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# OPTIMISATION OF THE CADIA HILL SAG MILL CIRCUIT

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## ABSTRACT

Commissioning of the Cadia Hill SAG mill Circuit followed a project Research and Development exercise in July 1998. The SAG mill quickly reached 90% of the design rate but it became evident that the mill would not meet design throughput at the design operating conditions of ball and rock charge, mill speed and power draw. Cadia Hill staff in conjunction with the Julius Kruttchnitt Mineral Research Centre (JKMRC) then embarked on a series of programs designed to address the shortfall. The process modifications were made with due consideration to maintaining high availability of the single line mill, and were categorised into the following broad areas;

Ø Manipulation of SAG Mill Operating Parameters (eg. load, ball charge, speed and density)
Ø Maximising Pebble Recycle Load and Crusher Interaction With the SAG Mill



Ø Effect of SAG Mill Feed Size Distribution and Ore Variability
Ø Mill liner design modifications, and
Ø Circuit Design Considerations That Influenced Throughput

The development process and techniques used to increase throughput of the concentrator to the design rate will be presented (including fragmentation by blasting), concluding with a summary of which projects in particular have influenced or are likely to further influence the operation the most. A statistical package (MillStat) has recently been used to assist in this evaluation

## INTRODUCTION

The Cadia Hill Concentrator was commissioned in July 1998. The 40-foot diameter SAG mill was designed to treat 2065tph of monzonite ore at a ball charge of 8% volume, total charge of 25% volume and an operating mill speed of 74% of critical. SAG mill availability was expected to be 94%, giving an annual processing rate of 17Mtpa of monzonite ore. As the deposit contains around 9 percent of a harder volcanoclastic ore (Allowances for slower throughput were made when volcanics are present in the feed). Following an extensive testing and surveying period during the project ramp up period, when ball loads were increased to 12% volume, it became clear that the SAG mill throughput was limited to about 1900tph. The reasons for this variance were:

Ø Treatment of the volcanic ore which was known to be harder than the monzonite.
Ø The pebble recycle load was significantly lower than design (500tph compared to 700tph for design).
Ø SAG mill efficiency was highly dependent on recycle crushing.
Ø The SAG mill liners packed reducing power draw and the liner design also caused overthrow of steel balls against the mill shell.
Ø Recycle crusher availability was lower than that of the SAG mill.
Ø SAG mill availability was lower than expected in the first year due to issues with the gearless drive and trommel panel failures.

Figure 1 shows the ramp up of the Cadia Hill SAG mill by quarter. Throughput and availability are presented compared to the target or design basis. The percentage of monzonite ore fed to the concentrator is also presented, the remainder being the harder volcanic ore.

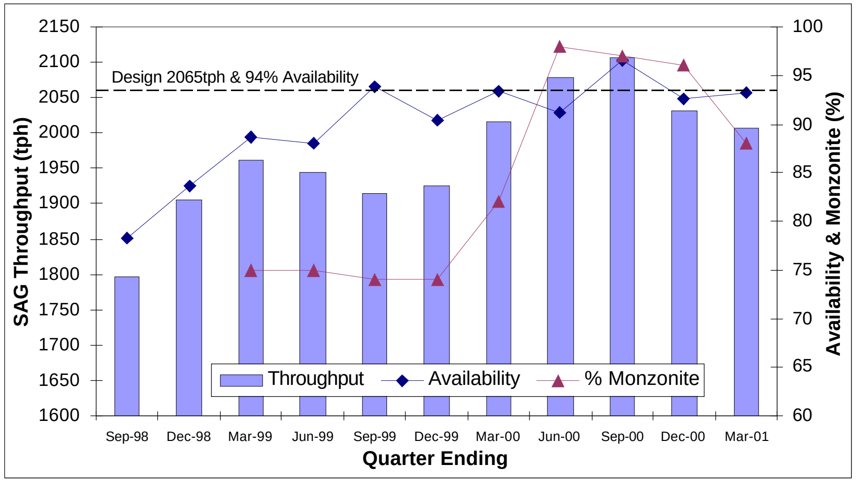



**Figure 1: Concentrator Throughput and Availability Project to Date**

SAG mill availability has reached the design level, however throughput has generally been below. The volcanic component of the orebody has contributed to this shortfall. De-bottlenecking an SABC circuit that within the first 2 months was operating at 12% ball charge, 25% total charge and was commissioned with 70mm grates has been challenging.

A number of operational and maintenance issues with the circuit design led to these rates not being met consistently until early 2000. In order to improve plant performance towards the design level, deviations from the design operating conditions was required. Key learning's from the first 3 years of operation are presented as well as future enhancements planned to lift production rates above the current level.

## SAG MILL OPERATING PARAMETERS

The key operating parameters identified as being critical to achieving design processing rates of the Cadia Hill SAG mill circuit and that could be easily manipulated were;

### SAG Mill Load

**Ball Charge** - SAG mill power draw was guaranteed by the vendor at 13% ball charge and 30% total volume to be 20.96MW for the 40 foot diameter SAG mill. In practice this power draw was never achieved



(Dunne et al 2001). Power draw ranged between 18.0MW and 19.0MW. In order to draw more power the options immediately available were to increase ball charge and/or increase total charge (ie rock charge) of the mill. Increasing the speed of the mill above the design point of 74% critical speed was also considered but did not result in greater power draw of the mill due to the mill motor design (Dunne et al 2001). The ball charge was increased from 4% volume to 12% volume during commissioning, giving an increase in power draw of 7.1MW to 18.0MW at a load of 26% total volume. SAG mill throughput increased by 500tph to about 1900tph. Further increases were made up to the current operating target of 14% volume.

