THE GRINDING EFFICIENCY OF THE CURRENTLY LARGEST VERTIMILL INSTALLATION IN THE WORLD

*D.B. Mazzinghy[1], J.F.C. Russo[1], J. Lichter[2], C.L. Schneider[3], J. Sepúlveda[4], and A.Videla[5]

[1]*Anglo American - Iron Ore Brazil*
Conceição do Mato Dentro
Minas Gerais, Brazil
*(*Corresponding author: douglas.mazzinghy@angloamerican.com)*

[2]*Anglo American - T&S Group Processing*
Denver
Colorado, USA

[3]*Centro de Tecnologia Mineral*
Ilha da Cidade Universitária
Rio de Janeiro, Brazil

[4]*J-Consultants Ltd*
Avenida Bicentenario 4035, Of. 4062
Santiago, Chile

[5]*Pontificia Universidad Católica de Chile*
Avenida Libertador Bernardo O Higgins 340
Santiago, Chile

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ABSTRACT

The Minas-Rio project, an Anglo American property located in Brazil, started operations at the end of 2014. The design production is 24.5 MTPY of Pellet Feed, obtained by processing an itabirite iron ore. The Minas-Rio regrinding circuit is currently the largest Vertimill installation in the world, consisting of sixteen VTM-1500 Vertimills, in closed circuit with hydrocyclones. The objective of this study was to verify the grinding efficiency of the industrial regrind circuit through a sampling campaign. The results showed that the target particle size distribution is being achieved, and that the specific energy is similar to design value.

KEYWORDS

Vertimill, Vertical Mill, Stirred Mill, Vertical Agitated Media Mill, Regrind, Regrinding, Iron ore, Itabirite, Minas-Rio.

INTRODUCTION

Vertimill

There are many different technologies that can be used for regrinding applications, such as ball mills, and high intensity stirred mills. Among the alternatives, the vertical stirred mill (Vertimill by Metso) has become a popular option for fine grinding in the minerals industry. This is due to a good balance between cost and energy efficiency. Recently, Vertimills have also become an attractive option for secondary and tertiary grinding circuits (Palaniandy *et al.*, 2015). Figure 1 shows the primary Vertimill features.

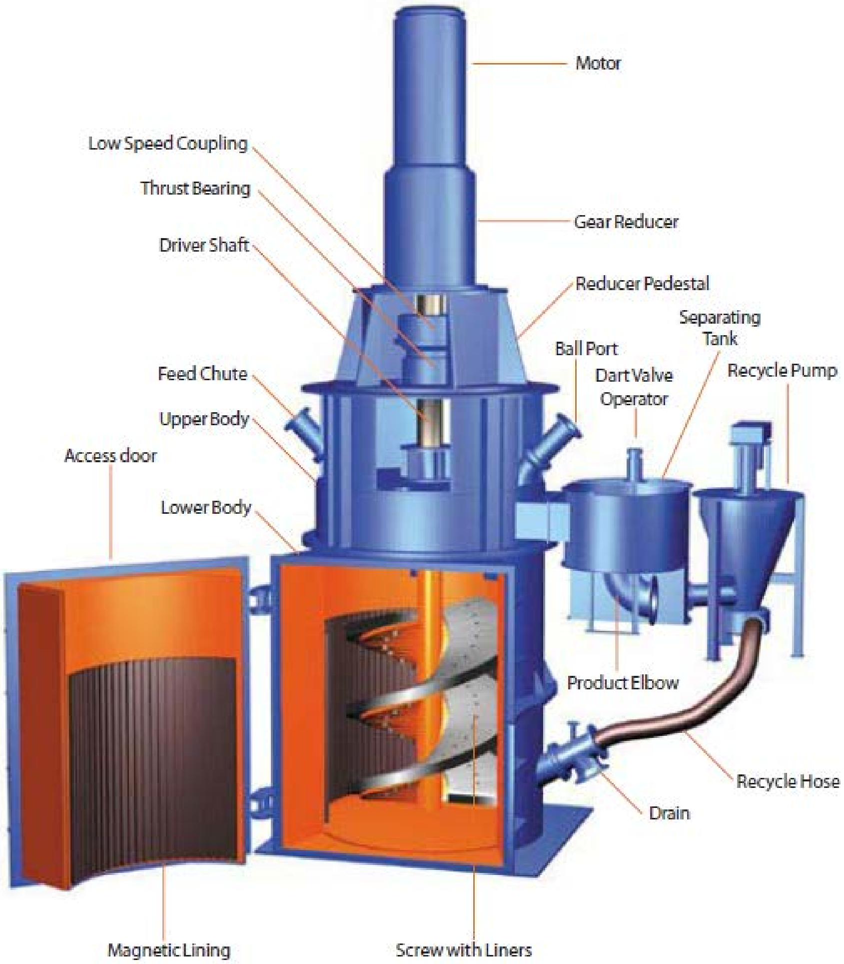

Figure 1 – Vertimill features (Metso, 2005)

