

Grinding Circuit Improvements at Evolution Mining's Edna May Operation

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ABSTRACT

Resurrected from its former life at the Big Bell operation, the grinding circuit at Evolution Mining's Edna May operation in Western Australia has many a story to tell. The task of optimising a plant designed for another orebody provides as many challenges as opportunities. Initially faced with a blend of primary and oxide ore, the circuit achieved in excess of 320 t/h until the oxide was depleted, leaving only the much harder primary feed.

The 2.0 MW semi-autogenous grinding (SAG) mill and 3.7 MW ball mill were assisted by a 150 kW pebble crusher, but the power limitation of the SAG mill resulted in a drop in throughput. Edna May personnel have been involved in a number of progressive improvements to restore the design capacity of the concentrator and work towards 3 Mt/a or even higher ahead of the gravity and leach recovery circuits.

These improvements include:

- a crush forward configuration of the SAG mill scats
- partial to full secondary crushing
- variable speed drive upgrade of the SAG mill
- lifter and grate design changes
- ball mill circuit grinding efficiency.

This paper summarises the chronology of events that has resulted in significant improvements in throughput by conventional (and in some cases, novel) methods of reconfiguring the existing grinding mills. Lessons learned and hindsight perspectives will be summarised, sharing this educational experience with other operations in a similar situation.

INTRODUCTION

The Edna May operation is an open pit mine located 350 km east of Perth in Western Australia (see Figure 1). It consists of predominantly gold, but includes silver and tungsten. Project development commenced in 2009, with a first gold pour in April 2010, and plant commissioning was completed in May 2010. The project is located near the northern end of the Westonia Greenstone Belt, in the Southern Cross Province of Western Australia's Archaean Yilgarn Craton. The Westonia Greenstone Belt comprises a series of outliers of predominantly amphibolite-grade metamorphic rocks extending approximately 100 km west-north-west from near Edwards Find, south of Southern Cross. The remainder of the terrain comprises granitic rocks and their metamorphosed derivatives.

Open pit mining is by conventional drill/blast, load/haul method. A bulk mining approach has been adopted to maximise the extraction of remnant high-grade reef structures and associated stockwork mineralisation with a life-of-mine strip ratio of 1.9:1. This allows the mine to employ a single mining fleet (owner operated) for most of the mine life.

The open pit is being mined in four stages, carried out on 10 m benches and 3.5 m flitches.

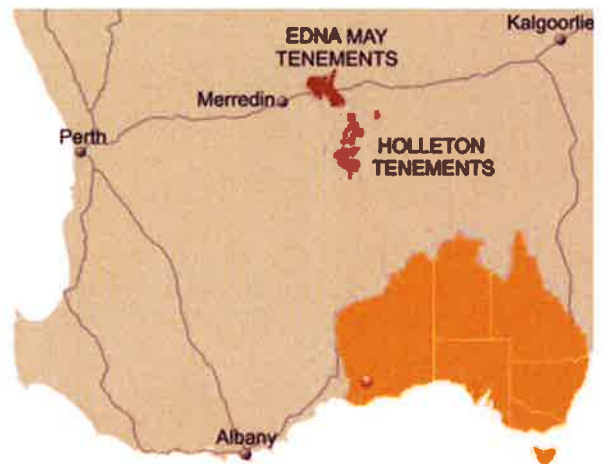


FIG 1 – Location of Edna May operation.

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Until recently, the Edna May process plant was achieving throughput in excess of 340 t/h on a blend of primary (or fresh gneiss) and oxide feed. With the depletion of oxide material, a fully primary ore feed has reduced throughput to about 260 t/h due to increased hardness and, possibly, a lack of fines in the semi-autogenous grinding (SAG) mill feed.

The process plant was purchased from the Big Bell mine in 2007 and consists of a 2.0 MW SAG mill, a 150 kW pebble crusher and a 3.7 MW ball mill in closed-circuit with 400 µm cyclones. The primary grinding circuit can be operated in a pebble crusher 'crush forward' configuration, where the SAG mill screen oversize material (scats or pebbles) is crushed and passed onto the ball mill using a feed belt conveyor.

The original Edna May grinding circuit flow sheet is shown in Figure 2. Crushed material from the jaw crusher is stockpiled ahead of a fixed speed SAG mill, which discharges over a trommel screen with the undersize passing to the ball mill circuit. The target 80 per cent passing (P80) size for the cyclone overflow is 150 µm. However, this has rarely been achieved since commissioning.

Trommel screen oversize scats (or pebbles) are sent to a bin ahead of the pebble crusher, which is batch fed based on the bin level and, as required, returns crushed pebbles to the SAG mill feed belt and back into the mill. The pebble crusher typically takes one minute to empty the bin and then waits for the bin to fill up again. The pebble crusher closed-side-setting is routinely set to around 16 mm, which is at the lower limit of the current liner configuration, but a relatively coarse liner design is required in order to handle up to 60 mm particles being discharged from the SAG mill.