The structural design of the SAG mill allowed for a ball charge filling of 15% by volume. Investigations are underway to determine the maximum ball and rock charge combination permissible given the current liner configuration and structural loading. Once determined, increases in ball charge level above 14% may be undertaken in order to increase throughput further.

**Rock Charge -** Total charge filling also influences power draw of the SAG mill. High rock charge volumes ie 15 to 20% gave maximum power draw from the mill motor but did not result in greater productivity of the SAG mill. The SAG mill total load is currently held at about 25% volume (14% ball charge and 11% rock charge), but has been as high as 32% volume. Finding the SAG mill load at which throughput is maximised has long been debated. One of the objectives of a review carried out by Conveyor Dynamics Incorporated, CDI was to confirm the correlation between SAG mill load and throughput, using the MillStat program. For the 12 months of operating data reviewed under 2 sets of mill liners and 2 different operating loads the following correlations were observed.

In Figure 2, Cycle 1 refers to a 52 row 25 degree lifter design, operated at high volumetric fillings (30% or above) throughout its life. SAG Mill load ranged from 980 to 1100 tonnes.

Cycle 2 refers to a 52 row 30 degree lifter design, operated at a lower volumetric filling 25-27%. SAG Mill load during this liner cycle ranged from 800 to 1100 tonnes.

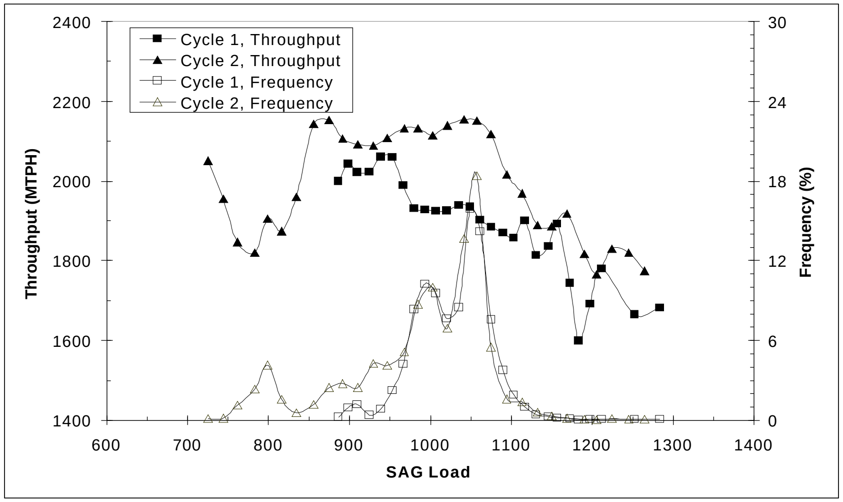



**Figure 2: Throughput Versus SAG Mill Load**

The relationship demonstrated improved mill performance as the SAG mill shell liners wore (the SAG mill load dropped), as well as an overall improvement in operating performance at the lower filling level. From the start of the first cycle (right hand side of the curve) mill throughput gradually increased to a maximum, at around 900 tonnes. In the second cycle mill throughput was consistently better than in the first, confirming the benefits of operating with a lower mill load as well as the increased face angle and slightly higher ball charge. Mill load is varied over the shell liner cycle and is routinely checked on shutdowns to confirm the load cell and bearing pressure measurements. Ball charge estimates are then confirmed by the power draw prior to shutdown by correlating the total charge volume estimate with a distribution of rock charge and ball charge. The higher the ball charge the higher the power draw. In this manner ball charge has been generally kept to within 1% of target, when the mill has been ground out to confirm the actual filling. SAG mill load versus power draw curves are presented in Figure 3.

## SAG Mill Speed

The design operating speed of the SAG mill was 74% of critical speed (9.02rpm). Operating at this speed during commissioning led to ball breakage due to overthrow of the charge, resulting in direct ball-to-liner impacts. The initial set of SAG mill shell liners were a 78 row, 12 degree face angle high/low design with a difference between the high and low lifter of 95mm. The high/low lifter spacing led to packing, which coupled with the differential in height between the low and high lifter, led to



