XXVI IMPC 2012 New Delhi, India

Paper No. 298

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COPPER CONCENTRATE REGRIND AT SOSSEGO PLANT USING VERTICAL MILL – AN EVALUATION ON THE FIRST YEARS OF OPERATION

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ABSTRACT

At the regrind or secondary grinding stages of base metal ores, the concern about energy efficiency is usually extremely important. In general, the specific energy consumption at this stage is higher than during the primary grinding stages. In addition, a tendency of finer grinding has been observed in the new projects of metallic minerals, due to the finer mineral liberation, which leads to increasing capital and operational costs. At Vale's new copper projects in Brazil, regrind sizes with a P80 of approximately 40 to 20 μm have been necessary. Conventional ball mills, adequate for primary grinding, usually bring about low energy efficiency with products bellow 50 μm. Vale is using the vertical mill on its copper projects – Sossego and Salobo, in order to optimize the regrind of rougher concentrates and reduce energy consumption.

This paper presents the results of industrial surveys carried out on the Vertical mill circuits of Sossego plant during its initial years of operation, and compares these results with the design criteria and laboratory regrind tests used for the mill scale up.

Keywords: grinding, regrinding, copper, vertical mill, stirred mill

INTRODUCTION

Sossego is the first Vale project concerning the copper business. It is based on a copper-gold resource discovered in early 1997 comprising Sequeirinho and Sossego adjacent ore bodies.

The mine is situated approximately 70 km south-west of Carajás area, near the town of Canaã dos Carajás, in southern Para state, Brazil. The concentrator was designed to process 41,000 metric tons per day which is equivalent to 15 million metric tons per year from an open pit mine. The proved reserve is 245 Mt with an average grade of 0.98% Cu and 0.28 g/t Au (Minbec, 2001). The ore is granite with significant incidence of magnetite, with typical ball mill Bond work indices of 15 to 20 kWh/t and very high indices of abrasiveness.

The operation of Sossego mine and processing plant started in April 2004 targeting an average concentrate production of 540,000 metric tons per year with 30% Cu and 8 g/t Au.

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Industrial Circuit

Sossego industrial plant comprises a typical high-tonnage primary crushing-SABC-flotation circuit based on large capacity equipment in each unit operation. A brief description of Sossego circuit follows. More information about the circuit can be obtained at Bergerman (2009).

Primary Crushing

Run-of-Mine ore is delivered to a 6089 gyratory crusher by 240 ton rear-dump trucks. The primary crusher operates under nominal closed side setting of 5.5”, which results in a P80 of 125-150 mm. Crushed ore is conveyed to a conical pile adjacent to the concentrator by a 4 km conveyor belt operating at a nominal rate of 2.300 t/h.

Crushed Ore Stockpile

The conical ore stockpile has a live capacity of 41 kt, equivalent to 24 h of plant operation. Three tandem apron feeders are located underneath the stockpile, feeding a single conveyor belt that supplies the SAG mill.

Grinding

The grinding circuit consists of a single line configured as SABC with a nominal capacity of 1,841 t/h.

A 38 foot diameter by 23 foot (EGL) SAG mill is driven by a 20 MW gearless motor. The SAG mill discharges onto two 12’ x 24’ horizontal vibrating screens whose oversize is conveyed to the recycle crushing building where two MP800 conical crushers reduce the pebbles to a nominal P80 of 12 mm. The crushed product is conducted to a SAG mill feed closing the circuit. The screen undersize is pumped to two separate nests of 33” hydrocyclones. Each nest underflow is directed to one of the two 22’ x 32’ ball mills, equipped with 8 MW motor single pinion fixed speed drive. The targeted P80 of hydrocyclone overflow is 0.21 mm at 40% solids.

Flotation & Regrinding

The hydrocyclone overflow from each ball mill circuit feeds the rougher stage consisting of seven 160 m³ cells. Rougher tailings from both lines are sent by gravity to the tailing dam. Rougher concentrates are pumped to the regrind circuit consisting of two vertical mills (1,500 hp motor each) operating in a reverse mode with 15” hydrocyclones. The regrind circuit product, with a nominal P80 of 0.044 mm, is pumped to the six cleaner flotation columns (4.27 x 10 m). The column tails feed the cleaner-scavenger cells i.e. one row of seven 70 m³ cells. The concentrate from the cleaner scavenger is combined with the rougher concentrate, thus forming the circulating load of the flotation circuit. The cleaner-scavenger tails are pumped to the tailing dam, whereas the cleaner concentrate is pumped to a thickener.