ORE CHARACTERISTICS

The current primary ore feed is significantly harder than the original blend of oxide and primary material. Hardness test work has indicated that primary ore is consistently high in its

resistance to impact breakage – associated with SAG milling and crushing.

Drop weight test work on samples since 2002 has shown very consistent A*b values for the fresh gneiss ore of between 38 and 53 with an average of 48.

From a ball mill perspective, the ore hardness is particularly dependent on grind size. Bond testing showed a ball work index of 12 kWh/t at a closing screen size of 212 µm compared to 16 kWh/t at 150 µm and 18 kWh/t at 106 µm.

With primary crushing alone, the SAG mill feed size is quite coarse, with a limited amount of fines being generated in blasting or crushing (see Figure 3 for an example). Historical underground workings in the current pit area make it challenging to use higher energy blast designs to generate a greater amount of -10 mm, which would result in higher SAG mill throughput (with either primary or secondary crushing).

EARLIER STUDIES AND OPERATING CHANGES

Evolution Mining (as well as the previous owners of Edna May) have been working with Orway Mineral Consultants



FIG 3 – Example of primary crushed semi-autogenous grinding mill feed size.

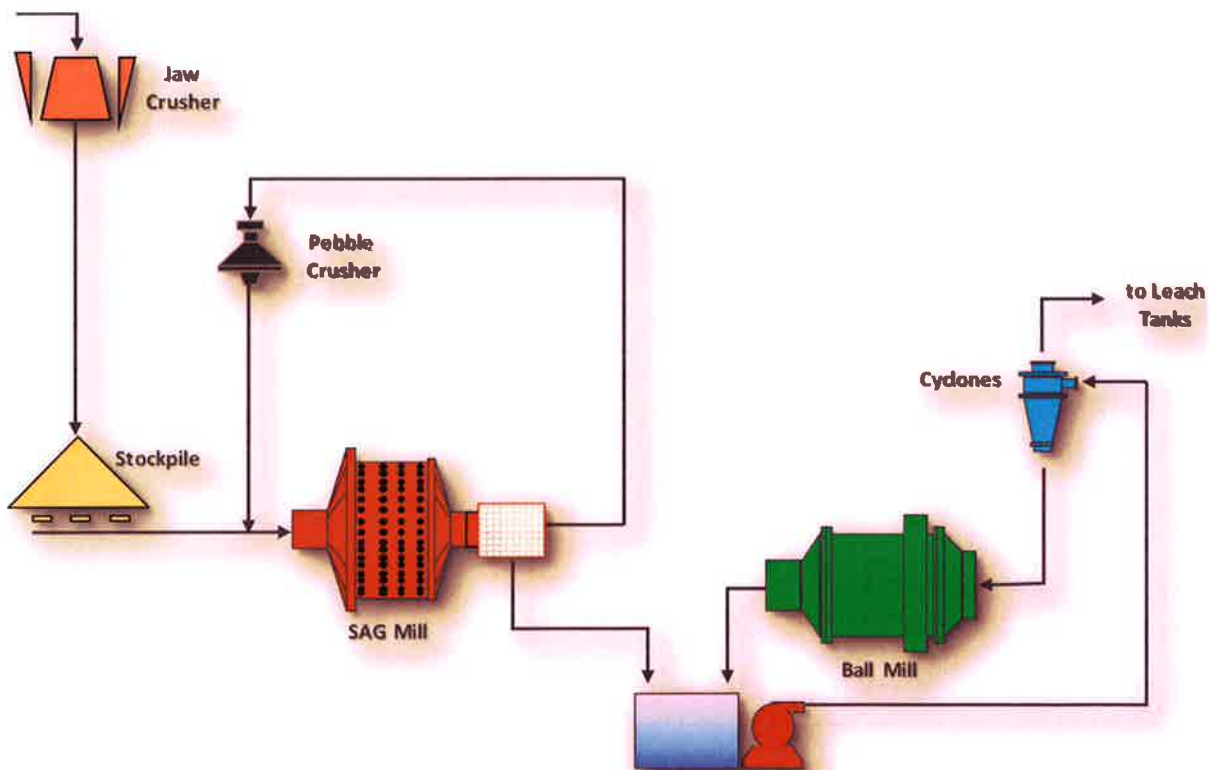


FIG 2 – Original grinding circuit flow sheet.

(OMC) since 2002 to improve mill throughput, and OMC have assessed and modelled the grinding circuit a number of times over the past few years (OMC, 2012, 2013a, 2013b, 2014).

A plant trial was completed in April 2013 with a range of primary and secondary crushed (100 per cent -40 mm) material being blended as SAG mill feed. At a blend of 40 per cent primary with 60 per cent secondary crushed feed, the SAG mill throughput achieved 315 t/h over a 14.5 hour period. Full circuit surveys were conducted at that time to calibrate models for simulation exercises aimed at finding throughput improvements.