The fundamentals of fine and ultrafine grinding in a stirred ball mill were detailed by Herbst and Sepulveda (1978). Shi *et al.* (2009) carried out tests in a laboratory scale vertical mill and found the mill to be 25% to 37% more efficient than ball mills. Mazzinghy *et al.* (2015) performed tests with a pilot scale Vertimill and concluded that the specific selection function (energy based) is approximately 35% higher (on average) than a ball mill in a similar duty. In addition, many investigations with industrial vertical mills have shown that vertical mills are typically 30% to 50% more efficient than ball mills (Pena *et al*., 1985; Vanderbeek, 1998; Jankovic *et al*., 2006; Brissette, 2009; Junior *et al.*, 2011).

A Vertimill typically operates with a ball charge of approximately 1.8 m to 2.0 m deep. There are two clearly defined zones inside the Vertimill: the grinding zone and the classification zone. Both zones are shown on Figure 2.

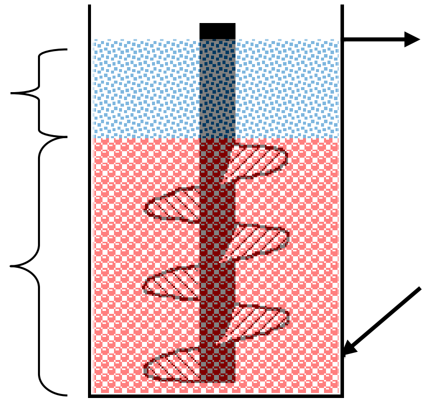

Figure 2 – Vertimill grinding and classification zones

Vertimills can be either top fed (the new feed is introduced into the top of the mill via a feed pipe that deposits the feed just above the grinding media), or bottom fed. In the case of Minas Rio, the cyclone underflow is fed by gravity into the bottom of the Vertimills. The feed is therefore first forced through the grinding zone (thereby minimizing the potential for bypass), before it reaches the classification zone. Coarse oversize material that is too large to leave the mill recycles back into the grinding media, whereas fine particles are carried by the slurry to the mill overflow, then to the cyclone feed sump.

Morrison *et al.* (2009), using discrete element method modelling, showed that the basic difference between vertical mills and ball mills arises from differences in the frequency and energy intensity of ball collisions. The higher efficiency of the vertical mills is due to the higher frequency of lower energy impacts and, by the same token, lower frequency of higher energy impacts when compared to conventional ball mills (Mazzinghy *et al*., 2013).

Minas-Rio

One of the world's largest iron ore projects, Minas-Rio is a fully integrated export iron ore operation, including a mine, processing plant, 529 km of slurry pipeline and a dedicated export facility at the port of Açu. The processing plant, located in the city of Conceição do Mato Dentro, in the state of Minas Gerais, is responsible for producing 24.5 MTPY of Pellet Feed. Minas-Rio is a property of Anglo American, and started operation at the end of 2014. Figure 3 shows the Minas-Rio project's flowsheet.

Hematite is concentrated in a reverse flotation circuit with the quartz impurities removed in the flotation froth phase. The hematite concentrate is then sent to the regrind circuit to reduce the particle size distribution to a P_{80} = 36 µm. This size reduction is required to prepare the feed to the slurry pipeline that transports the Pellet Feed from the processing plant in Minas Gerais state, to the port of Açu in the State of Rio de Janeiro.

The regrind circuit is currently the largest Vertimill installation in the world, with sixteen Metso VTM-1500 Vertimills (the larger VTM-3000's were not available at the time of the project inception). Provision has been made in the layout for the addition of four more VTM-1500's if required in the future.

Figure 4 shows a view of the regrind mill circuit installed at Minas-Rio.

