



## Original Article

# Scale up and simulation of Vertimill™ pilot test operated with copper ore

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### ABSTRACT

Vertimill™ has been used in regrind circuits during the past years due to its greater efficiency when compared to the conventional tube ball mill. This paper presents the Vertimill™ pilot grinding tests with a sample of copper ore carried out in closed circuit with a high frequency screen. The sample was crushed 100% to <6 mm. All operating variables were measured under controlled conditions to produce a mass balance of the test. A laboratory batch ball mill was used to characterize the sample in order to determine the energy specific selection function and the breakage function. Previous studies have shown that the Vertimill™ produces larger values of the selection function and a constant scaling factor can be used to simulate the product particle size distribution of the Vertimill™ from the batch ball mill grinding tests. The results of the simulations showed that it is possible to estimate the product particle size distribution of the Vertimill™ pilot scale from breakage parameters determined from a lab-scale batch ball mill. These results confirm that the Vertimill™ and the conventional ball mill use similar mechanisms of impact and that the main difference between them is the intensity and frequency of the impacts.

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## 1. Introduction

An investigation program of Vertimill™ was conducted with the aim of development of models to scale up and simulate this type of mill. Pilot tests with Vertimill™ was carried out under controlled conditions to produce a mass balance and

tests with small quantities of samples were carried out in lab to determine breakage parameters to simulate this type of mill. Some studies have showed that it is possible to simulate the Vertimill™ using the methodology that considers batch ball mill tests in different interval times and breakage parameters given by software that performs the optimization of the particle size distributions [1–3].

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Why the *Vertimill*<sup>TM</sup> is more efficient than the tube ball mill? Apparently, the answer is the spectrum of energies. *Vertimill*<sup>TM</sup> has higher frequency of lower energy impacts and smaller frequency of higher energy impacts when compared to conventional ball mills [4].

The objective of this paper was to simulate a pilot *Vertimill*<sup>TM</sup> test from batch mill lab tests using small quantities of samples.

### 1.1. Modeling approach

The population balance model was formulated for chemical engineering purposes [5]. The size-mass balance model that describes the batch grinding process through successive events of particle breakage is given in Eq. (1) [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  $t$ ;  $b_{ij}$  represents the size distribution produced by a breakage event;  $S_i$  represents the specific rate of breakage of particles in size class  $i$ .

#### 1.1.1. Breakage function

The breakage function model is given in Eq. (2) [6].  $B_{i,j}$  is the cumulative breakage function and the parameters  $\phi$ ,  $\gamma$ ,  $\beta$  are dependent on the ore.

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

#### 1.1.2. Specific selection function

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].

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

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

These equations have been used to determine the energy consumption required in grinding and they can also be used in the scale-up of industrial milling circuits from parameters obtained using a simple laboratory batch mill.

### 1.2. Scale up

The specific selection function  $S_i^E$  is independent of the dimensions of the mill and may be modeled using Eq. (4) [8]. The parameter  $S_i^E$  was multiplied by a scaling factor of 1.35 to represent the highest efficiency of the *Vertimill*<sup>TM</sup>, becoming  $S_i^{E*}$ . The scaling factor of 1.35 is applicable for different ores [1].

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

where  $(d_i/d_1)$  is the dimensionless particle size (normalized at 1 mm),  $S_i^{E*}$ ,  $\zeta_1$ ,  $\zeta_2$  are characteristic parameters of the material and the conditions of grinding.

This model was implemented in the *Modsim*<sup>TM</sup> plant-wide simulator [9]. For models references of *Modsim*<sup>TM</sup> is strongly recommendable to read King [10].

## 2. Experimental

### 2.1. Vertimill<sup>TM</sup> pilot test

A campaign of *Vertimill*<sup>TM</sup> pilot tests was carried out at Metso's York pilot plant facility. The *Vertimill*<sup>TM</sup> was operated in direct circuit configuration closed with a high frequency screen (Derrick Vibrating Screen) and with screw speed of 87 rpm. The mill motor gross power registered during the *Vertimill*<sup>TM</sup> pilot test was adjusted with Prony brake curve data to provide net power draw. A mass balance of the test was produced through the samples collected from all streams for solids concentration, density and particle size distribution determination. Fig. 1 shows the *Vertimill*<sup>TM</sup> Pilot Circuit Flowsheet.

The samples were crushed 100% to <6.3 mm following Metso recommendation. Fig. 2 shows the feed size distribution of the sample.

