Mining
Mineração

Simulation of the Mineração Serra Grande Industrial Grinding Circuit

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Abstract

Increasing throughput during the mining cycle operation frequently generates significant capital gains for a company. However, it is necessary to evaluate plant capacity and expand it for obtaining the required throughput increase. Therefore, studies including different scenarios, installation of new equipment and/or optimization of existing ones are required. This study describes the sampling methodology, sample characterization, modeling and simulation of Mineração Serra Grande industrial grinding circuit, an AngloGold Ashanti company, located in Crixás, State of Goiás, Brazil. The studied scenarios were: (1) adding a third ball mill in series with existing two ball mills, (2) adding a third ball mill in parallel with existing mills, (3) adding a vertical mill in series with existing mills and (4) adding high pressure grinding rolls to existing mills. The four simulations were carried out for designing the respective circuit, assessing the interference with existing equipment and installations, as well as comparing the energy consumption among the selected expansion alternatives. Apart from the HPGR alternative, all other three simulations resulted in the required P_{80} and capacity. Among the three selected simulations, the Vertimill alternative showed the smallest installed power.

Keywords: modeling, grinding, ball milling, vertical milling, simulations.

1. Introduction

Mineração Serra Grande is a gold mining operation located in Crixás, State of Goiás, Brazil. The beneficiation plant processes gold ore from three underground and one open pit mines. The current process includes multi-staged crushing, followed by

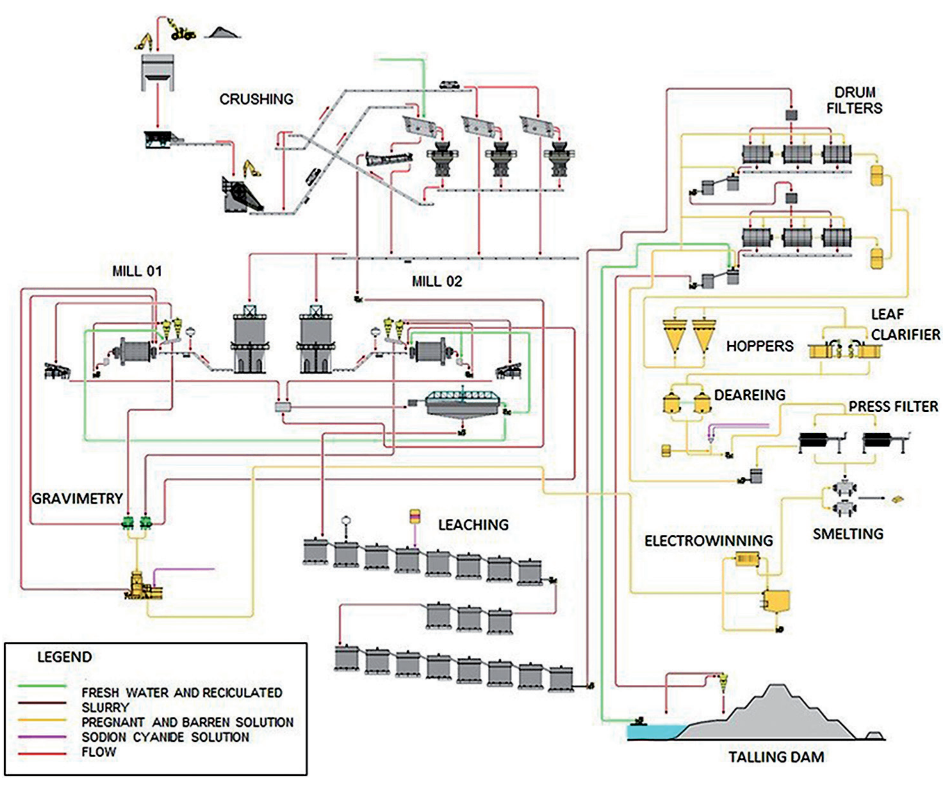

Figure 1
Mineração Serra Grande Flowchart.

ball milling in closed configuration with hydrocyclones. A gravity concentration circuit is fed by part of the circulating load, while the grinding circuit product is thickened and leached with sodium cyanide. After leaching, the pulp is filtered, clarified and precipitated with zinc (Merrill Crowe process). The solid tailings are pumped to the tailings dam. Gold is thus produced from both Merrill Crowe and gravimetric circuits. Figure 1 shows the current Serra Grande plant flow sheet. Mineração Serra Grande (MSG) started its operation in October 1989 with a single ball mill, processing 1,200 t of ore per day. Currently, plant capacity is approximately 3,600 t/day.

