Regrind of metallic ores with Vertical Mills: An overview of the existing plants in Brazil

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ABSTRACT

At the regrind or secondary grinding stages of metal ores, usually the concern about the energy efficiency is extremely important. In general, the specific energy consumption at this stage is higher than in the primary stages of grinding. In addition, it has been observed a tendency of finer grinding in the new projects of metallic ores, due to the finer mineral liberation, which leads to an increasing capital and operational costs. In Brazil, during the last 10 years, regrind P_{80} sizes of approximately 40 to 20 µm have been necessary in all new iron and copper plants. The use of conventional ball mills, adequate for primary grinding, can result in low energy efficiency with products below a P_{80} of 50 µm.

This paper presents an overview of the regrind circuits in Brazil that operate with vertical mills and the results of industrial surveys at selected vertical mill circuits. Where possible, comparison is made between the plant results and the design criteria and laboratory regrind tests used for the mill sizing.

INTRODUCTION

A significant demand for increasingly fine grinding to achieve the necessary mineral liberation for mineral concentration has been observed in recent decades in Brazil. The finer the product size, the greater the grinding energy consumption. In view of the significant impact of energy costs on the total costs of this mineral processing operation, which may reach or even exceed 50% of the overall cost, the correct choice, as well as the application of the grinding circuit to be used, is of fundamental importance to the viability of a mining venture. In addition, the type of technology used for comminution may have a significant impact on the subsequent stages of mineral concentration. In this context, various items of equipment have been developed in recent years, aimed at the regrind, fine and ultra-fine comminution of ores. The mills that have shown greatest application growth in wet-grinding circuits of metallic ores are the ones commercially called Vertimill® and Isamill®. The first one is a vertical stirred mill that works with a relatively low rotational speed, which will be referred to in this paper as a Vertical Mill. The second one is a horizontal mill whose impeller operates on higher rotational speed. There are currently 42 Vertimills® in operation or in plants under construction in Brazil, as indicated by Table 1. As far as the authors are aware, Brazil don't have any Isamill® in operation or in plants under construction.

Table 1 Vertimill® in operation or in plants under construction in Brazil

Project	Company	Ore	State	Mill type	Units	Projetc status
Sossego	Vale	Cooper	Pará	VTM-1500	2	In operation
Salobo	Vale	Cooper	Pará	VTM-1500	4	In operation
Maracá	Yamana Gold	Cooper	Goiás	VTM-1000	1	In operation
Paracatu	Kinross	Gold	Minas Gerais	VTM-1250	1	In operation
Jaguarari	Caraíba	Cooper	Bahia	VTM-200	1	In operation
Germano	Samarco	Iron	Minas Gerais	VTM-1500	1	In operation
Conceição do Mato Dentro	Anglo American	Iron	Minas Gerais	VTM-1500	16	In construction
	Vale			VTM-200	1	R&D
Serra Azul	MMX	Iron	Minas Gerais	VTM-3000	14	In construction
Serrote da Laje	Aura Minerals	Cooper	Alagoas	VTM-1500	1	In construction

Source: Metso, 2011 and Field survey of the authors.

Considering that each regrind and fine or ultra fine grind technology is usually developed by a research center or particular company, becoming, therefore, a proprietary technology - a true "black box", there is a lack of sound data available in the literature that is useful for benchmarking energy efficiency and particularly information that supports the vendors claims. The mineral sector lacks comparative and detailed studies that indicate which regrind equipment is more efficient for each regrind or fine and ultra fine grind application. The work conducted by the United States National Research Council (COMMITTEE, 2002) indicated that the technologies available for grinding under 52 μm are still inefficient and limited, in spite of the progress achieved with the stirred mills. The same research points out that further gain can still be achieved in this area, thus reducing specific energy consumption. Several authors also estimate that the grinding technology of stirred mills will be of fundamental importance to minimize energy consumption associated to grinding (Bergerman, 2013; Daniel, 2011; Marsden, 2009; Napier-Munn, 2012; Norgate & Jahanshari, 2011; Rule & Neville; 2012; Valery Junior & Jankovic, 2002).

This paper presents an overview of regrind circuits in Brazil that operates with Vertical Mills and the results of industrial surveys at selected Vertical Mill circuits, while comparing these results to the design criteria and laboratory regrind tests used for the mill sizing at the plants were these data were made available to the authors.

