Recent Improvements in the Milling Circuit at Tropicana Mine

G R Ballantyne[1], M Di Trento[2], I Lovatt[3] and B Putland[4]

1. GAusIMM, Research Fellow, The University of Queensland, Sustainable Minerals Institute, Julius Kruttschnitt Mineral Research Centre, 40 Isles Road, Indooroopilly Qld 4068. Email: g.ballantyne@uq.edu.au
2. MAusIMM, AngloGold Ashanti Australia Ltd, Tropicana Gold Mine
3. MAusIMM, Orway Mineral Consultants
4. FAusIMM, Orway Mineral Consultants

ABSTRACT

The Tropicana Gold Mine, owned by AngloGold Ashanti Australia Ltd (70% owned and managed) and Independence Group NL (30%) is located 330 kilometres east-northeast of Kalgoorlie, Australia, in the newly developed Albany-Fraser Orogen. Following extensive feasibility studies, a high pressure grinding roll (HPGR)-ball milling circuit was selected based on the reduced power requirements and thus reduced operating expenses. The HPGR-ball mill circuit was estimated to require 75% of the energy of a standard semi-autogenous grinding (SAG) mill circuit. Even with an anticipated greater capital cost, the HPGR-ball mill circuit was found to give significantly better financial returns in all cases investigated in the feasibility study. A comparison between the specific energy requirements of the HPGR, crush and SAG based circuits (SABC) from the feasibility work was conducted and the HPGR circuit was found to be considerably more energy efficient. A survey was conducted and the efficiency of the HPGR was similar to both the overall circuit design and the HPGR laboratory results, reflecting the accuracy that is possible for design and operation of HPGR circuits.

Between 2015 to 2016, the Tropicana circuit has achieved a 20% increase in throughput from 780 to 930 t/h, and this increase has been maintained in 2017. This improvement can largely be attributed to upgrades to material handling processes, increased HPGR speed and smaller HPGR screen apertures. The result of these changes has been to increase the ball mill capacity by increasing the breakage conducted by the HPGR.

INTRODUCTION

Tropicana is a recently constructed gold mine operated by AngloGold Ashanti Australia Ltd (70%, Independence Group NL 30%). The mine is located 330 km east-northeast of Kalgoorlie in Western Australia (Figure 1) in the Albany-Fraser Orogen geological region, an area not believed to be prospective for gold prior to the Tropicana Joint Venture in 2002. The design for the comminution circuit is based around a HPGR and as such has created a significant amount of interest within the mineral processing community. The circuit design was justified based on the reduced power consumption, and thus operating costs in comparison to a traditional SAG mill (Ballantyne *et al*, 2016). The circuit was commissioned in September 2013 and comprises two stages of crushing closed with a dry screen, followed by an HPGR closed with a wet screen and the screen undersize reports to a reverse closed-circuit ball mill. The cyclone overflow is thickened prior to a carbon-in-leach (CIL) circuit and gold refining.

Primary crushing is conducted in a single 1400 x 2100 gyratory crusher with 600 kW installed power. The coarse ore is reclaimed from the stockpile via two apron feeders and conveyed to the secondary screen feed bins. The secondary screens are two parallel 3.0 m x 6.1 m double deck banana screens (for duty and standby) operating with 90 mm top deck apertures and 45 mm bottom deck apertures. The oversize from both decks combines to feed the secondary cone crushers while the -45 mm reports to the HPGR circuit. The secondary crushing stage comprises two cone crushers (duty and standby) which operate in closed circuit with the secondary screens.

