IMPROVING ENERGY EFFICIENCY IN BARRICK GRINDING CIRCUITS

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ABSTRACT

Barrick Gold Corporation (Barrick) has undertaken innovative methods of evaluating and improving the performance of grinding mills in several of its operations around the world. The results have been positive with some of the mines showing more than 20% net energy improvement leading to more than 43,000 tonnes per year reduction in CO_2 emissions in four of the operations reviewed.

KEYWORDS

Grinding, semi-autogenous grinding, SAG, ball mill, energy, efficiency, greenhouse gas, GHG, carbon dioxide, CO_2

INTRODUCTION

Barrick and its subsidiary, African Barrick Gold, operates 26 mines world-wide and has a further six in feasibility or construction. Of these mines, 19 currently are operating grinding circuits with 6 additional installations either in construction or planned. Grinding is an essential, but energy-intensive, part of gold recovery requiring crushers, large diameter semi-autogenous grinding (SAG) mills and ball mills with up to 12,000 kW motors. Ore grinding can account for 60% of a site's electrical power load and more than 35% of the operation's greenhouse gases (GHG) as measured in tonnes of CO_2 equivalent. These comminution circuits typically include crushers, semi-autogenous grinding (SAG) and ball mills and are followed by a variety of down-stream processes including flotation, autoclaves, roasters, direct leaching, etc. Invariably, the grinding aspects are the largest single energy consumer in the processing facilities and as such offer some of the largest opportunities for net energy efficiency improvements.

In overall terms, electricity accounts for 38% of Barrick's total energy and the primary ore grinding consumes about 55% of the electricity and is associated with 1.7 million tonnes per year of greenhouse gases. Further, this comminution electricity costs about $300 million out of Barrick's annual energy spend of $1 billion.

In 2008 Barrick published a position statement on climate change and subsequently developed this into a Climate Change Standard. Inherent to the Standard is the requirement to improve energy and associated greenhouse gas (GHG) efficiency in operations. Initial observation of the grinding circuits indicated potential opportunities for improvement as both an economic and a GHG efficiency opportunity.

In light of the perceived opportunity due to large cost and observed improvement opportunities, Barrick undertook a review of the efficiency of the various grinding circuits worldwide and through the application of standardized measurements of key parameters, developed a plot of efficiency describing the various mills. The exercise begins with comprehensive sampling and modeling of the individual grinding circuits at each site. This is a difficult and painstaking procedure for the sites and they have been assisted by a grinding expert from the corporate Operational Support team in Toronto. Once the individual circuit has been modeled, the specific energy efficiency is plotted against a predetermined minimum efficiency line based on laboratory-derived ore hardness characteristics. Circuit modifications are then modeled and evaluated, which guides the site in making changes to their grinding circuit configuration. Another sampling campaign is performed on the modified circuit to confirm the predicted improvements have been achieved. Figure 1 is a comparison of plant performance from field sampling as compared to the anticipated performance based on ore characteristics in the Morrell and Metcom methodologies.