In 2008, the circuit was expanded by installing new equipment, together with various other actions, such as employing a better pumping system, hydrocyclone optimization, adequate ball charge, installing grates in the existing ball mill, as well as automation in the circuit. Further production increase was then focused on installing new equipment.

Figure 2 shows plant production and gold grade from 1990 to 2015. The chart shows a step change in gold production when the second ball mill was installed (2009), followed by a steady increase in following years resulting from optimization,together with a declining gold feed grade.

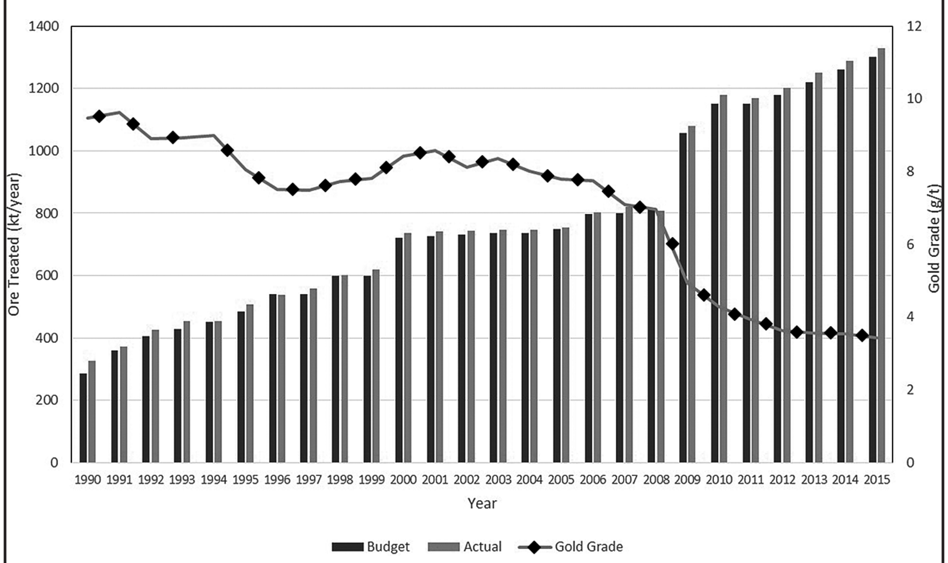

Figure 2
Plant production and gold grade history of Mineração Serra Grande.

MSG is currently studying alternatives for increasing current plant capacity from 1.3 MTPY to 2.0 MTPY. Apart from a 54%, increase in the current production, such an expansion would also result in further performance improvement by reducing operating costs.

2. Materials and methods

Sampling and data collection

This study began with a literature review to perform a survey campaign on the existing grinding circuit. The aim of sampling was to reduce the mass of a lot, without assigning significant changes to its properties. Data collection followed the sampling rules as proposed by Gy (1982).

Each selected stream was sampled for two hours during a steady-state period of the grinding plant. In some streams, automatic sampling systems were used, while manual sampling was carried out at all remaining selected points, as shown in Table 1.

Table 1
Information about the sampling campaign.

Sampling Procedure	Sampling point
Manual	Mill discharges
Automatic	Hydrocyclone feed
Manual	Hydrocyclone Underflow
Automatic	Hydrocyclone Overflow
Automatic	New Mill Feed

Table 2 shows the grinding circuit operating data as obtained during the sampling period for mass balance calculations.

Parameter	Unit	Mill_01	Mill_02
New Feed	t/h	114.9	42
Mill discharge Pulp Density	t/m^3	1.54	1.47
Water Flow in Mill discharge	m^3/h	110	50
Cyclone Feed Pulp Density	t/m^3	1.54	1.47
Cyclone Overflow Pulp Density	t/m^3	1.25	1.18
Cyclone Pressure	Bar	0.71	0.58
Motor Power	kW	1061	406
Bin Level	%	72.2	39.5

Table 2
Process data
obtained during sampling period.

Table 3 shows the equipment main characteristics as currently installed at MSG industrial grinding circuit.

Parameters	Circuit1	Circuit 2
Ball mill internal diameter (m)	3.48	2.57
Ball mill internal length (m)	5.34	3.74
Hydrocyclone Diameter (m)	0.508	0.508
Number of hydrocyclones in operation and installed	3/5	1/2

Table 3
Equipment main characteristics.

