, Québec G1V 0A6, Canada

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ABSTRACT

As minerals frequently appear in complex associations in nature, liberation is one of the most relevant aspects in ore processing, and is achieved through comminution, which certainly is one of the most important but also expensive operations in industry. The global efficiency of the plant often depends on the performance of the grinding circuit, so there is a compromise between particle size, energy consumption and liberation. An adequate prediction of the liberation of grinding products can be helpful in reducing overgrinding, and therefore, reducing energy consumption without disturbing downstream operations. This paper addresses the development and validation of a mineral liberation model which is intended to be integrated in a simulation framework for comminution processes. Mineral species contained in the ore are distributed into size and liberation classes. Firstly, the size-by-size mineralogical distribution is related to the size distribution of the ore by means of a polynomial model. The next stage is to sort the mass of every species in every size class into liberation classes by means of a beta distribution function, whose characteristic constants are parameterised according to the ore properties. Results show great potential of the model to represent commonly observed industrial data, which provides opportunities for process simulation, optimisation and, to a lesser extent at this point, process control.

1. Introduction

Most minerals processed in industry are found in more or less complex associations with other species of little or no economical interest. Because of that, comminution operations are to be performed in order to physically separate valuable minerals from the rest. This process is commonly carried out in a mineral pulp, which also facilitates material transport to downstream operations as a fluid. General plant performance depends largely on grinding performance and pulp characteristics such as its density and particle size distribution.

Comminution is an expensive and very inefficient operation that plays a key role in mineral processing, so it has been widely studied, specially in terms of energy consumption. Buckingham et al. (2011) consider that grinding can account for up to 60% of the energy consumed on site, moreover, only 1% or 2% of this power is used for breaking the ore while the rest is mainly lost as heat (Fuerstenau and Abouzeid, 2002; Tromans and Meech, 2002, 2004; Bouchard et al., 2016, 2017).

In addition to energy consumption, the liberation aspect is also of great interest, as it is the goal of comminution. Liberation can be defined as the degree of purity of a particle with respect to the species of interest. It could be assumed that it is just a matter of size, i.e., the finer the material is, the more straightforward separation is going to be. However, an extremely fine particle size is required in practice to achieve perfect liberation, which besides requiring mammoth energy inputs, often causes more harm than good, e.g., recovery, selectivity and dewatering issues.

On account of the above, there is then a compromise between achieving liberation and avoiding over-grinding while optimising energy consumption. To face such a complicated task, modelling and simulation can be powerful tools compared with pure experimental work. In the opinion of Lynch and Morrison (1999), modelling and simulation are cheaper, quicker and more conclusive as long as the models are accurate and their parameters well determined. In addition, modelling and simulation can be used for process control and optimisation purposes.

* Corresponding author.
E-mail address: edgar-manuel.perez-garcia.1@ulaval.ca (E.M. Pérez-García).

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Some of the very first attempts to conceive models to control and optimise comminution processes were made by Rittinger (1867) and Kick (1883), who developed some of the first comminution equations in terms of energy consumption. Since then, particle size and power input have been common control (automatic or not) variables in industry. Product particle size can be used as a controlled or manipulated variable depending on the control strategy purpose (e.g., a controlled variable for a comminution circuit or a manipulated variable for the downstream processes), while energy consumption is more commonly used as a controlled variable. On the other side, controlling liberation is not reported in the literature. One could argue that it is indirectly taken into account by particle size, but in reality, this parameter does not determine liberation solely by itself.

Although liberation is currently not widely used in control schemes, the existence of many liberation models presents an opportunity for assessing comminution control schemes focused on controlling liberation. What is required is the integration of liberation models in current comminution models. As summarised by Powell and Morrison (2007): "*It has long been the holy grail of comminution modelling to incorporate liberation, for after all, that is the objective of comminuting the particles in mineral processing*".

Gaudin (1939) developed one of the first simple geometrical models that was then improved by Wiegel (1976, 2011) and Hsih and Wen (1994). These simplified mineral models considered rocks to be composed of perfectly aligned cubic particles. Steiner (1975) stated that mineral liberation had to be described in a more realistic way and some of Steiner's ideas were exploited by Andrews and Mika (1975) to extend the classical comminution model (Reid, 1965) incorporating liberation. The so-called AM model is a population balance that considers binary material (mineral and gangue) breaking inside a mill. Liberation evolves as purer particles are generated from the parent ones. Their work was next extended by Klimpel and Austin (1983) and Klimpel (1984) to consider an indeterminate number of phases. Although these models are very representative of the breaking of a multiphase material, they resulted in high complexity and an excessive number of empirical parameters.