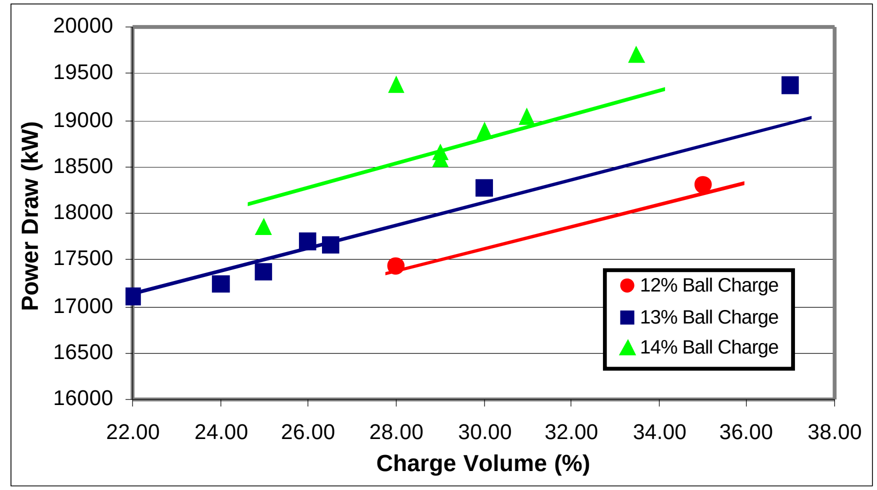



**Figure 3: SAG Mill Power Draw versus Load**

reduced power draw by about 0.5MW. The charge that was picked up by the lifters was thrown above the toe region and contributed to reduced milling efficiency as well as ball breakage. To counter this initially the ball hardness was reduced from 57 to 54 Rockwell Hardness (HRC). Towards the end of the original shell liner life (last 3 months) it was possible to increase mill speed above the design level without incurring ball or liner damage and throughput rates improved.

A review of liner designs was undertaken and an alternative 52 row, 25 degree face angle lifter design installed in December 1998. The change to a 52 row, shallow face angle design had the following benefits:

- Packing between the high/low lifters was eliminated and power draw increased.
- The SAG mill could be operated at a higher speed earlier in the life of the liner, without incurring ball breakage.
- As ball breakage was eliminated, ball hardness was increased back to 57 HRC, resulting in operating cost savings.
- SAG mill throughput increased by at least 50tph as a result of the higher operating speed and improved breakage conditions in the mill.
- SAG Mill shell reline times were reduced by 30% as fewer pieces were installed in the mill.

However, even with the 25 degree face angle lifter installed, operating at 76 to 78 % of critical speed immediately after the liner change out, overthrow of balls was still evident (although the simulation models predicted the charge would land material within the “toe” region). Metal peening on the liner plate as well as minor ball and liner breakage occurred. SAG mill speed was thus lowered and charge level raised until the noise levels from the mill dictated an increase in mill speed was possible. As a result of the ball throw issue lifter face angle was subsequently increased to 30 degrees, further reducing the effect of start up issues with a new lifter set.

The 30 degree angle lifter set was found to give higher throughput and lower energy utilisation than the 25 degree angle, although the analysis was complicated by the operating strategy during the two periods. The SAG mill load was operated lower in the second campaign (due to breakage of some of the shell liners following installation) and the ball charge between the two campaigns was not identical.

It was concluded from the two studies that the 52 row lifter with a 30 degree face angle gave an improvement of 5 to 10% in operational efficiency compared to the 78 row design. Further more the 52 row liner design was easier to change out and more cost effective than the 78 row conventional high/low design. Improved monitoring of SAG mill noise levels, in particular steel ball impacts above the toe of the charge was required, and a research project entered in to as a result.

## PEBBLE RECYCLE LOAD AND RECYCLE CRUSHING

The design pebble recycle load for Cadia was 35% of new feed or 723tph. During commissioning this rate was not achieved, the average being 500tph. The potential causes of lower than design pebble rates were considered to be:

- The grate aperture and open area was insufficient to pass the critical size component of the charge.
- The pebbles were being restricted from passing through the grate either by the charge or the grate lifter design.
- The critical size component was either not present in the feed or was effectively broken down in the mill.
- The pebbles passed through the grate but could not be discharged from the pulp lifter system.

The importance of pebble crushing on SAG mill throughput can be demonstrated from the following plant operating data. Depending on the



number of crushers available for use (or utilised) SAG milling efficiency ranges from 12.3kWh/t, with no pebble crushing down to 8.8kWh/t with both crushers operating fully. Thus maximising pebble extraction and crushing was a key performance criterion to be addressed.

**Table 1: Effect of Recycle Crusher Utilisation on SAG mill efficiency**

| **Measurement** | **Crusher Utilisation (Corrected[1])** | | |
|---|---|---|---|
| | None | Average | Full |
| Crusher Power (kW) | 0 | 854 | 1400 |
| SAG Throughput (tph) | 1860 | 2040 | 2150 |
| Relative Increase (%) | -8.5 | 0 | +5.4 |

1 Corrected for differences in SAG mill feed size, which has a direct influence on pebble rates from the SAG mill (Figure 5)

### Grate Aperture and Open Area

In order to investigate the cause of lower pebble extraction rates a number of plant trials were undertaken. Grate aperture size and open area of first half and then all of the outer grates was increased from 70mm and 7.66m$^2$ to 90mm and 9.24m$^2$. Figure 4 demonstrates that no net gain in pebble extraction rate was achieved during these trials. Immediately following the grate change out from 70 to 90mm pebble extraction rates actually reduced and the pebble size distribution remained unchanged. Due to the lower life and higher ball consumption incurred with the 90mm aperture grates the size was reduced to 80mm and open area reduced to the previous level.

