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HIGH PRESSURE GRINDING ROLLS AS AN ALTERNATIVE FOR COMMINUTION CIRCUITS

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ABSTRACT

The comminution steps associated with a mining plant play a crucial role in enabling the processing of low grade mineral deposits. The search for savings through the use of new technologies is the major challenge of the mining industry. The high pressure grinding rolls (HPGR) is a relatively new type of equipment, very efficient in terms of energy savings. There are several configurations for comminution circuits that utilize the HPGR technology replacing either AG / SAG grinding, or crushing/grinding stages or even as surface generation step prior to iron ore pelletizing. This study aims to compare test reports data from manufacturers and studies conducted by the engineering and consulting company ECM SA – Projetos Industriais, addressing the enterprises Salobo, Cerro Verde, and Minas Rio. A comparative table was developed to support the decision of implementing or discarding the HPGR at an early stage of the design process. What is clear from the results is that the application of HPGR can be justified due to technical factors, economic factors or, in most cases, both factors. The HPGR tends to be more easily justified in simple circuits, for example, where the ball grinding is fed directly by the roller press. This type of circuit benefits from the amount of fines generated by the press and it culminates in the reduction in the number and size of ball mills to be used.

Keywords: HPGR, high pressure grinding rolls, comminution circuits

1. INTRODUCTION

Comminution is required in mineral processing to provide the liberation between useful and gangue minerals and also to adequate the size distribution to operations such as pelletizing and pipeline transportation.

The high pressure grinding rolls, HPGR, presents as operation principle the idea that applying enough pressure to a bed of particles might bring gains regarding energy efficiency. The slow load application to the particles causes the grains structural collapse minimizing energy losses as heat and noise. Among the comminution equipments, HPGRs are the most efficient under the energy viewpoint.

The HPGR technology was introduced at the beginning of the XXth century for charcoal briquetting. In the last century mid 80^{ies}, it started to be used in the cement industry in the comminution of relatively brittle materials. Its first use to grind kimberlite, the diamonds host rock, occurred in 1987. The year 1996 represented the landmark of HPGRs being used to grind iron ore concentrates (pellet feed) as preparation for pelletizing. Since then the application has been expanded to harder and more abrasive materials.

Among the different HPGR applications, the most relevant in Brazil are: (i) replacing crushing and pre-grinding stages (the interparticles high pressure comminution yields a feed to the fine grinding stage that contains a large proportion of material already in the product size range; providing an increase between 30% to 50% in the ball mill feed rate); (ii) replacing AG/SAG grinding aiming at increased capacity, lower energy consumption, elimination of pebbles recycling, reduction of expenses with grinding media, operation of less complex circuits; (iii) regrinding stage for surface generation essential to adequate pelletizing performance for providing maximum mixing efficiency of the cake.

2. METHODOLOGY

This paper aims to compare data from different concentrators that successfully use high pressure grinding rolls providing a reference table that might help the decision regarding the application or not of the equipment at the early stages of a project.

The results were extracted from manufacturers test reports and by studies developed by the engineering and consulting company ECM S.A. – Projetos Industriais. The paper comprises data analyses of three mining projects: (i) Vale – Salobo; (ii) Phelps Dodge – Cerro Verde; (iii) Anglo Ferrous – Minas Rio.

The data comparison takes into consideration: (i) items referring to ore characterization (competence, moisture content and plasticity, presence of significant intrinsic magnetite content, abrasion index); (ii) economic analysis (economic benefits from CAPEX and OPEX return during the operation life cycle); (iii) other items to be evaluated (gains from the concentrator lay out, possibility to adapt the expected production to ore changes, structure solutions complexity for foundations, utilization of large electrical motors).

2.1. Case studies

The selected operations represent studies under development: HPGR versus AG/SAG grinding and HPGR versus crushing/pre-grinding stages.

Salobo and Cerro Verde

Salobo and Cerro Verde are similar operations. Both process copper ores and HPGR was selected in opposition to AG/SAG grinding. The observed similarities are: (i) the top size of the HPGR feed is approximately 50 mm; (ii) the HPGR product is screened; the oversize closes the HPGR circuit and the undersize feeds the ball mill.

Minas Rio

The Minas Rio operation selected HPGR in opposition to crushing/pre-grinding. The HPGR feed top size is below 25 mm, rendering possible to take advantage of a very simple circuit, the HPGR product feeding the ball mill with no need for previous screening.

2.2. Items related to the ore characterization

Due to the peculiarities of each ore, characterization is the starting point for the correct definition of the comminution circuit.

In the case of confirmed high hardness of the ore or when there are uncertainties regarding the hardness variation along the mine, the HPRG acquires advantages over the other circuit configurations, for the high and constant pressure applied to the material bed is sufficient to break harder mineral particles.

