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.


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 (VANDER-BEEK, 1998; JANKOVIC et al., 2006; JUNIOR et al., 2011).
plain 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 adequately 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 population balance model was used for simulating and scaling-up large laboratory batch grinding tests can be implemented in the Modsim™ plant-wide simulator. The models used in Modsim™ can be found in KING (2002).

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

$$S^E_i = S^E_i \exp \left\{ \xi_1 \ln \left( \frac{d_i}{d_1} \right) + \xi_2 \left[ \ln \left( \frac{d_i}{d_1} \right)^2 \right] \right\}$$

(3)

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

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).

$$S_i = S^E_i \left( \frac{P}{H} \right)$$

(2)

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

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 $\phi, \gamma, \beta$

$$B_{ij} = \phi \left( \frac{x_{i+1}}{x_i} \right)^\gamma + (1 - \phi) \left( \frac{x_{i+1}}{x_i} \right)^\beta$$

(4)

implemented in the Modsim™ plant-wide simulator. The models used in Modsim™ can be found in KING (2002).
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:

\[
e(d_i) = \frac{1}{1 + \left( \frac{d_i}{d_{50c}} \right)^{\lambda}}
\]

\[(5)\]

\(e(d_i)\) 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); \(\lambda\) is the sharpness classification parameter. The sharpness classification parameter \(\lambda\) can be estimated as follows in Equation 6.

\[
\lambda = \frac{21972}{\ln(SI)}
\]

\[(6)\]

The SI can be estimated as follows in Equation 7.

\[
SI = \frac{d_{25}}{d_{75}}
\]

\[(7)\]

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

Equation 8 presents the corrected classification function \(c(d_i)\).

\[
c(d_i) = \alpha + (1 - \alpha) e(d_i)
\]

\[(8)\]

\(c(d_i)\) is the corrected classification function; \(\alpha\) 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>
<thead>
<tr>
<th>Cylpebs (mm)</th>
<th>% Ret.</th>
<th>kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.7</td>
<td>52.8</td>
<td>719</td>
</tr>
<tr>
<td>9.0</td>
<td>36.2</td>
<td>492</td>
</tr>
<tr>
<td>6.7</td>
<td>11.0</td>
<td>150</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>1361</td>
</tr>
</tbody>
</table>

Table 1 Cylpebs size distribution used in the Vertimill pilot tests

3.2 Batch Mill Tests

The selection and breakage functions were determined using a batch ball mill. Three tests were carried out in different 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 \(P_{80}\) value. The batch tests were carried out considering the same cylpebs size distribution using on the Vertimill pilot test campaigning. Table 2 shows the operational variables used in the batch ball mill tests.

<table>
<thead>
<tr>
<th>Mill Diameter (m)</th>
<th>0.203</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mill Length (m)</td>
<td>0.254</td>
</tr>
<tr>
<td>Cylpebs Filing (%)</td>
<td>40.0</td>
</tr>
<tr>
<td>Critical Speed (%)</td>
<td>76.0</td>
</tr>
</tbody>
</table>

Table 2 Operational variables used in batch ball mill tests.
4. Results and discussions

4.1 Vertimill Pilot Test

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

<table>
<thead>
<tr>
<th>Circuit Configuration</th>
<th>Direct</th>
<th>Reverse</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F_{80} ) (( \mu m ))</td>
<td>65.2</td>
<td>64.6</td>
</tr>
<tr>
<td>( P_{80} ) (( \mu m ))</td>
<td>36.5</td>
<td>38.5</td>
</tr>
<tr>
<td>% &lt; 44 ( \mu m )</td>
<td>90.7</td>
<td>88.5</td>
</tr>
<tr>
<td>Specific Energy (KWh/t)</td>
<td>6.32</td>
<td>5.31</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Circuit Configuration</th>
<th>Direct</th>
<th>Reverse</th>
</tr>
</thead>
<tbody>
<tr>
<td>( d_{50c} ) (microns)</td>
<td>31.27</td>
<td>33.99</td>
</tr>
<tr>
<td>Short-circuit to underflow</td>
<td>0.29</td>
<td>0.39</td>
</tr>
<tr>
<td>Sharpness index</td>
<td>0.52</td>
<td>0.54</td>
</tr>
</tbody>
</table>

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\textsuperscript{TM} 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.

<table>
<thead>
<tr>
<th>Selection Function</th>
<th>Breakage Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S_{1}^{E} ) (t/kWh)</td>
<td>( \zeta_1 )</td>
</tr>
<tr>
<td>9.780</td>
<td>0.898</td>
</tr>
</tbody>
</table>

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

The parameters \( S_{1}^{E} \) 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 \( S_{1}^{E} \) produced the value 13.203 t/kWh.

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

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 shows the mass balance obtained from experimental data and the simulation results.

<table>
<thead>
<tr>
<th>Results</th>
<th>Circuit</th>
<th>$F_{80}$ (m)</th>
<th>$P_{80}$ (m)</th>
<th>C.L (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass Balance</td>
<td>Direct</td>
<td>65.2</td>
<td>36.5</td>
<td>174</td>
</tr>
<tr>
<td>Simulation</td>
<td></td>
<td>34.0</td>
<td></td>
<td>187</td>
</tr>
<tr>
<td>Mass Balance</td>
<td>Reverse</td>
<td>64.6</td>
<td>38.5</td>
<td>225</td>
</tr>
<tr>
<td>Simulation</td>
<td></td>
<td>35.9</td>
<td></td>
<td>234</td>
</tr>
</tbody>
</table>

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 $S^L$ 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.

6. References

RAJAMANI, K., HERBST, J.A. Simultaneous estimation of selection and breakage functions from batch and continuous grinding data, *Transactions of Institution of*
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