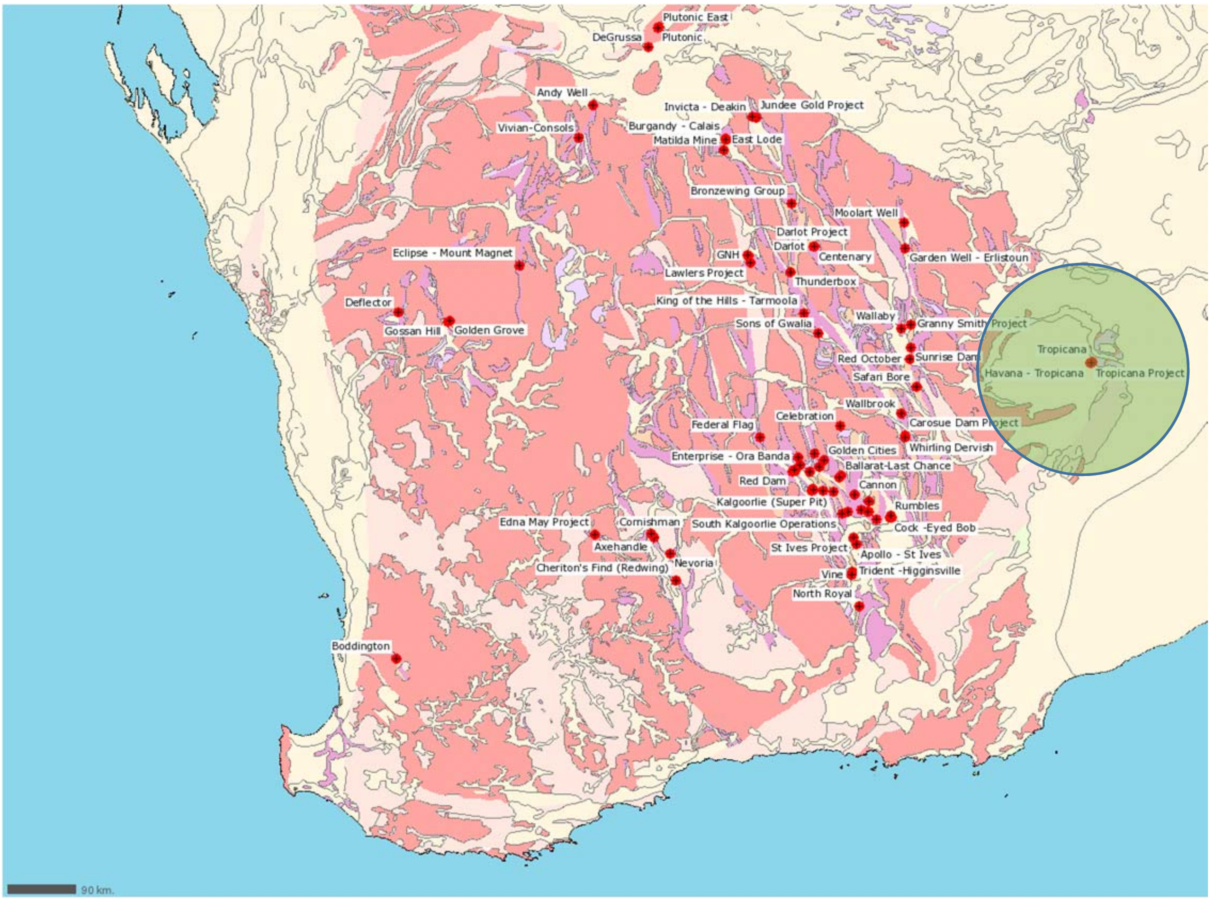


Figure 1 Location of Tropicana in relation to other WA gold mines (Geoscience Australia, 2015)

The secondary crushed product reports to the HPGR feed bin, which has 18 minutes live capacity. A belt feeder is used to maintain choke feed conditions to the HPGR. A single 2.0 m x 1.85 m HPGR is used for the tertiary crushing stage. This is fitted with two 2200 kW variable speed motors. The HPGR operates in closed circuit with wet screens. The design includes the ability to continuously divert a fraction from the HPGR discharge to create a HPGR fines emergency stockpile. This stockpile is then reclaimed using a front-end loader to feed the wet screens when the HPGR or secondary crushing plant is off-line. This stream is dry screened at 4 mm prior to stockpiling, with +4 mm material returned to the HPGR screen feed conveyor.

There are two parallel wet screens that classify the HPGR discharge. The screen pulping boxes de-agglomerate the flake ahead of the screens. The wet screens are 4.2 m x 8.5 m double deck banana screens which were originally fitted with 8 mm top deck and 4 mm bottom deck apertures. The combined screen oversize is conveyed back to the HPGR, with the ability to bypass the HPGR via actuation of a flop gate during metal detect events and periods of overly wet feed to protect the HPGR.