Thickening & Filtering

Final concentrate flows by gravity to a 20 m diameter thickener. The thickener overflow is recycled to the flotation feed and the underflow is pumped at 60% solids to the filtering plant tanks. From the filtering feed tank, concentrate is pumped to two filters. The filtrate returns to the thickener and the cake with 9% moisture is stocked in a 5250 t capacity conical pile, located in a moisture controlled building. The concentrate is reclaimed by front-end loaders to 35 t haul trucks that dump it in a storage building in the city of Parauapebas and then transported by a 800 km railway to the port of Itaqui, in Maranhao state.

CIRCUIT DESIGN

The SAG circuit (refer Figure 1) was designed based on a comprehensive pilot plant campaign carried out at CIMM – Centro de Investigaciones Mineras y Metalurgicas in 2000 where various grinding circuit configurations and operating conditions were tested using both Sossego and Sequeirinho ore samples. The SABC configuration was selected and equipment designed to the circuit nominal capacity of 41,000 metric tons per day.

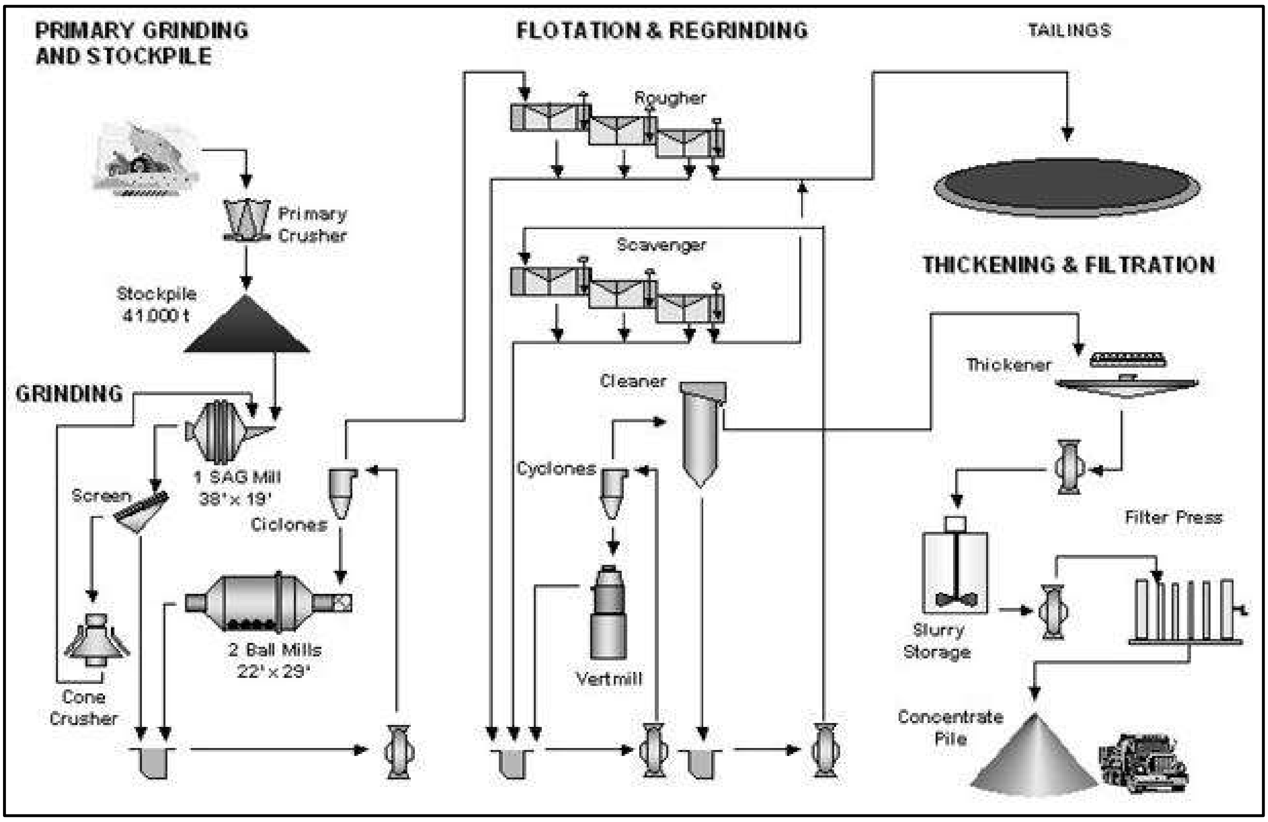

Figure 1. Summary of the Sossego flowsheet

It was clear from the pilot plant results that the performance of the primary grinding was strongly affected by the amount of critical size in the mill load. Accordingly, a combination of high ball charge and grate pebble port sizing resulted in a best overall performance of the circuit. The results indicated thus a competent ore as confirmed by DWT results that showed Axb of 32.2 and 49.5, respectively for Sequeirinho and Sossego ores.

The results of the grinding tests were the basis for equipment designing. Additionally, a study of ore variability was conducted on the basis of a drill core testing program. The variation of such characteristics on circuit performance was assessed by simulations carried out at JKSimMet simulator.

For the Vertical mill circuit, 4 samples from flotation concentrates were sent to Metso laboratory at York, USA for jar test characterization. The size analyses of the samples are illustrated at Table 1.