As the Edna May SAG mill was fixed speed and operating at a relatively high 78 per cent of critical (N_c) or 13 rev/min, there were concerns expressed by OMC about the stability of the mill under a full secondary crushed feed size. Without the addition of rock media, the charge may have a tendency to grind out, leaving the shell lifters and plates exposed to ball strikes and, therefore, excessive wear and possibly damage.

In addition, OMC commented in their reports about overloading the ball mill circuit with a coarser transfer size from the higher tonnage/finer SAG feed conditions.

In August 2013, Edna May contracted a crushing plant to generate a stockpile of -40 mm material. This was blended into the jaw crusher feed using a front-end loader. In addition, some of the -40 mm material was re-crushed to generate a -8 mm product size. This material was stockpiled adjacent to the ball mill feed conveyor (used in the past to transfer crushed pebbles as part of the crush forward circuit configuration) and fed directly to the ball mill circuit - a very novel approach to maximising plant tonnage.

Edna May conducted two surveys of the circuit streams after the SAG mill while feeding -8 mm material directly into the ball mill. One survey was with crushed pebbles returning to the SAG mill, and the second was without scats returning, but the -8 mm feedrate was increased to match the pebble rate (mimicking the crush forward circuit).

The practice of direct feeding -8 mm material into the ball mill feed was stopped shortly afterwards and attention was focused on options for reinstating the crush forward configuration along with preparing finer mill feed using partial or complete secondary crushing.

EFFECT OF SCATS/PEBBLES ON SEMI-AUTOGENOUS GRINDING MILL THROUGHPUT

The combination of competent primary ore characteristics and limited SAG mill impact breakage/residence time was resulting in a significant amount of scats being generated. With the mill able to routinely generate up to 35 per cent scats at higher mill loads, any material in the feed coarser than grate size (or 60 mm) could be considered 'future pebbles' and problematic for the SAG mill to process.

Figure 4 shows typical production data while the SAG mill was processing primary crushed feed. The fresh feedrate and per cent scats (or pebbles) can be seen to vary with the mill load (indicated by bearing pressure in kPa). The scats rate increases significantly with mill load, while the feedrate decreases for a higher mill filling.

While it is not uncommon for crushed scats recycle to reduce fresh feedrate by consuming some of the mill volume (Crawford, 2009), the Edna May SAG mill is particularly prone as these particles are not being broken down in the second pass. In Edna May's experience, it is relatively common for the feedrate to increase by the same amount as the scats generation rate when recycling is stopped. This was clear evidence that the crush forward circuit configuration should be reinstated and, once in effect, the SAG mill should be operated to generate the maximum amount of scats - allowing this tonnage to be passed onto the ball mill. In the future, the pebble crusher product can be screened and recycled back to utilise the spare pebble crusher capacity.