The -4 mm screen undersize reports to the ball mill discharge hopper along with the ball mill discharge stream. This is pumped to the cyclone cluster, which is fitted with 26 inch hydrocyclones. The cyclone overflow exits the grinding circuit, reporting to the trash screens and leach feed thickener, while the cyclone underflow returns to the 7.32 m x 13.12 m overflow discharge ball mill for further size reduction. The ball mill is equipped with two 7.0 MW Slip Energy Recovery (SER) drives, allowing variable speed operation and an over-rated total power of 15 MW at maximum speed. The final P_{80} target for the cyclone overflow is 75 µm.

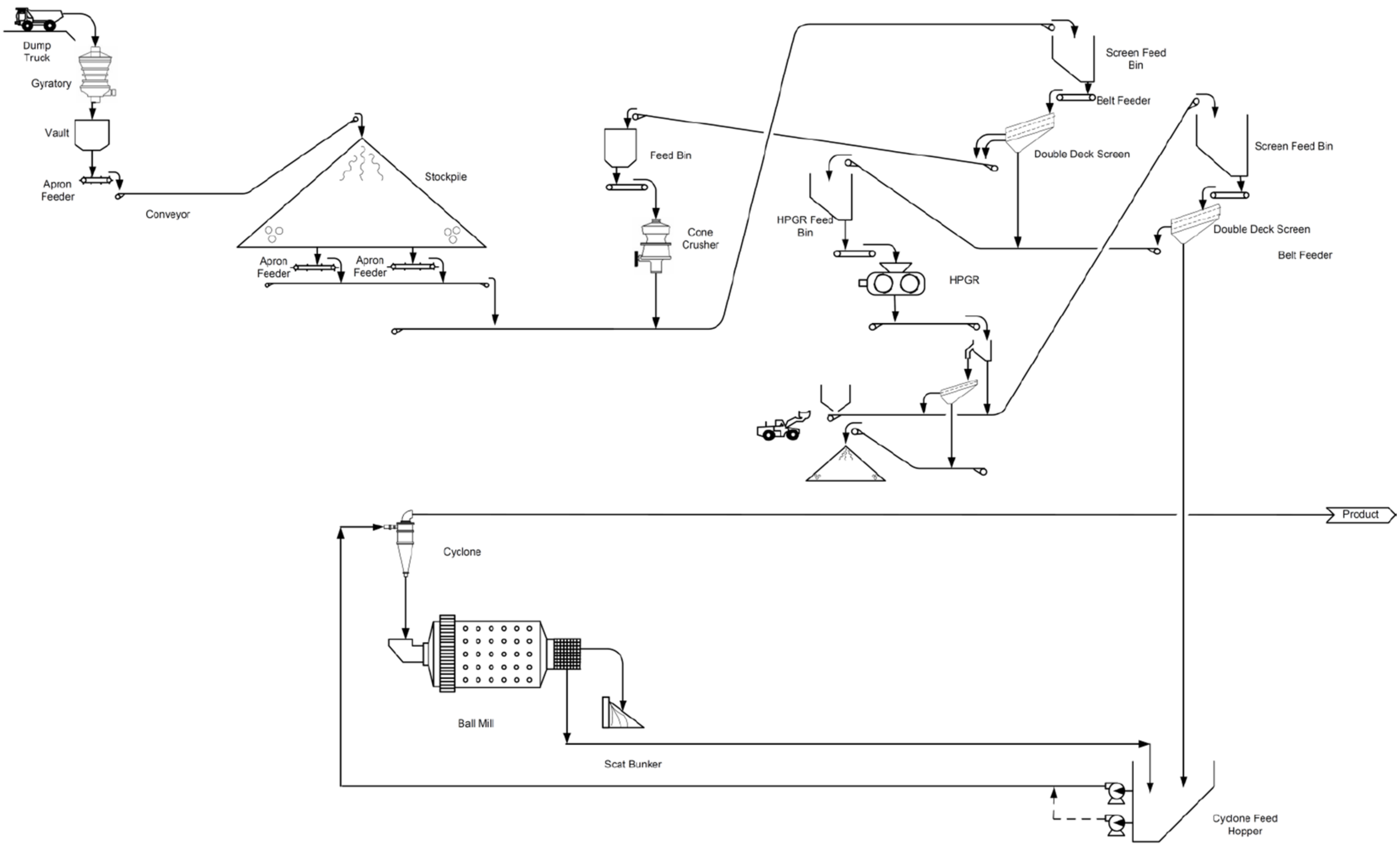


Figure 2 Simplified process flow diagram of the Tropicana comminution circuit.