Given the above observation and the consistent trend in improved pebble rates as the grate aged, it was concluded that pebble removal was restricted from the mill, and was more pronounced at the start of the grate life. Pebble extraction rates following a grate reline were almost half of those immediately prior to a reline. The effect was consistent with 70mm, 90mm and 80mm grate apertures, no matter what the theoretical ‘open area’, shell liner life, mill load, operating speed, ore type or feed size distribution, as many different combinations of each were encountered during the life of each liner set.

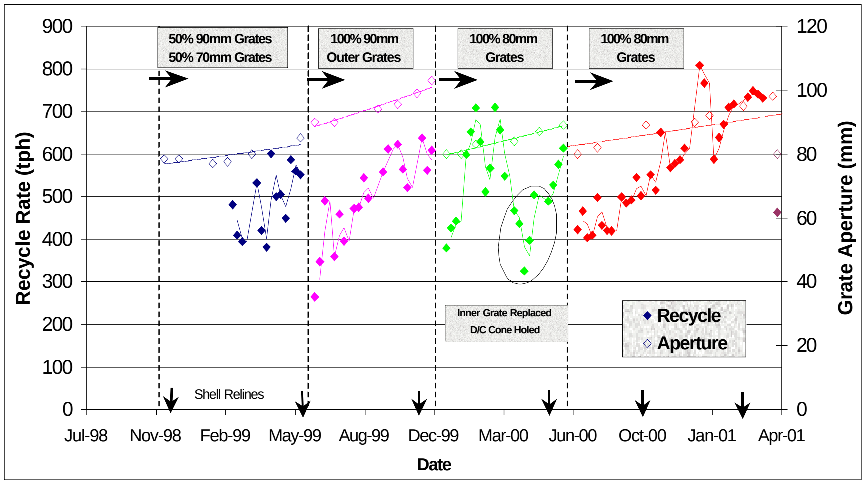



**Figure 4: Pebble Recycle Load versus Grate Aperture and Liner Life**

The restriction to pebble discharge at the start of the cycle was thought to be influenced by lifter height and profile. The greater the wear on the lifter and the flatter the lifter face angle the greater the charge exposure to the grate and the greater the penetration through the grate. The lifter height was dropped and face angle increased as a result of the observations made, and further modifications are planned in order to maximise material flow through the grate openings.

## Critical Size and Pebble Production

One possible reason for the lower than expected recycle rates was that the critical size component was either not present in the feed or was broken down effectively by the SAG mill. This was demonstrated not to be the case. Estimates of the mill feed and charge size distributions from plant surveys using the Split image analyser showed that up to 50% of new feed and 70% of the mill charge was between the grate and trommel aperture sizes. The size at which the material presented itself to the grate was also contributing to whether or not it passed through the opening or was retained. Pebble recycle load was shown to correlate well with SAG mill feed size distribution, further supporting this argument (Hart et al, 2000). When the SAG mill feed size dropped to around 80% passing 80mm, recycle pebble rates approaching the design level were achieved even with new grates installed and SAG mill throughput would increase as a result, see Figure 5 below. It was concluded that as the proportions of new feed and mill charge at or close to the grate aperture size increased, the ability of the grate to pass that material decreased.



The fines clearly passed through the grate easily, but the coarser material was more readily retained, even though the particles were smaller than the grate aperture. On this basis, and considering Figures 4 and 5, it would also appear that as the grate wore its efficiency at passing coarser material improved, the recycle load increased for the same feed size distribution to the mill and the size distribution of the pebble recycle load coarsened.

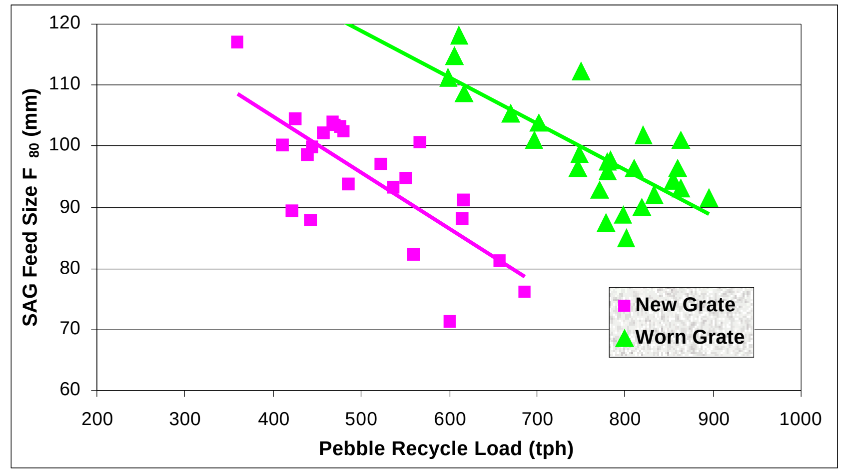



**Figure 5: Comparison of Grate Performance (New/Worn) with Feed Size**

## Pebble Removal from the SAG Mill

Pebble removal from the mill is also a function of pulp lifter efficiency. The distance material travels to reach the discharge cone on the 12.19m diameter mill is 4.76m and the flow from 40 pulp cavities on to the 10 discharge vanes which direct material on to the trommel complicates the discharge arrangement. The first set of outer and middle pulp lifters lasted 6 months or 5 million tonnes. Accelerated wear was observed in the pulp discharge cavity, due to backwash (or incomplete discharge) from the pulp lifter. The cause of the incomplete discharge was not a lack of open area at the discharge cone, as with a fine feed size distribution to the SAG mill ($F_{80}$ of 80mm) the discharge system could pass up to 2700tph of new feed up to 1000tph of recycle pebbles. The problem was again thought to be due to the size distribution of the pebbles.