METHODOLOGY

Visits were carried out and interviews with process teams of all Brazilian plants in operation with Vertical Mills were conducted. In four of these plants (Sossego, Maracá, Paracatu and Jaguarari), one or more samples were collected from their regrind circuits. It is worth noting the sampling difficulty in large capacity industrial circuits, described in detail in Bergerman (2013). At the four plants which samples were taken, flows of the regrind circuits, including the new feed, feed, overflow and underflow of the cyclones and the Vertical Mills' feed and discharge were sampled. The sampling was always carried out during a period of 2 hours, in which the plant was considered under stable operation, with samples taken every 15 minutes. Another aspect deserving attention during sampling was the operation of sump pumps, which, if in operation, may destabilize the circuit. In the current work, the procedure adopted was to not operate them for the two hours prior to sampling. For all samples collected, the percentage of solids and particle size distributions were determined. At Sossego and Paracatu plants, data of regrind circuit new feed were calculated based on field mass flow and density meters and with the cyclone partition data. At the others plants which samples were conducted, this instrumentation were not available. Bergerman (2013) describes in more details the methodology adopted, as well as the complete results from the sites surveys.

RESULTS AND DISCUSSION

Sossego mine – Vale S.A.

Figure 1 displays the regrind circuit at Sossego plant, composed by two VTM-1500 Vertical Mills, operating in closed circuit with cyclones, internal recirculation box and feeding through the lower portion of the mill.

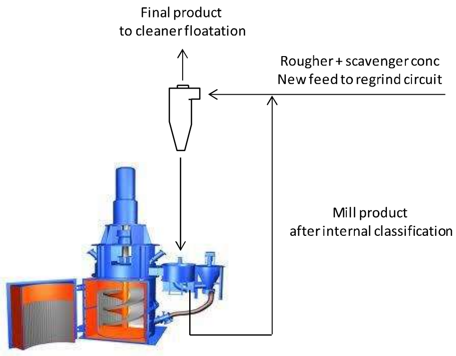

Figure 1 Sossego regrind circuit

Each Vertical Mill is 1,118 kW and has a mill feed pump of 110 kW and a cyclone feed pump of 200kW. The circuit features pressure gauges in the cyclones feed tank and density and flow meters on the cyclones' feed. The Vertical Mills operate with chrome steel grinding balls of 19 mm diameter, for a consumption of approximately 20 g/t of new flotation feed. In terms of maintenance, the team at Sossego reports few problems with this equipment. The main maintenance items are the mill feed pump and the screw liner, which is replaced every 12 months. Sossego's regrind circuit was designed based on jar mill tests by the manufacturer. The tests indicated a need for 6.0 kWh/t to reach a P_{80} of 44 µm from the ore at Sossego mine and 10.4 kWh/t for the same P80 from the ore of Sequeirinho mine. The installed equipment presents capacity to process approximately 165 t/h of new feed (rougher and scavenger concentrate), with a F_{80} feed of approximately 210 µm and a P_{80} of 44 µm.

Figure 2 exhibits the results of the samplings carried out on the industrial circuit, from the beginning of the operation, in 2004, until 2011, compared to the laboratory tests carried out by the supplier for the circuit sizing.

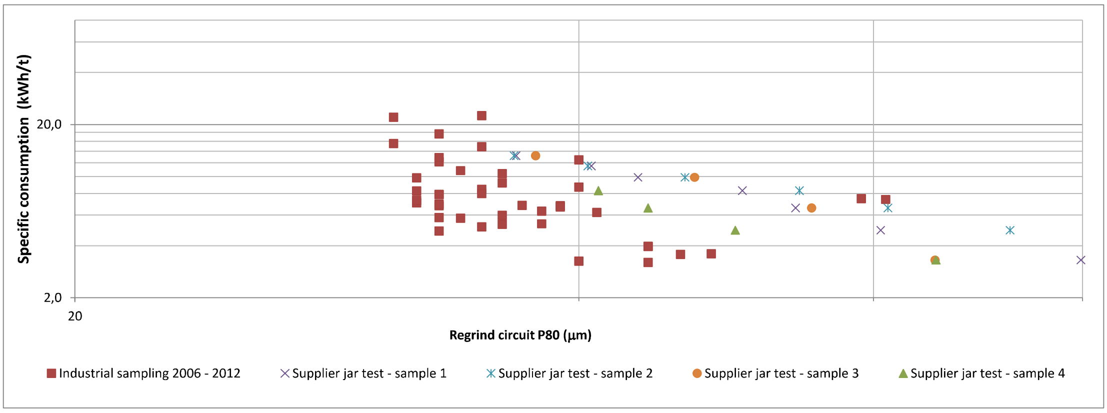

Figure 2 Relation between the energy specific consumption and the P_{80} of the regrind circuit

