Available online at www.sciencedirect.com

jmr&t
Journal of Materials Research and Technology
www.jmrt.com.br

Original Article

Vertical mill simulation applied to iron ores☆

Douglas Batista Mazzinghy[a,*], *Claudio Luiz Schneider*[b], *Vladmir Kronemberger Alves*[c], *Roberto Galéry*[a]

[a] *Programa de Pós-Graduação em Engenharia Metalúrgica, Materiais e de Minas, Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brazil*
[b] *Centro de Tecnologia Mineral (CETEM), Rio de Janeiro, RJ, Brazil*
[c] *Centro de Desenvolvimento Mineral, Vale S.A., Santa Luzia, MG, Brazil*

ARTICLE INFO

Article history:
Received 1 September 2014
Accepted 13 October 2014
Available online 30 November 2014

Keywords:
Simulation
Scale-up
Vertical mill
Iron ore

ABSTRACT

The application of vertical mills in regrind circuits is consolidated. This type of mill is now attracting interest in primary grinding applications, due to its higher efficiency when compared to ball mills, which are usually used at this stage. In this study, a coarse sample of iron ore was tested in a pilot scale grinding circuit with a vertical mill. Other three samples of pellet feed had already been tested with the methodology used in this study. The sample of coarse iron ore was characterized in laboratory tests carried out in a small batch ball mill. Selection and breakage function parameters were determined from the laboratory tests. The parameters were then used for simulating the pilot scale tests using *Modsim*™ software. The model previously implemented in *Modsim*™ has been successfully applied to represent the vertical mill operated with different ores. The simulations produced particle size distributions that were very close to the actual size distributions, and the predictions were accomplished only by imputing the calibrated parameters from the batch tests, the power draw and the feed size distribution of the pilot tests. The methodology is therefore useful for scale-up and simulation of vertical mills, only requiring laboratory tests that can be carried out in standard laboratory batch ball mills with small amounts of samples.

1. Background

The vertical mill was invented in Japan in the 1950s by the *Tower Mill Kubota Corporation* for applications in fine and ultrafine grinding and was the first vertical mill used in the mining industry [1]. Fig. 1 shows a vertical mill, also called tower mill.

The vertical mill is basically composed of a cylinder with an internal screw that promotes the movement of the grinding media and slurry. This movement is provided by a motor installed on the top of the cylinder and connected to the screw via a gear unit. A separator tank directs part of the material exiting the mill via a recirculation pump. The latest *Vertimill*™ designs, mainly for fine grinding applications, do not include

☆ Paper presented in Portuguese at the 14th Brazilian Symposium on Iron Ore, Belo Horizonte, Brazil, September 15th to 18th 2014.

* *Corresponding author.*
E-mail: douglasmazzinghy@ufmg.br (D.B. Mazzinghy).

http://dx.doi.org/10.1016/j.jmrt.2014.10.011

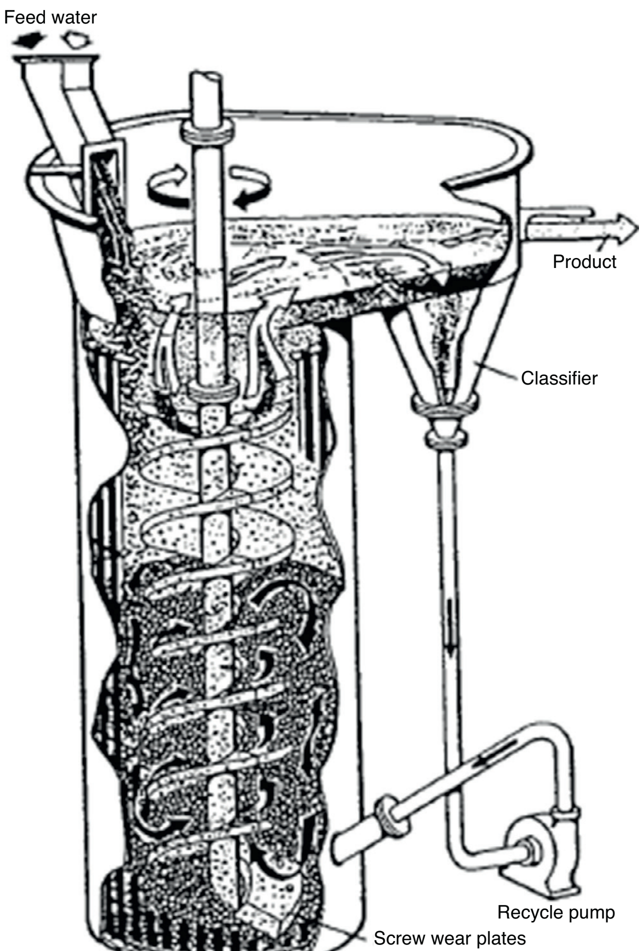

Fig. 1 – Tower mill [2].