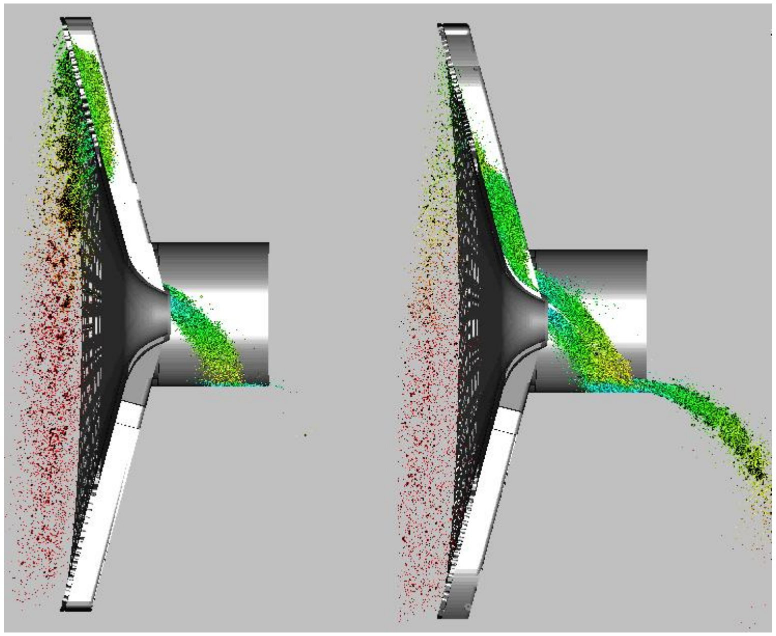
Confirmation of this was made during 'crash' stops of the mill, taking it from steady state operating speed to stop by applying the hydraulic brake. Material ranging in size from 25mm to 70mm was present on the pulp lifter vane at a horizontal position on the downward side, not able to be discharged by the mill (Figure 6). One of the pulp lifter pockets was full of material, covering all of the outer grate and 1/3 of the inner grate openings.

**Figure 6: Material Present on the Pulp Lifter Vane following a 'Crash' Stop**

The issue was discussed with mill liner suppliers and an offer received from ANI Bradken to supply the curved "Vortex" pulp lifter and grate design. Cadia Hill engaged the services of CDI to use a 3 dimensional granular flow model to predict discharge rates from the 2 alternative pulp lifter designs. A straight radial design (as per Cadia Hill existing design) and the proposed curved ANI design. Results of this analysis demonstrated the improved flow characteristics of the curved design and the observations made during the crash stops and inspections. Reduced flow back in the vane as well as fall back of material through the grate openings was observed.

Figure 7 compares the discharge rates from the 2 simulation exercises. A performance improvement of at least 10% was predicted by changing to the curved design. A trial of the curved lifter design commenced in April 2001 and full implementation is likely to take place in August 2001.





**Straight Radial Lifter** **Curved Radial Lifter**

**Figure 7: Comparison of discharge rates from straight radial and curved pulp lifters.**

## Pebble Crusher Selection and Installation

The pebble crushers also influenced capacity of the SABC circuit at times. They comprise 2 Nordberg MP1000 cone crushers, each with 750kW installed motor power. Feed to the crushers is regulated from a surge bin with separate belt feeders supplying each crusher.

The crushers have a capacity of approximately 400tph each at a gap setting of 12mm (range 10 to 14mm) and draw approximately 600kW under choke fed conditions. The pebble rate from the SAG mill rarely matches the throughput capability of the crushers, and as the gap can not be automatically regulated (nor it deemed appropriate to do so) or the crushers trickle fed, the circuit continually hunts between 1 or 2 operating crushers. This effect causes disturbances to the SAG mill, as demonstrated in Figure 8.

As the recycle crusher bin fills with one crusher operating, new feed is added to the SAG mill to prevent the load deviating below set point. Once the second crusher is started the additional 400tph of feed to the SAG mill (all be it 80% passing 12mm) increases the mill load above set point. It then becomes necessary to reduce new feed rate in the order of

100 to 200tph. Not all the crushed pebbles pass through the trommel however, about 30% returning to the recycle crushers a second time contribute further to circuit instability. This problem has been one of the major control issues since commissioning, and is yet to be fully overcome.