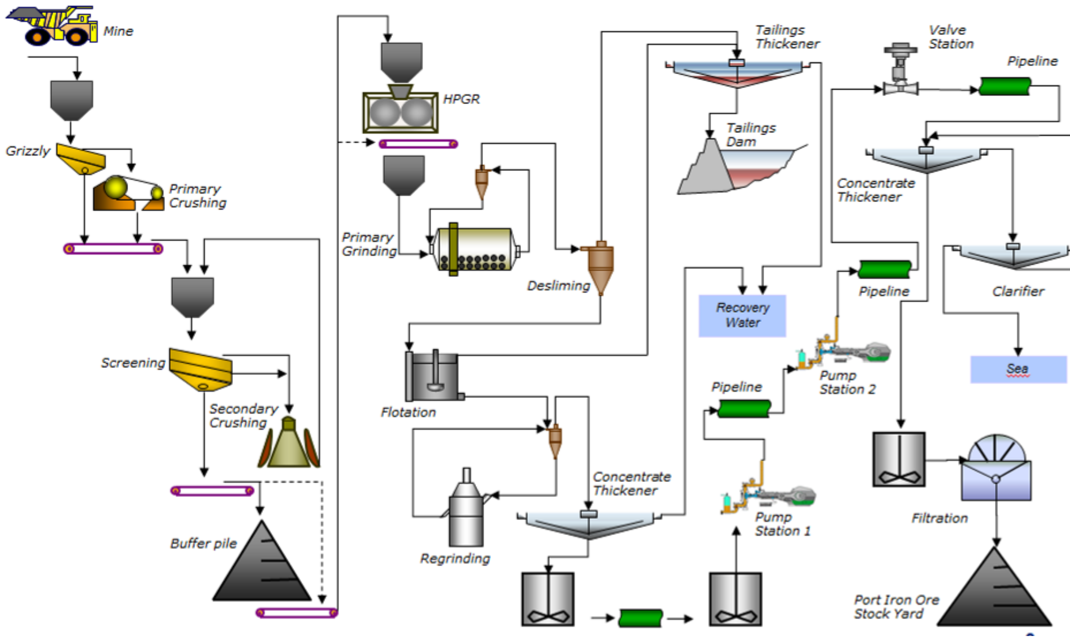

Figure 3 – Minas-Rio flowsheet

Figure 4 – Regrind mill circuit

The regrind circuit is closed with hydrocyclones clusters, in the reverse configuration (regrind feed reporting to the cyclone feed sump, and cyclone underflow reporting to the Vertimills). Figure 5 shows the layout of one of the two banks of eight VTM-1500's.

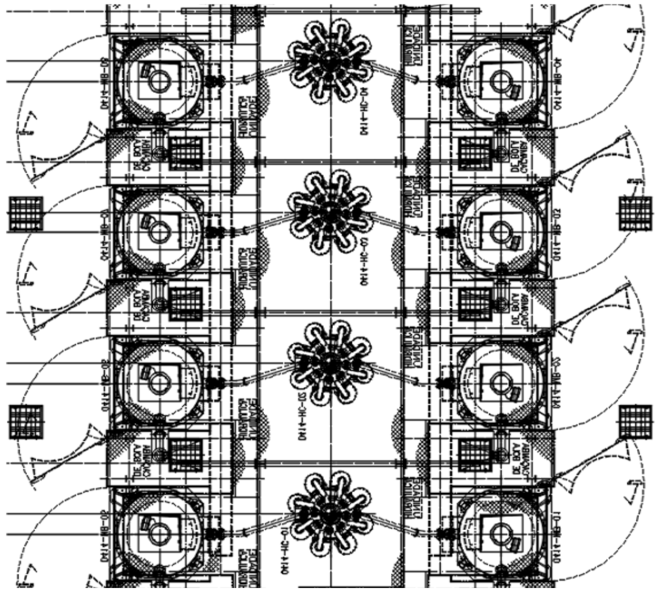

Figure 5 – Installation layout

Design Criteria

The Minas-Rio regrind mill circuit was designed using pilot scale test results, obtained from a Vertimill pilot test campaign (Metso, 2011). The tests were carried out using more than 8 tons of flotation concentrate that was prepared in Brazil and shipped to York, PA, USA. Before the pilot tests started, a batch ball mill test (jar mill test) was carried out to estimate the specific energy consumption in advance of the pilot test. This information was used for the pilot test design, in particular for definition of the feedrate. Figure 6 shows the particle size distributions as obtained from the jar mill tests performed with the hematite concentrate.

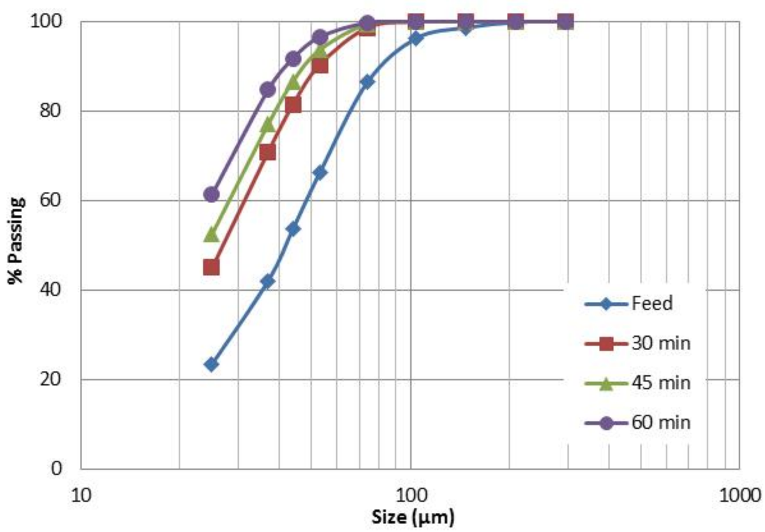

Figure 6 – Jar test particle size distributions (Metso, 2011)

The 60 minute jar mill test was selected, and the specific energy obtained from the test was multiplied by a factor of 0.65, to estimate the specific energy consumption (kWh/t) for a pilot or industrial Vertimill circuit.