HPGR/SAG TRADEOFF STUDY

A wide range of comminution circuit options were analysed in the Tropicana prefeasibility study (PFS). The motivation for assessing these options was the anticipated high cost of power due to the remoteness of the mine site. This factor was expected to favour more energy efficient circuit options. The assessment involved multiple phases of analysis using different techniques and consultants to calculate capital and operating costs. The analysis was done on a 3.5 Mt/y basis with grind sizes from 75 to 212 µm. The options assessed were:

- SAG-ball Milling (SABC) circuit
- single stage SAG milling
- two-stage crush with HPGR and ball milling
- two-stage crush with HPGR and pebble milling
- autogenous-grinding (AG) mill with recycle crusher
- three-stage crush with ball mill.

Orway Mineral Consultants (OMC) modelled all the circuits using JKSimMet in combination with its power modelling software.

The capital cost of each option increased in proportion to the fineness of grind, except for the HPGR-ball milling circuit which was found to increase at a slower rate and became more attractive at finer grind sizes. In comparison to the SABC circuit, the three-stage crushing circuit with ball milling had a 4.1% lower capital cost and an 8.9% lower operating cost. And although the HPGR-ball milling circuit had a 4.3% greater capital cost, it had a 19.7% lower operating cost, which resulted in a greater net present value (NPV). The HPGR with a pebble mill had a larger NPV, but the pebble mill was considered a higher technical risk. Alternative screening options were also explored including de-agglomeration, dry screening, direct feeding the ball mill and edge recycle. Wet screening was found to be the most effective by maximising the work done by the energy efficient HPGR and preventing oversize material reporting to the ball mill.

Although reduced consumables contributed to the lower operating costs of the HPGR, the reduced energy intensity was the significant factor. The difference in specific energy intensity (kWh/t) is benchmarked in Figure 3 on a Comminution Energy Curve developed at the JKMRC. The dominance of energy efficiency in the decision making process is highlighted by a case study presented by Ballantyne et al. (2016). In this case study, another AngloGold Ashanti project – Gramalote, in Colombia, conducted a similar feasibility study and made the decision to incorporate a SAG circuit into the design of the processing plant because the power costs were one third of those at Tropicana.

