ACHIEVEMENT OF HIGH ENERGY EFFICIENCY IN GRINDING MILLS AT SANTA RITA

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ABSTRACT

Horizontal grinding mills have been used in the mining industry for more than a century, and due to their operational and maintenance simplicity they remain a widely used technology for various stages of comminution. The relative 'efficiency' of horizontal grinding mills compared to other comminution equipment is often debated, and efforts to improve the energy efficiency of these mills is an on-going area of attention for process engineers.

The discharge arrangement design affects the material transport characteristics within a horizontal grinding mill. Material transport plays a significant role on efficiency of horizontal grinding mills. The magnitude of benefits that can be achieved with efficient material transport in AG/SAG mills has been demonstrated in a Greenfield milling operation at Mirabela Mineração's SantaRita Nickel operation in Brazil. This grinding circuit was commissioned in October 2009, which was designed as a typical SABC circuit to grind 4.6 mtpa (575tph) to produce a P80 of 125um with 10-12% ball charge in SAG mill. The nameplate design capacity has been achieved in few days in ABC circuit without grinding media in SAG mill, and has been operating in ABC mode. The through has gradually increased to an average of 800 tph and Recently 7% ball charge has been introduced to increase the throughput to +900tph.

This paper investigates improved material transport using Outotec's TPL™ (Turbo Pulp Lifter) technology and the opportunities this technology presents when designing horizontal grinding mills. Operational data, with particular reference to energy and throughput optimization, is presented.

KEYWORDS

AG/ SAG, Material Transport, Pulp Lifter, Grate Discharge

INTRODUCTION

The energy efficiency of a comminution device typically depends on how good the energy is used in breaking of new particles and how best the product size particles are classified and taken out. In other words it can be stated that the most energy efficient breakage system would be the one where the particles leave the energy field as soon as they become smaller than the required product size – a classic example of which is the crushers where free falling vertical (gravitational) material transport exists (refer Figure 1).

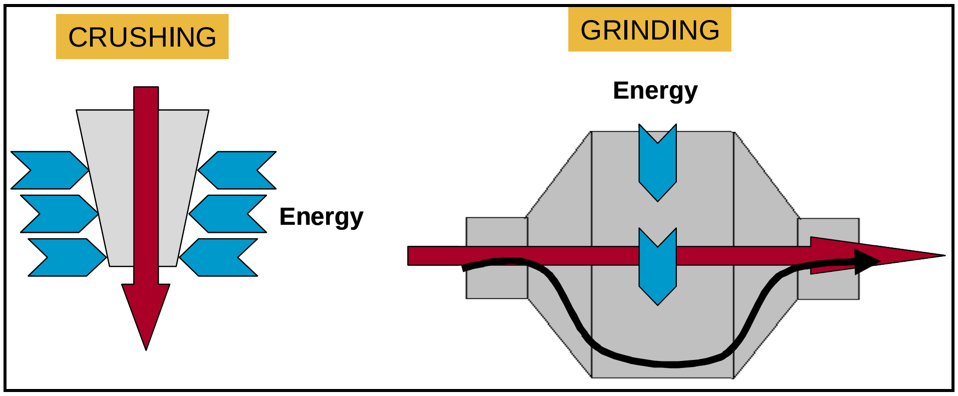

Figure 1. Material transport in crushers and horizontal grinding mills

Contrary to the crushers, the material transport in grinding mills is horizontal and therefore requires a suitable arrangement to remove the product. The grate and pulp lifter arrangement has been introduced in grinding mills to increase the material transport by providing high gradient across the grate. However, extensive research by Latchireddi (2002, 2003a, 2003b) has proved that the material transport across the grinding mill is not straight forward, but it consists of several inherent drawbacks. The magnitude of the problems- flow-back and carry-over depends on design of pulp lifters, grate and other operating parameters, have been discussed elsewhere (Latchireddi 2006, 2009).

The TPL system improves the material transport characteristics of the Mill, efficiently discharging slurry and particles that have passed through the grates. TPL has been demonstrated to provide the following benefits compared to conventional pulp lifter systems;

- increased mill throughput;
- reduction in grinding specific energy;
- lower operating ball charge;
- reduced over-grinding;
- improved operator control of the grinding circuit;

The benefits that can be attained by eliminating these material transport issues have been demonstrated successfully at brownfield operating plants- Alcoa (Nicoli et al, 2001), Cortez Gold mines operation (Steiger et al 2007) and few other places.

Mirabela Mineração’s SantaRita Nickel operation is the first Greenfield operation where the Turbo Pulp Lifter (TPL™) has been successfully tested and demonstrated the benefits of ensuring efficient material transport and good grinding conditions.

MIRABELA SANTARITA NICKEL OPERATION

The Santa Rita mine is located in north eastern part of Bahia in Brazil and is owned and operated by Mirabela Mineração do Brasil Ltda. The detailed comminution testwork program was undertaken during 2006 as part of the Definitive Feasibility Study (DFS) by GRD Minproc Limited (GRD Minpro)c for the Santa Rita nickel project.

