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Effects of slurry pool volume on milling efficiency

François K. Mulenga [a,*], Michael H. Moys [b]

[a] Department of Electrical and Mining Engineering, University of South Africa, Florida Campus, Private Bag X6, Johannesburg 1710, South Africa
[b] School of Chemical and Metallurgical Engineering, University of the Witwatersrand, Private Bag X3, Wits 2050, Johannesburg, South Africa

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ABSTRACT

In wet milling, the presence of a pool of slurry is generally the result of mill overfill. The effects of overfilling on milling kinetics have been examined. Assessment of milling efficiency has also been made.
To this end, batch grinding tests were carried out at 75% of critical speed. A laboratory mill, filled with 20 mm balls, was used for the tests. Two levels of ball volumetric filling were considered: $J = 20$ and 30%. Slurry filling U was varied from 1.5 to 3.0 with reference to 20% ball filling. Equal masses of slurry were also used for a 30% ball filling which made slurry filling U change accordingly. Net power draw was measured throughout the experimentation.
It was found that product size distribution is a definite function of slurry filling U. Graphical analysis of the results suggests that the voids within the media charge should be completely filled with slurry without allowing the formation of the pool. This way, optimal output shall be expected. Moreover, mill power drop due to slurry pooling did not result in a proportional decrease in the production of fines.

1. Introduction

The volume of grinding balls available inside a mill generally determines its capability to process a large volume of ore. However, overfilling the mill is not advisable because the ability of the mill to hold up more material depends on the volume of voids between media balls. Indeed, if the mill is supplied with more slurry feed than the media interstices can take, the extra material will form a pool of slurry around the toe of the media charge.

Tangsathitkulchai [1] hypothesised that for an overfilled mill (see Fig. 1), a pool of slurry (1) forms at the base of the ball mill charge. A fraction of the ball mass (2) is submerged in the slurry. This fraction works against the stationary suspension of slurry causing a liquid drag on the interstitial particles. Around the shoulder of the media charge, balls (3) moving out from the slurry suspension tumble down in either a cascading or a cataracting motion towards the slurry pool. For a cascading motion, coarse particles trapped (4) in the interstices are preferentially milled by attrition. Fine particles coating balls are also milled by attrition due to the relative motion of balls in this zone but not to the same extent as larger particles.

Following this study, Tangsathitkulchai [2] demonstrated experimentally that mill power alone does not define breakage. He postulated that milling kinetics is dictated by load orientation, i.e. the position of the shoulder and toe of the media charge as well as that of the slurry pool.

The present article is intended to find out the extent to which the pool affects milling efficiency. It is indeed believed that pool volume affects the impact energy distribution, product grind and therefore milling efficiency.

To this end, a series of batch grinding tests was carried out on slurries of constant density but different filling volumes. It was then possible to create pools of different volumes. In doing so, milling kinetics was studied as a function of slurry volume. And from there, the effects that the pool volume has on milling efficiency were measured. This set of tests was carried out in a laboratory grinding mill. Finally, in order to analyse the data, two industrial descriptions of milling were employed: the size reduction curves and the grinding index. They basically consist of a quantification of the degree of size reduction and are discussed in the next section.

2. Characterisation of ball milling

Three techniques used for the characterisation of milling as a size reduction process are presented. The significance of the associated outputs is also succinctly discussed.

2.1. Graphical assessment of grinding

Bazin and Hodouin [3] conceived a graphical method for the evaluation of size reduction by grinding that is applicable to both laboratory and industrial data. The method is easy to apply and was claimed to provide a flexible way of comparing mill performances under different conditions. It can also be used to simultaneously compare different ores.

Basically, the technique is a spatial transformation of milling from the space used to plot cumulative passing curves into what is called a "size reduction space", i.e. a space in which product undersize is expressed as a function of feed undersize.

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* Corresponding author. Tel.: +27 11 471 2692; fax: +27 11 471 3054.
E-mail addresses: mulenfk@unisa.ac.za, mk.francois@yahoo.com (F.K. Mulenga).

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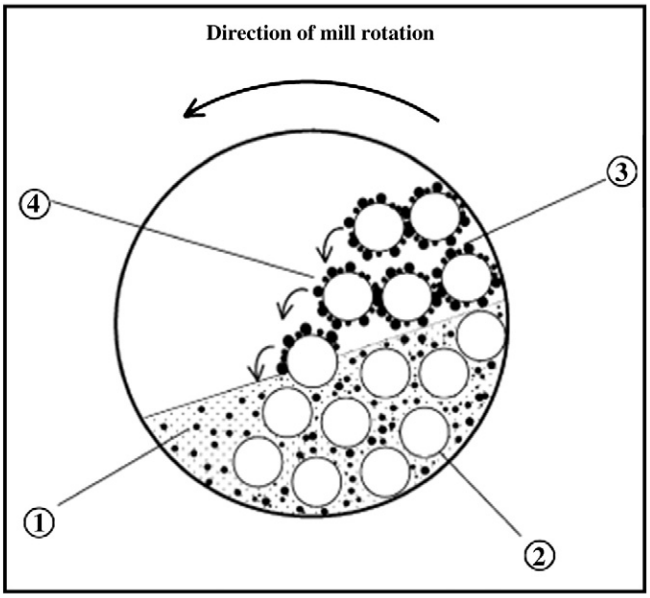

Fig. 1. Sub-processes promoting preferential breakage of coarser particles in wet ball mills (after [1]).