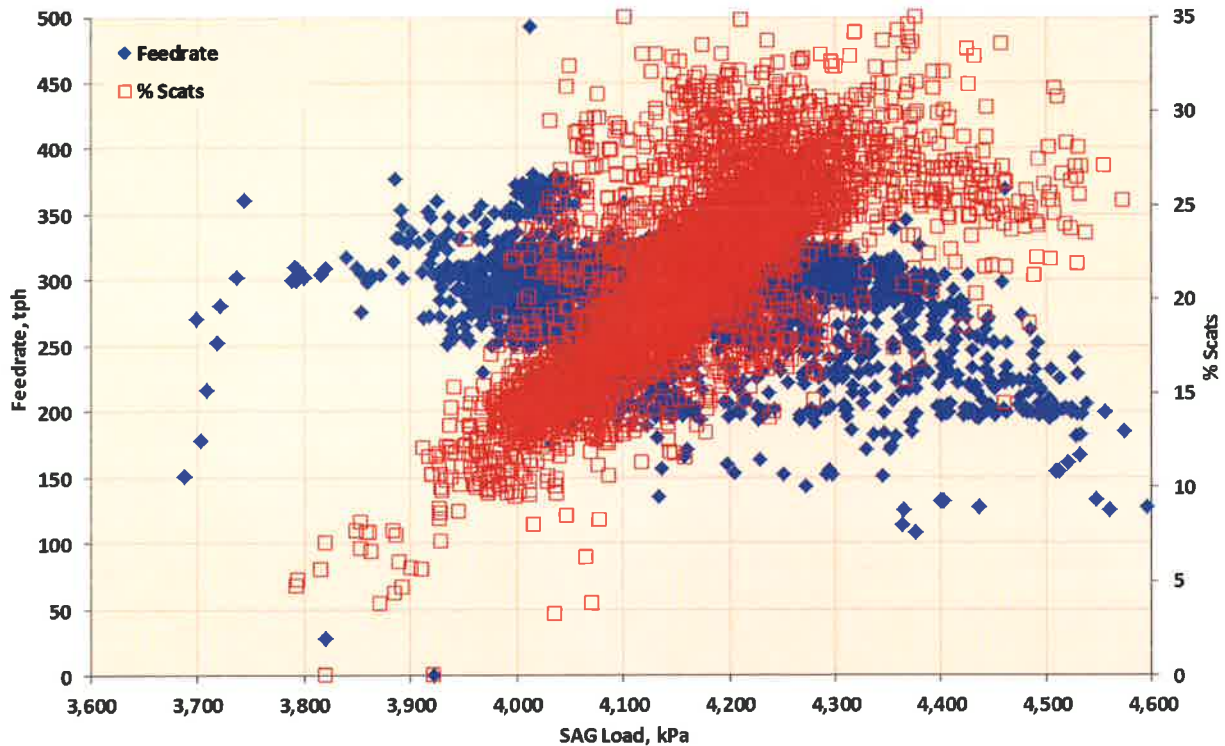


FIG 4 – Semi-autogenous grinding mill feedrate and per cent scats versus load (primary crushed feed).

FULL SECONDARY CRUSHED FEED TRIALS

To estimate the throughput increase possible from a full secondary crushed feed, two plant trials were arranged. One was conducted in August 2013 and a second was completed in November 2013, when three surveys were completed by OMC and Edna May personnel to update the circuit model.

Samples of the -40 mm crushed material showed an 80 per cent passing size of 25 mm with 45 per cent finer than 10 mm. This means that 45 per cent is finer than the trommel opening and should pass onto the ball mill circuit after exiting the SAG mill.

August 2013 trial results

Edna May personnel arranged for 6000 t of -40 mm material to be stockpiled and segregated for the trial. After allowing the stockpile to 'cone out' and drop down, the trial lasted 13 hours and during this period around 4500 t was processed before coarse material started infiltrating the feeders.

With the Edna May SAG mill power limitation, full secondary crushing offers an alternative to allow the SAG mill to operate at a lower specific energy (SE, in kWh/t) or higher throughput (Allaire, 2011; Castillo, 2011; Festa, 2014; McGhee, 2001; Thong, 2006). The effect of the finer feed was readily apparent in the first trial, with a decrease in scats production and the ability to maintain a lower mill load inference of 3800 kPa bearing pressure (estimated to be 18 per cent total filling or 14 per cent balls and four per cent rocks).

While the scats rate dropped to ten per cent or less, scats recycle posed some issues with mill load stability. With a crush forward circuit configuration, along with an optimised crusher liner configuration for finer pebbles, it is believed that mill load stability will not be an issue.

For the trial period, the feedrate was maintained between 350 t/h and 400 t/h with the SAG SE reducing from 8 kWh/t to 5.5 kWh/t. This change matches the performance improvement measured by other operations moving from

primary to full secondary crushed feed (Allaire, 2011; Festa, 2014).

With the finer feed, the per cent scats reduced significantly (see Figure 5) and, based on the trial data, it appeared that a scats rate of ten to 15 per cent could be expected for -40 mm feed. Including the crush forward configuration would therefore add an additional ten per cent to the throughput (assuming a similar 1:1 improvement in feedrate). In other words, the full secondary crushed feed was expected to achieve 350–400 t/h and 385–440 t/h in crush forward configuration.

The secondary crush trial produced an obvious change in size (and shape) of the scats being generated. Figure 6 shows the normal scat size compared to the secondary crush scat material. Despite the difference in image scale, the smaller and angular appearance of the scats is evident. The smaller pebble crusher feed topsize will allow an optimised liner design to be installed and achieve a finer product size passing onto the ball mill circuit with the crush forward configuration.

November 2013 trial results

The second -40 mm, full secondary crushed trial was conducted in late October and early November 2013. Three surveys were conducted to update the OMC circuit model:

1. 100 per cent primary crushed feed (base case)
2. 100 per cent secondary crushed feed with uncrushed scats returned to the SAG mill
3. 100 per cent secondary crushed feed with the SAG scats being dumped (to simulate the crush forward configuration).

The second survey returned uncrushed pebbles to the SAG mill as the crusher liner design was not considered suitable for the scat top size.