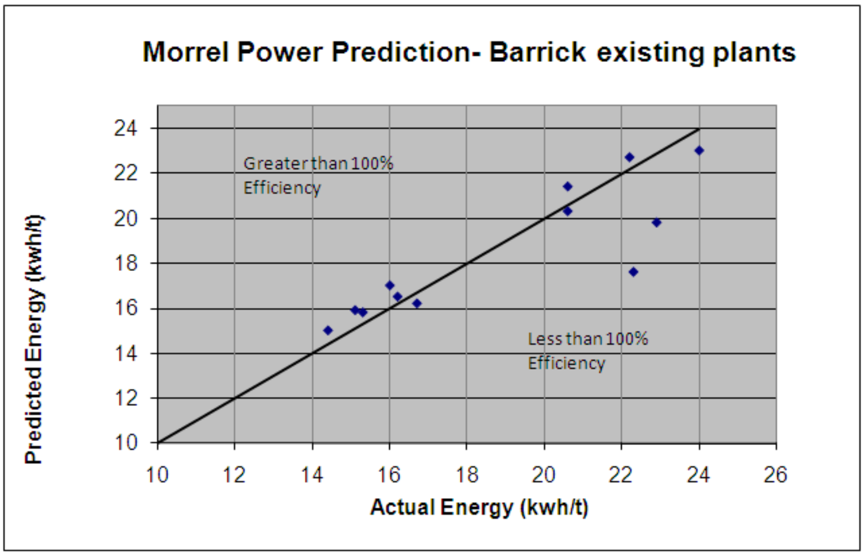

Figure 1 – Barrick Gold grinding circuits specific power

In light of the size and configuration of many of the grinding circuits, special techniques and sampling devices were developed to assure the safety of the personnel collecting the samples and the quality of the samples collected. Various modeling tools were chosen to evaluate the circuits and their components which included JKSimMet®, Metcom, MillSoft® FlowMod™ and several others. A common database was developed within Barrick to help operators at the various sites benchmark their performance. This paper will review the benefits achieved at three of Barrick's operations.

IMPROVEMENTS QUANTIFIED

Cortez Mine - Scenario

The Cortez processing facility, located in Landers County in Nevada, USA has been operating since mid-1997 and Barrick acquired 60% in 2006 and the remaining 40% in 2008. The comminution circuit comprises a primary jaw crusher, SAG mill with a cone crusher on mill scats and a ball mill with a single pack of cyclones in closed circuit with the ball mill. During the first decade of operation the mill was capable of processing in excess of 410 tonnes per hour (450 tons per hour) and was largely ball mill limited with processing well-matched to mine production. The ore became harder with increasing open pit depth and throughput suffered with the SAG mill commonly becoming the limiting factor. Various studies pointed to several design and operating opportunities, namely;

- Packing between SAG mill lifters
- Significant peening and breakage of SAG mill liner components
- High slurry pooling volumes in the SAG mill
- Coarse recirculating product from the scats crusher
- A bi-modal ore hardness aspect in the ball milling circuit

Cortez Mine - Actions Taken

A new SAG liner system was modeled and installed. This eliminated ½ of the shell lifter bar rows and also increased the lifter bar angle from 17º to 28º. The resulting profile eliminated packing between the lifters and also reduced the modeled impact of the ball charge on the unprotected liners above the slurry pool.

The discovery of excess mill pooling in the SAG mill prompted a review of the "pumping" capacity of the SAG mill. The excess slurry pool inhibited grinding and caused unnecessary power draw on the mill with the internally recirculating slurry. Crash stop inspections (Figure 2) of the mill interior components confirmed FlowMod^{TM} modeling and lead the team to a redesign of the pulp lifters which carry the slurry from the discharge grates to the discharge trommel for exit from the mill. The existing radial pulp lifters were replaced with a proprietary design known as the Turbo Pulp Lifter or TPL™.

Figure 2 - Crash stop of SAG mill showing pooling

The mill grate discharge included square pebble ports which had very limited open area at the periphery. This added to the pooling effect. The team was able to reconfigure them into a slotted arrangement parallel to the direction of rotation while maintaining the original 7.0 cm (2.75 inch) dimension.

The Omnicone 1560 cone crusher liner was changed from a "fine" profile to a "medium" profile to increase reduction ratio, reduce bowl float and to maximize the power per tonne used in crushing. This allowed for the pebble crusher to handle the now higher scats discharge rate and particle size from the SAG mill, as well as causing a significant reduction to the discharge particle size from the cone crusher returning to the SAG mill.

This is shown in Figure 3 and resulted in a consequent volume reduction in new scats generated by the mill.