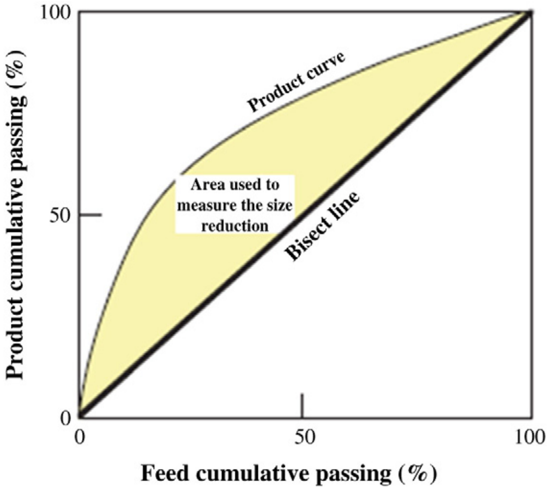

Fig. 3. Estimation of the size reduction index (after [4]).

To grasp the essence of this graphical technique, consider Fig. 2.

In order to construct the size reduction curves, several cut-off sizes are defined from the finest to the coarsest particle size. Next, fractions passing the predefined cut-off sizes are determined for different grinding times. Hence, plots of product size passing against feed size passing and the corresponding size reduction curves are generated. As seen in Fig. 2, it is understood that the curve moves far away from the bisect line for increasing degree of size reduction.

This idea prompted the definition of a single point estimate for the size reduction process. That is why, Bazin and Hodouin [3] went on to quantifying the degree of size reduction (SR) using the area (in yellow in Fig. 3) between the size reduction curve and the no-size reduction line (i.e. the bisect line):

$$SR = \left(\frac{A_0}{5000}\right) \times 100\% \tag{1}$$

where A_0 is the area between the bisect line and the product distribution line estimated using numerical integration methods $5000\%^2$ represents the maximum area that can be reached.

Important to remember is that the size reduction curve and the size reduction index (SR) should only be used to compare the degree of milling for materials with similar feed size distributions [3,4]. In addition, data for milling can be from laboratory or industrial tests.

2.2. Grinding index: Definition

There exist many ways of describing mill performance, they may be just different ways of expressing the same thing [5,6]. At times, they are ambiguous from one plant to another. But, the most commonly used definition of mill performance is the Grinding Index (GI). The criterion was symbolically defined as [7]:

$$GI = \left(\frac{S_D - S_F}{100 - S_F}\right) \times 100\% \tag{2}$$

where S_D and S_F represent the percent passing a specified size respectively in the mill discharge and in the mill feed.

$GI = 0\%$ simply signifies that there has been no size reduction whereas 100% represents a feed that has completely been milled below the specified size. The article by Bazin and Chapleau [8] is a good example of the successful use of GI to describe laboratory grinding tests.

Take note: Klimpel [5] used "Net production rate to less than specified size" while Moys [6] used "Grinding rate". Shi and Napier-Munn [7] used "Grinding Index" to refer to the same thing.

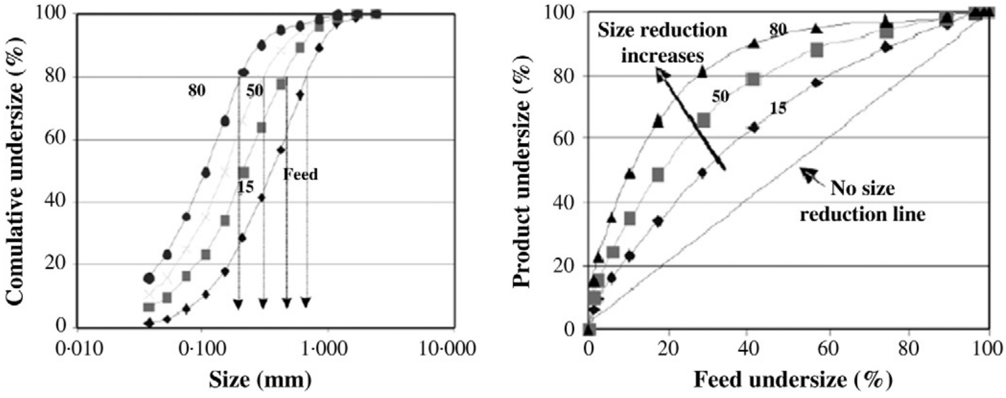

Fig. 2. Rationale of the generation of the size reduction curves (after [3]).