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Calibration of the perfect mixing model to a dry grinding mill

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Abstract

The perfect mixing model is calibrated to a dry grinding mill used to prepare iron powder for powder metallurgy applications. The calibration procedure was modified to account for possible error on both the mill feed and discharge size distributions, while the usual calibration criterion is based on the estimation error of the mill product size distribution. The calibration criterion was also modified to allow the simultaneous processing of several sampling campaigns to estimate common appearance, breakage and discharge rate functions. Calibration results are analysed in terms of reproducibility of model estimates and model capacity to predict the mill powder content as a function of the mill throughput and power drawn.

Keywords: Perfect mixing model; Grinding mill; Ball mill; Breakage rate; Iron powder; Power

1. Introduction

Modelling of grinding mill and circuit is and continues to be a challenging theme for many researchers. Grinding models are mainly used in grinding circuit simulators for process optimisation [1], design of control strategies [2,3] and for the analysis of the effect of a change of operating conditions (ball size, shape, rotation speed etc.) on the mill efficiency [4,5].

Current modelling approaches for grinding mills are based on the population balance model [6,7] and discrete element modelling [8,9] of the grinding mill charge movement. High fidelity simulation combines both approaches to simulate a grinding mill [10]. Despite the potential of the emerging DEM and high fidelity simulation, studies based on PBM are still presented in recent literature [11,12]. The perfect mixing model or PMM [13] is a popular model due to its simplicity and successful applications to different grinding mills [14,15]. The PMM assumes perfect mixing within a grinding machine and a discharge function for the particles in the mill load. The perfect mixing assumption eliminates the need for tracer tests required to estimate the mill residence time distribution. The model however requires the estimation of the grinding mill discharge rate function.

This paper analyses the results of the calibration of the PMM on data obtained from sampling of a dry grinding circuit used to produce iron powder. The PMM is described in the first section. The studied grinding circuit and the calibration technique are presented in the following sections, and the application of the technique is illustrated with data of several sampling campaigns in the last section.

2. Perfect mixer model

The PMM describes the mill operation as transport and breakage events and is formulated for steady-state operation as,

$$Wx_{\mathrm{f};i} - Wx_{\mathrm{d};i} - \mathrm{S}_i M x_{\mathrm{m};i} + \sum_{j=1}^{i-1} b_{i;j} S_j M x_{\mathrm{m};j} = 0 \qquad (1)$$

where W is the mill feed or discharge rate (t/h), x_i is the weight fraction of powder in size interval i, and M is the

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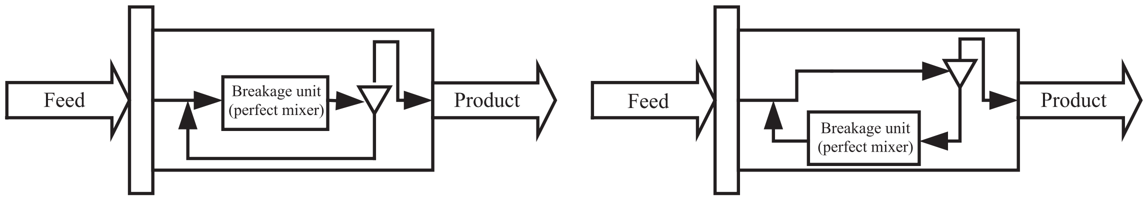

Fig. 1. Modified perfect mixing models for a grinding mill.

mass of powder in the mill. The subscripts f, d and m are used for the mill feed, discharge and load. The parameters that describe grinding within the mill are the appearance ($b_{i;j}$) and the breakage rate functions (S_j in h^{-1}). The appearance function gives the weight fraction of particles in size interval j that fall in size interval i following a breakage event. The breakage rate constant, S_j, gives the rate of breakage of particles in size interval j per load of unit mass assuming a first-order process. The mill discharge is related to the mill load by

$$Wx_{d;i} = C_i M x_{m;i} \tag{2}$$

where C_i is the discharge rate constant (h^{-1}) of particles within size interval i. The PMM model was recently used by Benzer et al. [14] for the simulation of cement clinker grinding mill.