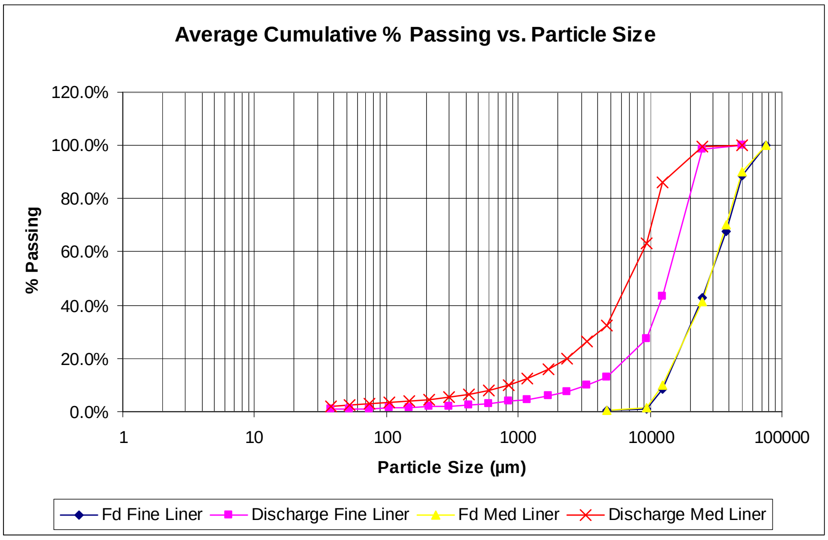

Figure 3 - Cone crusher performance curves

Following the upgrades in the SAG mill circuit, sampling and modeling of the ball mill circuit identified a bi-modal hardness characteristic of the ore. Evaluation with both MetCom and JK SimMet® lead to changes in the ball make up size from 75 mm to a 50:50 mix of 75 mm and 38 mm.

Cortez Mine – Results Achieved

The results of the various significant changes in the grinding circuit have been generally quantified in terms of throughput, energy and greenhouse gases as shown in Table 2. Electrical power is acquired from the NVEnergy grid and carries a GHG factor of 0.675 kg CO_2(e)/kWh based on the generation mix.

- The new liner configuration eliminated packing and provided a slight increase in throughput, a small associated reduction in specific energy and a reduction in liner wear.
- Changes to the pulp lifters significantly decreased the pooling in the mill and allowed operating at slower rotational speeds of the SAG mill. This significantly dropped power requirements and smoothed overall operation.
- The change to the liner profile in the recycle cone crusher increased the crusher power draw. The result was improved efficiency in the circuit as the cone crusher is several times more efficient on critical size material than is the SAG mill.
- The reduced size of pebble crusher product reduced the recirculating load around the SAG mill and the volume of near-sized particles presented to the ball mill.
- The reduction in over-grinding with reduced slurry pooling in the SAG mill caused an apparent increase in classification efficiency with less fines bypassing to the cyclone underflow.
- The final modification to the ball make-up size in the ball mill, when combined with the improved classification noted above, allowed a reduction in the power draw at the ball mill.

Table 1 – Cortez Mine grinding improvement summary

Change	Tonnes/hour Increase	kWh/t Reduction	kWh/yr Reduction	Tonnes CO2 /yr Reduction
Eliminate liner packing and excess ball throw	3	0.2	700,000	500
Improve pumping of slurry from the SAG mill	0	3.1	11,400,000	7,700
Cone crusher liner profile change	57	1.5	5,500,000	3,700
Ball mill power reduction	0	0.9	3,000,000	2,000
Net Savings			19,600,000	13,900

