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Development of Minerals Liberation Spectrum Simulator in Ball Mills

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Abstract: When comminution precedes mineral beneficiation processes, the liberation spectrum of the particles in a comminution process is of great importance. The calculation of the liberation spectrum in a continuous closed milling circuit is a vastly more difficult task. Here, a method has been incorporated into the CMCS simulation software to calculate the product size distribution and liberation spectrum in ball mills. The model requires a minimum amount of experimental data and is capable of calculating the detailed liberation spectrum. While, other existing methods account only for the completely liberated particles and a broad group of unliberated particles are not represented. An easy-to-use ball mill simulation environment has been developed and the results are compared with measured grinding data and previously existing simulators, particularly MODSIM, demonstrating firmly tested performance both in terms of accuracy and precision of obtained results.

Keywords: Simulation, Ball mill, CMCS, Minerals Liberation Spectrum.

INTRODUCTION

The purpose of a mineral processing plant is to separate the valuable component of the ore from the gangue, and to concentrate them to make a saleable product. The concentration steps are usually preceded by a comminution stage to break the ore to a size small enough to free or “liberate” the valuable components from the gangue. In mineral processing jargon, the term “liberation” is used as synonymous to the study of mineral particle composition. In the same way, “liberation spectrum” is used in a broad manner to refer to the distribution of particle grades in a particle population [1]. One of the most critical design criteria for mineral processing plants is the choice of size to which the comminution step must reduce the host (grind size) to ensure an economic level of liberation. The size reduction and liberation processes are inextricably linked. To ensure an efficient process, therefore, mineral liberation and its association with size reduction should be well characterized. However, the understanding of liberation, and its coupling to the prediction of size reduction, has not kept pace with the modelling of other operations in mineral processing, for three main reasons: first; the lack, until recently, of accurate and convenient means to measure the degree of liberation in process streams on a size-by-size basis, second: the lack of a validated and manageable

description of the process of liberation during comminution, and the last reason is: the complexity of the problem of describing of liberation [2]. With this interpretation, most of the grinding softwares are based on the size reduction phenomena regardless of the mineral liberation spectrum (USIM PAC [3], JKSimMet [2], BMCS [4], COMSIM [5], GrindSim [6]). Although the liberation models have not yet been widely applied, some of them have been included in computer simulation packages. Principally this includes King and Schneider's model which is incorporated in MODSIM [7]. In this paper an easy-to-use software (CMCS) has been developed based on minerals liberation spectrum.

METHODS

The population balance model is now universally accepted as the appropriate method for the calculation of the particle size distribution that will be produced in a continuously operating milling circuit. This method relies on the so-called breakage-selection function model for the mill and on a model that will describe the classification of a particle population in any classification unit in the closed milling circuit. These models have been well researched and the general characteristics of the selection function and breakage function are known for most industrially important mill types. This approach to milling circuit analysis is comprehensively described by Austin, Klimpel and Luckie [8]. Extensions to the original models to accommodate autogenous comminution effects have been thoroughly researched particularly by Austin's group and appropriate models are now available and widely used [9].

The fundamental population balance description of the comminution of composite solid materials in a perfectly mixed segment of a ball mill is given by Equation 1.

$$P(g,d_P)+S(g,d_P)P(g,d_P)\tau-\tau\int_{R'} b(g,d_P;g',d'_P)\,S(g',d'_p)\,dg'dd'_P=f(g,d_P) \quad (1)$$

In Equation (1) the variables have the following significance: the primary independent variables are the grade (mass fraction of mineral) and size of the particle. These are represented by g and dp respectively. Here, we restrict attention to binary ores so that g is a scalar quantity in the range [0,1]; $p(g,d_p)$ is the bivariate distribution density function with respect to the two variables g and dp in the mill contents. $S(g,d_p)$ is the specific rate of breakage of particles of grade g and size d_p. The grade of the particle affects the rate of breakage because the two different mineralogical components will usually not be equally brittle; $f(g,d_p)$ is the bivariate distribution density function that describes the distribution of particle composition and size in the material that is fed to the perfectly mixed zone; τ is the mean residence time in the perfectly mixed region. The function $b(g,d_p;g',d'p)$ is the main concern here. It is a bivariate density function in the two variables g and dp and it describes the distribution of these two variables in the progeny particles that results from the fracture of a particle of grade exactly equal to g′ and size equal to d'_p. A finite difference analogue to Equation (1) is required for practical calculations. Suitable finite difference representations are well known and provide convenient stable computational algorithms. We adopt the notation of Austin and Luckie (1986) and represent Equation (1) by [10]:

$$p_{ij}=\frac{f_{ij}+\tau\sum_{l=1}^{j-1}b_{jl}\sum_{k=K'_{ijl}}^{K''_{ijl}}S_{kl}b_{ijkl}p_{kl}}{1+S_{ij}\tau} \quad (2)$$

In Equation (2) the subscripts i, j, k and l index the variables g, dp, g′ and d′p respectively.