OMC's modelling work concluded that the full secondary crush feed with crush forward handling of the SAG scats would achieve a maximum throughput of 392 t/h (OMC, 2014) at a SAG mill SE of 5 kWh/t. The full secondary crush feed survey showed the SAG mill to operate at a SE of 5.8 kWh/t,

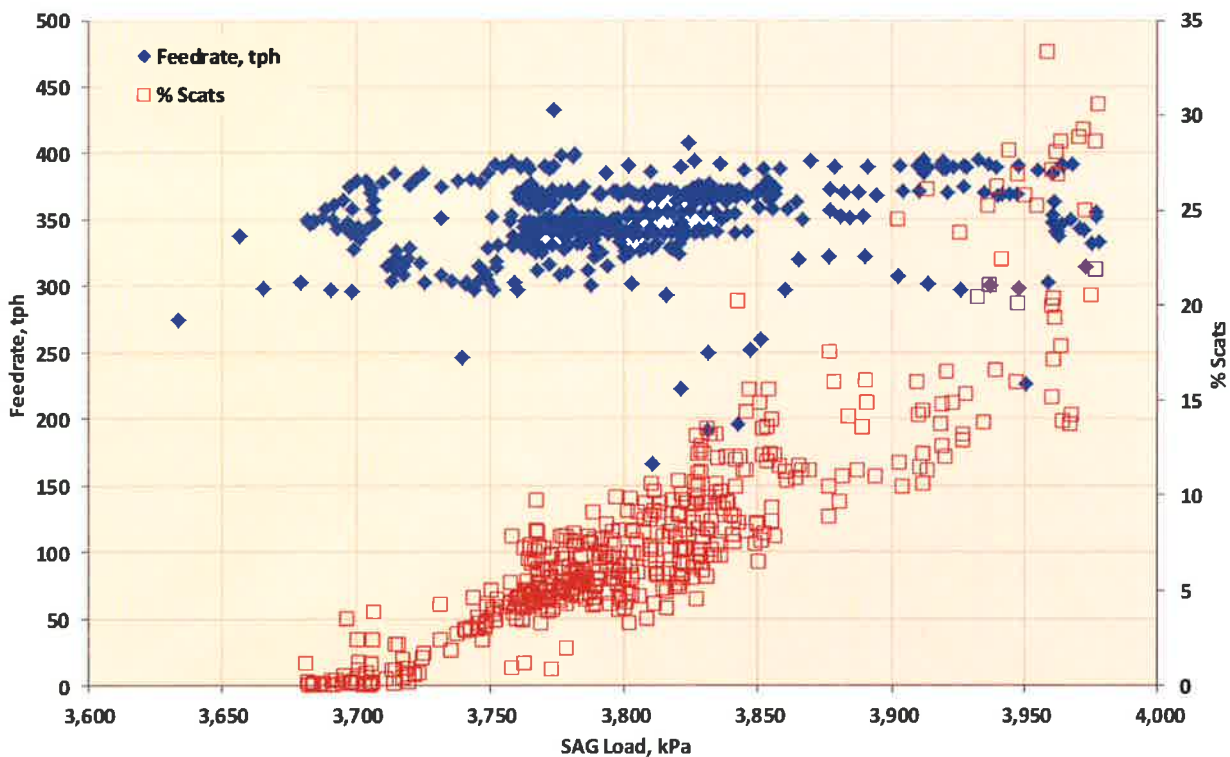


FIG 5 – Semi-autogenous grinding mill feedrate and per cent scats versus load (secondary crushed feed).



FIG 6 – Semi-autogenous grinding mill scats size for primary versus secondary crushed feed.

even with a very full 33 per cent total load (14 per cent balls plus 19 per cent rocks) drawing almost 2 MW of power.

Interestingly, the surveys showed the SAG mill to operate more efficiently than predicted in the April 2013 base case OMC model with a coarser feed.

With the full secondary crushed feed and at maximum tonnage, the cyclone overflow P80 size was simulated at 215 μm . To achieve a finer circuit grind size, significant reductions in SAG feedrate would be required or possibly additional grinding power installed.

GRINDING CIRCUIT IMPROVEMENTS

In the short term, Edna May has made a number of operational changes to allow it to sustain a feedrate in excess of 340 t/h without a significant deterioration in leach feed size. These changes include:

- the re-addition of 15 per cent to 20 per cent oxide to the feed
- implementation of the crush forward configuration
- redirection of the Knelson tailings stream
- the commissioning of a limited variable speed drive (VSD) on the SAG mill motor.

Re-addition of oxide material

Edna May was able to feed additional oxide material associated with an open pit cut back as well as previous stockpiled material of acceptable gold grade. Currently, it is maintaining 15 to 20 per cent oxide blended in the feed.

Crush forward configuration

The pebble crusher was changed to a crush forward configuration in late August 2013 with all crushed scats being passed to the ball mill feed. The new circuit flow sheet is shown in Figure 7 without a screen closed-circuiting the pebble crusher. Plans to include a screen after the pebble crusher are under review by Edna May as part of its life-of-mine strategy for additional plant capital.

Following this change, circuit tonnage was maintained at 300–350 t/h with a scats rate consistently around 20 per cent of the fresh feedrate. SAG mill SE was held at around 6 kWh/t with a relatively low rock load. However, the coarse transfer size (including any >12 mm particles in the pebble crusher product) resulted in ball mill stability issues that needed to be resolved.

