



**GOLD FIELDS GRANNY SMITH GRINDING CIRCUIT:  
A METALLURGIST'S JOURNEY OF PROGRESSION**

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## **GOLD FIELDS GRANNY SMITH GRINDING CIRCUIT: A METALLURGIST'S JOURNEY OF PROGRESSION**

### **ABSTRACT**

The Gold Fields Granny Smith mine in Western Australia has been operating their grinding circuit under a wide range of conditions: campaigning very competent underground ore followed by soft oxide, primary versus secondary crushed feed and finally single-stage SAG and conventional SAG, ball mill and pebble crusher (SABC) configurations. Full circuit sampling surveys were carried out in 2012 and again in 2014 with the results included in this paper. As well as detailing the highlights of the journey that unfolded, this paper will compare the efficiency of the circuit operating in different modes.

### **KEYWORDS**

Secondary crushed, SAG milling, optimisation, simulation, modelling

### **INTRODUCTION**

The Granny Smith mine (GSM) has a long history of collecting good quality grinding survey data from which to make circuit improvements. This started when the SAG mill was originally operating at the Placer Dome Kidston mine, after being relocated to Granny Smith for Barrick Gold and continuing now under Gold Fields Australia ownership. The same equipment processed a variety of ore types from highly competent, underground Wallaby Deeps ore to soft oxide material (as part of a toll agreement). In addition, the circuit configuration was changed a number of times to handle a wide range of tonnage.

Survey data provide an excellent historical record for comparison when the circuit was operating in different configurations as well as feed conditions. While power-based circuit evaluation techniques like the CITIC SMCC approach (Morrell 2009) can compare the overall circuit performance with a database estimate of theoretical or 'ideal', such methods cannot provide insight into options available for optimisation.

A review of the many improvements made by Granny Smith personnel over the past seven years shows what can be achieved through considered planning and benchmarking with high quality survey data...following the metallurgist's journey of progression.

### **HISTORY OF CIRCUIT IMPROVEMENTS**

#### **Prior to 2008**

During this period, the grinding circuit processed secondary crushed feed through a SAG mill followed by pebble crusher and ball mill (SABC mode). Prior to September 2006, GSM processed ore from both the Wallaby Deeps underground mine as well as material hauled 13 km from the open pit operation. With a blend of underground and open pit ore, Granny Smith processed material at 3.2 Mtpa to 4.0 Mtpa (or 400 tph to 500 tph). A schematic of the Granny Smith crushing and grinding circuit flowsheet is shown in Figure 1.

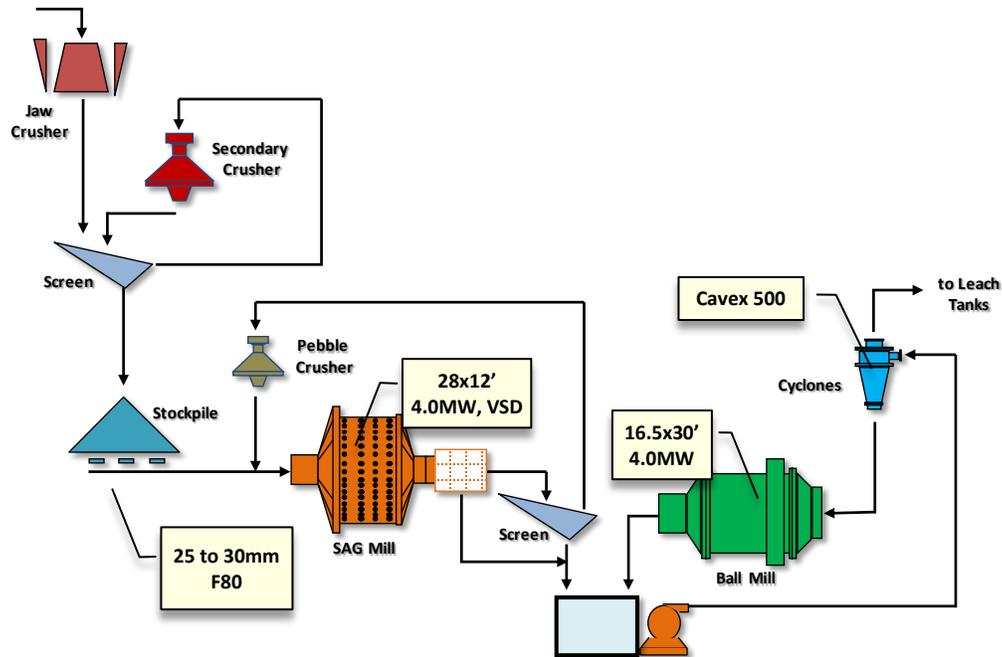


Figure 1 – SABC Grinding Circuit Flowsheet

After closed-circuit secondary crushing, the SAG mill feed 80% passing (F80) size was 25 mm to 30 mm. Installed grinding power is split equally between the two mills with the SAG mill fitted with a variable speed drive (VSD). SAG discharge screen oversize ('pebbles' or 'scats') was recycled through an 185 kW pebble crusher. The circuit was characterised by a high circulating load around the ball mill, with a bank of 20 inch (CAVEX 500) cyclones generating a coarse overflow P80 size of around 200 µm to 220 µm which reported to the leach circuit.

