Simulations of Vertimill Pilot Scale tests for Itabirite

Simulação de testes de Vertimill em Escala Piloto com Itabirito

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Abstract

The Minas-Rio Project is the biggest project from Anglo American in the world and considers Vertimill in the regrinding circuit to adequate the particle size distribution to feed slurry pipeline that will pump the ore from Conceição do Mato Dentro in Minas Gerais State to Acu Port in Rio de Janeiro State, Brazil. A Vertimill pilot test campaign was carried out at Metso's pilot plant facility located in York city, Pennsylvania State, USA, to provided information to sizing the industrial grinding circuit. The main objective of this work is proposing a way to simulate the industrial Vertimill using the population balance model, normally used to simulate ball mills. The simulations were based on the selection and breakage functions determined from the laboratory tests using a batch ball mill. The simulations were performed using a Vertimill model implemented in the *Modsim*™ plant-wide simulator. The results of simulations shows that was possible to simulate the pilot tests, with good accuracy, considering simple laboratory tests with small quantities of samples.

keywords: Vertimill, Simulation, Grinding, Population Balance Model, Itabirites, *Modsim*™.

Resumo

O Projeto Minas-Rio é o maior projeto da Anglo American no mundo e considera um circuito de remoagem com Vertimill para adequar a distribuição de tamanho de partículas para alimentar o mineroduto que irá transportar o minério da cidade de Conceição do Mato Dentro, no Estado de Minas Gerais, ao Porto do Açu, no Rio de Janeiro, Brasil. Uma campanha de testes em escala-piloto com Vertimill foi realizada nas instalações da Metso localizadas na cidade de York, Estado da Pensilvânia, EUA, para fornecer informações para o dimensionamento do circuito de moagem industrial. O principal objetivo desse trabalho é propor uma forma de simular o circuito industrial com Vertimill, utilizando o modelo de balanço populacional, normalmente usado para simular moinhos de bolas. As simulações foram baseadas na função seleção e na função quebra determinadas a partir dos testes de laboratório utilizando um moinho de bolas de batelada. As simulações foram realizadas utilizando um modelo de Vertimill implementado no simulador de processos minerais Modsim™. Os resultados das simulações mostraram que é possível simular os testes-piloto, com boa precisão, através de testes simplificados em escala de laboratório, com pequenas quantidades de amostras.

Palavras-chave: *vertimill, simulação, moagem, modelo do balanço populacional, itabiritos, Modsim™.*

1. Introduction

The Vertimill has been used in regrind circuits over last 30 years. The principle is very simple and there have been reports that this type of mill is approximately 30% more efficient than conventional ball mills (VANDERBEEK, 1998; JANKOVIC *et al*., 2006; JUNIOR *et al*., 2011).

MAZZINGHY *et al*., 2013 explain that the higher efficiency of the Vertimill is due to the higher frequency of lower energy impacts and, by the same token, smaller frequency of higher energy impacts when compared to conventional ball mills.

The Minas-Rio Project, located in Conceição do Mato Dentro city, Minas Gerais State, Brazil, predicts the largest slurry pipeline around the world with a length of 525km. The Vertimill circuits of the project were considered to adequate the particle size distribution of the iron ore concentrate to feed the pipeline. There are 16 Vertimills VTM-1500 in the regrind circuit. Anglo American carried out a Vertimill pilot test campaign in Metso's pilot plant facility, located in York city, Pennsylvania State, USA. The objective of the pilot tests was to determine the specific energy consumption required to obtain a product with 88% < 0.044mm. The samples were produced in Anglo American pilot plant facilities including crushing, grinding, desliming and flotation to obtain the final concentrate that was sent to Metso for Vertimill pilot tests.

The main objective of the paper is to propose a way to simulate the Industrial Vertimill using the population balance model, normally used to simulate conventional ball mills.

2. Modeling

2.1 Population balance model

The population balance was formulated for chemical engineering purposes by HULBURT & KATZ (1964). It is used to describe a wide range of particle processes as agglomeration, flocculation, crystallization, polymerization, etc.

The size-mass balance model that describes the batch grinding process through successive events of particle breakage is given in Equation 1 (AUSTIN *et al.* 1984).

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

$m_i(t)$ 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*.
The population balance model was used with success to represent an industrial Tower Mill operational by MORRELL *et al.* 1993.

2.2 Specific selection function

The selection function has a proportionality relationship with the power consumed by the grinding action according to Equation 2 (HERBST & FUERSTENAU, 1973).

$$S_i = S_i^E\left(\frac{P}{H}\right) \tag{2}$$

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; P(kW) is net grinding power.

Parameters obtained from simple laboratory batch grinding tests can be used for simulating and scaling-up large industrial mills.