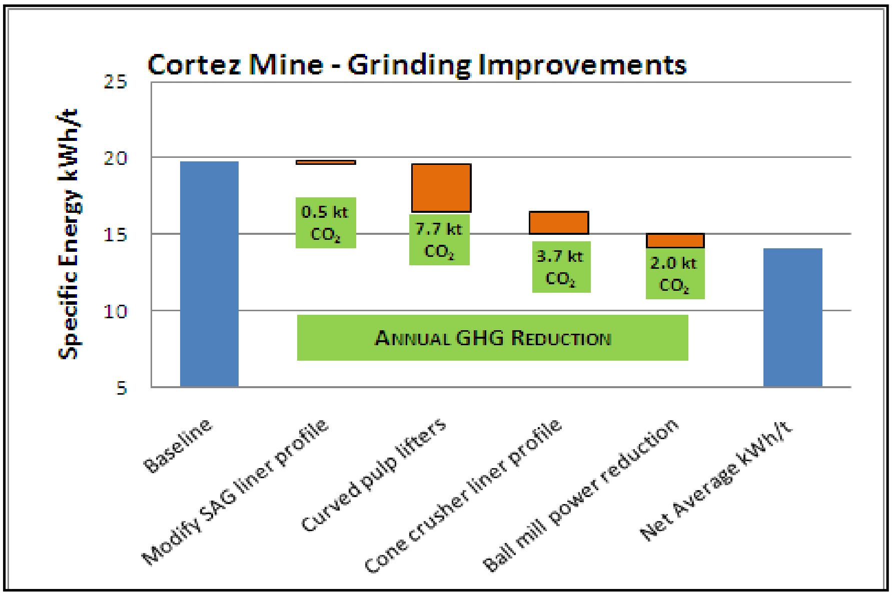

Figure 4 – Effect of improvements on Cortez energy and GHG profile

Cowal Mine - Scenario

The Cowal processing facilities, located northwest of Wyalong, New South Wales, Australia has been operating since 2005. The processing plant was designed for nominally 6.7 million tonnes per year through primary gyratory crusher, a SAG mill in closed circuit with a cone crusher on mill scats and a ball mill in closed circuit with hydrocyclone classification. The grinding circuit is somewhat complicated by the addition of both flash flotation and gravity recovery in the ball milling section. The final cyclone overflow product of the grinding circuit reports to flotation which then incorporates ultra-find grinding on the concentrate prior to concentrate leaching.

The site generally achieved budgeted throughput from the start, but studies and modeling revealed potential opportunities for improvement.

- Design parameters indicated a potential for significant variability in the ore body prior to equipment selection
- High slurry pooling was observed in the SAG mill following start-up
- The cone crusher product tended to be quite mono-sized, resulting in high recirculating loads of pebbles and was not conducive to down-stream ball milling
- The ball mill recirculating load was lower than most operations experience.

Cowal Mine – Actions Taken

The SAG mill and ball mill original design was reviewed and a change resulted in the application of a gearless drive wrap-around motors on both machines. This immediately delivered energy savings as the units are inherently more efficient in transferring incoming power to the shell of the mill. The use of the gearless drives also provides the opportunity to better trim the SAG mill speed and power to downstream constraints and overcomes damage concerns associated with frozen ball charge.

Review of the wear characteristics in the SAG mill discharge pulp lifters and the observations made during crash stops indicated a fluid pumping limitation may exist. Excess slurry pooling inhibits grinding and also acts as an unnecessary power draw due to internal recirculation of the fluids. Comparison of the SAG mill's pumping capacity with that of other mills lead to the redesign of the pulp lifters. Curved pulp lifters were designed and installed to ensure the SAG mill capacity was constrained by ore characteristics and not by its ability to pump slurry. The curved pulp lifters had an immediate effect on throughput as can be seen in Figure 5. The two dates noted of September 18, 2008 and July 16, 2009 refer to the applicable surveys and their associated throughput frequency group.

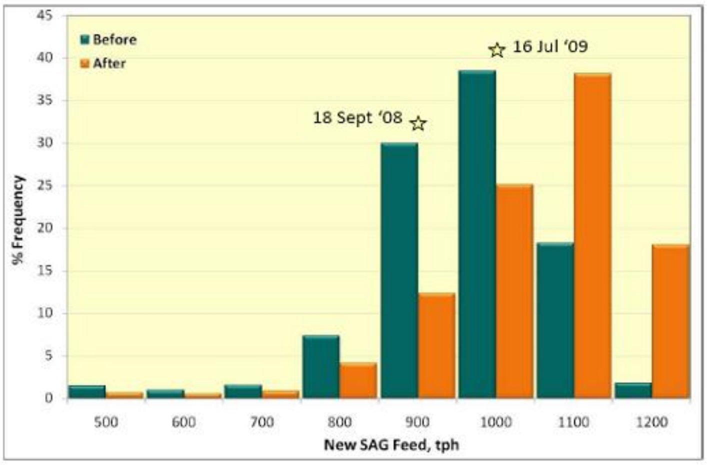

Figure 5 – Measured effect of curved pulp lifters in Cowal SAG

Observations of the performance of the cone crushers which operate in closed circuit with the SAG mill indicated that the crushed product, although finer than the feed, was very mono-sized or "pebbly". The recirculating load of SAG mill scats rose towards the 408 tonne per hour limit of the recycle conveyor and caused a bottleneck. In addition to the rising SAG load, the scats from the SAG mill were now becoming scat-sized to the ball mill.