It is important to highlight the relatively high dispersion of the data obtained industrially. The regrind circuit is a circuit whose particle size and feed flow fluctuate a lot more than the new feed of the grinding circuit. On the basis of these fluctuations, it is difficult to maintain the best condition of operation. The evaluation of data of the Vertical Mill feed flow from the beginning of the plant's operation, in 2004, indicates that the feed flow of the regrind circuit ranges between 50 and 400 t/h. The nominal flow rate considered in the project was 173 t/h.

Even with such dispersion of specific energy consumption data, it is possible to highlight some important points. The first one is a clear trend of specific energy consumption increase along with a finer product. Specific consumptions close to 20 kWh/t were required for products with a P_{80} of the order of 30 - 35 µm, although for the target P_{80} size of 44 mm, a specific consumption much lower, around 4 to 6 kWh/t, was necessary. Another point that draws attention is that the specific energy consumptions determined by tests performed by the supplier present higher values than those observed industrially for a same product size. The detailed analysis of the data obtained in the field and the samples sent for jar mill tests indicated a significant difference on the samples feed particle size. While in jar tests the samples had F_{80} varying between 116 and 185 µm, with an average value of 160 µm, observation of the available data over the 7 years of industrial samples indicated an average F_{80} of 92 µm, with variation between 42 and 216 µm. Hence the size of particles that feed the circuit is well below those used for mill sizing tests. This helps explain the lower energy consumption observed industrially. Since the particle size measured for the rougher flotation feed in the Sossego plant is close to the design value (210 µm), a detailed evaluation of these data was conducted, to better understand this differences. The rougher flotation feed particle size distribution was compared with that of the rougher concentrate, which constitutes the new feed of the regrind circuit. A clear tendency of the rougher concentrate's particle size to be significantly finer in relation to the feeding of the same step was observed. This difference is due to two factors. The first one is that coarser particles may not be released or are too heavy to be floated, thus being moved to the tailings. The second is that the sulfides in the ore of Sossego, which are concentrated in the rougher step, exhibit significantly higher densities than the rest of the gangue, composed primarily of oxides and silicates. This difference in density is likely to cause sulfide particles of same size of gangue's to be moved to the cyclone underflow of the ball mill, thus being grounded beyond need.

Rio Paracatu Mine – Kinross

Figure 6 shows regrind circuit of Rio Paracatu plant, composed of a VTM-1250 Vertical Mill, operating in closed circuit with cyclones, internal recirculation box and feeding through the lower portion of the mill.

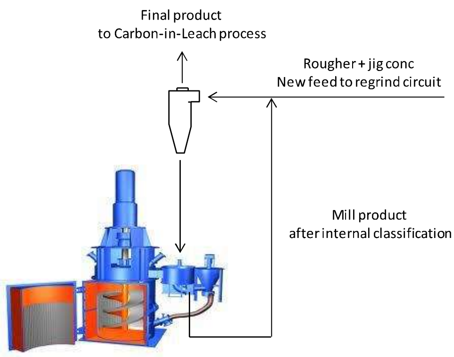

Figure 6 Rio Paracatu regrind circuit

Santos Júnior et al. (2011) presented some data on the Paracatu Vertical Mill circuit process, as well as its comparison to the plant's conventional ball mill. The authors calculated the grinding efficiency, based on the value of the Operating Work Index divided by the Bond WI of the circuits new feed. The calculated value for the conventional ball mill is 0.85, while the Vertical Mill is 1.5. It should be highlighted, although, that the ball sizes used at each circuit are different, due the limitations for small ball sizes at the conventional ball mill. The comparison of the selection function between the mills also indicated the Vertical Mill was the best performer. Santos Júnior et al. (2011) also reported lower consumption of grinding bodies in the Vertical Mill - 69 g/kWh versus 80 g/kWh observed in the ball mill. The specific energy consumption measured in the Vertical Mill was 9.7 kWh/t, while in the ball mill it was 11.2 kWh/t. It is important to note here that the ore that feeds the Vertical Mill has a higher WI than the ore that feeds the ball mill. The Vertical Mill uses a magnetic liner and the maintenance crew did not report any significant problems. Results from sampling carried out on the Vertical Mill circuit demonstrated that the reduction ratio was approximately 20, considering a F_{80} of 604 μm and a P_{80} of 30 μm. The specific energy consumption measured was approximately 8.4 kWh/t.