Ore Characterisation

The Santa Rita fresh rock mineralisation exhibits the most consistent rock competency and grindability characteristics encountered by GRD Minproc. On average, the ores can be described as being of moderate rock competency, moderate to high grindability and average abrasion potential. Little variation in competency is evidenced between the three major ore domains, pyroxenite (P), orthopyroxenite (O) and harzburgite (H). Pyroxenite has, on average, slightly higher Bond ball work indices and abrasion indices and as such processing of this ore alone would incur higher unit energy and wear costs. Balancing this, pyroxenite has the best flotation response of the ore types as it has the highest nickel recoveries.

Comminution Testwork

All of the testwork on drill core samples was carried out at AMMTEC Laboratories, Perth, Western Australia. In total about 42 samples have been subjected for different comminution tests - JK Droptest, Bond work index (Ball and rod), crushing work index (CWi), UCS and AI. The important observations from these tests are:

- The JK parameter Axb is consistent across the orebody except for a low competency zone in the upper north, and it generally indicated a medium to hard (36.5 to 54.9).
- The Bond ball mill work index (BWI) trends strongly upwards from north to south in the P zone, is relatively consistent in the O zone, is much harder in the south H zone than the central and north H zones. In general, BWI is only high (21 to 22 kWh/t) in the southern zone while the central and north zones range from 17 to 19 kWh/t.

The range and average values of different comminution parameters for SantaRita nickel ore are given in Table 1.

Table 1 - Summary of ore characterization and design data.

Parameter		Value		
		Range	Average	Design-80th percentile
JK Parmaters	Axb	36.5-54.9	46.2	41.3
Bond ball mill work index	kWh/t	15.8-23.5	19.1	21.8
Bond rod mill work index	kWh/t	16.8-18.4	17.6	17.6
Abrasion Index, AS test		0.082-0.591	0.282	0.346
SMC	Dwi	4.7-7.85	7	7.9
Unconfined compressive strength	Mpa	39.4-105.0	86.6	86.6

Design Criteria

The initial design criteria was to treat 4.0 Mt/a throughput increasing to 4.5 Mt/a by adding one pebble crusher in Year 3, to produce P80=125 micron product from F80=120mm with 91.3% plant availability. However, P80=145 micron was preferred based on the grind-size-recovery (Figure 2) and economic factors. The 80th percentile values (Table 1) of the average ore characteristics were used for design the grinding mills.

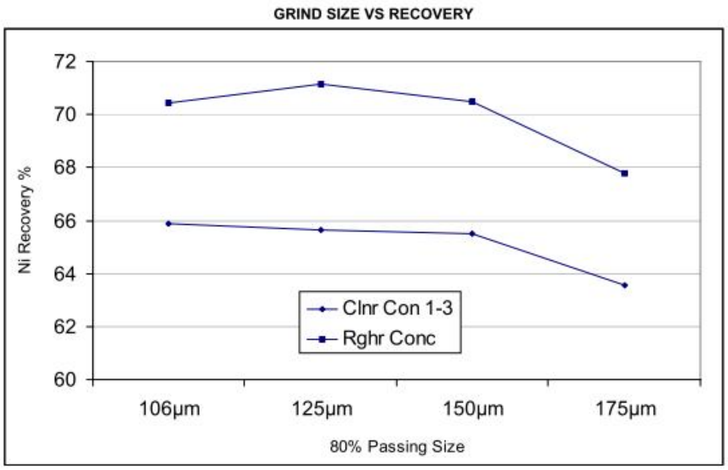

Figure 2 - Ni recovery and grind size relationship.

Alternative circuit configurations were entertained including conventional tertiary crush with ball milling, high pressure grinding rolls (HPGR) based tertiary crush with ball milling and single stage SAG milling. HPGR was discounted on the basis that an appropriate sample collection and testwork program could not be completed within the project schedule. The perceived technology risk and moderate competency and abrasion characteristics of the ores further discounted the applicability of HPGR. Tertiary conventional crushing was discounted on the basis that SAG milling in general offered advantages in capital and operating cost. SAG/Ball (SAB) and SAG/Ball/Pebble Crush (SABC) circuits were the preferred options for further analysis based on mitigation of mechanical and technical risk whilst offering a reasonable capital cost and a low operating cost regime.

The metallurgical test work has indicted that P80=145 micron could be preferred based on the grind-size-recovery and economic factors and hence Mirabela approached SMCC (2007)to estimate the maximum capacity of SABC circuit for both P80=125 micron and P80=145 micron scenarios using Mirabela's suggested ore blend – 60% P (Pyroxenite), 14% H (Harzburgite) and 26% O (Orthopyroxenite) and the predictions are given in Table 2.

Table 2 - SMCC predictions for SABC circuit.