Giving a schematic representation of the PMM operation is difficult. One can view the PMM as a perfect mixer reactor in which grinding occurs while an extractor pulls out the particles from the reactor charge. This extractor does not behave as a classifier that would return the material which is not ready to become the product back into the grinding zone, as shown by the postclassification representation of the grinding mill shown in Fig. 1. The post and preclassification schemes of Fig. 1 probably offer a better physical representation of the mill discharge phenomena than the above extractor; however, they complicate the grinding model equation (Eq. (1)) and the simulation procedure because of the recycling stream of material into the size reduction zone.

The appearance function is modelled using,

$$b_{i;j} = B_{i-1;j} - B_{i;j} \tag{3}$$

where $B_{i;j}$ is the cumulative appearance function that gives the weight fraction of particles initially in size interval j, that are broken into particles smaller than size interval i. The appearance function used in this study is energy independent and size invariant, i.e., independent of the mother particle size, and is represented by the parametric model,

$$B_{i;j} = \Phi\left(\frac{d_i}{d_j}\right)^{\beta_1} + (1-\Phi)\left(\frac{d_i}{d_j}\right)^{\beta_2} \tag{4}$$

where Φ, β_1 and β_2 are adjustable parameters, and d_i is the top size of size interval i [6]. The parameters Φ, β_1 and β_2 are constant with the size of the mother particle size.

In this study, the variation of the breakage rate with particle size is described by the empirical equation,

$$S_i = \exp\left(a_0 + a_1\tilde{d}_i + a_2\tilde{d}_i^2 + a_3\tilde{d}_i^3\right) \tag{5}$$

where the a_k are calculated so that the breakage rate passes through specified knot points, as shown in Fig. 2. The knot points are the minimum breakage rate, S_{min} for $\tilde{d}_i$=0, the reduced size $\tilde{d}_{opt}$ for the maximum breakage rate S_{max} and the breakage of the top size interval particles (S_a) at $\tilde{d}_i$=1. The reduced geometric mean particle diameter $\tilde{d}_i$ is given by,

$$\tilde{d}_i = \frac{\ln\left(\frac{\bar{d}_i}{\bar{d}_{min}}\right)}{\ln\left(\frac{\bar{d}_{max}}{\bar{d}_{min}}\right)} \tag{6}$$

where $\bar{d}_i$, $\bar{d}_{min}$ and $\bar{d}_{max}$ are the geometric mean diameter for size interval i and for the bottom and top size intervals of the considered size distribution. Eq. (6) yields reduced particle size diameter that lies between 0 and 1. The

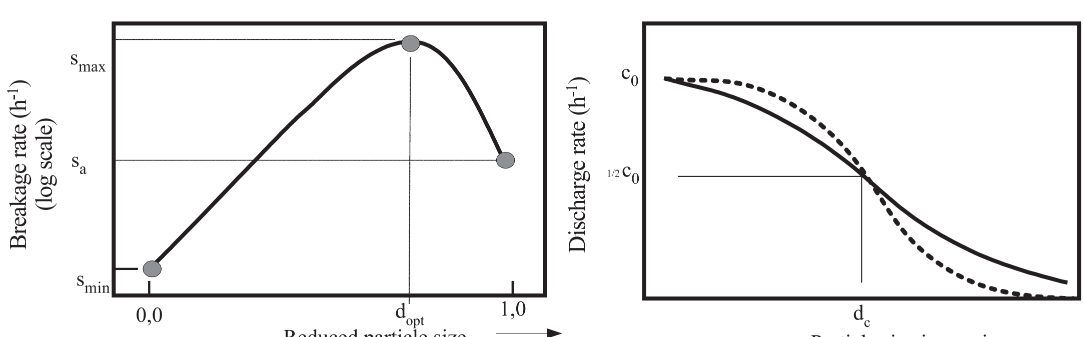

Fig. 2. Breakage and discharge rate functions.