Further information about sampling of this work can be found in Leite (2016).

Ore characterization

Samples obtained in the survey campaigns were sent to the Laboratory of Simulation and Control (LSC) of the University of São Paulo for screening, as well as for specific gravity assessment and comminution testing, which included the Bond Work Index, Drop Weight Test, Piston Press Test and Jar Mill Grinding Test.

The Bond Work Index (BWI) was performed to estimate energy requirements for ball milling using the Bond equation shown below, together with the Rowland (1982) efficiency factors – EF.

$$E = 10Wi\left[\frac{1}{\sqrt{P_{80}}} - \frac{1}{\sqrt{F_{80}}}\right] . EFi \tag{1}$$

Drop Weight Tests (DWT) were also performed to calibrate the Whiten´s ball mill model, while a Piston Press Test (PPT) was carried out to calibrate the High Pressure Grind Roll (HPGR) model used throughout simulations. Both DWT and PPT procedures were carried out according to Napier-Munn et al., 1996. DWT and PPT resulted in A and b parameters, as obtained from equation 2, together with respective breakage matrices.

$$t_{10} = A\left(1 - e^{-(bE_{cs})}\right) \tag{2}$$

Jar Mill Grinding Test (JMGT) was performed to estimate energy consumption for an industrial vertical mill. The energy calculation for the JMGT was carried out through equation 3, following Metso procedures described by Wills, 2016.

$$E = \frac{6.3.D^{0.3}.sen\left(51-22\left(\frac{2.44-D}{2.44}\right)\right).(3.2-3V_p).CS.\left(1-\frac{0.1}{2^{(9-10\,C_s)}}\right).t.m_b}{m_m 60} \tag{3}$$

E = specific energy consumed during JMGT; D = mill internal diameter; V_p = mill volume fraction filled with grinding media; Cs = fraction of the mill critical speed; t = time jar operation; m_b = media mass; m_m = ore mass

Mass balancing was carried out using experimental data obtained during the sampling period. This procedure included estimating best flow rates and size distributions around the entire grinding circuit.

Equipment and process models

The Nageswararao (2004) model was used for modeling the industrial hydrocyclones. The model includes both operation and design data, together with partition curve parameterization. Calibration constants were back calculated for model fitting exercises.

The adapted Perfect Mixing Model proposed by Whiten (1976) was used to model industrial ball milling.

The grinding kinetic parameter *(r/d*)* was determined for each ball mill during the model fitting exercises, as described by Napier-Munn (1996).

The HPGR model proposed by Morrell/Tondo/Shi (1997) includes three breakage zones i.e. the pre-crusher zone, the edge effect zone and the compression zone. The throughput model component uses a standard plug flow model version that has been used extensively by manufacturers and researchers. Power consumption is based on throughput and specific comminution energy input. (Morrell *et al.*, 1997).

3. Results and discussion

Ore characterization

The BWI test performed in the surveyed grinding circuit feed sample resulted in 11.6 kWh/sht. Such a value was used to estimate the overall grinding circuit energy consumption. The combination between such an energy consumption and the stipulated 2.0 MTPY resulted in 624 kW power to be installed in the additional parallel ball mill.

The appearance function and breakage parameters as obtained from DWT, carried out on surveyed samples are shown in Tables 4 and 5.

Table 4
Appearance Function data - DWT.

t_{10}	t_{75}	t_{50}	t_{25}	t_4	t_2
10	2.9	3.7	5.6	22.7	49.5
20	5.8	7.5	11.2	42.5	77.3
30	8.7	11.2	16.8	59.4	90.4

Table 5
Breakage parameters - DWT.

A	54.4
b	0.84
IQ	45.4

The appearance function and breakage parameters as obtained from PPT carried out on -6.35 +4.75 mm size fraction are shown on Tables 6 and 7.

Table 6
Appearance Function data - PPT.

t_{10}	t_{75}	t_{50}	t_{25}	t_4	t_2
10	3.3	4.3	6.3	17.4	31.7
30	10.6	13.4	19.1	46	72.1
50	18	22.7	31.4	72.7	100

Table 7
Breakage parameters - PPT.

A	28
b	1.44
IQ	40.3

JMGT was carried out for 3, 5 and 10 min grinding periods. Table 8 shows the results obtained in terms of specific energy and resulting product P_{80}.

Table 8
Batch grinding test results.