According to Danilkewich and Hunter [1], the use of HPGR is recommended for BWI - Bond Ball Mill Work Index - above 15 kWh/t. Ores presenting lower competence and work indexes may not benefit from the advantages imparted by the HPGR.

The ore high hardness or its hardness variation along the mine may be harmful to the SABC circuit, for the highly competent ores are not comminuted and overload the SAG Mill, reducing its efficiency. It is then necessary to remove the pebbles from the circuit and transfer them to a re-crushing stage. The pebbles re-crushing is overcharged in the case of competent ores. Variable ore hardness along the mine will require a larger number of cone crushers to absorb instant fluctuations from the mine. The pebbles circuit will operate most of the time with a small number of cone crushers but must be designed for the critical demand.

The above mentioned condition may require more crushing stages and a larger grinding circuit. The Minas Rio ore presents low BWI, but even though a circuit consisting of two crushing stages, one HPGR and balls milling (two mills) was selected in opposition to a circuit consisting of three crushing stages and three ball mills. The second configuration, beyond the three ball mills, includes a larger number of cone crushers and screens, used in the tertiary crushing, a larger number of pumps and hydrocyclones in the grinding circuit and, finally a larger number of bulk materials handling equipments which significantly increase both the CAPEX and the OPEX.

The HPGR is not adequate to wet and sticky ores. The control of the feed ore moisture content and plasticity is very important.

According to Oliveira et al [2], the feed moisture content must be between 0,5% and 11%, ideally at the average value 5%. Operation at high moisture content and high operation pressure may lead to the extrusion of the material between the rolls.

The plasticity of the ore is related to the attrition coefficient between the mineral particles. A standard test procedure is available [3].

The abrasion index is directly related to the rolls liners useful life. Higher abrasion index values lead to shorter liners life. Despite the advances concerning the liners life, this topic is still a concern for, beyond the liners high cost, the equipment availability affects the plant operation pattern.

According to the classification by Polysius, the abrasion index ATWI < 10 g/t represents low abrasion, between10 and 40 g/t medium abrasion and > 40 g/t high abrasion.

2.3. Economic analysis

CAPEX is an acronym derived from the expression Capital Expenditures and means in the context of the paper the capital used for commissioning a concentrator. CAPEX includes the costs of equipments ready for operation, and other costs such as electrical and piping components, electromechanical assemblage, civil construction, earthmoving, contingencies etc.

OPEX is an acronym derived from the expression Operational Expenditures and means in the context of the paper the capital used for operation costs such as manpower, maintenance, replacement parts, electrical energy, grinding media etc.

Even when the CAPEX is high, savings in energy consumption strongly affect the

OPEX, bringing overall benefits, especially if locally the unit energy cost is high.

Associated to CAPEX and OPEX is the useful life cycle of the concentrator. The high HPGR CAPEX requires a longer concentrator life cycle to dilute the costs.

Despite the relevance of the enterprise financial impact, the analysis must take into account the technical/economical aspects. Decisions must be taken based on the performance peculiarities of the HPGR and not only on the economic viewpoint.

2.4. Other items to be evaluated

A pre-requisite to start a construction is to minimize its area to reduce earth moving as a function of costs, geographic restrictions and, last but not least, environmental issues. Concentrators using HPGR require a larger number of conveyor belts and screens but the plant layout is more compact than when the choice is for SAG.

Due to the huge dimensions of the AG/SAG mills, the investment required for layout changes is very high. The impact of ore variations on a HPGR circuit is less significant and, if necessary, an extra HPGR may be added to the circuit.

The dynamic loads generated by a SAG mill are higher than the loads generated by a HPGR. The loads reflect on the foundations (CAPEX) and also on the required construction period.
AG/SAG mills require one single high power motor. Generally the variable frequency drives required for the motor are not available by the manufacturers. The AG/SAG mill should then be set in motion by a cycle converter. The cycle converter plays a role similar to that of the variable frequency drive, but the inverser harmonics are less predictable and harder to be filtered.

There are no technical restrictions to the use of converter cycles, but special attention must be given to problems with the local electrical energy supplier. During Sossego´s mine, Pará state, Brazil, start up energy peaks at the supply central, located at 120 km from the concentrator, caused voltage variations in the electrical circuit. The combination of the voltage variations with the harmonics generated by the converter cycle caused the SAG mill to stop suddenly, increasing at each stop the risk of damage to the equipment. The weakness of the energy supply system in the north of Brazil is a typical local problem.

The HPGR motors reach up to 3.000 kW per roll, so there are no restrictions to the use of variable frequency drives.