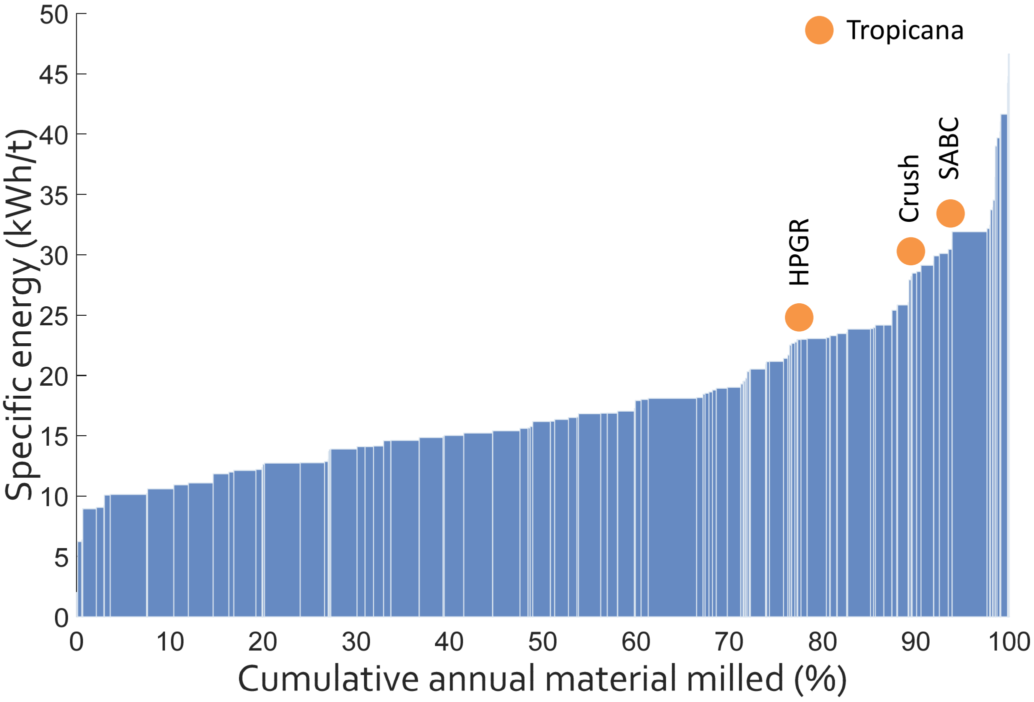


Figure 3 Specific energy intensity of three options explored in the PFS

A bankable feasibility study (BFS) assessed these options at a greater depth. Further ore tests were completed to increase the accuracy of the BFS, however, there were no indications of any requirement to change the operating or capital costs used in the PFS. The test work indicated that the HPGR may generate an improvement in gold recovery due to micro cracking or the production of a greater portion of fines in the HPGR product which could potentially impact either ball mill grind and/or power consumption. The result was that the HPGR–ball milling circuit remained the preferred option for the Tropicana project.

The laboratory HPGR test work was completed by Polysius on a pilot scale HPGR with a 500 mm diameter and 300 mm width. The test that best mimicked the full scale operation was a locked cycle test with a 4 mm closing screen and a pressure of 3.2 N/mm^2.

2015 SURVEYS

Two surveys were conducted in September 2015 by OMC. The crushing, HPGR and ball milling circuits were sampled once, and a second survey was conducted around the ball milling circuit alone. The balanced size distributions from the first survey are shown in Figure 4. A power function has been fitted to each of the three size distributions and the equations of the fit are presented. "Power laws" fit these data well demonstrating that they are fractal distributions. These size distributions support previous assertions that the HPGR produces more fines (proportionally) than the crusher or ball mill. This is evidenced by the lower gradient of the size distribution (in log-log space) and the smaller exponent in the power function, hence larger fractal dimension (Turcotte, 1986). This effect is similar to a SAG mill (although to a lesser extent) and results in the P_{80} being an ineffective measure of the degree of size reduction. Thus, the Size Specific Energy (SSE75) methodology, developed at the JKMRC, will be used to characterise the energy efficiency of the comminution devices (Ballantyne *et al*, 2015b).

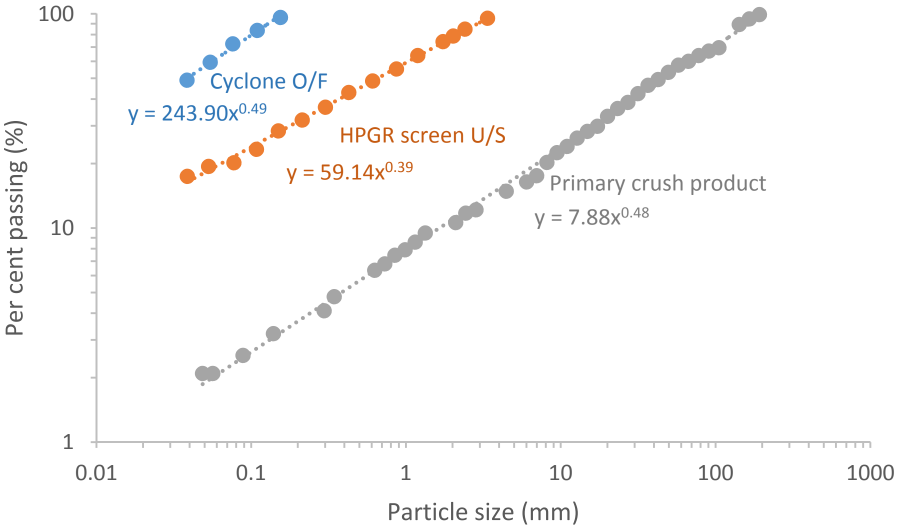


Figure 4 - Gradient of mass balanced size distributions measured during the 2015 survey.