The pilot test was carried out in reverse configuration in closed circuit with a high frequency screen. Figure 7 shows the Vertimill pilot plant layout. As the Minas Rio regrind circuit would use cyclones as classifiers, part of the slurry feed to the high frequency screen was by-passed directly to the mill, to more accurately emulate a typical hydrocyclone partition curve.

Figure 7 – Vertimill pilot plant (Metso, 2011)

A ball mill (483mm x 908mm) equipped with a feed chute was used without media as a mixer as shown in Figure 7. Figure 8 shows the particle size distributions obtained from the Vertimill pilot test.

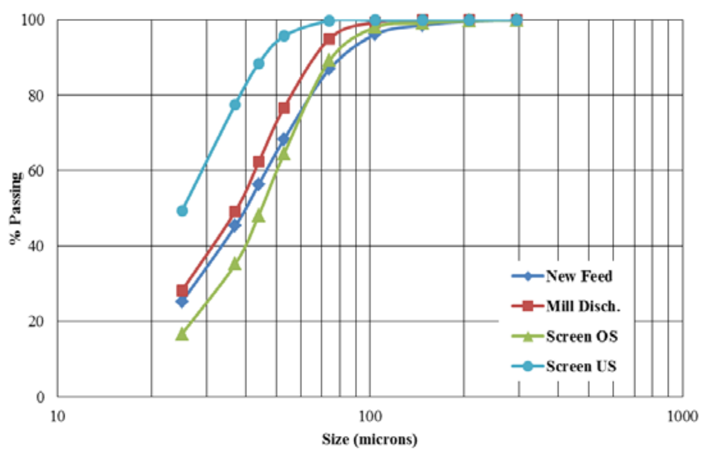

Figure 8 – Particle size distributions obtained from the Vertimill pilot plant (Metso, 2011)

Table 1 contains the results from the jar mill test and from the pilot test. All specific energy consumptions shown were calculated using the net power draw. The 6.5 kWh/t SE for the jar mill test shown in Table 1 is after the application of the 0.65 multiplier.

Table 1 – Results from jar test and Vertimill pilot test campaign (Metso, 2011)

Data	Jar Test	Pilot Test
F_{80} (µm)	66	66
P_{80} (µm)	36	39
SE (kWh/t)	6.5	5.3
OWi (kWh/t)	14.9	13.9

The Operating Work Index (OWi) was used to compare the performance of the jar mill test and the pilot test by allowing for differences in the product size distributions. Equation 1 was used for these calculations (Bond, 1952).

$$OWi = \frac{E}{10\left[\left(\frac{1}{\sqrt{P_{80}}}\right)-\left(\frac{1}{\sqrt{F_{80}}}\right)\right]} \quad (1)$$

OWi = Operating Work Index (kWh/t), E = Specific energy (kWh/t), F_{80} = 80% passing on feed size (µm), P_{80} = 80% passing on product size (µm).

The Operating Work Index (OWi) of the jar test was approximately 7% higher than that obtained from the pilot milling tests. The jar test was considered to be a more conservative (and less accurate) estimate. The specific energy obtained from pilot test was therefore used for the design of the Minas-Rio industrial regrind circuit (5.3 kWh/t).

OBJECTIVE

The objective of this study was to verify the actual grinding efficiency of the circuit, through a sampling campaign of the regrind circuit.

EXPERIMENTAL

Sampling Campaign

The samples collected during the survey of the Minas-Rio regrind circuit were used to generate a mass balanced data set. Each hydrocyclone cluster feeds two Vertimills. Figure 9 shows the regrind flowsheet with the sampling points.

The particle size distribution (fractions < 38µm were determined by cyclosizer), solids concentration and specific gravity were determined for each stream sampled, these being: New Feed, VTM Discharge, Cyclone Feed, Underflow and Overflow.

Specific Energy Estimation by Batch Mill Test

Batch grinding tests were carried out on samples of the new feed to the regrind circuit. A conventional tubular ball mill was used for these batch tests. The tests followed the same procedures used by Metso to estimate Vertimill specific energy consumption. The procedure involves grinding the material in increasing time intervals until the required product specification (P_{80}) is achieved.