Table 1 shows the media size distribution used in the *Vertimill*<sup>TM</sup> pilot test.

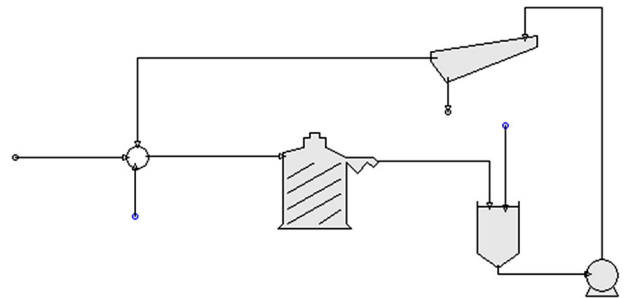


Fig. 1 – *Vertimill*<sup>TM</sup> pilot circuit flowsheet.

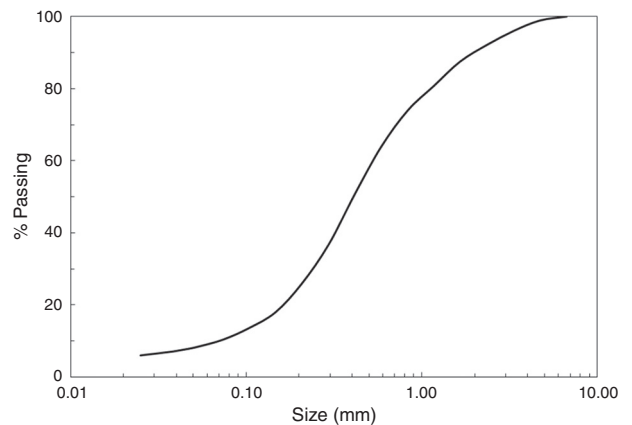


Fig. 2 – Particle size distribution of the *Vertimill*<sup>TM</sup> pilot circuit feed.

**Table 1 – Media size distribution.**

Size (mm)	% Ret.
35	38.4
30	27.5
25	14.5
19	17.7
12	1.9
Total	100

**Table 2 – Batch mill test.**

Mill diameter (m)	0.254
Mill length (m)	0.254
J – ball charge level	0.40
U – voids	1.00
Critical speed	0.70

2.2. Lab batch test

The batch tests were carried out in a conventional batch tube mill. Samples were crushed at 100% to <3.6 mm in order to maintain proper proportion between the larger particles and the diameter of the ball mill used in the tests.

Table 2 shows the batch mill test variables.

The tests were carried out considering the same media size distribution as that used in the Vertimill™ pilot test. The samples were ground for four different time intervals in dry basis and one test in wet basis was carried out considering an interval time 30% less than the last grinding interval in dry basis. The wet test was carried out to consider the selection function of Vertimill™ pilot test that was carried out in wet basis.

3. Results and discussion

3.1. Breakage parameters

BatchMill™, an optimization software developed by Mineral Technologies International [11], was used to determine the grinding parameters. Table 3 shows the selection and breakage function parameters determined from the laboratory tests using a laboratory batch ball mill. The parameter  $S_1^E$  was multiplied by a factor of 1.35 to correct for the higher efficiency of the Vertimill™ with respect to the standard ball mill [1].

Fig. 3 shows the particle size distributions obtained in the batch mill tests and the model fitting obtained by the BatchMill™ software.

Figs. 4 and 5 show the specific selection and breakage functions determined from batch ball mill test results.

**Table 3 – Selection and breakage functions.**

Selection function		Breakage function			
S1E* (t/kWh)	$\zeta_1$	$\zeta_2$	$\varphi$	$\gamma$	$\beta$
0.941	0.665	-0.011	0.463	0.615	3.328

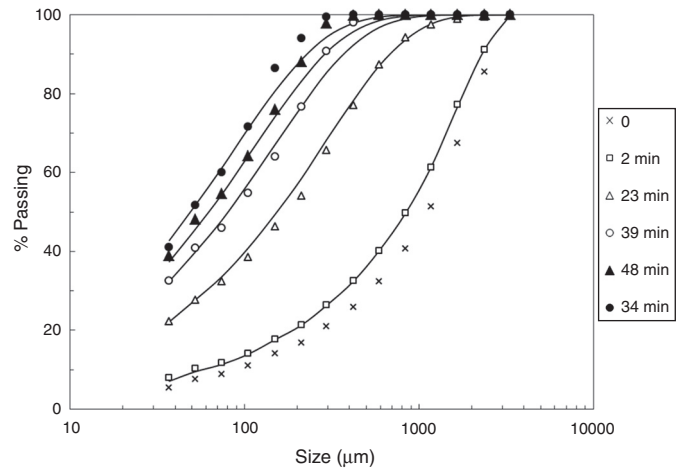


Fig. 3 – Particle size distribution of the batch ball mill test and the model fitting by BatchMill™ software.