the recirculation pump [3]. In this case, the vertical mill is fed through the bottom and the product is overflowed from the top of the mill without a separating tank. Vale S.A. has investigated the use of vertical mills for fine grinding and also for coarse grinding to replace ball mills in new projects or increase the grinding capacity in existing operations.

2. Grinding modelling

The population balance modelling technique has been used to model biological populations in the early 1960s [4] and later it was formulated for chemical engineering purposes [5]. Currently this tool is used to describe and control a wide range of processes such as agglomeration, flocculation, crystallization and polymerization [4]. Eq. (1) represents the population balance model equation for batch grinding [6]

$$\frac{dm_i(t)}{dt} = -S_i m_i(t) + \sum_{j=1}^{i-1} b_{ij} S_j m_j(t) \quad (1)$$

where $m_i(t)$ is the mass fraction of particles contained in size class i after grinding time t; S_i represents the specific rate of breakage of particles in size class i and b_{ij} represents the size distribution produced by a single impact breakage event of a particle of size j.

The breakage function model is given in Eq. (2) [6]. B_{ij} is the cumulative breakage function and the parameters φ, γ, β are ore dependent.

$$B_{i,j} = \phi\left(\frac{x_{i-1}}{x_j}\right)^{\gamma} + (1-\phi)\cdot\left(\frac{x_{i-1}}{x_j}\right)^{\beta} \quad (2)$$

The selection function for each size class, S_i, presents a proportionality relationship with the power consumed by the grinding action according to Eq. (3) [7,8].

$$S_i = S_i^E\left(\frac{P}{H}\right) \quad (3)$$

S_i is the selection function for each size class i (h^{-1}), S_i^E is the energy specific selection function (t/kWh), H is mill holdup (t) and P is the net grinding power (kW).

The energy specific selection function S_i^E is independent of the mill dimensions and may be modelled using Eq. (4) [9].

$$S_i^E = S1^E \exp\left\{\zeta_1 \ln\left(\frac{d_i}{d_1}\right) + \zeta_2\left[\ln\left(\frac{d_i}{d_1}\right)\right]^2\right\} \quad (4)$$

$S1^E$, ζ_1, ζ_2 are characteristic parameters of the material and the grinding conditions and (d_i/d_1) is the dimensionless particle size (normalized at $d_1 = 1$ mm).

For vertical mill simulations the parameter $S1^E$, which is measured from tests carried out in tumbling tube ball mills, is multiplied by a factor k to represent the highest efficiency of this vertical mills, becoming $S1^{E^*}$ [3] as shown in Eq. (5).

$$S_i^E = S1^{E*} \exp\left\{\zeta_1 \ln\left(\frac{d_i}{d_1}\right) + \zeta_2\left[\ln\left(\frac{d_i}{d_1}\right)\right]^2\right\} \quad (5)$$

Eq. (5) is used to describe the selection function of a vertical mill of any scale, pilot or industrial [10]. Three samples of iron ore (pellet feed), here named samples A, B and C, were tested in a pilot vertical mill. The samples were also characterized in order to generate parameters for Eqs. (4) and (5). The simulations predictions (product size distributions) were satisfactory for the three samples studied when a scaling factor $k = 1.35$ is used. All other parameters were either measured in the plant or measured in the lab (ore characterization).

The objective of this work is to verify whether factor k, adopted in previous studies, is applicable for the simulation of a fourth sample (sample D) pilot test. Sample D is considerably coarser in comparison with the three samples tested before (A, B and C). All samples are compared with regard to their selection and breakage functions.

3. Experimental

3.1. *Pilot test*

Four different samples of iron ore were tested in a pilot-scale grinding circuit with a vertical mill (Metso) and a high frequency screen (Derrick). The tests were performed using a