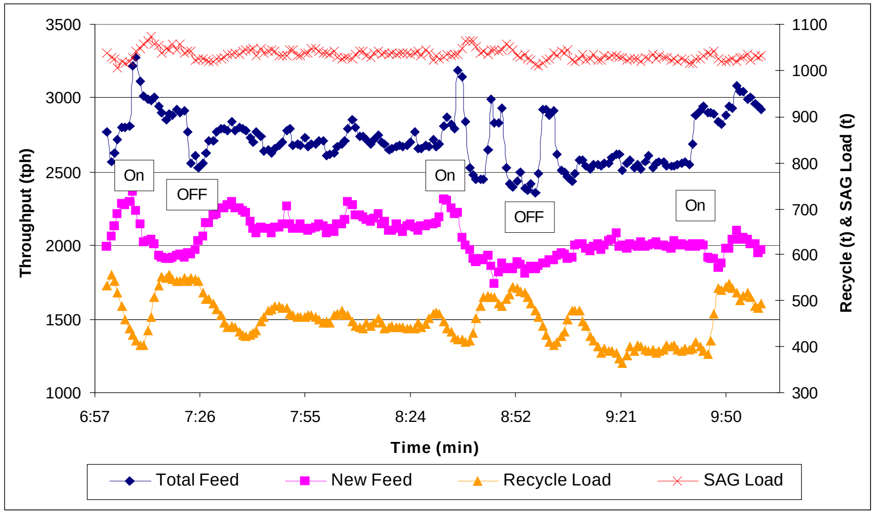



**Figure 8: Effect of Recycle Crusher on SAG Mill Circuit Stability**

Pebble stockpiling trials have been conducted which demonstrated improved control of the circuit by decoupling the SAG mill and recycle circuits. Trials are planned over a longer duration in order to prove the concept and performance enhancements prior to seeking financial approval. The benefits of this, aside from the control improvements will be increased crusher availability, utilisation and improved dewatering of the pebbles.

## Carry Over Of Water and Fines From The SAG Trommel

The SAG mill trommel is undersized for the design duty, contributing fines and water carry over to the recycle crushing stage and reduced crushing performance. A combination of 450mm high and 300mm high dams inside the trommel assist with holding the material flow back in order to improve dewatering efficiency. Operating without some of the dams has been tried unsuccessfully, leading to increased carry over of slurry from the trommel. Above 2000tph new feed and 500tph recycle rates the trommel efficiency drops. This results in increased amounts of water in the recycle crushers, packing in the crushing zone and reduced crusher performance, leading to a coarse product, more trommel



oversize (up to 50% of the crushed pebbles can return as trommel oversize). Trommel efficiency drops further resulting in more slurry carry over, more problems with crusher performance and so on. The crushers have been fitted with vibration sensors to detect the tramping and reduce the likelihood of damage but the management of water in the recycle load is still a major issue.

Gap setting does not appear to improve the crusher performance when there is excessive water in the feed. The crusher may be run at 12mm or 20mm and still vibrations are present. Under these feed conditions the crushers are impossible to keep choke fed.

Modifications to the trommel wash water addition system have helped reduce fines carry over. A static screen on the pebble transfer chute from the trommel removes some of the fines carried over the end of the trommel, and further dewatering is carried out at all transfer points feeding the crushers and in the pebble surge bin. This coupled with relocation of belt scrapers has assisted in the removal of some of the water. Managing the spillage and cleanup from these transfer points is an ongoing, time consuming and non productive duty, and one which is not often given sufficient consideration during project design.

To fix this problem is an expensive project. The possible integration of a stockpile in the Cadia Hill pebble circuit will allow sufficient drainage of water from the pebble load. It is anticipated that this will significantly reduce the packing and tramping difficulties experienced in the recycle crushers and lead to less downtime, improved liner wear rates and increased SAG mill productivity. A full scale plant trial is planned later this year to provide a financial justification for the project.

## Pebble Crusher Closed Circuit

Simplifying the recycle crusher design by returning crushed pebbles to the SAG mill as at Cadia results in a reduction in grinding efficiency. Once the pebble recycle load has been crushed to a $P_{80}$ of about 12mm most of this material would be better managed by the ball mills rather than returning it to the SAG mill. Throughput could be increased by 10% (200tph) from the current level by not returning the crushed pebbles to the SAG mill. This concept was proven during a number of plant trials when it was found that for every 1tph of crushed pebbles not returned to the mill, 0.3tph of new feed rate were added during the trial.

In order to take advantage of this however the ball mill circuit needs to be sized to take the additional capacity and a coarser feed size distribution. Ball milling capacity is currently limited at Cadia, although alternatives are being investigated to overcome this in the future.

Although pebble recycle rates were not initially at the required level to achieve design operating efficiencies a number of projects have been undertaken or are currently in progress to address the shortfall. These projects are focussed on efficiency of the grate to remove material from

the mill and the pulp discharge cavity to transfer that material on to the trommel. Pebble rates have increased gradually from an average of 500 to 600tph as a result, and further increases are still considered possible.

The SAG mill control strategy has been manipulated to assist with the generation and removal of pebbles from the mill by operating with a high ball load (target 14% volume), low charge level (25% volume), large aperture grates (80mm) and further encouraged by operating a low slurry density (65% solids). Speed is maximised within target noise limits and feed size to the SAG mill manipulated to generate maximum recycle load.

## SAG MILL FEED SIZE DISTRIBUTION

SAG mill feed size distribution was recognised as being critical to the performance of the SAG mill circuit. The Split on line image analysis system was installed in the Cadia Hill SAG mill circuit in June 1999 to confirm observations made since start up. A correlation between SAG mill feed size F80, throughput and specific power consumption was developed from plant operating data. CDI confirmed the magnitude of the relationship, filtering the data for the influence of all other factors, during an analysis of 12 months of process data. The following conclusions were drawn.