The jar tests were done on a steel jar mill following Metso internal procedure. Size analyses were performed using ro-tap and tyler series screens and Malvern Mastersizer 2000 particle size analyser. The jar mill test results are presented at Table 2.

Table 1. Size distribution of the flotation rougher concentrates

	Cumulative passing (%)			
Micron	**Sample A**	**Sample B**	**Sample C**	**Sample D**
833	<0.1	<0.1	<0.1	0
589	<0.1	0.2	<0.1	<0.1
417	0.1	0.5	<0.1	0.1
295	0.6	2.0	1.0	0.1
208	7.6	13.1	10.3	3.1
147	24.6	32.2	28.3	13.2
104	38.4	44.5	40.3	23.1
74	49.9	54.3	51.0	33.2
53	59.9	62.9	60.3	43.3
44	65.2	67.2	65.5	49.0
37	68.3	69.8	68.4	52.7
25	74.3	75.4	75.1	60.7
P80 (□m)	162.6	185.3	174.2	116.4

Table 2. Jar mill test results

Time (min)	Net kWh/mt	80% passing size of samples, microns			
		Sample A	**Sample B**	**Sample C**	**Sample D**
0	0	162.6	185.3	174.2	116.4
10	3.3	79.8	105.0	65.3	65.4
15	4.9	60.6	72.4		49.6
20	6.6	53.9	61.2	55.1	44.0
25	8.3	50.1	54.2		41.1
30	9.9	43.4	46.3	46.9	
35	11.5	40.7	40.5		
40	13.2	36.7	36.6	37.7	

Based on the jar test results and the vendor experience, a specific energy consumption of 15.53 kWh/t was considered for project purposes. The decision for the selection of the Vertical Mill for this application was based on industrial experience with this equipment at similar operations, were energy savings, compared to the classical ball mill regrind circuit, of approximately 30 – 40% have been achieved (Knorr and Allen, 2010; Menacho and Reyes, 1987; Pena, 1990). Savings of around 30 to 50% with the consumption of balls and liners have also been reported (Pena, 1990). Nappier-Munn *et al* (1999) highlight that “tumbling mills are ultimately limited in terms of the energy they can transmit to the media”, what could explain the trend towards stirred mills for fine (15-40 μm) and ultrafine grinding (bellow 15 μm). Figure 2 illustrates the interior of the vertical mill used at Sossego.

The final feasibility study was conducted by a consortium initially formed by Minerconsult (today associated with SNC Lavalin) and ECM, both Brazilian engineering companies, as well as with Bechtel. A review on the design criteria and methods were later conducted by Kvaerner. The main design specifications for the grinding circuit are given in Table 3.