The lack of a pre-leach thickener required the circuit to operate with a very high overflow density; typically in excess of 50% (by weight, w/w). This placed severe limitations on the cyclone classification efficiency due to the need to operate at >70% w/w solids cyclone feed density.

### 2008 to 2010

With the depletion of the open pit in September 2006, the underground mine could only sustain 125 tph to 160 tph (1 Mtpa to 1.3 Mtpa) and options to either campaign the ore in on/off periods or operate at a lower tonnage needed to be evaluated.

Utilising existing steady-state, *JKSimMet* models of the Kidston SAG mill and Granny Smith ball mill, a range of different circuit options were evaluated. The high-aspect, variable-speed SAG mill allowed GSM to consider a number of different circuits due to the wide range of possible operating conditions.

### Single-stage SAG Circuit

The selected configuration converted the SABC circuit to a single-stage SAG mill by diverting the cyclone underflow stream back to the SAG mill. The closed circuit operation started in April 2008 along with smaller, 16 inch (400 mm) cyclones instead of the previous 20 inch (508 mm) cyclones. A schematic of closed circuit, single-stage SAG mill flowsheet is shown in Figure 2.

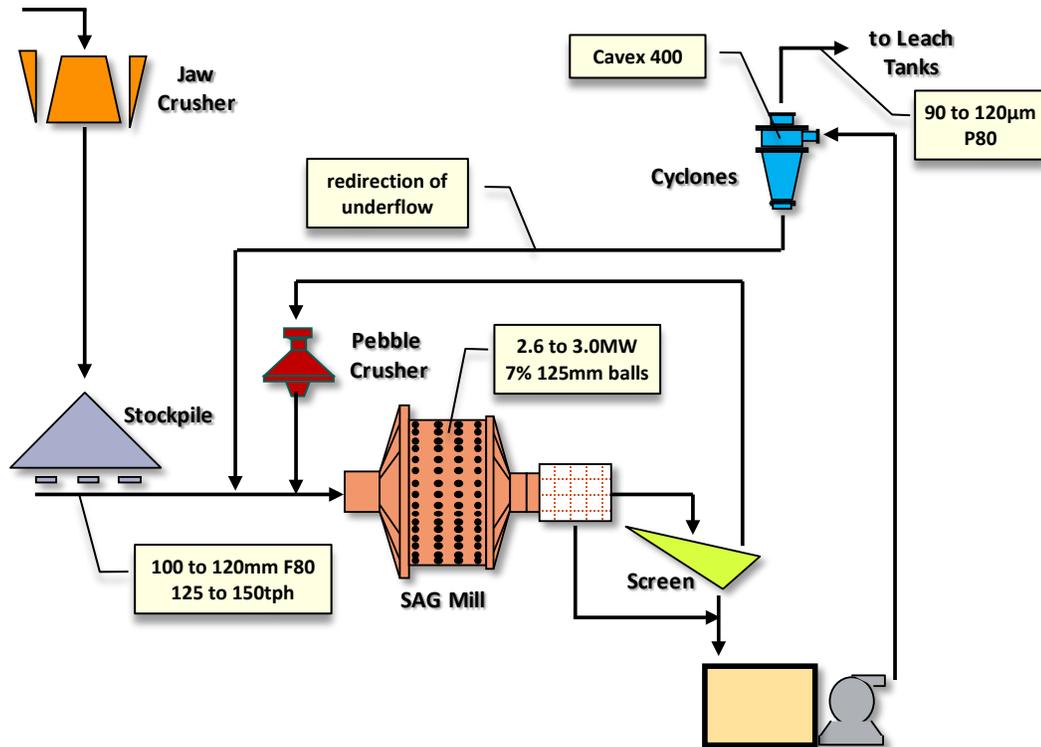


Figure 2 – Single-stage SAG Mill Grinding Circuit Flowsheet

The circuit feedrate of 125 tph to 150 tph was primary crushed to an F80 size of between 105 mm and 120 mm and the SAG mill slowed down and charged with a 7% (by volume, v/v) load of 125 mm balls. The smaller diameter CAVEX 400 cyclones produced an overflow P80 size of 90 µm to 120 µm. The circuit operating conditions were described in detail in an earlier SAG conference paper (Dance, et. al., 2011).

During this period, two circuit sampling surveys were conducted on the single-stage mill. With the same ball charge, lower and higher rock loads were surveyed and showed the circuit could generate a range of cyclone overflow product sizes. This allowed GSM to better control the leach feed size by operating with a higher total load for a finer product size or a lower load for a coarser product size. *JKSimMet* breakage rate distributions were fitted to the two surveys and showed the effect of rock load on the rate of fine particle (attrition) breakage as well as coarse particle (impact) breakage (Dance, et. al., 2011).