Ore type		Blend	Blend
sg		3.24	3.24
DWi		7.9	7.9
A*b		41.3	41.3
BWi		21.8	21.8
F80	mm	120	120
P80	microns	125	145
One ball mill			
Maximum throughput	**tph**	**500**	**575**
	mtpa	**4.00**	**4.60**
sag power	kW	5673	6359
ball power	kW	5376	5376
total power	kW	11049	11735
sag spec. energy	kWh/t	11.3	11.1
ball spec. energy	kWh/t	10.8	9.3
total spec. energy	kWh/t	22.1	20.4

Grinding Circuit Flow-sheet

The milling circuit flowsheet of SantaRita operation is shown in Figure 3. The SAG mill accepts the primary crushed feed ore and operates in closed circuit with pebble crusher. SAG mill discharge passes through grates and screened by a trommel with the oversize being recycled by conveyor back to the SAG mill. Combined product from the SAG mill (trommel undersize) and the Ball mill discharges into a common mill discharge hopper. This product pumped to a set of cyclones with the underflow being directed back to the Ball mill.

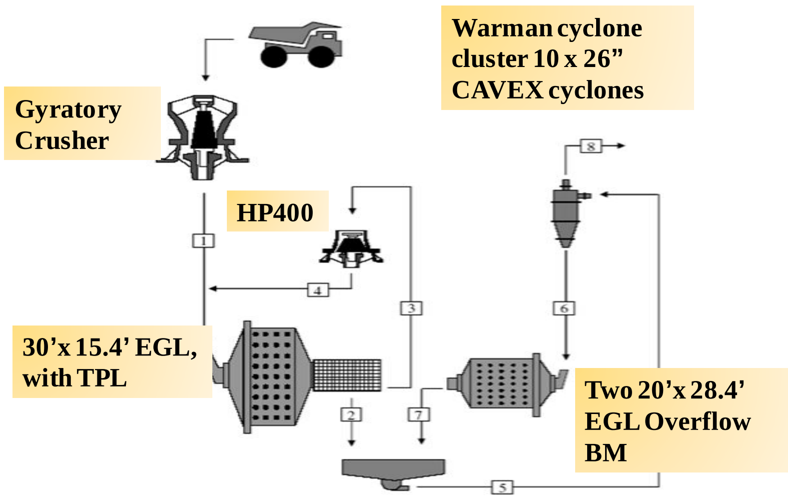

Figure 3 – Mirabela SantaRita grinding circuit flowsheet.

The Santa Rita grinding circuit consists of one 30’x 15.4’ 8.5MW SAG Mill fitted with Outotec patented Turbo Pulp Lifters (TPLTM) in close circuit with HP400 short head pebble crusher and one 20’ x 28.4’ 5.5MW Ball Mill in closed circuit with Warman cyclone cluster fitted with 10 x 26” CAVEX cyclones.

STARTUP AND COMMISSIONING

The milling circuit commenced commissioning on the 29th of October 2009 and it was immediately apparent that the milling circuit would have very little trouble in achieving the design throughput target of 575tph (annualised rate 4.6Mt). The plant has not realised this over a continuous extended period (a month) the only reason is ore availability. If the ore was available there is very little chance the milling circuit will not achieve the throughput targets. During the first month (November 2009) shown in Figure 4, the milling circuit has treated over periods (days) between 550-575tph, with power draws, mill loads and other parameters well under control and below expectations.

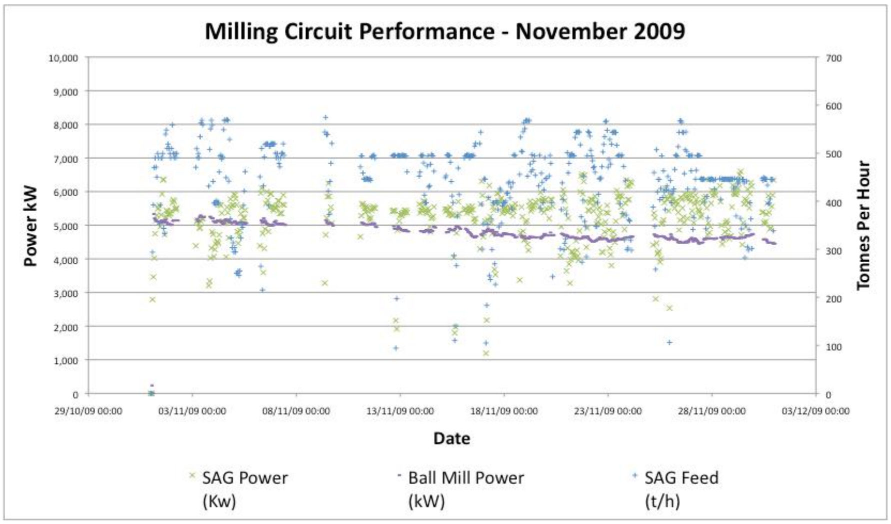

Figure 4 – Performance of SantaRita milling circuit during November 2009.