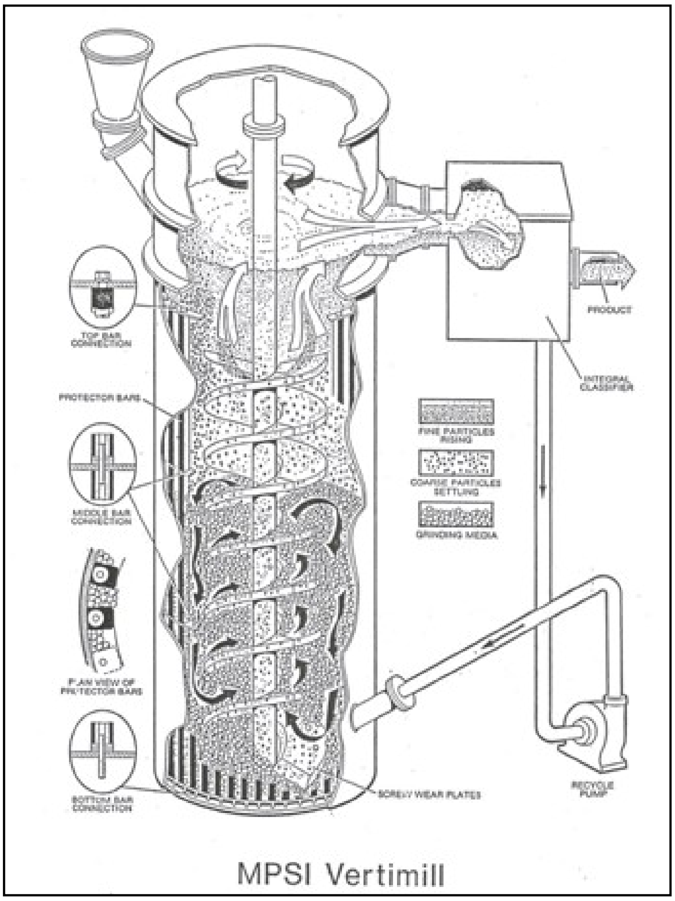

Figure 2. Interior of the Vertical Mill (Pena, 1990)

Construction started in 2002 including an 80 km road between the city of Parauapebas and the mine, infrastructure for the city of Canaã dos Carajás, in conjunction with facilities to operate in a remote area. After a commissioning period, Sossego plant started a ramp-up period in the first semester of 2004.

Table 3. Design specifications for the Sossego Grinding Circuit

SAG Mill	
Selected mill	38 foot x 23 foot diameter (EGL)
Feed rate, t/h dry basis	1.841
Feed F_{80}, mm	150
Motor power, MW	20
Ball charge, %	12% (operating); 15% (maximum)
Speed	Variable
Average circulating load, %	30
Total charge, %	30
Speed, % critical	Up to 82
Product, P_{80}, mm	2.5
Specific power at motor, KWh/t	10.8
Ball mill	
F_{80}, mm	2.5
Total installed power, MW	8 x 2
Ball charge, %	33
Ball size, inch	3
Final product P_{80}, mm	0.21
Specific power at motor, KWh/t	8.7
Vertmill	
Product P_{80}, mm	0.044
Specific regrinding energy, kWh/t	15.53
Grinding media	25,4 mm Steel balls
Ore characteristics1	
Bond Ball Mill WI, kWh/t	16.0
JK DWT (A*b)	33
Bond Abrasion Index	0.48

INDUSTRIAL EVALUATION ON THE FIRST YEARS OF OPERATION

Since the startup of the Sossego grinding and flotation plant, several routine samples have been made at the vertical mill circuit, in order to evaluate its performance. Figure 3 illustrate the Sossego Vertical Mill circuit and its sampling points.