The single-stage SAG mill circuit was shown to efficiently operate on primary crushed, Wallaby Deeps underground material. With relatively coarse, competent feed and a reasonable ball charge, the variable speed SAG mill generated a product with sufficient fines content that the cyclones could manage without excessive recycle. More competent material exited the mill and was handled by the existing pebble crusher before being returned to the mill. Some stability issues with the SAG discharge pumps obtaining steady flow to the cyclones were experienced early on in the process and changes to motor size and discharge line pipe diameter were implemented to resolve this.

#### Return to SABC Circuit

In February 2009, Barrick signed a memorandum of understanding with Crescent Gold to process oxide ore from the Laverton mine through the Granny Smith mill. Starting in October 2009, GSM returned

to operating their full SABC circuit on campaigns of Crescent Gold oxide followed by Wallaby Deeps underground ore. In January 2010, a further agreement was signed with Range River Gold to purchase ore from the Mount Morgan Gold Mine and treat it at Granny Smith from February 2010 onwards.

In June 2010, follow-up sampling surveys were conducted on the ball mill circuit while processing underground ore. The objective of the circuit review (including modelling and simulation work) was to improve mill throughput on competent, secondary crushed feed and correct operational issues such as bogged SAG discharge lines due to periods of very coarse transfer size.

The list of recommendations from the circuit review included a smaller, 30 mm screen opening around the secondary crusher, a reduction in SAG mill make-up media size to 105 mm (and increased ball charge), a reduction in SAG discharge screen size to 8 mm and smaller, 65 mm ball mill make-up media instead of the 80/65 mm blend.

The smaller SAG mill media size was recommended due to the wide range of conditions the mill was experiencing: periods of coarse, competent feed followed by high tonnage campaigns of soft, oxide feed with little or no rock load in the mill. The 105 mm media was suggested to avoid excessive ball-liner impact damage while processing Crescent Gold oxide material. In addition, survey data indicated the secondary crushed, Wallaby Deeps feed was similar to that surveyed in 2003 at Kidston with an F80 size of 25 mm.

At the end of 2010, the SAG mill ball size was changed to 105 mm but proved to be unsuccessful, with the mill becoming unstable due to insufficient ball charge and a feed topsize of between 38 mm and 50 mm. A blend of 125/105 mm media was used from December 2010 until March 2011 when the 125 mm media was fully restored as the make-up ball size. With the coarser mill feed, the 105 mm ball size was unsuitable and the mill throughput dropped from 350 tph down to 275 tph.

With the return to SABC circuit mode, GSM reintroduced the larger diameter, CAVEX 500 cyclones for the higher tonnage. At 400 tph to 600 tph feedrate (depending on the ore conditions), typically three to five of the ten available cyclones were in operation. The restriction on cyclone overflow density continued and resulted in a variable grind P80 size of 150  $\mu$ m to 200  $\mu$ m with Wallaby Deeps feed. Issues with bogged lines due to coarse transfer size from the SAG mill were partially resolved by blending 10% oxide with the Wallaby Deeps underground material. While somewhat successful, it did not fully resolve the instability of the product size being generated by the SAG mill.

## **2011 to 2012**

A focus was placed in 2011 on crushing circuit maintenance and availability and the secondary crusher banana deck screen panel openings were reduced in size in January 2012. The top deck was reduced from 60x110 mm down to 55x70 mm while the bottom deck was changed from 35x75 mm down to 20x53 mm at the discharge end.

The outcome of the crushing circuit improvements was a finer feed size to the SAG mill on Wallaby Deeps underground ore. SAG mill feed size distributions from samples collected in late 2011 (before screen changes) and early 2012 (after changes) are shown in Figure 3.