The SSE75 is defined as the specific energy required to generate new material finer than 75 µm. This approach has historically been used by many authors without it being a formalised procedure (Hukki and Allenius, 1968; Levin, 1992; Mokken, 1978; Schönert, 1988).

Ballantyne et al. (2015a) formalised the procedure for using SSE75 to benchmark energy efficiency of different equipment within a circuit. The suite of Comminution Energy Curves (Ballantyne and Powell, 2015) include one graph that relates to SSE75. This graph can be used to display the results in relation to a substantial database of operating mines. It should be noted that the authors don't suggest there is anything special about 75 µm except that it is a good indicator of surface area in SAG/ball milling circuits. Alternative marker sizes can be just as appropriate (Ballantyne and Powell, 2016).

The SSE75 methodology was used to investigate the differences between the original laboratory HPGR tests done for the feasibility study, the final circuit design and the first site surveys. The difference between the competence of the rock used for design and measured in the survey was marginal. The Bond standard work indices (BWi's), which incorporate crushing, rod milling and ball milling (GMSG, 2015), were 18.9 and 18.7 for the design and survey respectively. Therefore, all three datasets can be compared directly without any modification required due to differential competence. Regarding the HPGR testing, design and operation, the SSE75 figures were all consistent, with the survey results only 3% higher than design and laboratory (Figure 5). On the other hand, the two surveys of the ball mill at different rotational speeds showed dramatically different efficiencies. The second survey with the ball mill operating at 75% critical speed achieved a higher throughput and finer grind while the mill consumed less power (Table 1). This resulted in a large drop in SSE75 of 30%, moving the ball mill from the 70th percentile on the SSE Intensity Energy Curve, to below the HPGR at the 30th percentile.

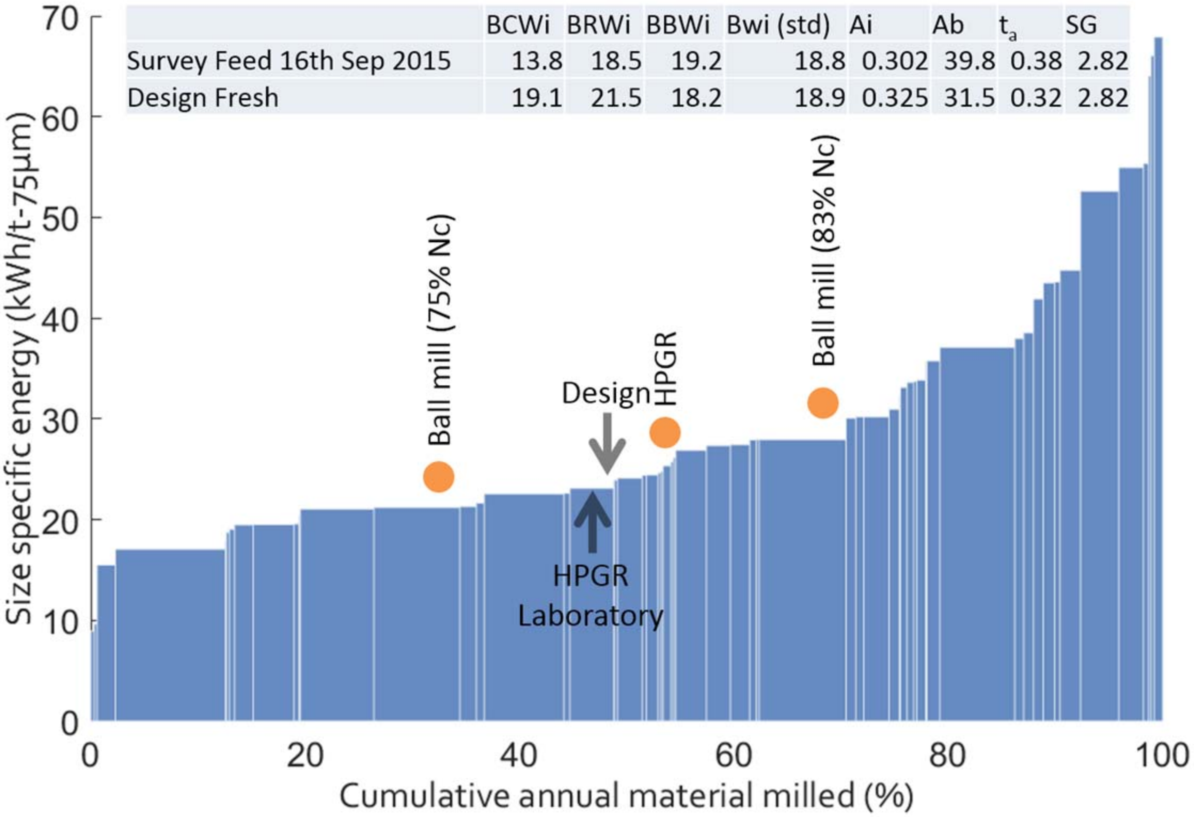
It was unclear exactly why this large change occurred, but there were several hypotheses:

- the higher speed increased the ratio of impact to attrition breakage past a point where optimal breakage of the fine feed occurred
- the trajectory of the mill contents wasted energy in liner impact and media wear at the high speeds
- the SER drive that was being used to alter the speed did not work efficiently at high speeds resulting in a situation where the measured motor current was not proportional to pinion power.

One caveat on this result was that calculating the milling throughput at Tropicana was complicated by the lack of flow rate measurement of the HPGR screen undersize since the flume on the cyclone overflow was decommissioned. The throughput was calculated from the crusher screen undersize conveyor weightometer, while accounting for the filling and emptying of the various bins and stockpiles that follow this point. In addition, the two surveys were completed on different days, therefore, the HPGR circuit was likely to be operating differently. The 2016 survey results would address these two issues.

Table 1 SSE results from 2015 surveys

	Survey 1			**Survey 2**
	Ball Mill 83% Nc	HPGR circuit	Circuit total	Ball mill 75% Nc
Throughput (t/h)	883	883	917	895
Feed -75%	21	9	32	13
Product -75%	73	21	80	78
Power (kW)	14 335	2625	13 480	12 793
SE (kWh/t)	16.2	3.0	14.7	14.3
SSE (kWh/t -75 µm)	31.1	24.6	30.7	21.7



	BCWi	BRWi	BBWi	Bwi (std)	Ai	Ab	t_a	SG
Survey Feed 16th Sep 2015	13.8	18.5	19.2	18.8	0.302	39.8	0.38	2.82
Design Fresh	19.1	21.5	18.2	18.9	0.325	31.5	0.32	2.82

Figure 5 SSE intensity benchmarking of laboratory, design and operation of the Tropicana circuit.

2016 SURVEYS

An additional survey was conducted on 14th November 2016. The largest change between these two cases was the HPGR screen aperture which was reduced from 4 mm to 2.5 mm. The parameters which most affect the circuit throughput, namely the BWi and impact resistance (A*b), were notably 'softer' in 2016 than 2015 and the design point. This resulted in finer, broader particle size distributions and a higher throughput in the 2016 survey (Figure 6). One outcome from this work was that the smaller HPGR screen aperture resulted in a significant reduction in the screening efficiency (alpha reduced from 7.1 to 3.3). A previous study with a 2 mm aperture observed the HPGR circuit becoming overloaded with moisture from carryover of the screen oversize. Therefore, the smallest practical aperture size for the HPGR screen appeared to be 2.5 mm, without the installation of an additional HPGR or screening capacity.