Time (min)	Specific Energy kWh/t	P_{80} (μm)
0	0	165
3	2.54	81.9
5	4.24	60.7
10	8.48	43.8

Model calibration

The obtained sample values are similar to the calculated data and resulted in a consistent mass balance, as well as adequate fitted models.

Figure 3 shows experimental and calculated size distributions obtained for each individual stream around the MSG industrial grinding circuit.

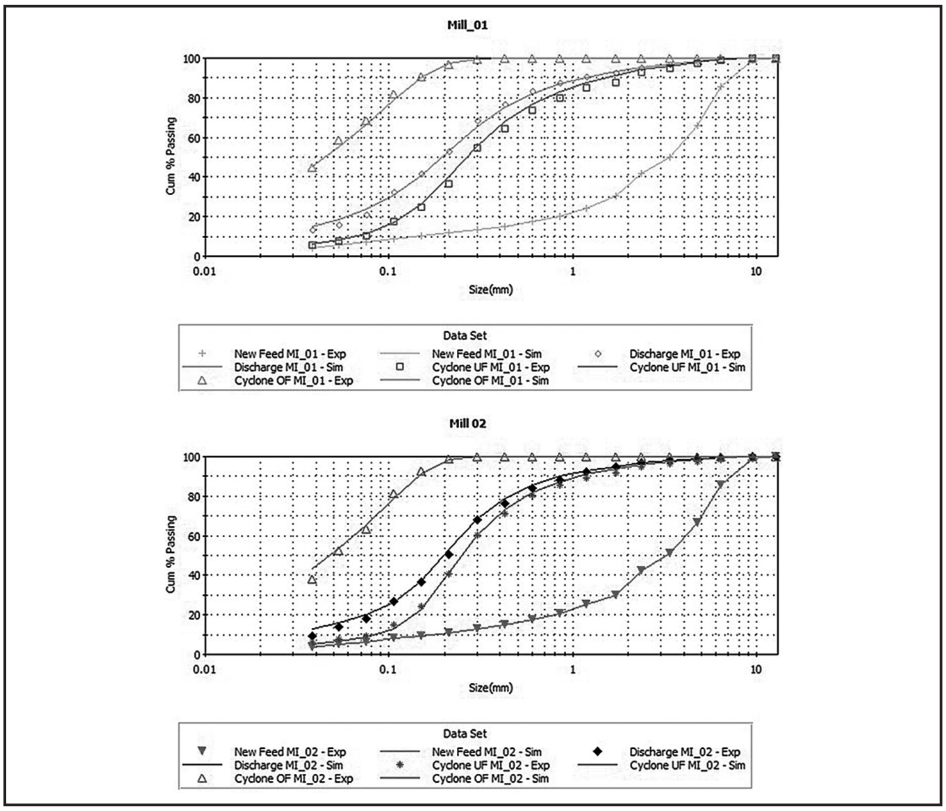

Figure 3
Experimental and simulated size distributions as obtained for individual grinding circuit streams.

The calibrated parameters obtained from hydrocyclone modeling are shown in Table 9, while Table 10 shows the parameters obtained from ball mill modeling.

Table 9
Nageswararao hydrocyclone model calibration for MSG hydrocyclones.

Model Parameters	Hydrocyclone Nest 1	Hydrocyclone Nest 2
D50 Constant - KD0	8.14E-05	7.89E-05
Capacity Constant - KQ0	510.7	601.9
Volume Split Constant - KV1	7.15	9.11
Water Split Constant - KW1	10.66	14.44
Sharpness of Efficiency Curve - Alpha	2.01	2.81

Table 10
Whiten model calibration for MSG ball mills.

Knot	Size (mm)	Ln (r/d *)	
		Mill_01	Mill_02
1	0.2	1.674	1.503
2	1.5	3.712	3.966
3	5	5.232	5.733

Simulations

Four circuit alternatives were assessed through simulations for increasing the current 1.3 MTPY capacity to the stipulated 2.0 MTPY for the expansion project. Each alternative was simulated to obtain the respective mass balance and equipment design, together with the installed power and energy consumption. Simulations were carried out with calibrated models using JKSimMet 6.0 software.

Each simulated alternative is described as follows.

Alternative 1 – Additional ball milling line in series

The first alternative consisted in simulating an additional ball mill in the existing grinding circuit. The third ball mill would regrind the product of the two existing ball mills, as shown in the Figure 4 flow sheet.