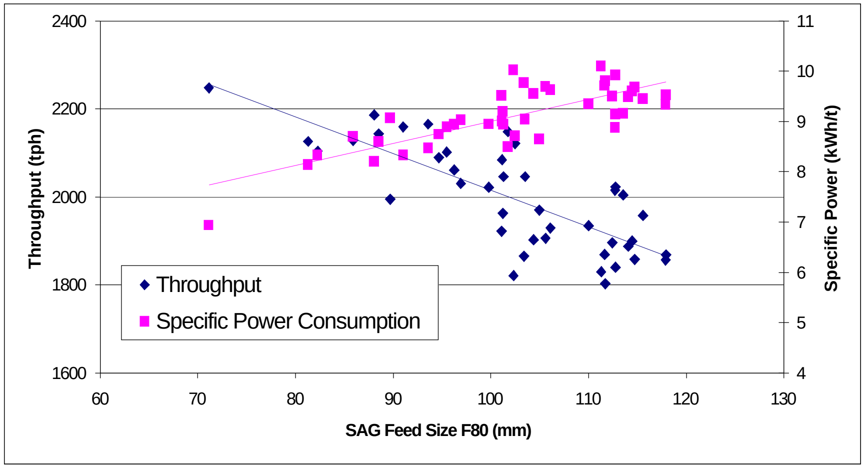



**Figure 9: SAG Mill Feed Size Versus Throughput**



**Table 2: Feed Size versus Throughput Relationship from MILLSTAT**

| Measurement | Effect of Feed Size (Corrected[1]) | | |
|---|---|---|---|
| | Coarse | Average | Fine |
| Feed Size F80 (mm) | 110 | 92 | 70 |
| Throughput (tph) | 1795 | 2040 | 2320 |
| Relative Increase (%) | -11.9 | 0 | +14.0 |

[1]Corrected for differences in Recycle Pebble Crusher Rates

A reduction in SAG mill feed size $F_{80}$ to 70mm was found to increase throughput by 10 to 15%. Model simulations carried out by the JKMRC as part of the AMIRA sponsored mine to mill project also confirmed the feed size relationship. Limited manipulation of feed size could be obtained by adjustment of primary crusher gap, as the closed side setting was operated at or close to 110mm at Cadia. Much below this setting maximum power draw was reached with the current liner profile and feed material. Further opportunities for reducing feed size distribution to the SAG mill were considered.

### Feed size Reduction by Blasting

Previous studies and experience gained through AMIRA mine to mill project sponsorship had indicated that significant throughput improvements were possible by increasing the powder factor and modifying blast implementation techniques in the mine (Lam et al, 2001, Morrell and Valery, 2001).

To validate this work at Cadia a number of 'benchmark' (current practice) and 'trial' blasts were conducted between 1999 and 2000. Powder factors were increased from the standard 0.8 kg/m$^3$ up to 1.2 kg/m$^3$, drilling practices measured and explosive loading parameters manipulated. The blasts were closely monitored with video and geological data mapped and correlated with concentrator performance demonstrating that:

- Poorly implemented 'conventional' blasts with high powder factors did not result in improved fragmentation or SAG mill performance.
- A 10% increase in SAG mill throughput could be achieved by closing the drill pattern spacing, increasing the powder factor and improving the quality of drilling.

- Ø A finer feed size distribution from the high powder factor blast resulted in higher power draw from the SAG mill yet overall lower specific power consumption. Charge density may have influenced power draw of the SAG mill, given a difference in feed size distribution
- Ø The Split on line system used for monitoring feed size distribution was not able to accurately monitor fines percentages in the SAG mill feed due to the single camera location on the SAG mill feed conveyor and further work was required.
- Ø The modified blast design produced more 'fines', visually evident during the trial and confirmed by lower pebble recycle rates. The additional fines produced were finer than trommel opening size and thus considered "free milling".
- Ø Measuring the feed size presented to the crusher had great potential for linking the mine and mill databases, providing direct feedback to the mine on blast fragmentation "quality".

In order to demonstrate this over a longer duration and under more variable operating conditions, a two month trial was planned and is due to commence in June 2001.

### Feed Size Reduction By Crushing

Pre crushing part of the SAG mill feed has been considered as an option to increase SAG mill throughput given the previous observations. A number of operations have demonstrated this previously. In April 2000 the Cadia Hill concentrator commenced treatment of "development" ore from a new underground mine (Ridgeway) at a rate of 100,000 tonnes per month. The Ridgeway ore comprises monzodiorite and volcaniclastics, having similar breakage properties to the Cadia Hill ore.

As the SAG mill was the bottleneck to achieving higher production rates from the concentrator, tertiary crushing was preferred, yielding higher returns over the project life and improved conditions for sampling the ore from the mine.