The Sossego Vertical Mill circuit has a density and flow meter at the cyclone feed. With this information and the percentage solids and size distribution of the five points illustrated at Figure 3, the circuit was mass balanced, the cyclone underflow and overflow partitions determined, and thus the energy consumption indexes could be obtained. Two main pieces of information were calculated

a) Bond operating work index (WIop): As stated by Rowland and Kjos (1978), the Bond work index can be used as an indicator of industrial operation energy efficiency, based on the operating work index. This operating work index is obtained based on the F80 and P80 of the grinding circuit (in Sossego circuit, flows 1, 2 and 5 from Figure 3), new feed mass flow and mill power (minus the energy losses). Rowland and Kjos (1978) apply some factors at the WIop, for ball mill circuits. As these factors were not developed/validated for vertical mill, and the WIop calculated here will not be compared to any WI, some corrections were applied.)

b) Specific energy consumption (P/T): mill power (minus the energy losses) divided by the new feed mass flow.

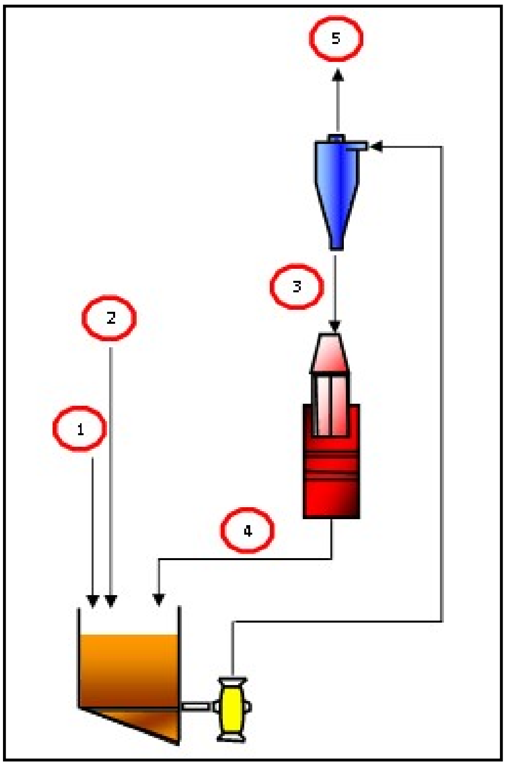

Figure 3. Sampling points at the Sossego vertical mill circuit for mass balance

Table 4 and Figure 4 illustrate the operating data obtained since 2006 and the WIop and P/T values. In conjunction with the operating values, we plotted the design data (Metso Jar test, nominal and project circuit data) and also the results from the Donda/PCM jar test data, conducted with the methodology described by Donda (2003).

As can be observed at Table 4 and Figure 4, the operating data from Sossego matches the design, Metso Jar mill test and Donda jar mill test quite well. It shows that the energy consumption for the vertical circuit was properly designed. This information confirms the operator’s observation that, since the startup of the grinding and flotation plant, the vertical mill has never been a bottleneck for the flotation circuit. A comment about the vertical mill new feed should be remarked here. The flotation circuit has an operational alternative to feed part of the rougher concentrate direct to the thickener. This explains why the new feed data for the regrind circuit is lower than the design in some of the samplings.

Table 4. Sossego Vertical Mill operating data since 2006 compared with design and laboratory data

Date	Mills Power (kW)	New feed (t/h)	F80 (µm)	P80 (µm)	RR	Wiop (kWh/t)	P/T (kWh/t)	Operating mills
Jar test Metso			174	44	4.0	13.9	10.4	Lab. Data
Jar test - Donda/PCM			74	44	1.7	11.6	4.0	Lab. Data
Nominal	1940	167	210	44	4.8	14.3	11.7	MO01 and MO02
Project	2160	173	210	44	4.8	15.3	12.5	MO01 and MO02
04/19/2006	600	89	95	39	2.4	11.8	6.8	MO01
04/19/2006	584	101	88	34	2.6	8.9	5.8	MO02
06/20/2006	578	119	64	33	1.9	10.0	4.9	MO02
08/16/2006	584	27	59	31	1.9	44.0	22.0	MO01
08/16/2006	572	25	58	35	1.6	C3	22.5	MO02
09/18/2006	578	146	106	44	2.4	7.4	4.0	MO01
09/18/2006	578	93	78	41	1.9	14.6	6.2	MO01
10/30/2006	578	46	107	40	2.7	20.3	12.5	MO01
10/30/2006	584	163	98	48	2.0	8.2	3.6	MO02
11/28/2006	578	163	68	46	1.5	13.5	3.6	MO01
11/28/2006	584	180	97	40	2.4	5.7	3.2	MO02
02/23/2007	572	86	88	39	2.3	12.5	6.7	MO02
11/23/2009	701	165	117	33	3.5	5.2	4.3	MO01
08/13/2010	1403	411	96	44	2.2	7.0	3.4	MO01 and MO02
10/07/2010	797	109	149	61	2.4	15.9	7.3	MO01
04/05/2011	791	140	81	37	2.2	10.6	5.6	MO01
04/05/2011	836	141	89	38	2.3	10.6	6.0	MO02
04/27/2011	791	93	73	33	2.2	14.9	8.5	MO01
07/24/2011	701	88	216	35	6.2	7.9	8.0	MO01