This effect was modeled following sampling campaigns of the circuit and then a set of "what-if" scenarios were performed in JKSimMet® and with Metso crusher modeling tools. The result was a modification of the crusher liners to achieve a flakier product that is inherently more suitable to ball milling.

The apex spigots of the hydrocyclones were changed from 165 mm to 180 mm. This increased the circulating load from about 180% to 240% of new feed. In the future, the cyclone feed line will be increased to 650mm from 600mm. Once this change is completed, the spigot size will be further increased to 200 mm to further improve the circulating load in the ball mill.

Cowal Mine – Results Achieved

The results of the various changes in the grinding circuit have been generally quantified in terms of throughput, energy and greenhouse gases as shown in Table 3. Electrical power is acquired from the supplier and transmitted through the Country Energy grid of New South Wales. Accordingly it has a GHG factor of 0.89 kg CO_2(e)/kWh based on the generation mix.

The wrap-around gearless motor on the mills improved net mill energy efficiency by up to 4.4% as the traditional gear and pinion mechanical losses are replaced with lesser electrical losses through the thyristor power convertors. In addition the variable speed aspects of the thyristor drive allow the SAG mill to be slowed down during periods when downstream constraints dictate.

The installation of the curved pulp lifters caused an immediate and significant throughput improvement in the SAG mill. The net average effect was an increase of 60 tonnes per hour. This was coupled with a reduction in power requirements in the SAG mill of 6%.

The focus around the cone crushers was two-fold; to remove the recycle bottleneck and to lower the crushing point in the chamber to minimize damage to the crusher components. The cone crusher liner system was changed from a fine concave to medium concave. The power draw of the H6800 crusher following the change rose significantly from 140 kW to 220kW and produced a finer product. The net effect on the overall grinding circuit is an observed increase in throughput of more than 50 tonnes per hour.

The adjustments made to the classification circuit have not resulted in any quantifiable energy reductions, but have supported the operation of the overall circuit, minimizing the amount of time that the ball mill is the bottleneck.

Table 2 – Cowal Mine grinding improvement summary

Change	Tonnes/hour Increase	kWh/t Reduction	kWh/yr Reduction	Tonnes CO_2 /yr Reduction
Install SAG mill with variable speed gearless drive		1.0	7,400,000	6,600
Improve pumping of slurry from the SAG mill with curved pulp lifters	60	1.3	11,600,000	10,300
Cone crusher liner profile change	50	1.1	8,000,000	7,100
Net Savings			**27,000,000**	**24,000**

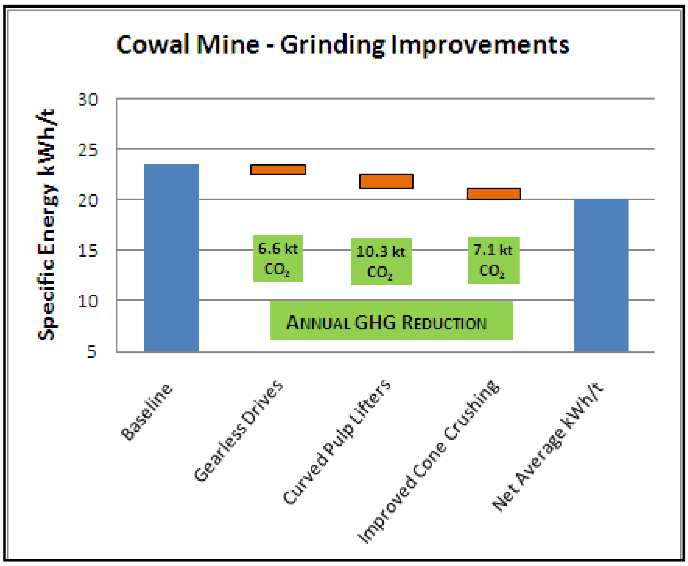

Figure 6 - Effect of improvements on Cowal energy and GHG profile

North Mara Mine – Scenario

The North Mara mine is located in the Tarime district of northern Tanzania about 20 kilometers south of the Kenyan border. It started operating in 2002 and was acquired by Barrick in January 2006. The comminution circuit comprises a primary jaw crusher and a banana screen feeding a secondary cone crusher. Grinding includes a SAG mill with a cone crusher on mill scats and two ball mills with a single pack of cyclones close-circuit with the ball mills. The design basis was 3.0 million tonnes per year. Several reviews have been performed over the years and the following issues have been identified:

- Significant breakage of grinding balls in the SAG mill
- Poor availability of the primary crushing circuit, often resulting in loss of feed to the SAG mill and pushing of the stockpile with a dozer to maintain feed to the milling circuit
- The feed to the SAG mill was generally coarse.
- The liquid resistance inverter (LRI) was controlling the SAG motor speed.
- Poor power draw on the scats cone crusher
- Low volume of scats in the SAG mill discharge.
- Low ball mill efficiency relative to the Bond work index.

North Mara Mine – Actions Taken

Review of the SAG mill ball quality and the conditions of operation pointed to two problems. A selection of both new and broken balls was submitted to an independent third party laboratory for analysis. The balls were highly variable in their composition and had poor metallurgy relative to the impact application found in the North Mara SAG mill. This situation was taken up with the supplier, who acknowledged the inferior quality of the balls they supplied. The composition of the new steel balls was changed and the plant was reimbursed.

The grinding operation at North Mara suffered from sporadic feed as the primary crusher was frequently out of service with mechanical challenges. This caused frequent grind-outs of the SAG mill as the stockpile emptied and the operators struggled to get a bulldozer to push in new feed.

The combined effect of the ball quality and the frequent grind-out was quite evident in the ball rejects form the circuit shown in figure 7.

Figure 7 – North Mara SAG mill reject steel

The review of the upstream Metso C140 jaw and Sandvik H6800 secondary cone crushing system indicated poor availability, with a lot of the downtime associated to liner changes. The jaw crusher was getting about 15 days on a fixed jaw liner and about 6 days on a swing jaw liner. Only about 10% of the steel was consumed prior to the change out. The secondary cone crusher mantle liner was being changed out every 4-5 days and the concave liner was lasting through 2 mantle changes. The downtime for cone crusher liner changes required the entire system to be down and this directly affected SAG mill feed on each event with sporadic feed provided by the dozer on the rather limited stockpile. Accordingly new feed was lost for up to 12 hours every 4 days.

The Metso review of the system resulted in a change to the jaw liner from the original configuration to a “quarry” configuration which has a lower tooth profile and a much thicker liner plate. Various liners from three different suppliers are still being evaluated on the primary crusher. The life of a liner depends significantly on the ratio of feed coming from the three pits at North Mara. The ore from the different pits vary in hardness and therefore an extended test period is needed before a decision can be made on which liner type to standardize. The interval between fixed liner changes is still 15 days but the interval for the swing liners improved to 10-12 days.

The metallurgy in the secondary cone crusher mantle and concave liners were changed out to a harder metal. Finally the liner configuration was changed from the original “short head coarse” to a “short head fine” configuration. These two adjustments on the secondary cone crusher increased the relining interval from 4-5 days to 15 days.

The final product size from the crushing circuit to the SAG feed had been significantly improved with F80 reduced from 32 mm to 26 mm.

The effect on the SAG mill circuit was quite dramatic as the stockpile required much less pushing and the feed to the mill had been substantially improved. Although the power draw on the crushers increased by about 0.2 kWh per tonne, the overall circuit power went down by about 3.5 kWh/t as shown in Figure 8. Additionally the SAG mill was now much steadier and did not suffer from repeated grind-outs.