Jaguarari Mine – Caraiba

Figure 7 shows the regrind circuit of Jaguarari mine plant, composed of a VTM-200 Vertical Mill, operating in closed circuit with internal recirculation box and feeding through the lower portion of the mill. This was the only circuit visited that operates in open circuit, were the Vertimill Product was sent directly to the cleaner flotation circuit.

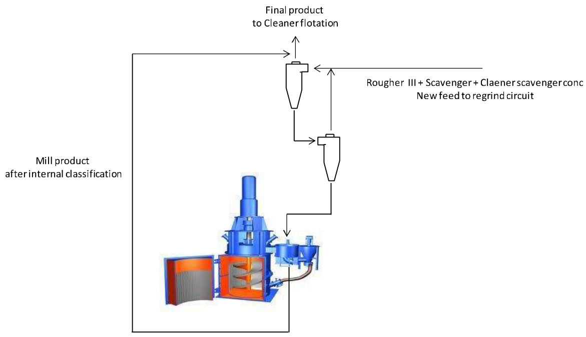

Figure 7 Jaguarari regrind circuit

In this operation 25 mm grinding balls are employed. The mill uses a magnetic liner and the maintenance area did not report significant problems. The equipment had been operating for a short period by the time the visit happened, on August 2012. As soon as the operation began, the company's team noted that the reduction ratio obtained was very low, even with the mill operating at its maximum amperage capacity – with a F_{80} of 150 μm and a P_{80} of 105 μm. Due to circuit restrictions in instrumentation, it was not possible to determine the new feed mass to the regrind circuit. In order to achieve a finer product, industrial testing were done on the recirculation valve and on the increase of solid percentages, but without significant effects. At the end of 2012, the circuit was modified so that the Vertical Mill operated in closed circuit with cyclones. Despite the lack of sampling data, the information transmitted by Caraíba's operation team is that after this change the project values had been reached, with P_{80} ranging from 45 to 53 μm.

Maracá Mine – Yamana Gold

Figure 8 displays the regrind circuit of Maracá plant, composed of a VTM-1000 Vertical Mill, operating in closed circuit with cyclones, without the internal recirculation box, and feeding through the upper portion of the mill.

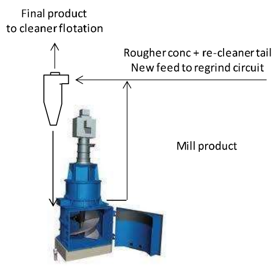

Figure 8 Maracá regrind circuit

The Vertical Mill installed power is 746 kW and the feeding pump for cyclones is 225 kW. The mill operates with 25.4 mm diameter steel grinding balls, and the consumption is approximately 29 g/t of new flotation feed. The maintenance work reported by Maracá's team is focused on the wear parts of the mill's screw lower portion, which are replaced every 3 to 6 months, depending on the component. Wear components of the mill screw upper portion are replaced within 12-month intervals. Data from industrial sampling carried out on three occasions, in 2011 and 2012, indicated that the Maracá mining circuit operates with a very low reduction ratio. The regrind product is not reaching the project specification, with a approximately P_{80} of 44 µm, which has resulted in metallurgical recovery losses at the plant. Currently, the mill's new feed presents an approximate F_{80} of 120 µm while the product's P_{80} ranges from 75 to 100 µm. Due to circuit restrictions in instrumentation, it was not possible to determine the new feed mas to the regrind circuit.

Germano Mine – Samarco

Figure 9 illustrates the Germano regrind circuit, consisting of a VTM-1500 Vertical Mill, operating in closed circuit with cyclones, without internal recirculation box and feeding through the mill's lower portion.