Knelson tailings redirection

It was identified that the ball mill would be a limitation at higher feedrate due to unscreened crushed pebbles reporting directly to the ball mill feed and resulting in reduced milling efficiency. A further reduction in efficiency occurred because

the Knelson gravity concentrator tailings (and large quantities of associated dilution water) was returned to the ball mill feed and reduced its residence time. Edna May redirected the Knelson tailings stream to the cyclone feed pump box, which allowed much better control over the ball mill circulating load. With the redirection of the tailings stream, ball mill efficiency improved and the SAG mill became the grinding circuit bottleneck once again.

Semi-autogenous grinding mill variable speed drive

As already mentioned, one of the concerns of converting a SAG mill circuit to full secondary crushed feed is uncontrolled grind outs and the resulting exposure of shell plates/lifters to ball strikes without an adequate protection by the rock load. To alleviate this concern, as well as provide a highly effective means for controlling the SAG mill load, Edna May commissioned a limited variable speed drive in late February 2014.

The limited VSD allows for the SAG mill to operate between 62 and 82 per cent N_c (or 80 to 105 per cent of normal range). In addition, Edna May has modified its shell lifter design to a steeper, 20° face angle, which allows it to achieve efficient outermost ball trajectories throughout the life of the lifter. Edna May is currently operating with 20 rows of lifters, which may be increased in the future once experience is gained operating the mill in variable speed mode.

In the month following the VSD commissioning, the SAG mill consistently operated at around 70 per cent N_c with the new, steeper face lifters and achieved 330–350 t/h at a SAG SE of 5 kWh/t.

EFFECT ON LEACH FEED SIZE

Another concern facing Edna May in its pursuit for higher tonnage with a secondary crushed feed is the impact on the circuit product or leach feed grind size. Recent test work indicated that a one per cent decrease in leach extraction is expected for every 25 μm increase in grind P80 size up to 300 μm . (A 25 μm change in P80 size corresponds to a five per cent change in per cent -150 μm .)

Figure 8 plots the trend of shift sample sizings and shows how the per cent -150 μm has varied since January 2013, with the target grind size highlighted as a solid line. Varying between 70 per cent and 80 per cent -150 μm , the circuit product size was improving up to August 2013, which was likely due to the increased primary ore proportion in feed and the associated lower tonnage. The change to a crush forward configuration at the end of August is quite apparent, with a coarsening of the leach feed as the ball mill circuit was loaded with the crushed pebbles.