SAG Mill power

The SAG mill power draw realized in the operation of the plant on a blend similar to the simulation data shows the mill consumes less power than predicted without the need for pebble crushing to 12mm (if pebble crushing was performed the power draw on the mill could be lower, however it is less expensive to draw more power per ton than operate the pebble crusher).

SAG Mill Ball Charge

The SAG mill was simulated to require a 10-12% ball charge with a top size of 125mm. During the commissioning phase no balls were required to be added to the SAG mill to achieve the target throughput of 575tph. This allows for great flexibility in the future and significant security for the future.

Ball Mill Power

The simulations suggested that the power input required to achieve 575tph at a product size 80% passing 125um was 6210kW. This is 110% of the maximum available power that is available. To ensure the milling circuit would achieve the 575tph throughput rate in the simulations the product size had to be coarsened by to 145um. This result in the test work indicated little to no impact on the recovery of the ore. The actual power draw that required from the mill is 3450kW. This relates to a 61% of maximum power draw at a ball charge volume of 19%. Initially the mill was charged to full charge (30%) however the product sizing was too fine and the mill load was reduced to reduce the power draw and coarsen the product.

Ball Mill Recirculating Load

The ball mill's recirculating load was expected to be 250%. This corresponds to a volumetric flow of 2700m3/hr. However as with a large number of base metal milling circuits the Santa Rita milling circuit operates at a maximum recirculating load of 150%. The result of the lower recirculating load is that the cyclone feed pumps are operating at lower speeds and less cyclones are required during the operation.

Problems Past and Present

The milling circuit commissioning resulted in surprising small and relatively simple measures to rectify. This is reflected in the rapid commissioning of the milling circuit and it achieving nameplate capacity so quickly. The problems that were experienced were part and parcel with commissioning, ie conveyor setup, transfer chutes and electrical problems.

Pebble conveyors

Initially the pebble conveyors had tracking problems and significant spillage. Maintenance has since corrected the tracking of the conveyors and the circuit is now operating with minimal spillage.

Transfer chutes

The rock transfer chutes were wearing rapidly. The maintenance team identified that the liners that were installed were not suitable for the high impact duty they were exposed to. The wear plates now have been changed to a different material that is more durable.

Trommel screens

This is the most significant item in the list. The trommel on the SAG mill has experienced significant amounts of wear and this wear resulted in the most downtime experienced in the commissioning.

The downtime resulted from segments of the spiral within the trommel coming loose and wedging in the pebble transfer chute. This in turn blocked the chute and the pebbles backed up the chute, overflowed into the mill discharge hopper, blocked the operating cyclones and then overflowed onto the flotation trash screen. The site maintenance team have fixed this problem in the interim by modifying the spirals to make the fixings more secure. The manufacturers of the trommel have visited site and recommended a solution to the problem that has fixed this problem for other customers.

Pipe work

The original pipe work has suffered above expected wear in the underflow of the cyclones that feed the ball mill. Once again the site maintenance team has rectified this problem and the system appears to be working satisfactorily now.

SER Problems

The variable speed of the SAG mill has had an intermittent fault. The fault would manifest itself and result in the SER tripping and the mill would switch to fixed speed. The suppliers have since found a fibre optic cable defect and since the repair the mill has been operating well.

MILLING PERFORMANCE HISTORY

The performance of the milling circuit in terms of throughput and power draw of both AG and Ball mills is shown in Figure 5 as daily average values from the start-up (24th October 2009) till April 2012.

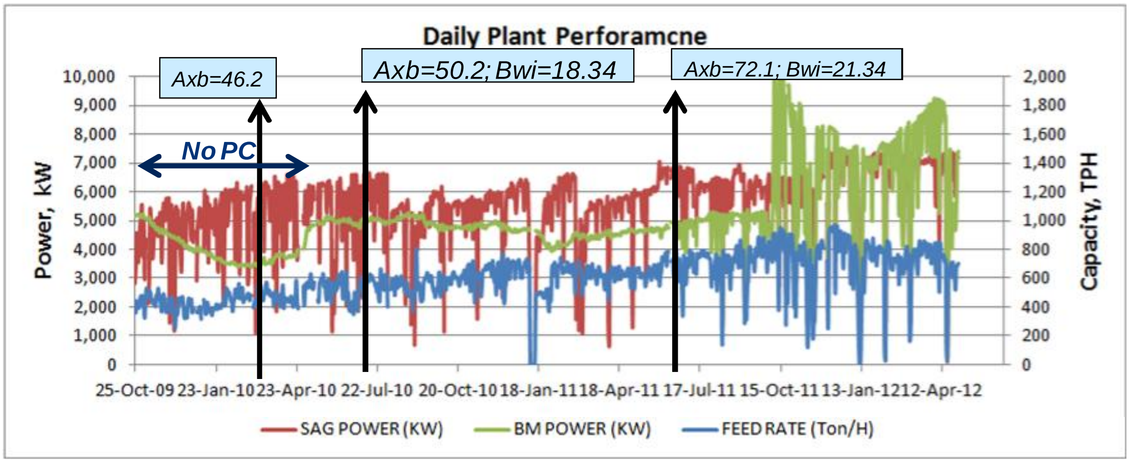

Figure 5 - Daily average throughput and power draw of AG and BM since start-up.