The specific selection function S_i^E is independent of the dimensions of the mill and may be modeled using Equation 3 (RAJAMANI & HERBST, 1984).

$$S_i^E = S1^E \exp\left\{\zeta_1 \ln\left(\frac{d_i}{d_1}\right) + \zeta_2\left[\ln\left(\frac{d_i}{d_1}\right)\right]^2\right\} \tag{3}$$

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

The parameter $S1^E$, from Equation 3, is multiplied by a scaling factor equal 1.35 to represent the highest efficiency of the Vertimill, (MAZZINGHY, 2012 MAZZINGHY *et al.*, 2013).

The Vertimill model was implemented in the *Modsim™* plant-wide simulator.

The models used in *Modsim™* can be found in KING (2002).

2.3 Breakage function

The breakage function model is given in Equation 4 (AUSTIN *et al.* 1984), where B_{ij} is the cumulative breakage function and the parameters ϕ, γ, β are dependent of the ore.

$$B_{i,j} = \phi\left(\frac{x_{i-1}}{x_j}\right)^{\gamma} + (1-\phi).\left(\frac{x_{i-1}}{x_j}\right)^{\beta} \tag{4}$$

2.4 External Classification

The external classification can be described by the logistic function model developed by AUSTIN *et al*. (1984), defined as shown in the Equation 5:

$$e(d_i) = \frac{1}{1 + \left(\frac{d_i}{d_{50c}}\right)^{-\lambda}} \quad (5)$$

$e(d_i)$ is the actual classification function; d_i is the particle of fraction size i (mm); d_{50c} is the particle size corrected (50% chance to go to underflow or overflow); λ is the sharpness classification parameter. The sharpness classifcation parameter λ can be estimated as follows in Equation 6.

$$\lambda = \frac{2{,}1972}{\ln(SI)} \quad (6)$$

The *SI* can be estimated as follows in Equation 7.

$$SI = \frac{d_{25}}{d_{75}} \quad (7)$$

d_{25} is the size of 25% passing (mm); d_{75} is the size of 75% passing (mm).

Equation 8 presents the corrected classification function *c(di)*.

$$c(d_i) = \alpha + (1-\alpha)\, e(d_i) \quad (8)$$

$c(d_i)$ is the corrected classification function; α is the feed's short circuit directly to the coarse product.

3. Experimental

3.1 Vertimill Pilot Tests

Metso's pilot plant facility is equipped with instruments to measure and register the data from the pilot test. The target of the continuous test was to determine the specific energy required to grind the material to eighty eight percent (88%) passing 0.044mm.

The tests were performed in closed circuit with a high frequency screen and in direct and reverse configuration.

The screw speed of the Vertimill was 87rpm. Samples from different flows of circuit were collected during the tests for solids concentration and particle size distribution analysis.

Table 1 shows the cylpebs size distribution used in the Vertimill pilot test.

Table 1
Cylpebs size distribution used in the Vertimill pilot tests

Cylpebs (mm)	% Ret.	kg
12.7	52.8	719
9.0	36.2	492
6.7	11.0	150
Total	100.0	1361

3.2 Batch Mill Tests

The selection and breakage functions were determined using a batch ball mill. Three tests were carried out in diferent time intervals on a wet basis (70% solids concentration by weight). The time intervals considered were: 15, 30 and 45 minutes. The tests are designed to reach the desired product size distribution specified as a P_{80} value. The batch tests were carried out considering the same cylpebs size distribution using on the Vertimill pilot test campaing. Table 2 shows the operational variables used in the batch ball mill tests.

Table 2
Operational variables used in batch ball mill tests.

Mill Diameter (m)	0.203
Mill Length (m)	0.254
Cypebs Filing (%)	40.0
Critical Speed (%)	76.0

4. Results and discussions

4.1 Vertimill Pilot Test

Table 3 shows the results obtained during the Vertimill pilot tests.

Circuit Configuration	Direct	Reverse
F_{80} (μm)	65.2	64.6
P_{80} (μm)	36.5	38.5
% < 44 μm	90.7	88.5
Specific Energy (KWh/t)	6.32	5.31

Table 3
Results from
the Vertimill pilot test campaign.

Table 4 shows the classification parameters for high frequency screening determined based on mass balance of the Vertimill pilot tests.

Circuit Configuration	Direct	Reverse
d50c (microns)	31.27	33.99
Short-circuit to underflow	0.29	0.39
Sharpness index	0.52	0.54

Table 4
Classifications parameters for high frequency screening obtained from Vertimill pilot tests.

4.2 Breakage Parameters

An optimization software developed by Mineral Technologies International, called *BatchMill*™ was used to determine the grinding parameters.