The specific energy for the test material (kWh/t) was calculated from the measured net power draw (kW), mass holdup (t) and grinding time (h) to achieve the product specification. The specific energy (kWh/t) was then multiplied by a factor of 0.65 to obtain the estimated specific energy required for an Industrial Vertimill regrind circuit.

Table 2 shows the conditions of the batch grinding test performed.

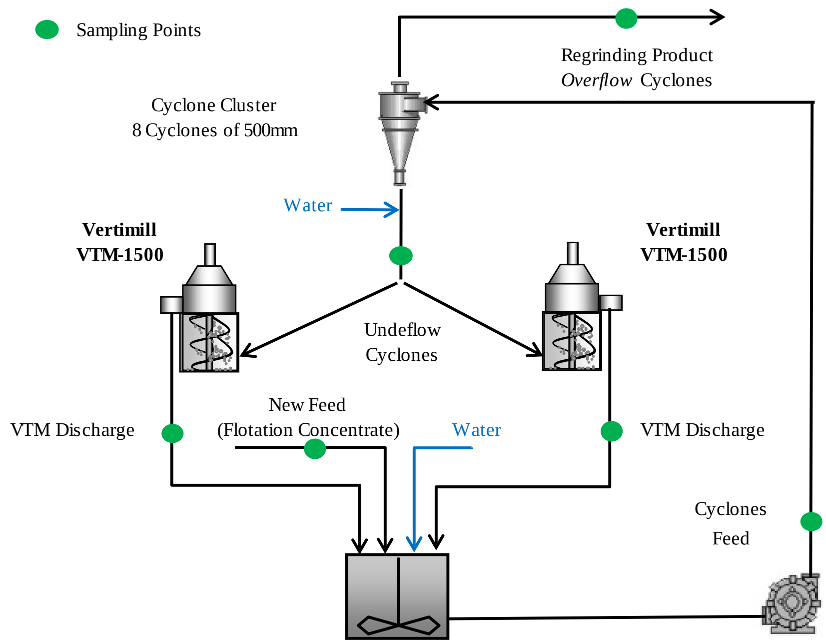

Figure 9 – Regrind mill flowsheet with sampling points

Table 2 – Batch grinding test conditions

Diameter (mm)	208
Lenght (mm)	208
Ball Bed Porosity (%)	40
Ball Charge – *J* (%)	42
Powder Filling – *U* (%)	100
Critical Speed (%)	76
Solids Concentration (%)	70

RESULTS AND DISCUSSION

Mass Balance

Three sampling campaigns were completed and the data was used to produce a mass balance. Figures 10 to 14 show the particle size distributions in each stream. The experimental data is represented using points, and the mass balanced data is represented using lines.

The cyclone overflow data showed the most significant deviations between the individual samples collected. It is possible to infer that these deviations are related to circuit instability as the samples were collected during the ramp up phase. In general, repeatability was considered to be acceptable.

Figure 15 shows the mass balanced data from all sampling campaigns.