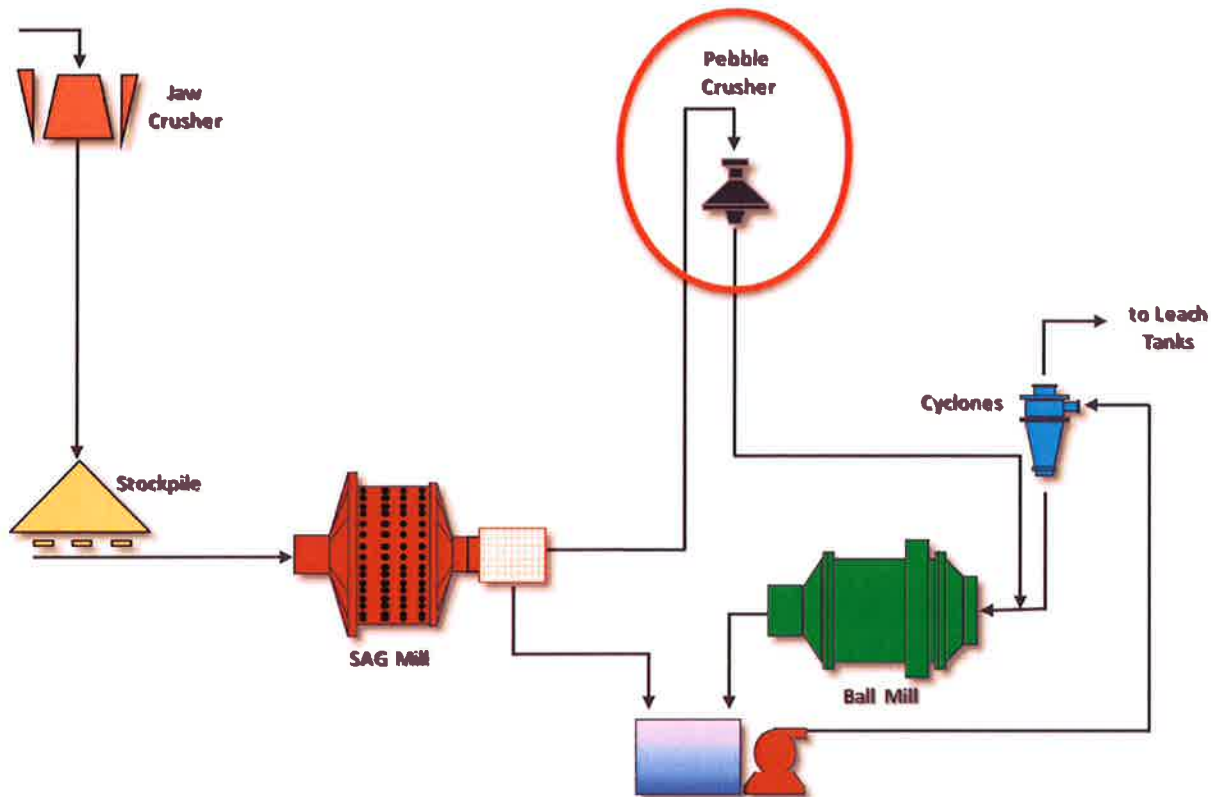


FIG 7 – Grinding circuit flow sheet with crush forward configuration.

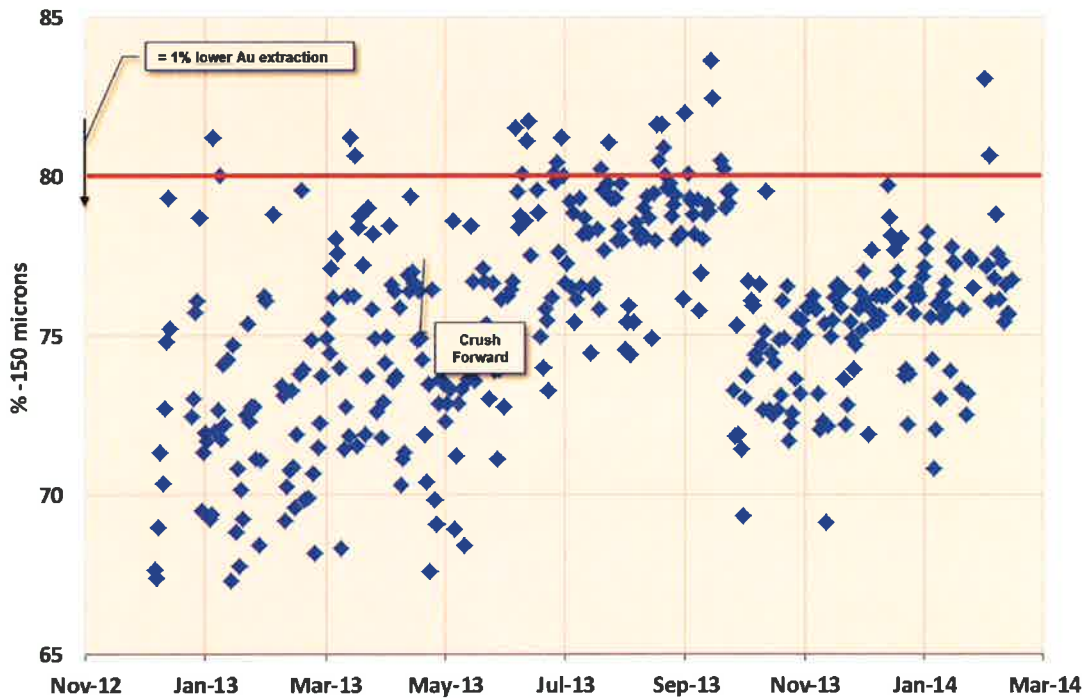


FIG 8 – Trend of grinding circuit product size (per cent -150 μm) since January 2013.

Redirection of the Knelson tailings stream and improvements in the pebble crusher product size have allowed Edna May to maintain around 75 per cent -150 μm at the higher feedrate.

OPPORTUNITIES FOR THE FUTURE

Based on the results obtained from the two trials, higher throughput is possible with the implementation of full secondary crushed feed. OMC simulation results suggest close to 400 t/h can be achieved. This represents a 54 per cent

increase over the baseline 260 t/h that occurs with limited oxide material in the feed.

The flow sheet for the full secondary crush circuit in the crush forward configuration is shown in Figure 9.

The secondary crusher should be in closed-circuit with a screen to ensure no oversize passes to the SAG mill. If the crushers are all operated in a stable and consistent fashion, SAG mill performance should also be stable and very predictable.