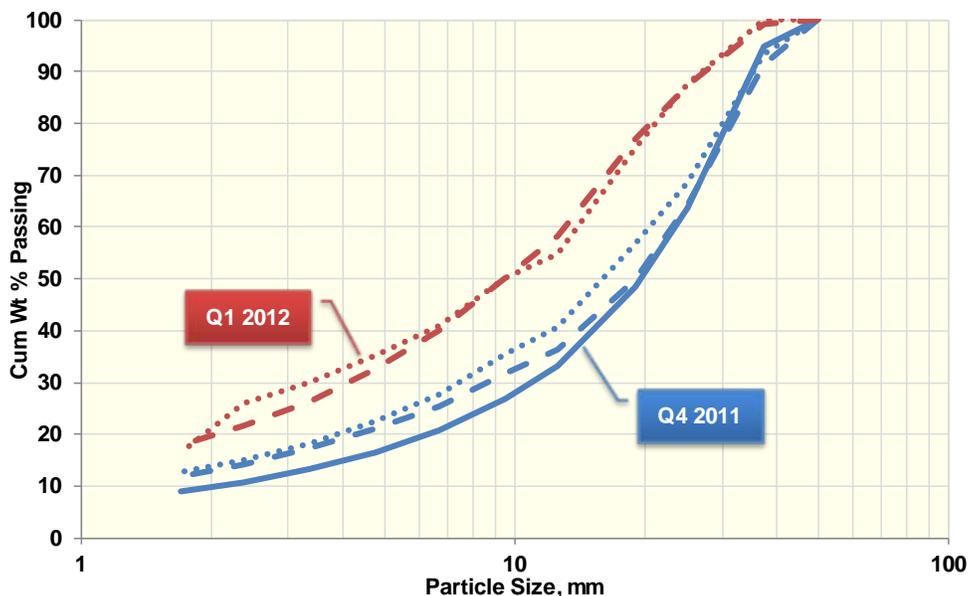


Figure 3 – Secondary Crushed SAG Mill Feed During 2011 to 2012 Period

The distributions show a significant improvement from the crushing changes, with both a decrease in P80 size from 30 mm down to 20 mm as well as an increase in fines content. In addition, the amount of minus 9.5 mm particles increased from 30% to almost 50% in the SAG feed. It is important to note that during this period no changes were made to the secondary crusher bowl or mantle profile.

With the shift in circuit feed size on competent material along with the continued campaigning of soft, oxide feed, 105mm SAG media were reintroduced in January 2012 and the ball charge was maintained at 10% v/v or higher. The ball size change was implemented very aggressively to ensure adequate ball load in the SAG was achieved and the problems experienced with SAG performance during the first trial were not repeated. The SAG discharge screen panels were also changed progressively from 10mm down to 8mm as they needed replacing.

Under these conditions, the circuit was achieving consistently 350 tph to 400 tph (2.8 Mtpa to 3.2 Mtpa) at a grind P80 size of around 140  $\mu$ m. As the first of the two recommended changes had been implemented, it was decided that another full circuit sampling survey would be conducted in late 2012. This coincided with a Barrick metallurgical group training exercise and proved extremely valuable for both graduate and plant metallurgists.

### 2013 to 2014

Upon completion of the oxide ore toll agreements in June 2013, reduced feedrate conditions were once again facing GSM. A review of the 2012 circuit survey data and modelling results allowed three options to be considered at a process rate of 1.5 Mtpa:

- Secondary crushed feed with single-stage SAG mill
- SABC circuit configuration at reduced power/mill speed
- Campaign milling at normal SABC circuit conditions

After a site review of the economics of each option, a decision was made to campaign mill at a budgeted rate of 350 tph and renewed focus was placed in 2013 on crushing circuit stability as well as

upgrade/replacement of grinding circuit instrumentation. This included variable speed cyclone feed pumps which were installed in June 2014.

### Secondary Crusher Improvements

It was quickly recognised that control over the secondary crusher product topsize and fines content was very important to ensure stable circuit tonnage and allow the SAG mill to operate at a relatively slow speed (<70% critical,  $N_c$ ).

GSM focussed on consistently delivering a SAG mill feed 80% passing size of <20 mm with a topsize of 37.5 mm. This is in contrast to other operations with secondary crushed feed that are targeting an F80 size of 40 mm or even 50 mm. The key component to GSM's success is having the secondary crusher in closed-circuit. To achieve a consistent product, improved crusher instrumentation and maintenance practices were implemented including weekly stringent banana screen inspections and a screen change out regime. Figure 4 shows the SAG mill feed and transfer size (discharge screen undersize) distributions from the 2012 and 2014 sampling surveys.

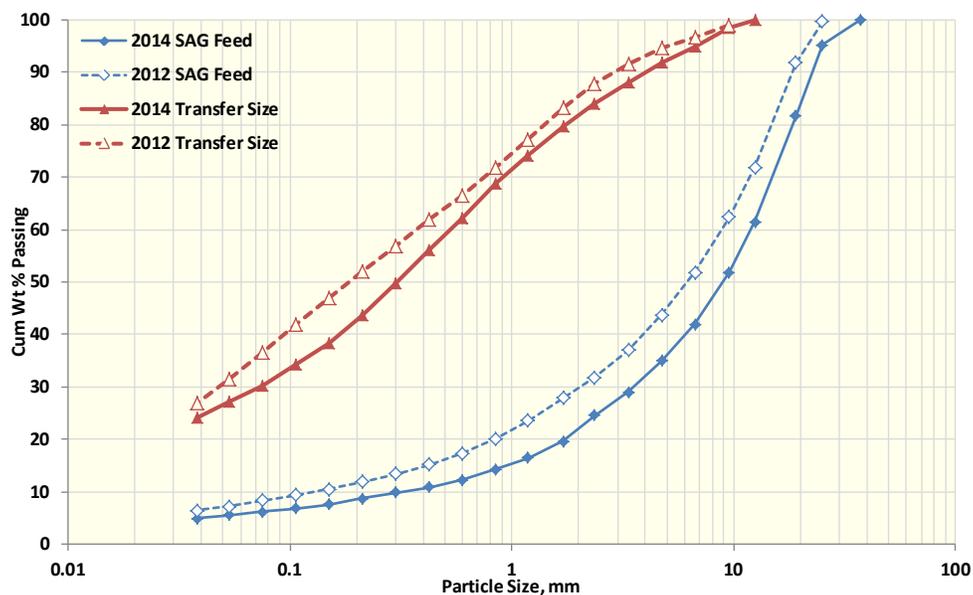


Figure 4 – Secondary Crushed SAG Mill Feed vs Transfer Size

The 2012 result was particularly fine, with an F80 size of less than 15 mm compared to the 18 mm surveyed in 2014. The finer feed was reflected in a finer transfer size as well as lower pebble rate and finer pebble topsize.