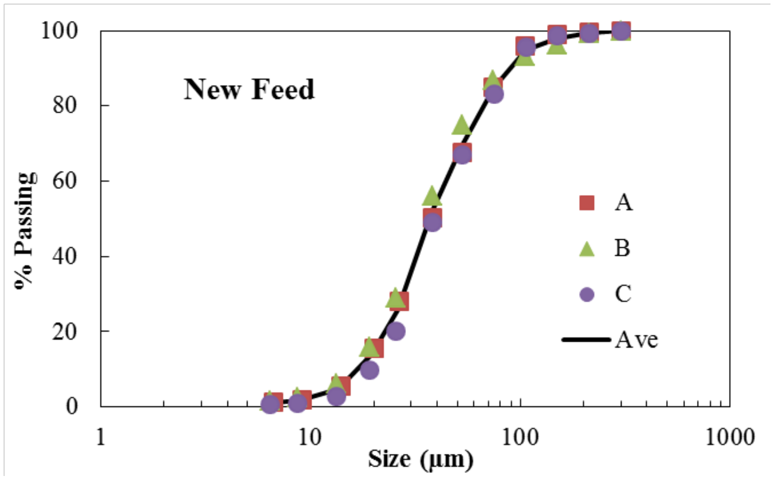

Figure 10 – Particle size distribution for new feed

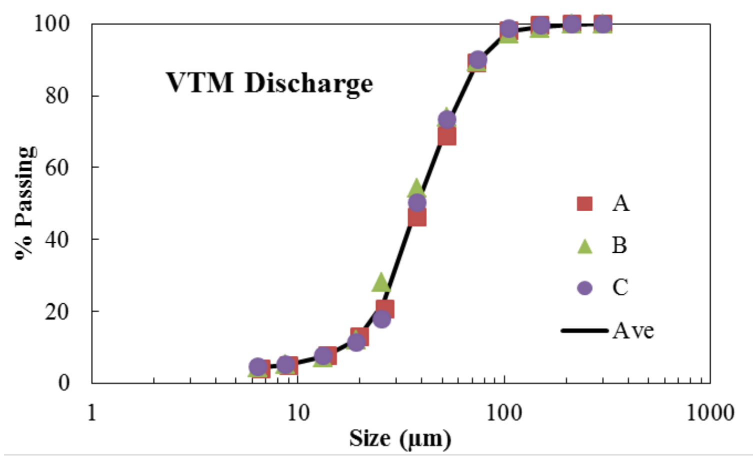

Figure 11 – Particle size distribution for VTM discharge

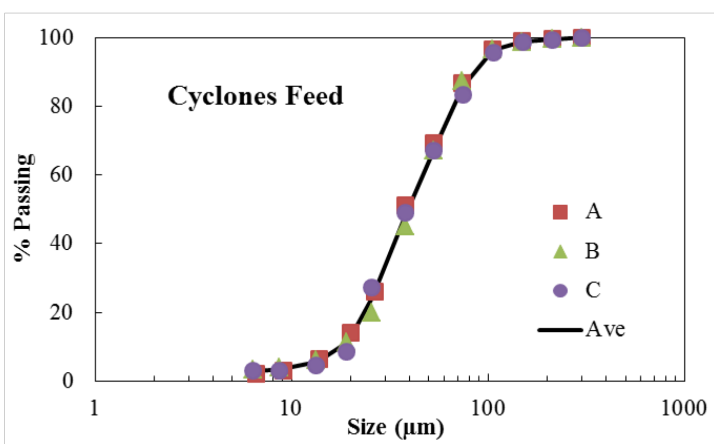

Figure 12 – Particle size distribution for cyclone feed

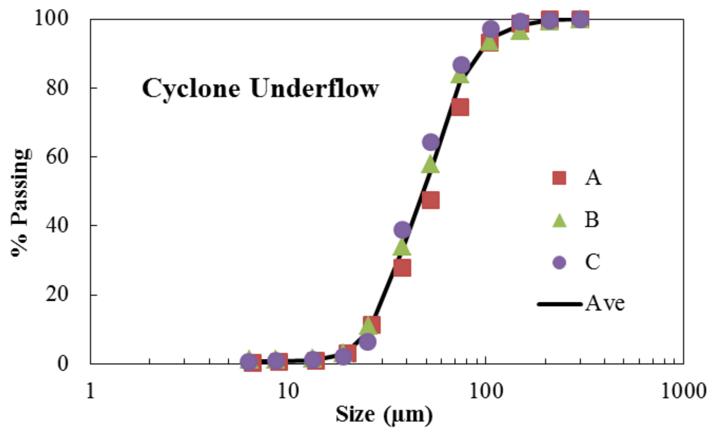

Figure 13 – Particle size distribution for cyclone underflow

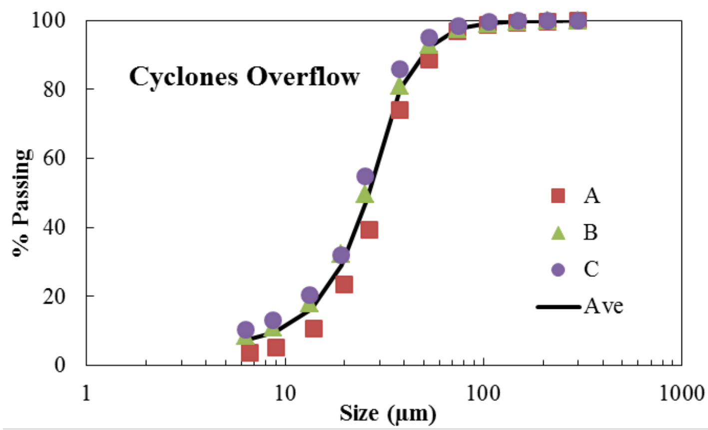

Figure 14 – Particle size distribution for cyclone overflow

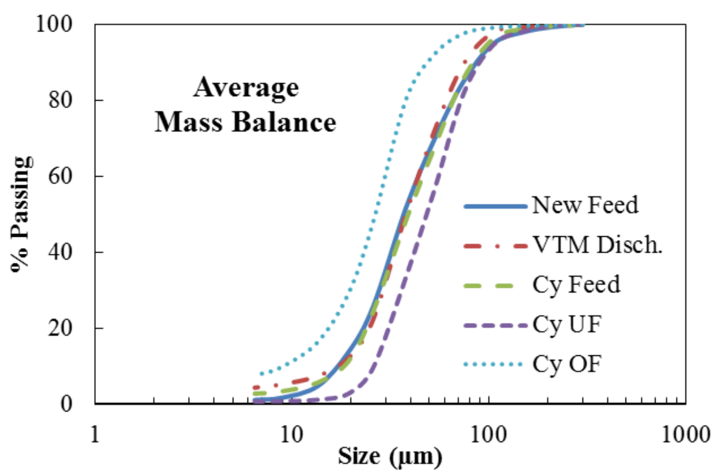

Figure 15 – Mass balanced data

Batch Grinding Tests

Batch grinding tests were run on the samples collected during the sampling campaign. The sample was milled for three time intervals, set at 20, 40 and 60 minutes, until the product specification of a P_{80} = 36 μm was achieved. Figure 16 shows the particle size distributions obtained from the batch grinding tests using the new feed sample (the hematite concentrate).

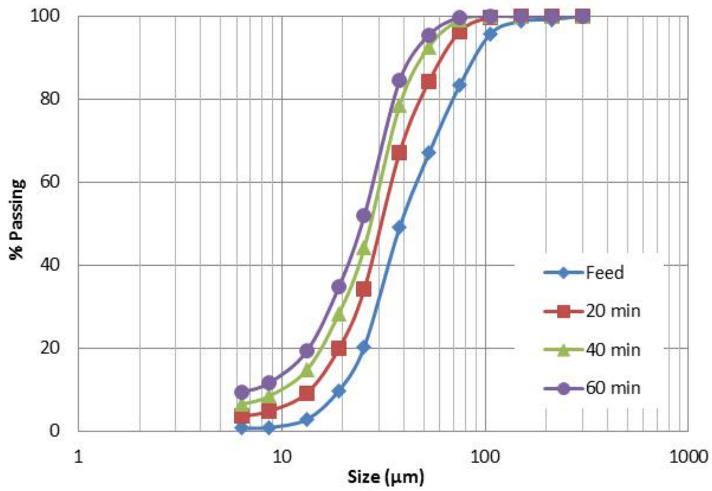

Figure 16 – Batch grinding test results