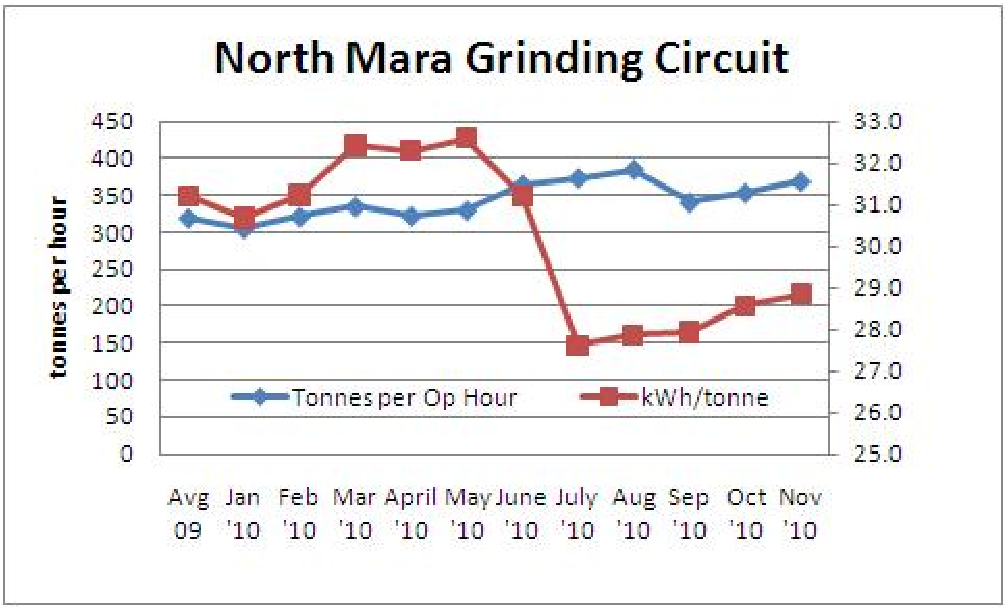

Figure 8 – Effect of improved crushing and "quality" grinding media on North Mara grinding

The make-up balls were sourced from a new supplier with a much better quality control program and an improved metallurgy. This combined with steady SAG feed from the crushing circuit resulted in a major drop in the number of SAG balls rejected as splits and spalls.

Efforts to perform effective sampling and modeling of the SAG mill circuit at North Mara proved challenging. A JKSimMet® model was developed but it indicated problems with the SAG mill discharge coefficient. This lead to the conclusion that either the discharging system was too restrictive or the pulp density was too high. The latter proved true with the discharge measured at 84% solids w/w. The model gave a reasonable approximation of the operation at North Mara and showed a modeled 327 tonnes per hour with grate openings of 35 mm. The modeled scats feeding the recycle crusher were in the order of 10% of new mill feed, whereas the actual recycle was in the order of 1-5%. This has been observed to be a common situation for a SAG mill with fine feed like North Mara.

The preliminary model indicated that opening the grates to 50 mm would provide a throughput increase of about 8 tonnes per hour and the recycle crusher feed would rise to 15% of the mill feed rate. Grates with pebble ports of 35mm by 65 mm openings were ordered and installed and increased scats recycle to about 8.5% of new feed. The result was a small increase in the Svedala Nordberg HP 200 (pebble) recycle crusher power draw to 90 kW. However, as new crusher feed was now double, the net energy efficiency was improved.

North Mara Mine – Results Achieved

The results of the various changes in the grinding circuit have been generally quantified in terms of throughput, energy and greenhouse gases as shown in Table 4. Electrical power is now sourced from the Tanzanian grid (TANESCO). In the past all of the power was self-generated using a bank of diesel-powered Caterpillar 1 MW gensets. This is now used only as a back-up power source, with some critical equipment still on permanent genset power as the TANESCO power grid is unstable and the site generation assists with a faster plant start up after grid failure. The power for grinding is normally sourced from the grid and accordingly a default of 0.35 kg of CO_2(e)/kWh is used. Improvements to the jaw crusher and the secondary cone crusher resulted in an average throughput rate improvement of 80 tph and a reduction in the specific energy in the SAG mill of 1.35 kWh/t.

When the additional power drawn by the crushers was deducted, the net improvement was 1.15 kWh/t. Cleaning up the SAG mill's ball charge aided the throughput capacity of the mill, but as the changes were simultaneous to the improvements in the crushing area, they have been included as part of the overall throughput improvement.

The modifications to the SAG mill grates increased the scats rejection from about 5% of new feed to 8.5%. This then put more new feed to the recycle crusher. The cone crusher liner system was changed from a coarse liner configuration to a medium-fine configuration. The power draw of the H6800 crusher rose significantly from 100 kW to 300 kW, and the net effect on the overall grinding circuit is modeled at 80 tonnes per hour.