### Smaller Diameter Cyclones

With the mill tonnage stabilised at the budgeted rate of 350 tph (2.8 Mtpa), the smaller CAVEX 400 (16 inch) cyclones were reinstated to generate a finer cyclone overflow. These cyclones were already on site from the 2008 single-stage SAG mill period and minimal cost was involved as 70% of the parts were shared with the CAVEX 500 units.

The smaller cyclones were installed in January 2014 and commissioned in February and March 2014, following a shutdown period between campaigns.

As they had been used previously at a much lower feedrate, typically eight of the eleven available cyclones were now required at the 350 tph to 400 tph conditions. The high cyclone overflow % solids restriction caused an increase in ball mill circulating load as they were classifying at a finer cutpoint than the CAVEX 500 units. Cyclone capacity was commonly reached when the throughput was pushed to above 375 tph with a high circulating load around the ball mill.

The finer cyclone overflow did somewhat alleviate the limitation on leach feed density to 48% solids w/w from greater than 50% w/w. Until the variable speed cyclone feed pumps were installed in July 2014 the variation in cyclone pressure was quite high. After implementing the smaller cyclones and variable speed pumps, the grind size consistency vastly improved. The absence of a pre-leach thickener meant that a limitation on allowable cyclone feed dilution water would always be present and cyclone inefficiency at feed densities around 68% w/w solids could not be avoided entirely.

The trend in cyclone overflow P80 size during the transition from 500 mm to 400 mm cyclones is shown in Figure 5.

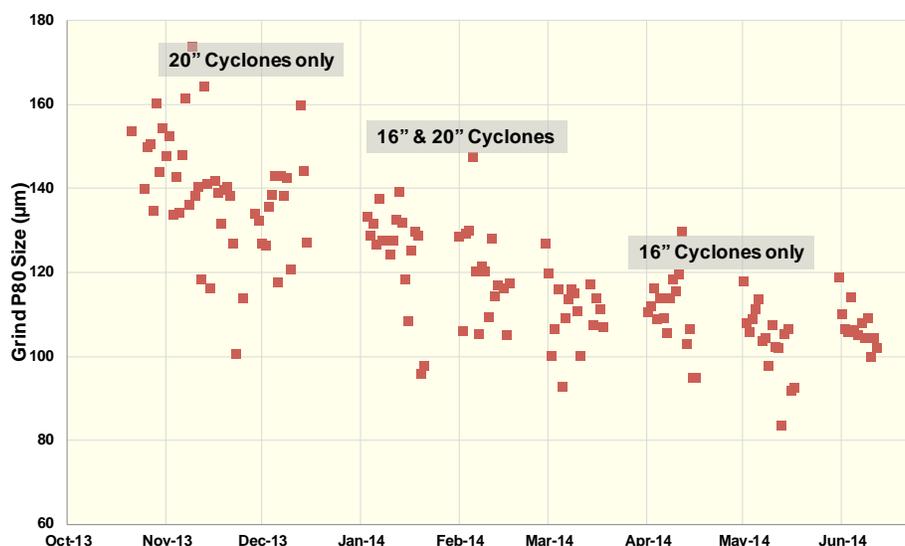


Figure 5 – Trend of Cyclone Overflow P80 Size (2013 to mid-2014)