The last grind time (60 minutes) produced a product with a P_{80} = 36 μm, at a specific energy consumption of 8.9 kWh/t. The measured specific energy from the last test of 8.9 kWh/t was multiplied by a factor of 0.65 resulting in a value of 5.8 kWh/t as an estimate for the required specific energy for the Vertimill's at Minas Rio.

No-load Power Estimation

The no-load power draw of one Vertimill installed in Minas-Rio was measured during the unloading of a ball charge. The no-load power draw measured was equal to 130 kW, which is equivalent to 11.6% of the installed power (130 kW / 1119 kW = 11.6%). Figure 17 shows the gross operating power measured with time. The Vertimill was unloaded after approximately 3 minutes.

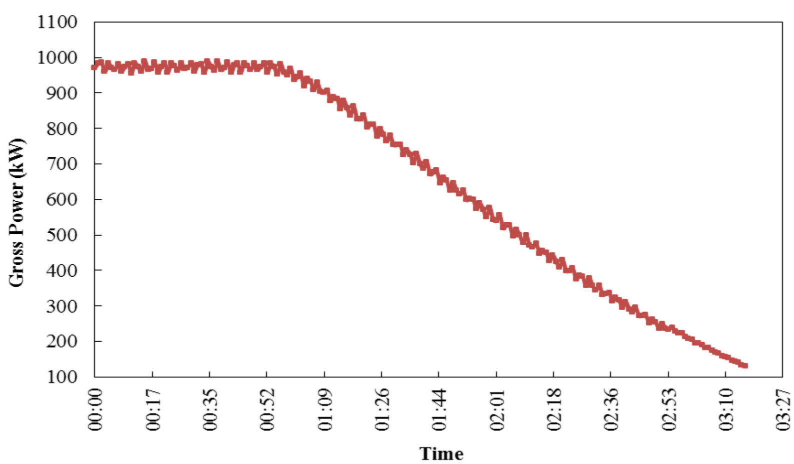

Figure 17 – No-load power measure during the mill charge unload

Therefore, the Vertimill had the unloading interrupted when the balls and water stopped to leave the open gate. When the Vertimill was opened, there were some balls between the bottom and the screw as showed in the Figure 18.