Depending on the magnetic pebbles flow intrinsic to the mineral resource, this material should be reintegrated to the circuit. If the amount of valuable pebbles is significant they should not be discarded. If the magnetic pebbles are not associated with the mineral resource they should be removed from the circuit.

3. RESULTS AND DISCUSSION

Table 1 summarizes the items relative to the ore characterization.

Table 1. Summary of items relative to the ore characterization [4].

	Reference value	Salobo	Cerro Verde	Minas Rio
Ore competence				
BWi	HPGR recommended >15 kWh/t	20 kWh/t (yes)	15,5 kWh/t (yes)	6 kWh/t (no)
Ore hardness variation along the mine		identified	not identified	not identified
Moisture content	5% average	2,5%	4,0%	7,0%
Ore plasticity		not observed	not observed	not observed
Significant presence of intrinsic magnetite		yes	no	no
Abrasion index	<10 g/t abrasion >10 < 40 g/t medium abrasion >40 g/t high abrasion	10,8 g/t low/medium abrasion	not available	31 g/t medium/high abrasion

In the case of the enterprises Salobo and Cerro Verde, the BWI > 15 kWh/t, mentioned by Danilkewich and Hunter [1] was a reference, favored the HPGR selection. In the case of Minas Rio, the BWI value was lower than the reference.

The variation of the ore hardness along the years and the presence of magnetic pebbles intrinsic to the mineral resource were problems only in the case of the Salobo mine.

The ore moisture content in all three cases is within the range mentioned by Oliveira et al. [2], between 0,5% and 11%, close to the ideal value 5%.

As a function of the abrasion index, the expected life of the rolls liners is 6.500 to 8.000 hours for Salobo and 4.800 hours for Minas Rio. The abrasion index for Cerro Verde was not made available, but according to the HPGR manufacturer the expected liners life is 6.000 hours.

Table 2 presents a summary of the enterprises economic analysis.

Table 2. Summary of the enterprises economic analysis [4].

	Salobo	Cerro Verde	Minas Rio
Economic benefits from CAPEX	Not available	Negative (-US$53 millions)	Positive (+US$15 millions)
Economic benefits from OPEX	Not available	Positive (+US$253 millions along 30 years)	Positive (+US$76 millions along 20 years)

The use of HPGR at Cerro Verde indicates US$53 millions CAPEX increase and US$253 millions OPEX savings considering 30 years mine life time. The CAPEX dilution along the years is evident.

At Minas Rio, the HPGR selection brought benefits to both CAPEX and OPEX. The lower CAPEX was due to a simpler circuit, consisting of a smaller number of less robust equipments.

Salobo´s economic data were not made available. The HPGR circuit resulted in higher CAPEX and lower OPEX.
Table 3 summarizes other evaluated items

Table 3. Other evaluated items [4].

	Salobo	Cerro Verde	Minas Rio
Benefits from plant layout	Low significance	Low significance	Not evaluated
Possibility of adapting to ore changes that might impair the production	Yes	Yes	Not applicable
Complexity of foundations structure solutions			
Economic benefits	Not evaluated	Not evaluated	Not applicable
Gains on construction timetable	Not evaluated	Not evaluated	Not applicable
Complexity from the use of large electric motors	Yes	No	No

The items discussed under this topic are not essential. They should be considered peculiarities which do not prevent the evolution of the studies: (i) the benefits from plant layout are not significant, except in the cases of serious environmental restrictions and/or geographic limitations; (ii) the need for plant corrections is related to problems in the ore characterization, human mistakes that should be minimized; iii) the impacts caused by the foundations are related to the timetable efficiency and to the equipments acquisition plan; (iv) the complexity of huge electric motors use is related to local problems of energy supply.

4. CONCLUSIONS

The items related to the ore characterization may, in specific cases, justify the selection of HPGR. The Salobo enterprise reflects this situation. The amount of magnetite intrinsic to the mineral resource and the ore hardness variation along the mine were the key factors for the HPGR selection.

A high BWI value is not necessarily a factor to justify the HPGR selection. The Minas Rio enterprise showed economic CAPEX and OPEX advantages irrespectively of the BWI.
The HPGR utilization should be justified by either technical or economical factors, but in most cases by a combination of both. It is now clear that its use is particularly adequate in simple circuits, such as Minas Rio where the HPGR product feeds directly the ball mill. The major issue is the fact that the amount of fines generated by the HPGR reduces the number and size of required ball mills, with significant impacts in both, CAPEX and OPEX.

Salobo and Cerro Verde circuits are more complex, increasing the enterprise costs. The HPGR product presents a large amount of fines and a certain degree of aggregation, varying with the ore. Wet screening the HPGR product will bring water together with the oversize to the press feed, severely contributing to the wear of the rolls liners.

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