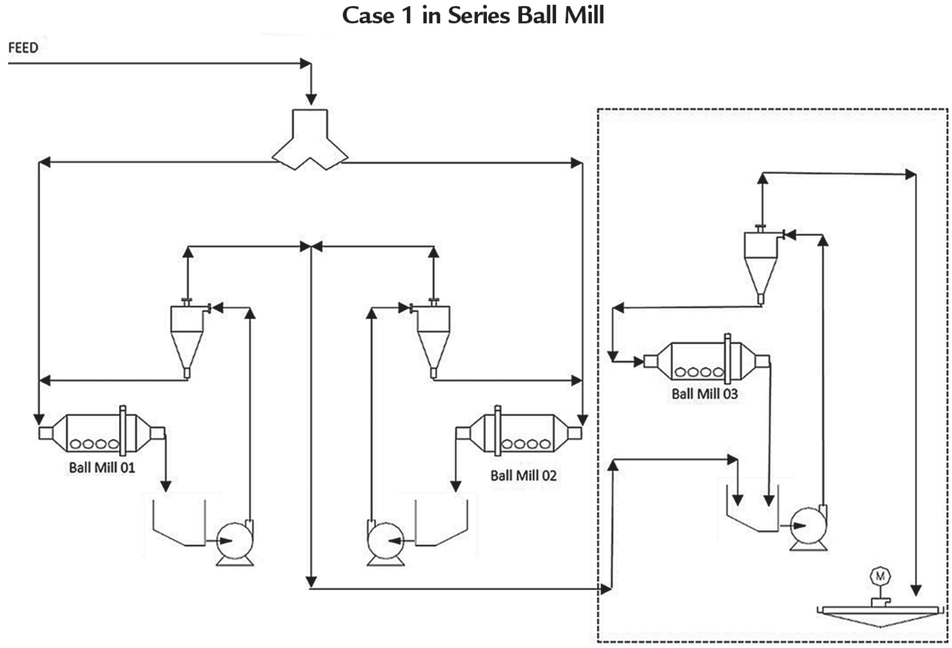

Figure 4
Additional ball milling stage flow sheet.

The two existing ball mill lines were thus simulated for the 2.0 MTPY increased throughput, therefore producing a relatively coarser product, in this case a P_{80} equals to 165 µm. The third ball mill was thus designed to grind such an intermediary product to the stipulated P_{80} of 109 µm.

The designed ball mill showed 3.2 m in diameter and 4.6 m in length, operating at 35% ball charge, 70% critical speed and 60 mm steel ball top size. The calculated ball mill installed power was 618 kW-.

Alternative 2 - Addition ball milling line in parallel

The second alternative comprised of simulating an additional ball milling line in parallel with the two existing ones, as shown in the Figure 5 flow sheet.

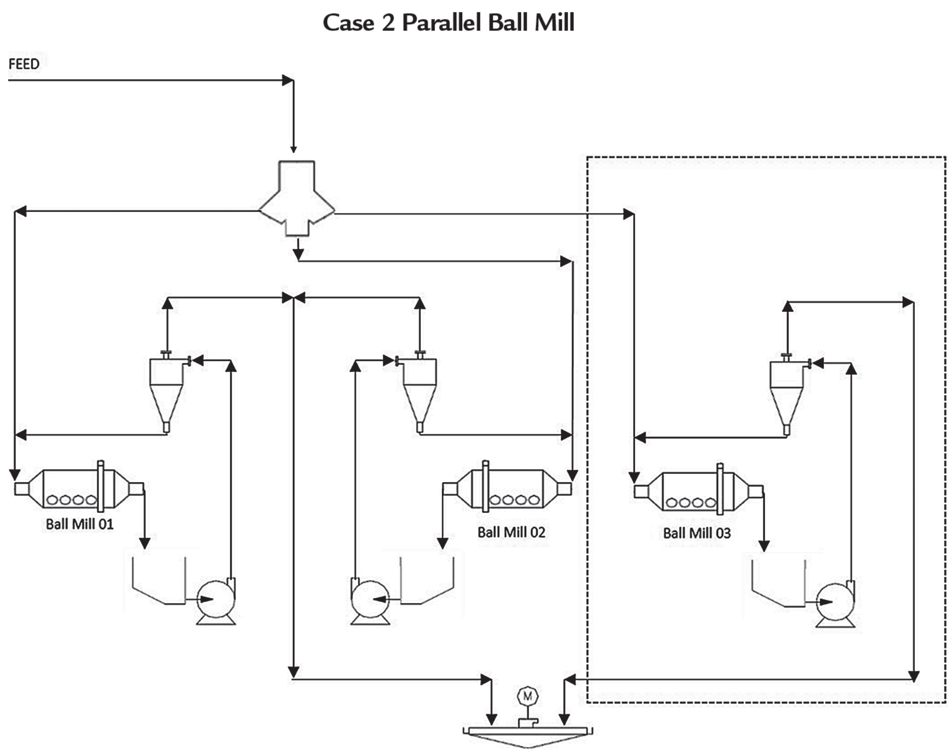

Figure 5
Additional ball milling line flow sheet.