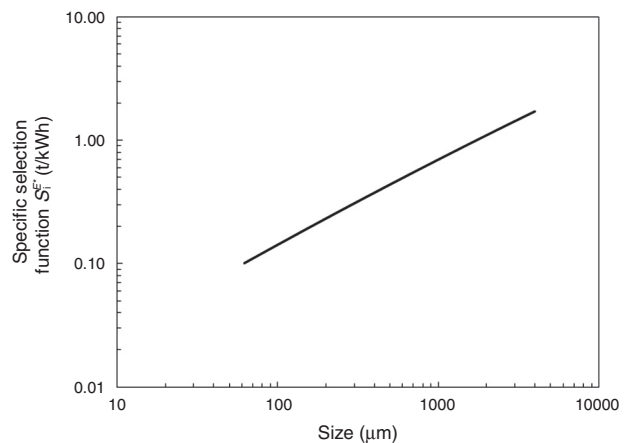


Fig. 4 – Specific selection function.

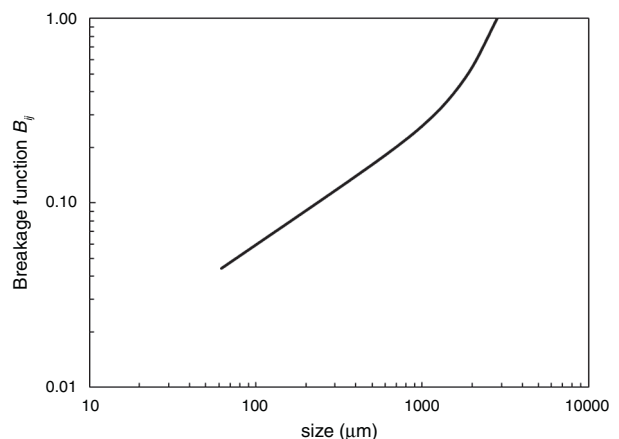


Fig. 5 – Breakage function.

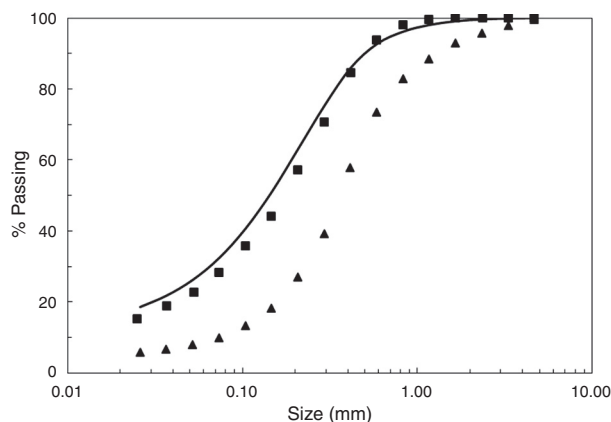


Fig. 6 – Simulation results obtained using Modsim™.

### 3.2. Simulations

Data from the mass balance were used to perform simulations using the *Vertimill*<sup>™</sup> model implemented in the *Modsim*<sup>™</sup> plant-wide simulator. The feed and product size distributions of the mill were considered to check the accuracy of the model. Fig. 6 shows the feed and product size distributions measured in the pilot tests as well as the predicted product from the scale-up model.

The square symbols represent the measured particle size distribution obtained in the *Vertimill*<sup>™</sup> pilot test product stream and the solid line is the corresponding model response using the parameters determined and power scale-up.

## 4. Conclusions

The simulations indicated that it is possible to predict the particle size distribution and the net power of a *Vertimill*<sup>™</sup> using population balance model. The energy-based model [7] used to simulate a ball mill, was modified to include a scaling factor of 1.35 applied on one of the parameters that describe the specific selection function to represent the most efficient of *Vertimill*<sup>™</sup> [1]. These results indicate that the breakages by attrition, abrasion or chipping are not favored in the *Vertimill*<sup>™</sup>. The differences of *Vertimill*<sup>™</sup> and Ball Mill are in the frequency of high and low energy impacts.

## Conflicts of interest

The authors declare no conflicts of interest.

## Acknowledgements

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