Simulations carried out by the JKMRC suggested that one tonne of Ridgeway ore crushed to a $P_{80}$ of 10mm would displace 0.4 tonne of Cadia Hill ore. Plant trials were conducted with Ridgeway ore "on" and "off" and have confirmed the original estimate. Although the 3 stage crushing facility is temporary, until a stand-alone concentrator is commissioned in early 2002, the argument for reducing SAG mill feed size distribution through modified blasting practices in the Cadia Hill pit has been further strengthened.



## SABC CIRCUIT DESIGN CONSIDERATIONS

### SAG Mill Availability

In the first full year of operation SAG mill availability reached 82%. The mill motor issue and frequent trommel panel failures contributed to 2.5% of total downtime (unplanned). This figure was reduced to 0.5% in the second year, once the motor was repaired and SAG mill availability averaged 92% for that year. For the past 12 months SAG mill availability has averaged 94%.

Although this is widely recognised as the measure of plant operating performance, just as important have been the individual component performances that make up the SABC circuit. The ball mills, recycle crushers and cyclone feed pumps are critical to overall plant efficiency for the single grinding line. Neither have performed particularly badly but each have contributed on occasion to lower than expected monthly performance. The average cyclone feed pump and ball mill availability has been 98.5% of SAG mill run time and the recycle crushers 96.0% of SAG mill run time.

### SAG Mill Operating Costs

The following table summarises the cost of operating the 40 foot diameter SAG circuit at Cadia. SAG mill power consumption averages 9.3kWh/t and the recycle crushers 0.45kWh/t. Ball consumption is typically 0.54kg/t

**Table 3: SAG Mill Circuit Major Operating Costs**

| Operating Expense | OPEX $/t |
|---|---|
| **Power** | |
| SAG Mill | 0.34 |
| Recycle Crushers | 0.02 |
| **Grinding Media** | |
| SAG Mill | 0.52 |
| **Liners** | |
| SAG Mill | 0.17 |
| Recycle Crushers | 0.03 |
| **Total SAG Circuit** | **1.08** |

These costs alone account for 33% of the total concentrator operating expenditure. The average processing cost year to date is $3.29 per tonne. The entire grinding circuit makes up 70% of the total processing cost.

# CONCLUSIONS

The following conclusions have been drawn from three years of operating experience with the 40 foot diameter SAG mill at Cadia:

- Ø It was necessary to increase the SAG mill ball charge to around 14% volume in order to meet target throughput rates for the monzonite ore. Increased ball charge has contributed to the average milling performance of 1900tph being achieved soon after start up. Further increases in ball charge may be undertaken depending on the structural capability of the SAG mill and the success of other key projects.
- Ø Increasing the grate aperture and open area had little benefit in terms of increasing pebble recycle rate from the SAG mill. Extraction of pebbles from the SAG mill has been shown to be particularly dependent on the relative age and wear profile of the grate's lifter. Further design modifications are planned to maximise the pebble rate under all conditions.
- Ø Pebble production from the mill is influenced by feed size distribution of the SAG mill and new feed to the SAG mill. Up to 50% of the new feed and 70% of the mill charge is between grate opening and trommel screen cut size and should report to the recycle load stream. Removal of coarse material from the pulp discharge cavity could be improved by installing a curved pulp lifter design. Plant scale trials have commenced and full implementation will occur in August 2001.
- Ø Operating the SAG mill with a reduced number of lifter rows (52) and with a steeper face angle (30 degrees) has increased SAG mill throughput by about 50tph comparing the last 3 months of operation with the previous (78 row) and current (52 row) liner designs.
- Ø Reducing the rock charge from 16% to 11% has resulted in an increase in SAG mill throughput of the order of 50tph. This coupled with ball charge increases up to 14% volume helped to increase the average milling rates to about 2000tph.
- Ø Reducing the SAG mill feed size distribution from an average F80 of 100mm to 80mm resulted in an increase in SAG mill throughput of 200tph. Modified blast designs have demonstrated this during closely monitored trials and the concept is currently being tested over a longer period. The potential for throughput rates of the order of 2100 to 2200tph has been recognised.
- Ø Recycling crushed SAG mill pebbles back to the mill reduces the operating efficiency of the SAG mill by about 10%. Opening up the pebble crushing circuit at Cadia resulted in a throughput increase of about 200tph during plant trials. The ability to wet screen and ball



mill the crushed pebbles would be beneficial, providing sufficient ball mill capacity exists. The ball mills are the current bottleneck to future expansion plans at Cadia.
- Ø The availability of the SAG mill, ball mills and recycle crushers has been high. However, the ball mills availability of 98.5% and crushers availability of 96.0% lead to reductions in plant capacity of up to 40%.
- Ø Decoupling the SAG mill and recycle crushing circuit will be evaluated in the next 6 months. It is anticipated that this will lift annual throughput rates by reducing the impact of crusher shutdowns on plant performance as well as providing steady feed to the SAG mill, improved control and improved ability to optimise circuit performance.
- Ø Operating at or close to the mill speed at which liner damage occurs due to overthrow from the 30 degree face angle lifters has highlighted the requirement for improved monitoring of SAG mill noise levels. A research project has been structured by the JKMRC and a number of other companies to develop improved techniques.
- Ø Managing the interaction of the pebble crushers with the SAG mill has been one of the greatest challenges to date. It is anticipated that through a number of alternative process control strategies this can be managed.

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