As to the maintenance aspects, the Sossego Vertical mill presents very low liner consumption. Internal screw liners are changed only once a year. The ball mill consumption is also very low, about XX g/ton. Based on these good results, Vale continues to consider the application of the vertical mill at its new circuits, such as Salobo (Godoy *et al*, 2010).

The efforts are now being focused on the development of a simplified laboratory test to determine the energy consumption of the industrial Vertical Mill using small ore samples, as it is difficult to obtain mass samples to perform all vendor tests during the project stages. This would benefit the new projects under development, which would be able to implement variability tests for the regrind circuit scale up, and also help the analysis of the industrial data, with a laboratory reference test for comparison.

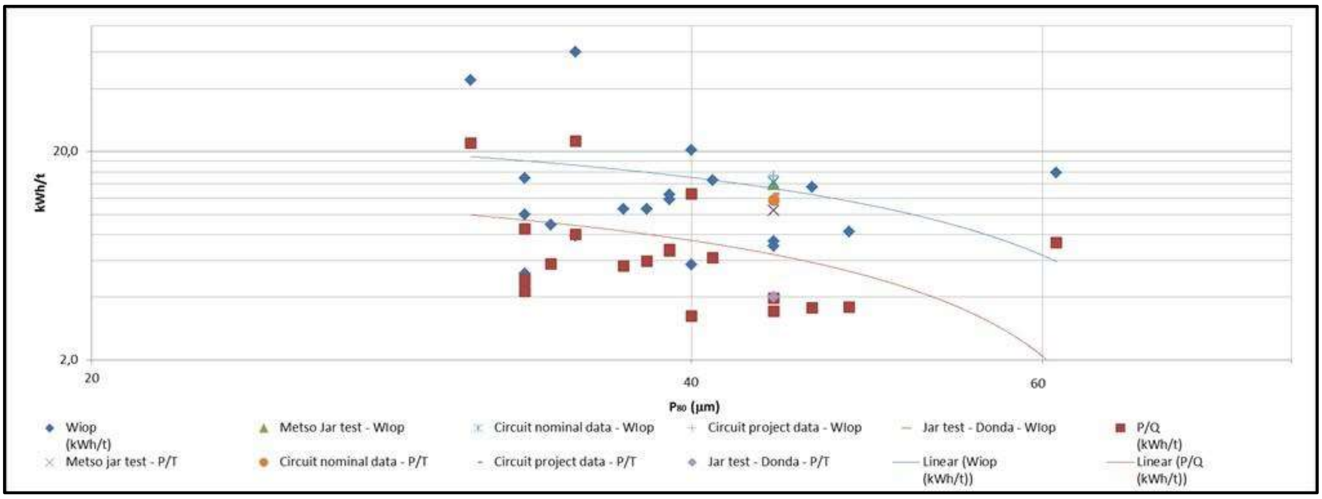

Figure 4. Sossego vertical mill operating data since 2006 compared with design and laboratory data

CONCLUSIONS

The present work described the design and operational data from the Sossego vertical mill circuit during its first years of operation. The operating data illustrates that the circuit design was correct, whereby most of the operational results are equal or lower than designed. Thus, this circuit has never been a bottleneck for the flotation circuit at Sossego. The maintenance costs and ball mill consumption are also very low. Vale continues to consider the application of the Vertical mill at its new circuits, such as Salobo.

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