King (1994) developed a quantitative approach, free of empirical parameters, that was after related to batch comminution (King and Schneider, 1998). Mineral texture was measured by microscope image analysis using linear intercepts on the mineral grains. Liberation could then be calculated by relating particle size reduction with the measured texture. This technique has, however, two disadvantages: firstly, many measurements are needed to describe the liberation spectra, and secondly, it considers equivalence between bidimensional and tridimensional space, which in practice is not always true. In this sense, Barbery (1991), inspired by the work of Bodziony (1965) on integral geometry and that of Serra (1983) on image analysis, wanted to extend the work of King and Schneider (1998) to all three dimensions. This resulted in a liberation model that relates multiphase textures and considers that texture generation and breakage are completely independent random processes. Barbery (1991) used a beta function to describe the distribution of fragments when a particle breaks apart in a comminution process.

In more recent years, improvements in computational capabilities have allowed outstanding advances in liberation modelling by different methods such as automated image analysis (Bonifazi and Massacci, 1995; Neumann and Schneider, 2001; Partsinevelos et al., 2012), numerical methods (Gay, 1999, 2004; Stamboliadis and Gaganis, 2008), texture simulation (Bazin, 2006; Hilden, 2014) and simulation by the discrete element method (DEM) (Herbst and Potapov, 2004).

The objective of this paper is to propose a liberation model that will be integrated in a mineral processing simulation library developed in MATLAB/Simulink by Sbárbaro (2010) and updated by Légaré et al. (2016). The proposed model parameterises a beta distribution function to account for ore properties. This function is then applied to the size-by-size mineralogical distribution which has previously been simulated by means of a polynomial approach (Bazin et al., 1994).

This paper is organised as follows. Section 2 introduces different coupling options between comminution and liberation models and justifies the selection of a decoupled approach. The comminution equation used for simulation and the mentioned polynomial approach are reviewed as well. Section 3 presents the step-by-step liberation model development. Calibration and validation for a practical case and a preliminary discussion on its potential to be used as an automatic control variable are given in Section 4. Finally, some conclusions are drawn in Section 5.

2. Interaction between comminution and liberation models

An important concept being taken into account for the development of this approach is the possibility of modelling comminution and liberation simultaneously or sequentially. With a focus on the interaction of comminution and liberation, this section presents the concept of model coupling and the possible choices regarding this matter. The complementary models that make the link possible for the developed approach are also introduced.

2.1. Model coupling

Leroux (1993) introduces three different types of model coupling, namely decoupled, hybrid, and coupled models. In the first type, there is one model for every process (comminution and liberation), and the information is passed in series from one to the other. Some examples of this approach are found in Sosa-Blanco et al. (1999), Girard (2004) and Ruel (2010). The former simply considers all material as liberated and the latter two, apply liberation matrices to comminution outputs before flotation simulation. The hybrid approach is illustrated in Leroux (1988), with both models working in parallel and sharing information about particle size and liberation between them. Lastly, a coupled model predicts both processes at the same time, as in the approaches developed by Andrews and Mika (1975) and Bellec (2012), where the fragmentation of biphasic materials is considered.

These coupling approaches are schematically presented in Fig. 1, where $\mathbf{u}_1$ is input data for the comminution model (e.g., particle size distribution, hardness, density, etc.), $\mathbf{u}_2$ is input data for the liberation model (e.g., grade, grain size, etc.), $\mathbf{y}^*$ represents an intermediate result (e.g., size-by-size mineralogical distribution), and $\mathbf{y}$ is the final output data (liberation distribution). It is worth mentioning that complexity increases from decoupled, hybrid and coupled in this order. Thus, the decoupled approach seems a good starting point to integrate a liberation model into a grinding circuit simulation platform.

2.2. Comminution model

The existing grinding simulator is based on the classic comminution

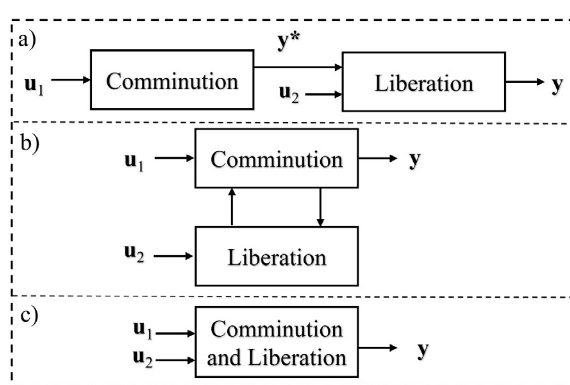

Fig. 1. Comminution and liberation coupling approaches (Leroux, 1993). (a) Decoupled modelling. (b) Hybrid modelling. (c) Coupled modelling.