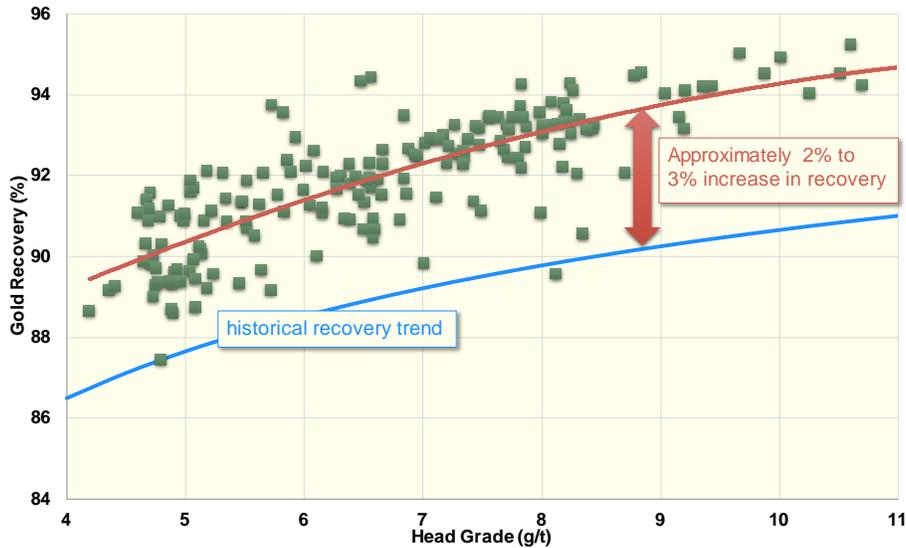


Figure 6 – Improvement in Gold Recovery for 2014 vs Historical

Figure 6 shows the improvement in gold leach extraction as a result of the finer grind size and stabilised crushing and grinding circuit. The historical trend of recovery versus head grade (blue line) is 2% to 3% lower than the recent data trend since the smaller diameter cyclones were re-commissioned (red line). GSM are reasonably confident that small incremental improvements in recovery are possible with the proposed installation of an up-front gravity gold circuit, as well as an upgrade of the existing tailings retreatment circuit which utilises deslime cyclones, spirals and a regrind tower mill.

#### Grinding Circuit Control

Although the circuit was more stable, the mills and pump boxes were manually operated so a concerted effort was made to repair and upgrade the grinding circuit field instrumentation. This scope of work preceded the implementation of a *Manta Cube*<sup>®</sup> advanced control system in August 2014. The system was commissioned by December 2014 and allowed the grinding circuit to be run under automatic control, at 350 tph to 375 tph and achieve a grind P80 size of 110 µm to 120 µm.

A reduction in ball mill media make-up size was implemented in August 2014 from a blend of 80/65 mm to 65 mm alone. This was final recommendation remaining to be implemented from the 2010 circuit review. Figure 7 shows a comparison between the measured, in-situ media size distributions during the 2010 circuit review compared with the 2014 full circuit sampling survey. Very little difference was noted overall or from measurements taken down the length of the mill.

It appears that the very coarse ball mill feed in 2010 (P80 size of 1.2 mm) was preferentially wearing the 80 mm media down to 70 mm. The finer ball mill feed in 2014 (P80 size of 700 µm) was more suited to the 65 mm media make-up size.

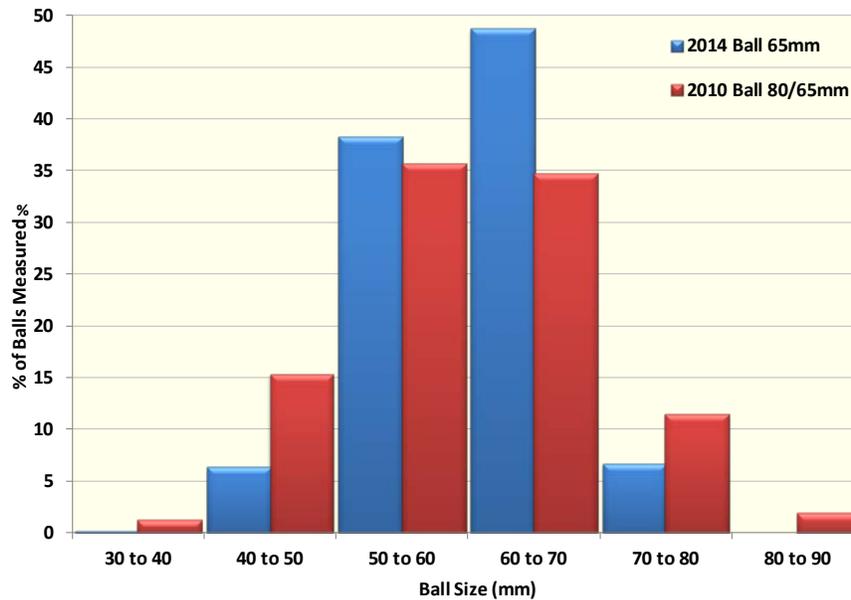


Figure 7 – Ball Mill In-situ Media Distributions for 2010 vs 2014

## 2015 and Beyond

### Crushing Circuit Control

With improvements in secondary crushing circuit instrumentation, an extension of the advanced control system to include crushing is currently underway. This will assist in maintaining the target product P80 size of 20mm (or finer) under a range of ore types. Instrumentation upgrades include two new weightometers, level sensors and tramp metal magnets. It is expected that commissioning of the crushing circuit *Manta Cube*® system will be complete by the end of 2015.

### Gravity Gold Circuit

Another planned addition to the GSM grinding circuit is gravity gold recovery from the cyclone feed stream. This will include two, Knelson QS40 batch concentrators along with a Gekko in-line leach reactor. The Knelson units will be fed 20% of the cyclone feed flowrate and return the diluted gravity tails stream back the cyclone feed hopper.

As all the original recommended changes had been implemented over the previous four years, it was decided to conduct another full crushing and grinding circuit sampling survey. The objective of this survey was to look for further opportunities for improvement and, more specifically, review the impact of the gravity gold circuit being installed around the ball mill.