Important observations made since the commissioning of grinding circuit are given below:

- The most important outcome of this operation is that the SAG mill is able to perform the duties beyond the design values in fully autogenous (AG) mode with no grinding balls.
- The performance of the milling circuit (without Pebble Crusher and no grinding balls in SAG mill) during the first few months (until May 2010) by operating around 500 tph on average while treating the hardest ore so far (Axb= 46.2) shows the high capability of the milling circuit to grind higher tons, but could not be done mainly due to non availability of ore.
- There are distinct periods during the first few months, where the mill throughput was 575tph or more with the power draw of SAG and Ball mill were well within the operating range.
- Initially the BM was filled to about 30% as part of commissioning, which produced very fine product (100% passing 106 micron) causing severe problems in flotation and filters. Hence, to coarsen the product size, no grinding balls were added in BM for almost 4 months as indicated by the large dip in BM power draw. Ball Mill feed was diluted to reduce the residence time in ball mill also helped in coarsening the product size.
- The AG mill power draw became significantly more stable as the months progress. The power draw of 6000kW for 575tph-the design capacity, in AG mode and without optimization tools, reflects the ability of ensuring good grinding conditions by Turbo Pulp lifter (TPLTM)- an Outtoec patented design.
- As the ore availability has improved, the throughput gradually increased to +650tph on average after commissioning the Pebble Crusher.
- Relatively softer ore (Axb=72.1) coming from the transition zone from September 2011, has allowed the mill to treat higher throughput up to +850tph still in AG mode. However, the product size was getting coarser along with higher scats discharge from the Ball mill, which necessitated the use of second ball mill.
- The AG mill power draw did not change significantly with the change in tonnage and the blend that ranged from 70:30 (Pyroxenite to Hharburgite) to 50:50.
- As time progresses the trends are becoming increasingly steadier and the operations team is controlling the milling circuit in a more optimal way.

Conversion from AG to SAG

After completion of ore from transition zone during January 2012, the throughput started slowly decreasing towards 700-800 tph which appears to be due to increases in ore hardness with fresh pyroxinite ore. In month of April, the throughput has further decreased to below 700tph, resulting in higher specific energy of AG mill which can be observed from Figure 6. The consistently reduced throughput and continuous variations in feed ore has started effecting the flotation performance and plant economics. In addition, the laboratory tests have also indicated that the finer grind size (P80=125 microns) would yield a better recovery, which required the use of two ball mills leading to higher specific energy as shown in Figure 7.

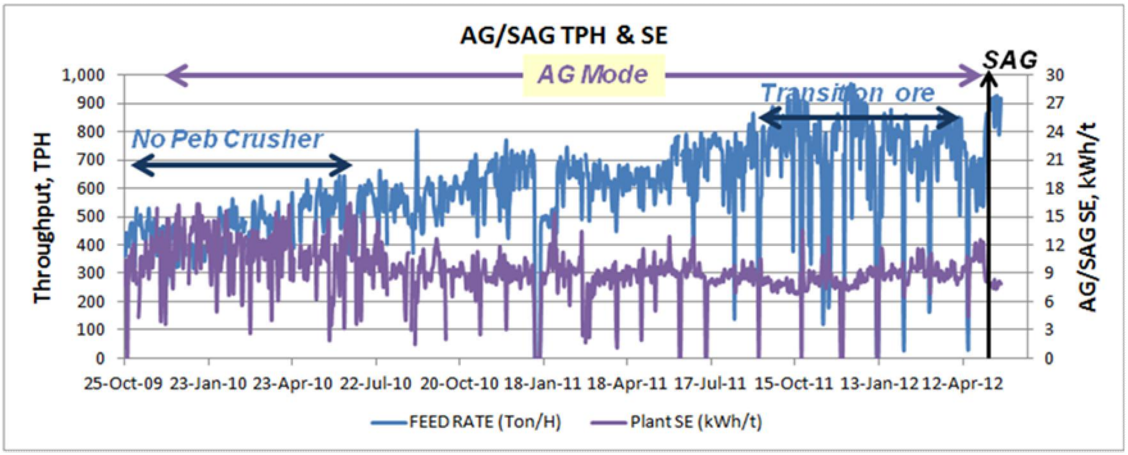

Figure 6 – Daily throughput and specific energy consumption of AG/SAG mill.