The model for liberation by comminution of two-phase particles based on Equation 2 developed in CMCS (Continuous Milling Circuits Simulation) for the calculation of the liberation spectrum of products produced in a continuous ball mill. CMCS has been coded based on php and javascript [11].

FINDINGS AND ARGUMENT

From a software engineering point of view, verification and validation (V&V) is a required step in the development of any computer program. A considerable effort was spent to check consistency and finding

semantic and syntactic errors of CMCS. To verify the performance of CMCS, many tests were run to detect various errors and bugs. To demonstrate the validity of CMCS simulation results, a number of real grinding circuits were simulated. Here, the results simulations using CMCS and MODSIM software and their comparison with measured particle size distribution are presented. The grinding circuit of the Fairlane Plant, located at mile 4 on county road 17, south of Eveleth (USA), was chosen to be the subject of CMCS validation. It was assumed that the transport in the mill can be described by three perfectly mixed regions in series. The breakage function model chosen for the Taconite ore was Broadbent and Calcot's three parameter normalizable function. The selection function for the Taconite ore was modeled by:

$$S_i = S_1 \left(\frac{d_p}{1000} \right)^{\propto} \tag{3}$$

It is interesting that the best model for the selection function did not require a description for an abnormal breakage region, perhaps due to the comparatively small particle sizes in the mill's feed. The final parameters for the comminution model of the ball mill are shown in Table 1, including breakage function and selection function parameters, and the residence times in the mill.

Table 1. The comminution model parameters for the ball mill used in CMCS simulation [1]

Selection function parameters	$\alpha = 1.28855$ $S_1 = 1.28076\ min^{-1}$
Breakage function parameters	$\emptyset = 0.46085$ $\beta = 0.44601$ $\gamma = 0.98684$
Average residence time in perfectly mixed region n (min)	$\tau_1 = 0.0548$ $\tau_2 = 0.8492$ $\tau_2 = 3.0960$
Total residence time (min)	$\tau_1 = 4.0$

The measured and simulated size/grade spectrum in the Ball Mill Discharge is shown in Figure 1. The calculated spectrum is considerably smoother than the measured spectrum, and the main reason for this is the smooth nature of the liberation model, which is continuous in both size and grade domains, and consequently dampens the noise from stereological correction that is imputed through the measured spectrum of the feed streams. Clearly, the simulation results obtained from CMCS are highly in agreement with the results obtained from the MODSIM simulator.

CONCLUSIONS

The method has been incorporated into the CMCS simulation software and thus the product size distribution and liberation spectrum can be calculated in ball mills. The model requires a minimum amount of experimental data but is capable of calculating the detailed liberation spectrumWhile, other existing methods account only for the completely liberated material and a broad group of particles that contains all incompletely liberated particles. The authors developed an easy-to-use ball mill simulation environment. By comparing the outputs of CMCS with measured grinding data and previously existing simulators, particularly MODSIM, its performance was firmly tested both in terms of accuracy and precision of obtained results.

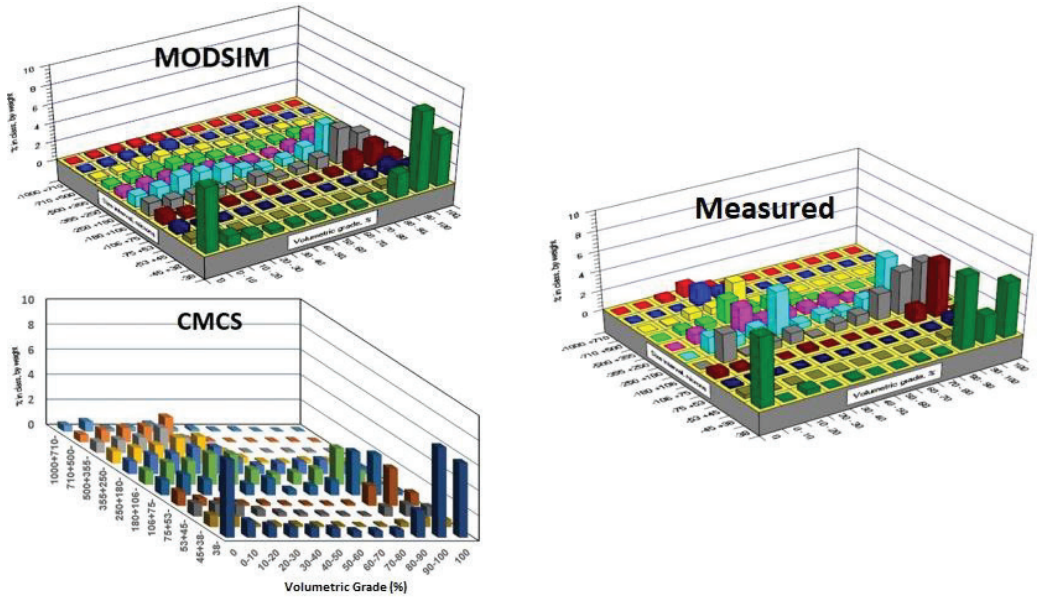

Figure 1. The measured and simulated (MODSIM-CMCS) particle size/grade spectrum in the Ball Mill Discharge

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