### Partial Recycle to SAG Mill

Following an update to the *JKSimMet* crushing and grinding circuit models based on 2014 survey data, it was clear that the SAG mill had spare capacity that could be utilised to assist the overloaded ball mill. With the finer grind P80 size now consistently feeding the leach circuit with the CAVEX 400 cyclones, the leach feed density limitation was reduced to 48% solids w/w. Unfortunately at times, the capacity of the smaller cyclones was reached due to the high recirculating load requiring ten or more cyclones to operate at high pressure.

However, addition of dilution water anywhere in the circuit (to improve classification) would end up reporting to the cyclone overflow. Simulations using the latest calibrated *JKSimMet* model showed that recycling a portion of the cyclone underflow back to the SAG mill would produce:

- A finer transfer size to the ball mill circuit
- A slightly higher pebble rate (well within the pebble crusher capacity)
- A finer cyclone feed... and finer cyclone overflow

By returning a portion of the cyclone underflow back to the SAG mill, additional fine grinding (assisted by the 105 mm media and relatively slow operating speed) could be applied to the material **without** the need for dilution water. This was shown in the simulations to generate a finer grind size and not drop the overflow density below 48% w/w.

This circuit configuration change is being considered by GSM as the recycle launder is already in place from the single-stage SAG operating period in 2008. A decision on implementing the partial recycle will be made later in 2015. To avoid overloading the SAG mill with excess slurry, it would be necessary to monitor the recycle flowrate and include the underflow split as a parameter in the *Manta Cube*<sup>®</sup> advanced control system.

### **Advantages of Survey Analysis for Optimisation**

Granny Smith has invested considerable time and effort in conducting full circuit sampling surveys and/or circuit reviews using *JKSimMet* modelling and simulation methods. The most recent was conducted in December 2014 on both the secondary crushing and SABC circuits. This provides an excellent historical record of performance under a variety of feed conditions and circuit configurations.

Full circuit surveys were completed every two years for the past eight years. This frequency allows sufficient time for the operation to make the recommended changes; some of which cannot be done quickly and may involve capital investment. GSM is proud to state that after four years, all the recommendations from the 2010 circuit review were implemented, resulting in a steadier circuit operation and significant improvement in grind size (and consequently, gold recovery).

A focus was also placed on ensuring instrumentation was installed and operating correctly prior to implementation of process control systems (conventional or advanced).

By operating the GSM circuit under such a wide variety of operating conditions – from single-stage SAG mode to higher tonnage, secondary crushed SABC mode with both competent feed and soft oxide material – valuable knowledge has been gathered on different operating philosophies depending on business needs.

### **Comparison with Theoretical Specific Energy Requirements**

Table 1 is a summary of the surveyed circuit conditions from the original 2003 Kidston data, through the two 2008 surveys in single-stage SAG mode and the 2012 and 2014 SABC mode results. The last column shows simulated results for partial underflow recycle back to the SAG mill. As well as mill performance parameters, the actual Operating Work Index (OWi) and circuit Specific Energy (SE) values are shown.

From a SE perspective, the single-stage SAG mode survey results of 19.8 kWh/t and 23.3 kWh/t are higher than the SABC mode results – showing the impact of primary versus secondary crushed feed. The 2012 survey at 430 tph and an F80 size of <15 mm matches the SE values from 2003. The change to smaller cyclones in 2014 reduced the overflow P80 size from 153µm to 120 µm – and gained 2% higher gold recovery – but increased the circuit SE values from 16.8 kWh/t to 18.2 kWh/t.

Table 1 – Summary of Surveyed Circuit Specific Energy

Conditions		2003	2008 #1	2008 #2	2012	2014	2015*
		SABC sec crush; 20” cyclones (Kidston)	Single- stage SAG; 16” cyclones	Single- stage SAG; 16” cyclones	SABC sec crush; 20” cyclones	SABC sec crush; 16” cyclones	SABC sec crush; 16” cyclones; 20% recycle
<b>Feedrate</b>	tph	450	140	140	430	375	375
<b>Feed F80</b>	mm	24.6	97	97	14.5	18.3	18.3
<b>SAG Power</b>	kW	3,480	2,775	3,256	3,398	3,200	3,330
<b>Transfer T80</b>	mm	2.50	–	–	1.24	1.72	1.41
<b>Ball Power</b>	kW	4,000	–	–	3,818	3,626	3,626
<b>Overflow P80</b>	microns	200	155	95	153	120	102
<b>Actual OWi</b>	kWh/t	25.8	25.7	23.4	23.1	21.7	20.2
<b>Actual SE</b>	kWh/t	16.6	19.8	23.3	16.8	18.2	18.5
<b>CITIC SMCC SE</b>	kWh/t	15.2	20.8	24.1	16.7	18.0	19.2

\* Simulation based on 2014 circuit model

Lastly, the simulated result for recycling the underflow back to the SAG mill increased the SE slightly to 18.5 kWh/t. This generated an overflow P80 size of 102 µm at higher SAG mill power draw.