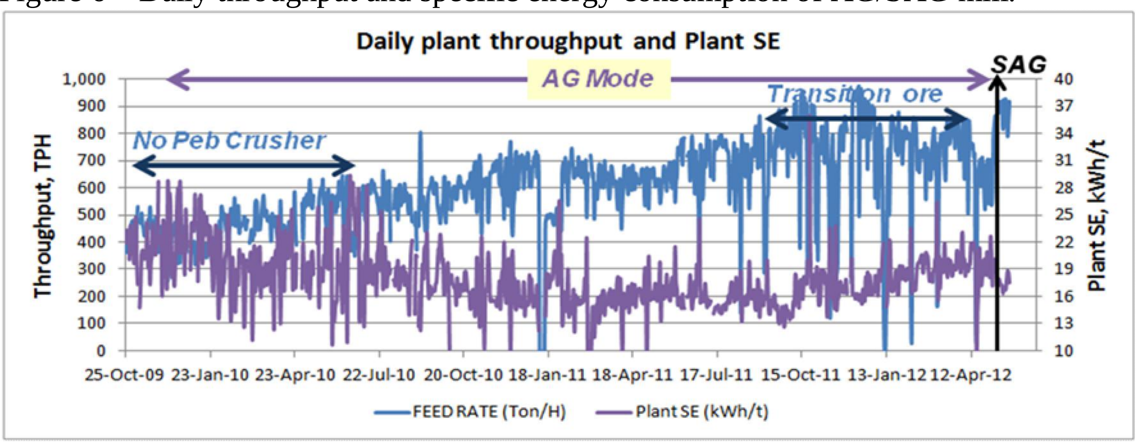

Figure 7 – Daily Plant throughput and plant specific energy consumption.

It is known fact that the AG mill performance depends significantly on ore hardness unless a good blending and particle size control is implemented. The AG mill energy consumption has been 11-12 kwh/t until installation of the Pebble Crusher. After pebble crusher installation, the AG mill throughput increased from 550-900 tph at an average specific energy consumption of 9 kWh/t (Figure 5), which indicates how the AG mill performance varies with the ore hardness as shown by changing Axb value from 46.2 to 72.1 (Figure 5).

In order to maintain a consistent throughput at 900 tph (capacity of flotation circuit) with P80-125 microns for stable operation of flotation circuit, grinding balls have been added to move from AG to SAG mode. The grinding balls have been added in three stages to reach 7% by volume, which was estimated to be required to attain capacity of 900 tph in SAG mill. The performance of the grinding circuit during the transition from AG to SAG mode is shown in Figure 8. The monthly productivity of the Grinding circuit (Figure 9) shows that the plant is consistently operating well above 900tph in SAG mode with 7.5% ball charge. It also indicates that the throughput can be further increased by going for the designed ball charge of 15%.

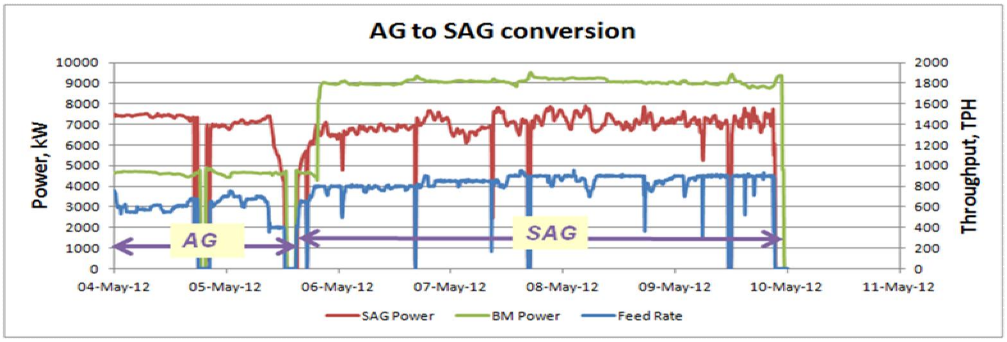

Figure 8 – Performance of grinding circuit with grinding balls (SAG mode).

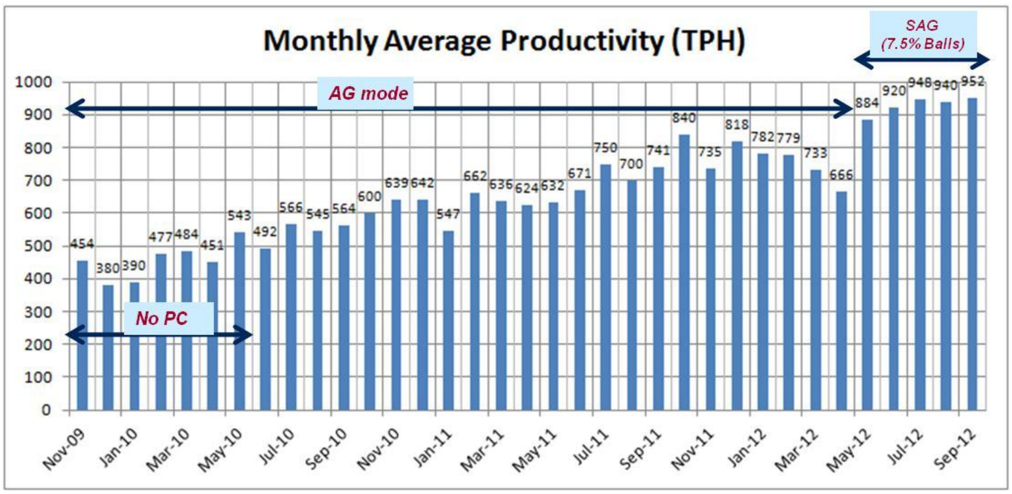

Figure 9 –Monthly productivity of SantaRita grinding circuit.