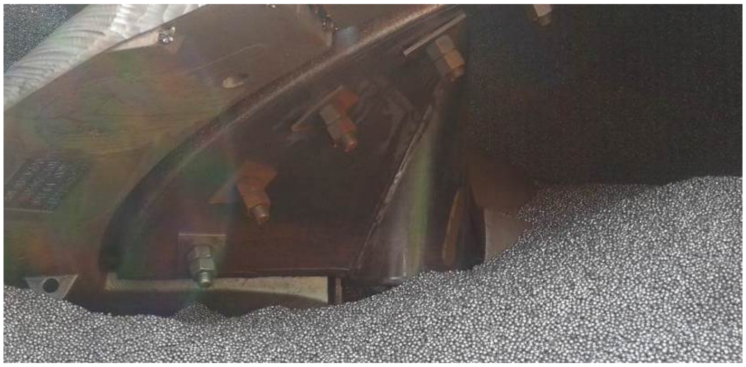

Figure 18 – View inside the Vertimill after the media charge unloading

A no-load power of 10% of the total power for VTM-1500 was used for this analysis, as a conservative estimate. This value was considered to correlate well with the measured value (mill not totally empty), and estimated losses for the motor, reducer bearings and bushings in the Vertimill drivetrain. Using this estimate for the drive losses, a comparison can then be made for the results from the laboratory, pilot, and industrial milling tests. A detailed investigation of the no-load power for Vertimills VTM-1500 is ongoing (Esteves *et. al.*, 2015).

Comparison between Design Criteria and Sampling Campaign

The available gross specific energy consumption for the industrial circuit is 5.9 kWh/t, calculated as shown below:

16 Vertimills * 1119 kW = 17900 kW / 3040 t/h = 5.9 kWh/t (total)

These calculations are based on the Vertimill's total power. Discounting 10% for no-load power (1119 kW – 10% = 1007 kW) the specific energy consumption would be 5.3 kWh/t, calculated as shown below:

16 Vertimills * 1007 kW = 16114kW / 3040 t/h = 5.3 kWh/t (available)

The industrial (plant operating) SE was calculated using the average feedrate during the sampling campaign of 159 t/h, and the measured gross power of 994 kW. The no-load power was estimated at 10% of the gross power, and subtracted from the gross power measured, to calculate a net power equal to 895 kW. This resulting in a calculated SE of 5.6 kWh/t (895 kW / 159 t/h). The SE calculated (5.6 kWh/t) is higher than the available SE (5.3 kWh/t) primarily due to the regrind circuit still being operating below the design feedrate during the ramp up phase of the project (3040 t/h / 16 VTM's = 190 t/h for each VTM). Improvements in efficiency are expected once the mills reach full design capacity and are fully optimized.

Table 3 shows the values used for the design (Metso, 2011), and the actual data obtained from the sampling campaign.

Table 3 – Comparative: Design Criteria vs Sampling Campaign

Data	Design Criteria (Metso Tests)		Sampling Campaign	
	Lab Test	Pilot Test	Lab Test	Industrial
F_{80} (µm)	66	66	62	62
P_{80} (µm)	36	39	36	35
SE (kWh/t)	6.5	5.3	5.8	5.6
OWI (kWh/t)	14.9	13.9	14.6	13.3

The product specification is being achieved, the actual P_{80} = 35 µm closely matches the design P_{80} = 36 µm for the project.

The pilot tests results compare well with the measured specific energies determined during this sampling campaign. Both of the lab mill tests returned values slightly higher than the pilot and measured SE's confirming that the lab mill test is a conservative option for the estimation of the specific energy for the selection of Vertimills. The design margin is appropriate.

Also, the specific energy obtained from lab tests and pilot tests campaign are close to values obtaining in the industrial circuit, which demonstrates the representativeness of the regrind circuit feed samples employed in the design of the project.

The Operational Work Index (OWi) was used to allow a comparison of the lab test, pilot test and industrial data, making allowances for the small differences in feed and product size distributions during the different tests. Equation 1 was used for these calculations (Bond, 1952). The OWi obtained from the industrial operation (13.3 kWh/t) was approximately 4% lower than the OWi from pilot test (13.9 kWh/t). The OWi derived from the batch ball mill tests conducted on the survey sample was ~2% lower than that derived during the original laboratory work. Differences between laboratory and industrial (operational) OWi are therefore negligible and well within the limits of accuracy for such a comparison.

CONCLUSIONS

The sampling campaign results showed that the target product is being achieved, with a project design P_{80} = 36 µm and an actual P_{80} = 35 µm. The specific energy obtained (5.6 kWh/t) is close to the specific energy predicted during the design stage (5.3 kWh/t). With allowances for feed and product sizes, the OWi for the industrial plant is within 4%, or less, of the original design value, with some room still expected for optimization as the plant ramps up to full design capacity.

In addition, the use of the 0.65 factor used in adjusting the laboratory ball mill data to estimate the industrial Vertimill specific energy consumption was demonstrated to be an acceptable (conservative) method of estimation for design purposes.

The sampling campaign at this stage of the Minas Rio Project has shown a number of opportunities for optimization, and additional potential to reduce the specific energy consumption.

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