The designed ball mill resulted in the same dimensions as obtained in Alternative 1, i.e. 3.2 m in diameter and 4.6 m in length, operating at 35% ball charge, 70% critical speed and 60 mm steel ball top size. The calculated ball mill installed power was 618 kW-.

Alternative 3 - Additional vertical mill

The third alternative consisted in simulating a vertical mill to regrind the product from the existing two ball mills. Figure 6 shows the simulated circuit flow sheet.

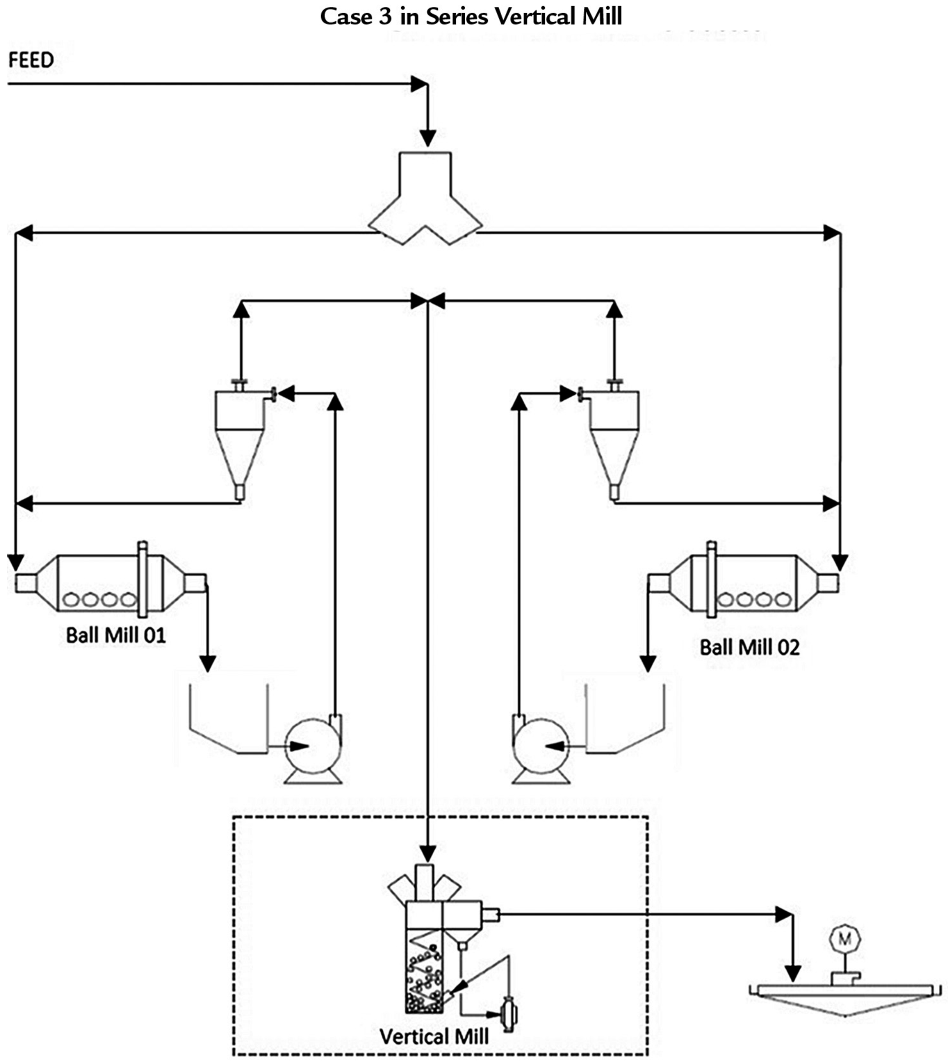

Figure 6
Vertical mill flow sheet.

As per Alternative 1, the existing ball mill circuit product showed a P_{80} of 165μm for processing 2.0 MTPY.