PERFORMANCE ASSESSMENT

The SAG mill in SantaRita grinding circuit has been designed to operate with 10-12% ball charge to grind 575tph to produce p80 of 145micron. However, it has been consistently operating in fully autogenous (AG) mode and successfully operated upto +850 tph over a range of ore hardness (Axb from 46.2 to 72.1).

Efficient energy utilization is the main reason behind this success and has been possible only by the efficient material transport and good grinding conditons, ensured by the Turbo Pulp Lifters (TPL) – an Outotec patented design. To assess the effects of TPL on grinding efficiency of AG/SAG mill, a complete grinding survey was conducted on 15th July 2010, and the results are summarised in Table 3 together with the design expectations.

Table 3 - Comparison of design and actual operating data.

Parameter	Design	Survey
Throughput, mtph	575	650
Fed size, F80, mm	120	141
transfer size, T80, mm	0.8 - 2.0	0.342
Product size, P80, micron	145	146
JK Axb	41.3	50.2
Bond Wi, kwh/mt	21.8	18.4
SAG Mill		
SAG Mll Size (Dia X Length), m	9.15 x 5	9.15 x 5
Open Area (PP-70mm), %	12	12
Ball Charge, %	12	0
SAG Power draw, kW	6359	6667
SAG Specific Energy, kWh/mt	11.06	10.26
Pebble Crusher		
Pebbles flowrate	25-40%	20-35%
CSS	12 mm	20 mm
Pebble Crusher Specific Energy, kWh/mt	0.37	0.47
Ball Mill Circuit		
Ball mill Power draw, kW	5376	5085
Ball mill Specific Energy, kWh/mt	9.35	7.82
Recirculating Load, %	270	115
Oerating Cyclones	8	3
Total Specific Energy, kWh/mt	20.78	18.55

Comparison of Breakage Rates

Turbo pulp lifter technology has been proven to eliminate all the material transport problems such as flow-back and carry-over of slurry/solids (inherent to the conventional discharge designs) that lead to excessive mill loads (due to slurry/solid pooling) (Latchireddi 2002, 2003, 2006). Once the product size particles pass through the grate, they will be completely discharged into the trunnion by TPL, thus ensuring the effective utilization of energy in breaking newer particles. The presence of any amount of excess slurry (>voids) has two bad effects – 1) minimizing impact breakage due to damping and 2) the smaller particles (usually <5mm) tend to slip into the slurry pool and escape the attrition breakage action. However, with TPL, there is no way these smaller particles can escape and are forced to stay inside the voids and get nipped between the coarser particles. All the above factors suggest for a better or higher breakage rates with TPL system compared to the mills with conventional discharge systems. In order to study this aspect, the following have been carried out:

- JKSimMet modelling to 15th July 2011 grinding survey data.
- Use of JK default breakage rates to simulate the performance with conventional discharge systems.
- Use of 40ft Cadia SAG mill rates (provided by JK) to simulate the milling circuit.

The AG/SAG mill breakage rates obtained from the above three situations for the same work are depicted in Figure 8 and the corresponding results are summarized in Table 4.

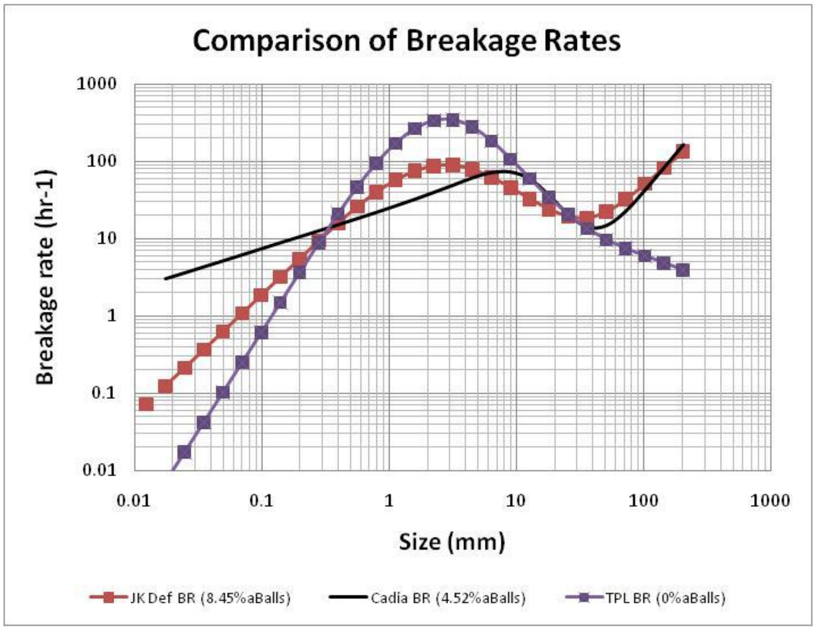

Figure 8 - Comparison of milling circuit performance and SAG breakage rates (TPL, JK default and Cadia).