Table 3 – North Mara mine grinding improvement summary

Change	Tonnes/hour Increase	kWh/t Reduction	kWh/yr Reduction	Tonnes CO_2 /yr Reduction
Improve product fineness from jaw and cone crusher circuit with improved ball charge	42	3.5	10,600,000	3,700
Increase pebble crusher power draw and volume of recirculating scats	8	0.5	1,600,000	600
Eliminate the use of the LRI as a speed controller for the SAG mill	0	0.6	1,900,000	700
Net Savings			**14,100,000**	**5,000**

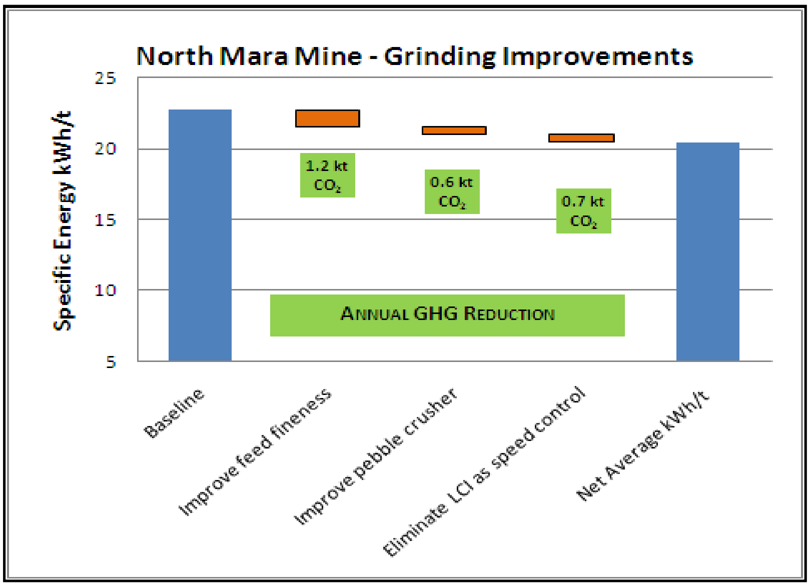

Figure 9 - Effect of improvements on North Mara energy and GHG profile

CONCLUSIONS

Grinding is an essential, but energy-intensive, part of Barrick's world-wide operations requiring crushers, classification systems, SAG mills and ball mills. Careful sampling and review against modeled baselines has allowed focused efforts on the identified poor performers. In this paper we have reviewed three of the Barrick's mines that have achieved measureable and significant gains in specific grinding energy.

The sampling campaigns required to pinpoint the improvement opportunities can be a difficult and painstaking procedure for the sites and they have been assisted by a grinding expert from the corporate Operational Support team in Toronto. This internal expertise is further augmented by external technology providers from Metcom, Morrell and JKTech. Once the individual circuit has been modeled, the specific energy efficiency is plotted against a predetermined minimum efficiency line. This guidance provides direction to the site for optimization of their systems.

The results have been very positive with more than 20% net grinding energy improvement in one case. These actions have lead to more than 43,000 tonnes per year reduction in CO_2 emissions in the three operations reviewed. Relative to Barrick's total "carbon footprint", this represents a net efficiency improvement of almost 1% and supports one of the key pillars of Barrick's climate change standard. Overall the three sites reviewed have reduced energy consumption by about 61 million kWh per year in relative terms. This cost savings of about $5 million per year has been further augmented with more than 200 combined tonnes per hour of throughput providing in the order of 60,000 ounces of gold annually.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of Barrick Gold Corporation in the development of this grinding efficiency strategy. Further recognition is directed to JKTech, Metcom, Metso and Morrell, amongst others for the development of tools and strategies for modeling and quantifying the performance of grinding circuits.

The various metallurgists, technicians and mill operators throughout Barrick's operations are to be commended on their significant efforts in sampling, data analysis and dogged persistence in evaluating their various mills under often trying circumstances. Added to that, they have made great improvements to their circuits that have reduced Barrick's carbon footprint and conserved energy.

Finally, Valerie Dupont is thanked for the many days that she contributed to J-F's efforts away from the family as he wandered the globe sampling circuits.

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