In order to calculate the required energy for a vertical mill in reducing the P80 from 165μm (feed) to 109 μm (product), the graph showed in Figure 7 was used. Such a graph resulted from the JMGT carried out specifically for such a purpose. According to Figure 7, the required energy for such an operation was calculated as 1.71 kWh/t, which resulted in 416 kW for a 243 t/h throughput. A Metso VTM-800 was selected considering safety factor suggested by the manufacturer Wills, 2016.

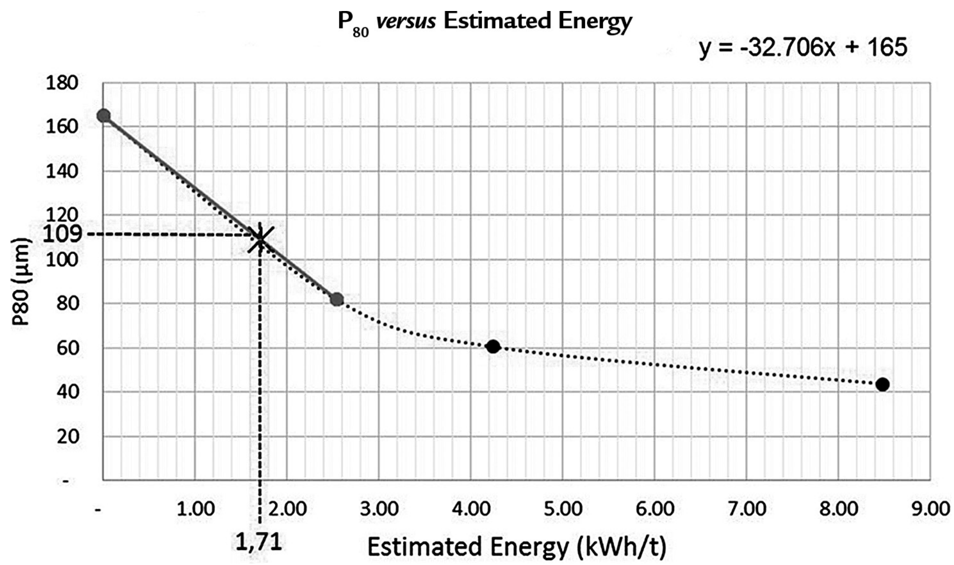

Figure 7
Estimated P_{80} as a function of the specific energy for different grinding times - JMGT.

Alternative 4 - Additional HPGR

The fourth alternative included a HPGR in a single pass (open circuit) for providing a finer size distribution to the existing ball mills. Such a finer size distribution would thus increase the installed ball milling capacity to the required 2.0 MTPY. Figure 7 shows the simulated circuit flow sheet.