Table 5 shows the selection and breakage functions parameters determined from batch mill tests based on the specific energy model.

Selection Function			Breakage Function		
$S1^E$ (t/kWh)	ξ_1	ξ_2	γ	β	ϕ
9.780	0.898	-0.154	1.250	2.765	0.237

Table 5
Parameters based on the specific energy model obtained from laboratory tests

The parameters $S1^E$ presented in Table 5 were multiplied by a factor of 1.35 to correct for the higher efficiency of the Vertimill with respect to the conventional ball mill (MAZZINGHY, 2012).

In this case, the parameters $S1^E$ produced the value 13.203 t/kWh.

Figure 1 shows the selection and breakage functions for the Vertimill considering the specific energy model.

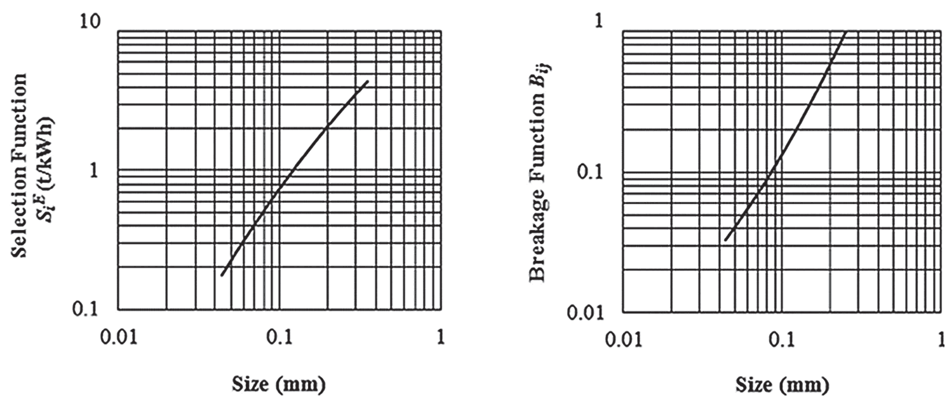

Figure 1
Selection and breakage functions based on the specific energy model.

4.3 Simulations

Data from the mass balance of each test was used to perform simulations using the population balance model. Figure 2 shows the simulations based on the specific energy model for direct and reverse circuit configuration, respectively.

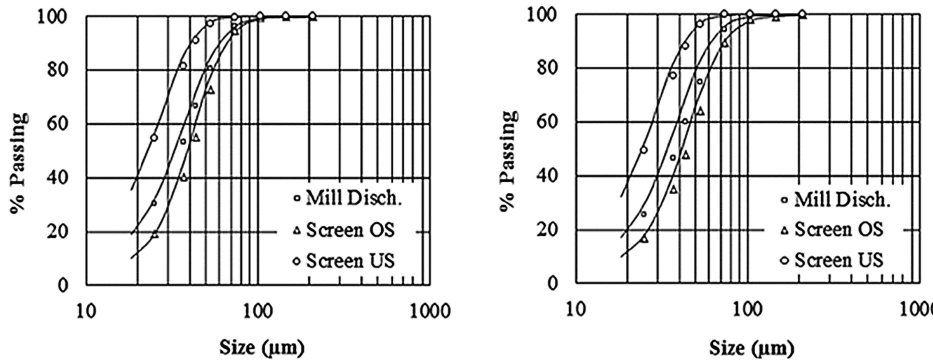

Figure 2
Simulation results for direct (left) and reverse (right) circuit configuration.

Symbols represent the measured particle size distribution obtained in the Vertimill pilot tests and the solid line is the corresponding model response.

For both circuit configuration, direct and reverse, the specific energy model predicted more fines in the product.

The multiplier factor equaling 1.35 was considered to represent the higher efficiency of Vertimill when compared to the conventional ball mill.

Table 6 show the mass balance obtained from experimental data and the simulation results.

Table 6
Mass balance obtained from experimental data and simulation results.

Results	Circuit	F_{80} (m)	P_{80} (m)	C.L (%)
Mass Balance	Direct	65.2	36.5	174
Simulation			34.0	187
Mass Balance	Reverse	64.6	38.5	225
Simulation			35.9	234

The values of P_{80} and the circulating loads found in the simulations present a small difference between the mass balance values.

5. Conclusions

The particle size distribution of the Vertimill pilot scale tests in direct and reverse configurations was obtained, with good accuracy, by simulations using the population balance model. The methodology used in this study can help the process engineers to understand and scale-up to industrial Vertimill from batch ball mill tests. A multiplier factor equal to 1.35 was applied on the parameter $S1^E$ to simulate the higher efficiency of the Vertimill when compared with conventional ball mill.

For both circuit configurations, direct and reverse, the specific energy model predicted more fines in the product.

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