Table 4 - Simulation results (Exisitng with TPL, JK default and Cadia 40ft).

Parameter	TPL	JK Def BR	Cadia BR
Throughput, mtph	650	650	650
Fed size, F80, mm	141	141	141
Product size, P80, micron	146	146	146
JK Axb	50.2	50.2	50.2
Bond Wi, kwh/mt	18.4	18.4	18.4
SAG Mill			
Total Load, %	33.18	25	28.6
Ball Charge, %	**0**	**8.45**	**4.5**
SAG Power draw, kW	6667	7526	7287
SAG Specific Energy, kWh/mt	10.26	11.58	11.21
Transfer Size, microns	342	1561	1777
Ball Mill Circuit			
Ball Charge, %	27.5	27.5	27.5
Ball mill Power draw, kW	5082	5077	5079
Ball mill Specific Energy, kWh/mt	7.82	7.81	7.81
Recirculating Load, %	106	191	155
Operating Cyclones	**3**	**5**	**4**
Total Specific Energy, kWh/mt	**18.08**	**19.39**	**19.02**
Extra Energy required	-	7.3%	5.3%

The important observations made from comparing the TPL breakage rates with that of JK default and 40ft Cadia breakage rates are discussed below:

- The 3-4 fold increase in breakage rates for 0.5-10mm particles with TPL, when compared to JK default and Cadia 40ft rates, amply indicate that these particles are kept in voids and are nipped between the tumbling media and subjected for breakage without slipping into excess slurry pool.
- Lower breakage rates at finer end with TPL indicates minimal or no over-grinding of <0.5mm particles as they behave like fluid and discharge faster than the coarse particles, and there is

no chance for these finer particles to return back through grate since the flow-back and carry-over are completely eliminated with TPL.

- The coarser end indicates the self breakage rather than impact breakage which is typical of AG mill to maintain the grinding media.

In contrary, to achieve the same throughput of 650 tph as in the existing AG mill, the JK default rates required minimum of 8.45% of ball charge, whereas the 40ft SAG Cadia breakage rates required 4.52% ball charge. Lower rates for 0.5 to 10mm particles suggests improper fine particle breakage and higher for <0.5mm particles suggest over-grinding, which could be the result of flow-back.

CONCLUSIONS

The successful and consistent operation of SantaRita milling circuit in fully autogenous mode (ABC) instead of SABC (as per the design) demonstrates the importance of efficient material transport in ensuring good grinding conditions. The use of Turbo Pulp Lifters (TPL) technology, in AG/SAG mills allows to achieve the following:

- increased mill throughput;
- reduction in grinding specific energy;
- lower operating ball charge;
- reduced over-grinding;
- improved operator control of the grinding circuit;

Rapid commissioning and achieving the nameplate capacity within days, emphasizes how an efficient discharge system in AG/SAG mills helps in effective utilization of energy and attaining higher breakage rates.

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REFERENCES

Latchireddi, S R.,2002. Modeling the performance of grates and pulp lifters in autogenous and semiautogenous mills, Ph.D. Thesis, University of Queensland, Australia.

Latchireddi, S R and Morrell, S, 2003a. Slurry flow in mills: Grate-only discharge mechanism part-1, Minerals Engineering, 16(7), 625-633.

Latchireddi, S R and Morrell, S, 2003b. Slurry flow in Mills: Grate-Pulp lifter discharge mechanism part-2, Minerals Engineering, 16(7), 635-642.

Latchireddi, S., 2006. WO 2006134200A1, Apparatus for discharging a material from a mill, Outokumpu Oyj.

Latchireddi, S., 2006. A New Pulp Discharger for Efficient Operation of AG/SAG Mills with Pebble Circuits. Proc. SAG 2006, Vancouver, Canada.

Latchireddi, S., 2009, Improving Autogenous/Semi-Autogenous Grinding Performance and Energy Efficiency with Optimised Pulp Lifter Design. Tenth Mill Operators Conference, AusIMM, pp.84-93.

Steiger, J., Plummer, D., Latchireddi, S. and Rajamani, R.K., SAG Mill Operation at Cortez: Evolution of Liner Design from Current to Future Operations. CMP 2007, Ottawa, Canada.

Report No.52043-3000-05-104-001 Rev D(2007). SantaRita Grinding Circit Design. GRD Minproc, Australia.

Final Report Rev 2(2007). Assessment of the proposed SantaRita Grinding Circit . SMCC Pty Ltd., Australia.

Report (2011). Ramp-up of SantaRita grinding circuit. Outotec.

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