The point being made here is SE is only one measure of circuit efficiency and should be used in conjunction with others such as OWi and even simply, final grind size. A comparison of GSM’s specific energy values since 2008 (and prior when the mills operated at Kidston), show values between 17 kWh/t and 23 kWh/t – depending on the duty of the circuit. All these results are from processing the consistently competent Wallaby Deeps feed material (typical DWi of 10kWh/m<sup>3</sup>), but very different in feed size.

Comparing actual SE values to theoretical or database-derived estimates like the CITIC SMCC approach is commonly done to measure overall circuit efficiency. From frequent circuit reviews, GSM was able to measure and monitor their circuit performance over an eight year period on the same feed material. Most other operations are challenged to benchmark against their own performance and typically need to look to ‘similar’ operations or database averages.

For comparison, the CITIC SMCC approach SE values are shown in Table 1. They were calculated based on feed hardness values ( $M_{i_a}$ ,  $M_{i_b}$ ) and feed/product 80% passing sizes (Morrell 2009). Figure 8 is a plot of actual SE versus the CITIC SMCC estimate for the six surveys and one simulation result.

Within the accuracy of the method, it appears that all results are close to the expected circuit efficiency (within ±10%). The single-stage surveys from 2008 are understandably higher and showed GSM performed slightly better than expected. The secondary crushed results from Kidston (2003) and more recently showed higher SE values as the circuit grind size improved over time. The simulated result of partially recycling the cyclone underflow back to the SAG mill (labelled 2015), is more efficient than the SE estimated using the approach.

Once again, evaluating grinding circuit performance is more than just benchmarking against a database of expected SE. In particular, power-based modelling methods poorly describe feed size distributions using only the F80 value. Granny Smith was able to demonstrate significant improvement in throughput, grind size and ultimately gold recovery by operating at a higher SE and only slightly improved OWi. Would such incremental improvements in operation been made purely on the results shown in Figure 8? Likely not, as the circuit is running ‘efficiently’ based on specific energy alone. It is the author’s

opinions that evaluating grinding circuit performance using SE alone is not a substitute for collecting high quality, full circuit sampling survey data.

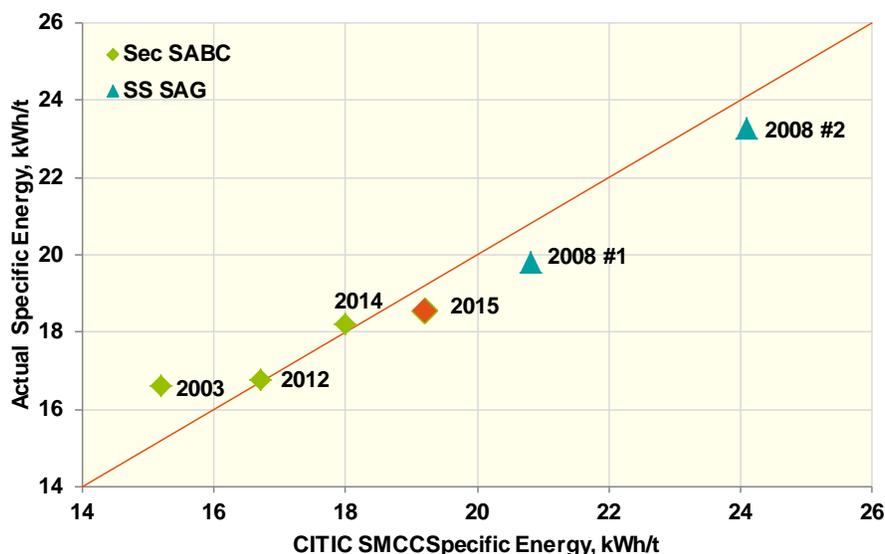


Figure 8 – Comparison of Actual vs CITIC SMCC Estimated Circuit Specific Energy

## CONCLUSIONS

Granny Smith have taken the approach of incremental crushing and grinding circuit improvements based on high quality survey data (collected frequently) as well as stabilising/optimising control methods. They have operated their circuit under a wide variety of configurations, tonnages and feed sizes over the past eight years and performed as expected, when benchmarked against specific energy estimates.

To date, they can directly attribute an increase in gold recovery to grinding circuit changes, while having to operate within a high % solids cyclone feed restriction. One of the reasons for their circuit stability is the very fine secondary crushed product size they are consistently achieving. This allowed them to reduce the SAG mill media size and operate at a slower speed without the rock load building and destabilising the mill. In turn, this provided spare mill capacity which can be used to assist the ball mill. This was shown by the partial recycle of cyclone underflow back to the SAG mill; another improvement under consideration by GSM.

Current power-based modelling methods are very useful to quickly determine if the overall circuit efficiency is 'reasonable' compared to the database. However, to fully evaluate the circuit performance (in particular, the individual elements involved), a full sampling survey is required – followed by an optional modelling/simulation exercise to compensate for hardness variations and operating conditions.

## ACKNOWLEDGMENTS

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