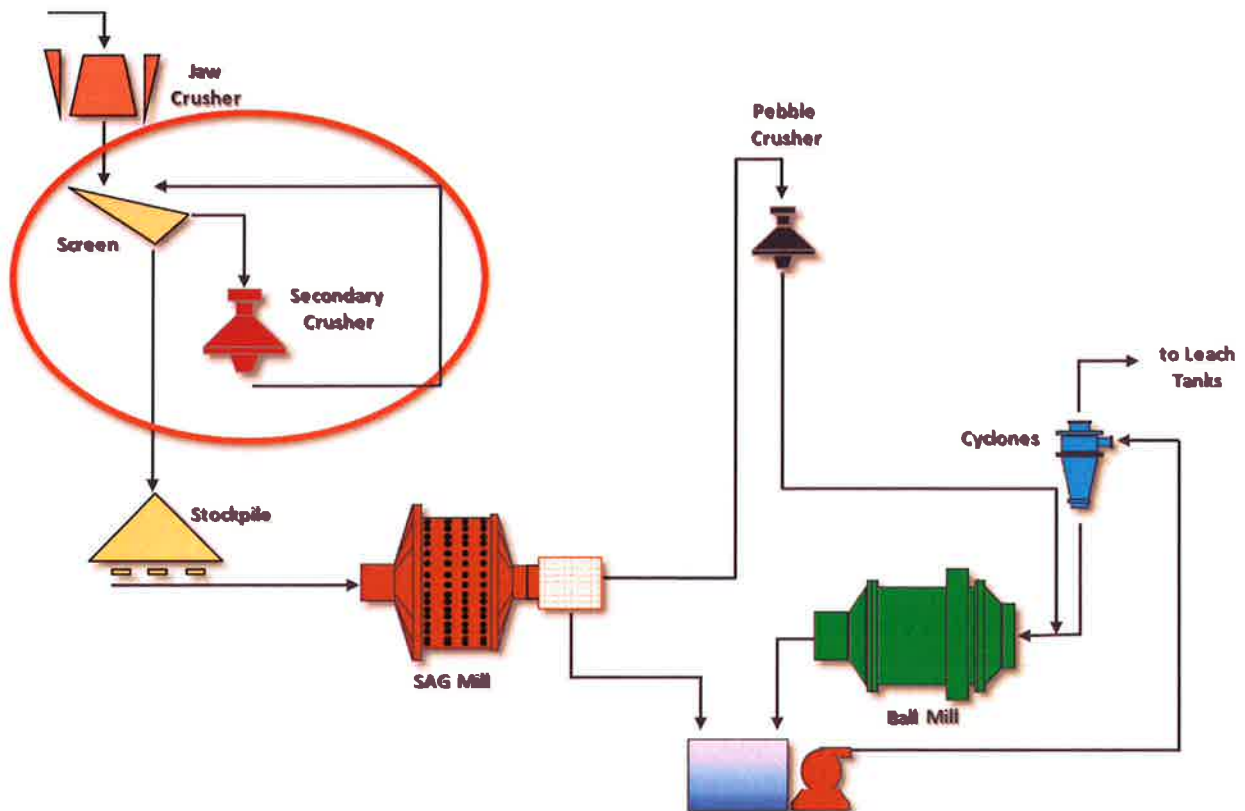


FIG 9 – Secondary crushed feed circuit with crush forward configuration.

In addition, if the secondary crusher is down for maintenance the SAG mill can operate as it does currently. The smaller scat size should allow optimisation of the pebble crusher liner profile as the crush forward configuration also works well with the secondary feed and the ability to still generate scats.

As of March 2014, Edna May was maintaining 330–350 t/h at a SAG SE of 5 kWh/t, with only ten to 15 per cent scats being handled by the pebble crusher. The circuit grind size was not overly coarse at 75 to 78 per cent $-150\ \mu\text{m}$. This was achieved with a blend of 15 to 20 per cent oxide in the feed.

On 100 per cent primary ore, the circuit is expected to achieve close to 400 t/h with full secondary crushed feed. However, without optimisation of the ball mill and cyclones, the grind size could be considerably coarser.

CONCLUSIONS

A significant improvement in grinding circuit throughput has been achieved by Edna May when faced with a depletion of oxide feed, with mainly much harder primary feed remaining to process. The relatively low residence time and limited capacity of the 2.0 MW SAG mill meant that Edna May needed to be creative with ways to shift the load to the 3.7 MW ball mill.

Contract crushing of the SAG feed to $-40\ \text{mm}$ was investigated as was further crushing to $-8\ \text{mm}$ to generate direct ball mill feed. Plant trials have indicated that full secondary crushing of the feed can achieve higher throughput, provided that the SAG mill is operated in variable speed mode to closely control the rock load. In addition, the pebble crusher has been configured to operate in crush forward configuration, although the product is not screened and this can cause the ball mill circuit to overload at times.

To partially alleviate this issue by maximising ball mill grinding efficiency, the Knelson gravity tailings stream was redirected from mill feed to cyclone feed.

With a lesser amount of oxide (15 to 20 per cent) and primary crushing alone, the crush forward circuit configuration has achieved 330–350 t/h at 75 to 78 per cent $-150\ \mu\text{m}$ in the leach feed.

Simulations indicate that on 100 per cent primary ore, secondary crushing with a crush forward configuration can achieve close to 400 t/h. With a 15 per cent oxide blend, quantities in excess of 400 t/h are expected to be able to be processed, representing a 54 per cent increase in tonnage over the 260 t/h baseline conditions from early 2013.

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