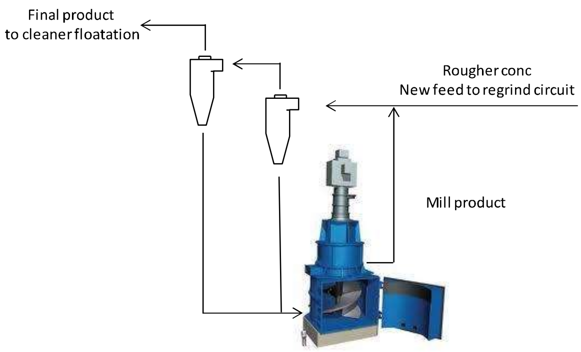

Figure 9 Germano regrind circuit

The Vertical Mill installed power is 1,118 kW and the 2 feeding pumps for the cyclones has 168 kW of total power. The Vertical Mill at Samarco operates in parallel with ball mills. The regrind is fed with the product from the rougher flotation of coarse and fine particles, with an approximate F_{80} of 120 µm. The grinding circuit's product has a P_{80} of approximately 38 µm. In the Vertical Mill, 15 mm diameter grinding balls of high chromium cast iron are used. The ball mill operates with 25 mm grinding balls. The operational solid percentage of both mills is between 78 and 80%. Samarco's process team reports a reduction of approximately 30% in specific energy consumption of the Vertimill, when compared to tubular ball mills, for the same grinding job. The specific consumption of ball grinding is approximately 13.5 kWh/t, while the Vertical Mill consumes approximately 10.4 kWh/t. It should be noted, although, the fact that the ball mills can't operate with smaller media, what could improve the ball mills energy consumption results. With regards to maintenance, the team at Samarco reported that the equipment features low consumption of wear parts. The Vertical Mill has been operating since the end of 2011 and so far only the screw low portion liner has been replaced.

Salobo Mine – Vale S.A.

The regrind circuit at Salobo is similar to the one at Sossego, which is described above. In this circuit, 4 VTM-1500 Vertical Mills operates in paralel. Each Vertical Mill features power of 1,118 kW, in addition to mill feed pumps of 150 kW and cyclones feed pumps of 250 kW. The circuit has pressure gauges on the cyclones' feed and density and flow meters on the cyclones' feed lines. The circuit was designed from the jar tests performed by the manufacturer. The tests indicated a need of 13.5 kWh/t in order to reach the desired product. The installed equipment presents processing capacity of approximately 601 t/h of new feed (rougher 2 concentrate and scavenger concentrate), with F_{80} ranging from 74 to 96 μm and P_{80} between 21 and 23 μm. Until now, no sampling was performed on this circuit, as it just started operation when the plant visits were realized.

CONCLUSION

When comparing the circuits of the plants mentioned in this study, we can observe that the plants of Sossego, Salobo and Rio Paracatu operate in closed circuit with feed through the lower portion of the mill. In these circuits a higher reduction ratio is observed, reaching up to 20 times, as the designed product sizes are obtained. The mining circuits at Maracá and Caraíba, which operate with different settings – in the case of the Caraíba with open circuit, and in the case of Maracá with feeding through the upper portion - the reduction ratios achieved are much lower, in the order of 1.1 to 1.5, and the products are coarser than the designed size. This observation indicates that Vertical Mills operating in closed circuit and being fed through its lower portion can lead to better energy efficiency results, although more detailed study is need, especially regarding the lower or upper feed to the mill. The specific energy consumption values observed in the 4 sampled plants cannot be compared directly, in view of the different ores processed in each one. The case at the Germano mine illustrates an specific energy consumption reduction of approximately 30% on the Vertical Mill operating in similar conditions to a conventional ball mill, what can be at least in part explained for the coarse grinding media at the conventional ball mill.

Another important point, observed in the case of Sossego, was the difference in flotation feed’s particle size and that of the rougher concentrate, which feeds the regrind circuit. The flotation rougher concentrate was approximately 50% finer than the flotation rougher feed, a fact that impacts significantly the operation of regrind mills. With this observation, it should be highlighted the importance of taking into account these difference in the design of new circuits.

Finally, we highlight the great variation in the regrind's feed flow which is due to ore grade fluctuations on the plant's feed. This point can be clearly observed in the data from the Sossego plant. This ore grade variation, common to all processing plants that do not use homogenization stockpiles, does not impact substantially the crushing or primary and secondary grinding operations, but it causes great impact over the regrind feed tonnage, which will suffer significant feed flow oscillations, as described here. This aspect must also be taken into account in the design of the regrind circuits and their auxiliary equipment such as pumps, froth collectors, among others.

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