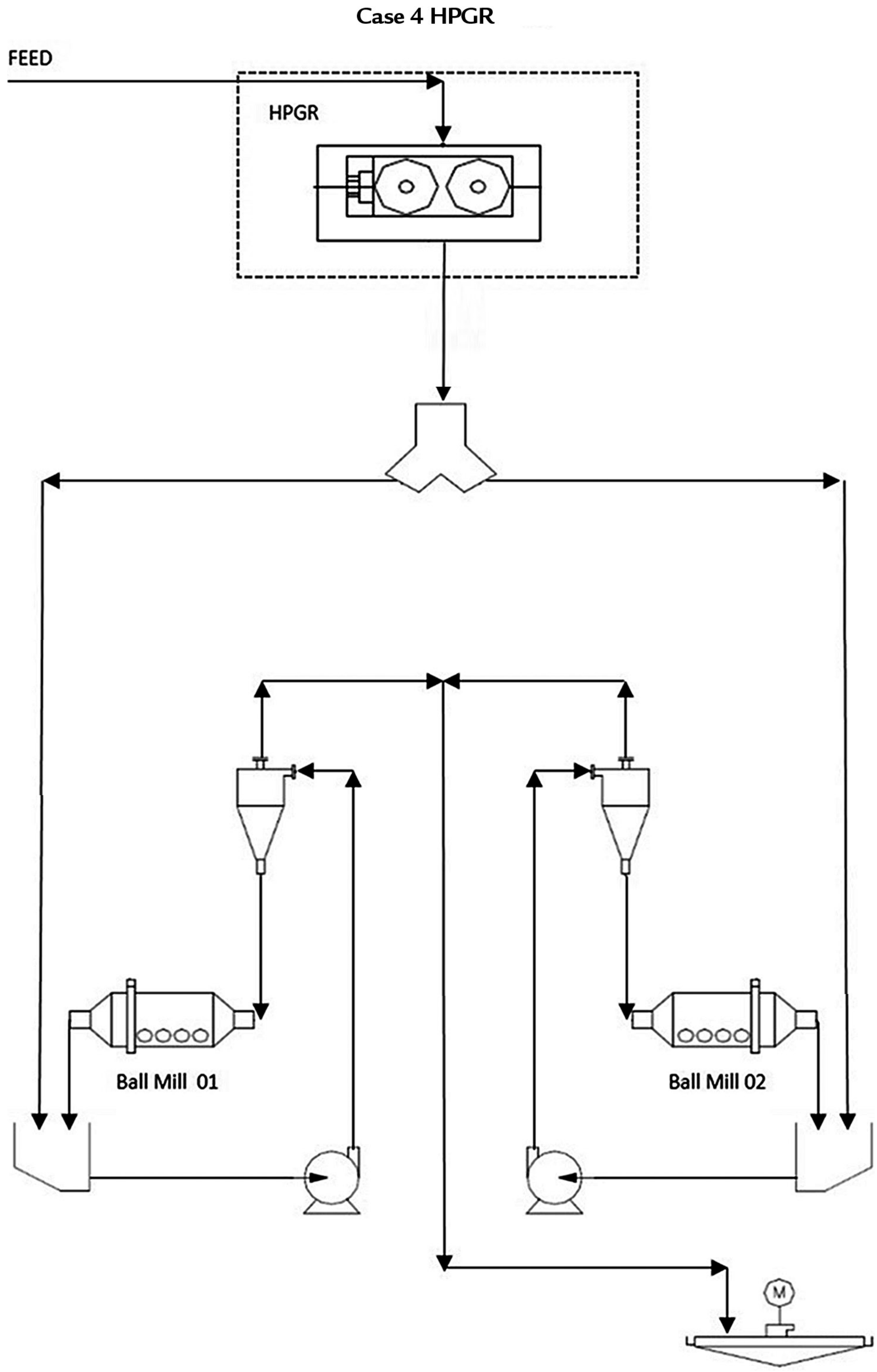

Figure 8
HPGR circuit flow sheet.

Based on simulation results, the selected equipment was one that had 1200 mm in roll diameter by 750 mm in roll length, with a 6.35 mm working gap, 324 ts/m³h specific throughput (m dot) and 1.48 m/s roll speed.

Even though the simulations indicated that the existing grinding circuit would only achieve the required capacity of 2.0 MTPY for a finer feed, HPGR benchmarking indicated that a realistic product would not be finer than a 2500 µm P_{80}. For such a feed size distribution, the existing grinding circuit product would show P_{80} of 141 µm, therefore coarser than the required value (P_{80} of 109 µm).

Alternative comparison

A summary is shown in Table 11of the equipment selected for the simulated alternatives with required power, installed power and P80 of the product for each case.

Simulated Alternative	Description	Aditional Euipament	Required Power (hp/kW)	Installed Power (hp/kW)	Grinding Circuit Product P_{80} (mm)
1	Second ball miling stage	Ball Mill, o=3.2m, L=4.5m	830/618	900/671	105
2	Additional ball milling line	Ball Mill, 0=3.2m, L=4.5m	830/618	900/671	105
3	Vertical mill stage	Vertical Mill - VTM 800	724/540	800/597	105
4	Additional crushing stage with HPGRR	HPGR 0=1.2m, L=0.75m	837/624	590/880	141

Table 11
Additional equipment selection summary.

4. Conclusions

The grinding circuit of Mineração Serra Grande was surveyed for obtaining consisted and representative operating data, which in turn were used for model fitting and simulations, the latter using JKSimMet simulator.

BWI, DWT, PPT and JMGT were carried out on selected samples for obtaining comminution characterization parameters. Four simulation alternatives were selected for increasing the grinding circuit capacity from current 1.3 MTPY to 2.0 MTPY. In each case the simulations resulted in designing the additional crushing/grinding equipment, and respective installed power. The alternatives included (1) an additional ball milling stage, (2) an additional ball milling line, (3) an additional Vertimill stage and (4) an additional crushing stage by using a HPGR piece of equipment.

Apart from the HPGR alternative, all other three resulted in the required P80 for the 2.0 MTPY circuit capacity. Among the three selected simulations, the Vertimill alternative showed the smallest installed power.

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