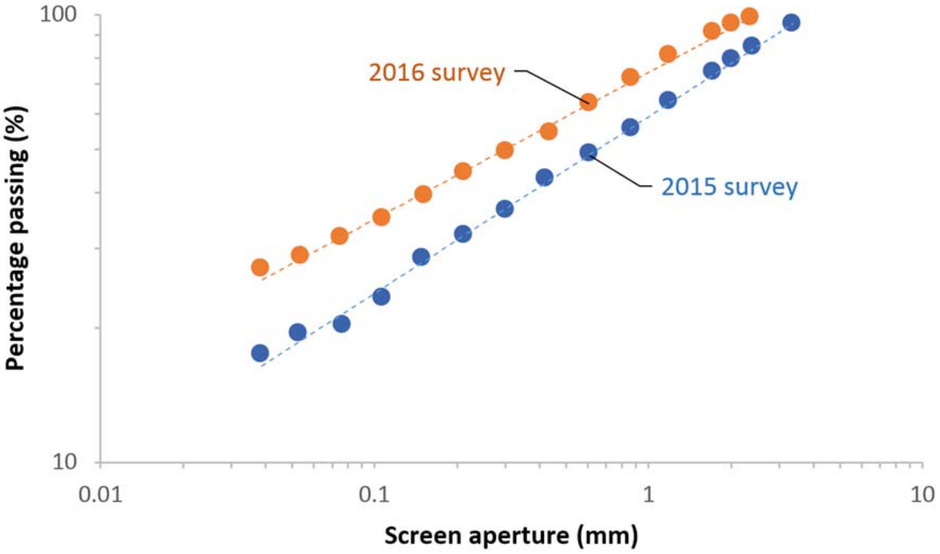


Figure 6 Cumulative particle size distributions of the HPGR screen undersize (mass balanced) for the 2015 and 2016 surveys.

In addition to the full circuit survey, three snap-shot surveys were conducted on the ball milling circuit. One aim was to re-assess the effect of mill speed on the ball milling circuit. To reduce the effect of feed size and throughput variability, all three tests were conducted in close succession, and the HPGR circuit was controlled at steady state. The result was that when the mill speed was reduced from 83% to 79% critical speed (Nc) the grind size and the mill power reduced. Further decrease of the speed to 76% Nc resulted in further power reduction, but the grind size became coarser. The SSE75 calculated for these snap-shot surveys found a 10% efficiency improvement when the speed was reduced from 83% Nc, but there was no significant difference between either of the slower speeds (Table 2). Therefore if the power can be increasing at the slower speed by increasing the ball load, the result will be improved grinding efficiency and increased throughput or grind size reduction.

Table 2 SSE results from 2016 surveys.

	Ball Mill snap-shot surveys			Full circuit survey			
	Ball Mill 83% Nc	Ball Mill 79% Nc	Ball Mill 76% Nc	HPGR circuit	HPGR Indiv.	Ball mill 83% Nc	Total circuit
Throughput (t/h)	930	930	930	917	2 382	917	917
Feed -75%	30	30	30	8	5	32	8
Product -75%	80	81	77	32	14	80	80
Power (kW)	13 514	12 534	11 738	2 843	2 843	13 480	16 323
SE (kWh/t)	14.5	13.5	12.6	3.1	1.2	14.7	15.7
SSE (kWh/t -75 µm)	29.1	26.6	27.0	13.0	13.9	30.7	21.9

The results from the HPGR in 2016 were significantly different to 2015. The reduction in the closing screen size increased the circulating load from 205% to 260%, which required a corresponding increase in the conveyor capacities and HPGR speed. The amount of final product (-75 µm) in the HPGR screen undersize increased from 21% to 32% in response to the 'softer' feed and finer screen aperture. In addition, the HPGR speed was increased in response to the higher circulating load, resulting in a reduced operating gap. Although the SSE75 efficiency of the HPGR in 2015 was comparable to the ball mill, the results from 2016 showed that the HPGR performance was dramatically improved in comparison to the ball mill.

The HPGR required less than half the energy to produce new final circuit product (-75 µm) (Figure 7). This improvement may be attributed to the combination of the finer screen aperture and the faster HPGR roll speed. Alternatively, the 2016 feed ore may have reduced coarse ore competence in comparison to fine ore competence, but that is not reflected in the characterisation data which saw equal reduction in both A*b and BWi. The other potential is that the ore has multiple components that result in a soft component crushing easily in the HPGR and the hard component requiring additional ball milling energy. Finally, the HPGR screen undersize was not actually measured, instead relying on the mass balance, but conducting the SSE75 calculation across the individual HPGR, as opposed to the circuit, resulted in a very similar result (Table 2).

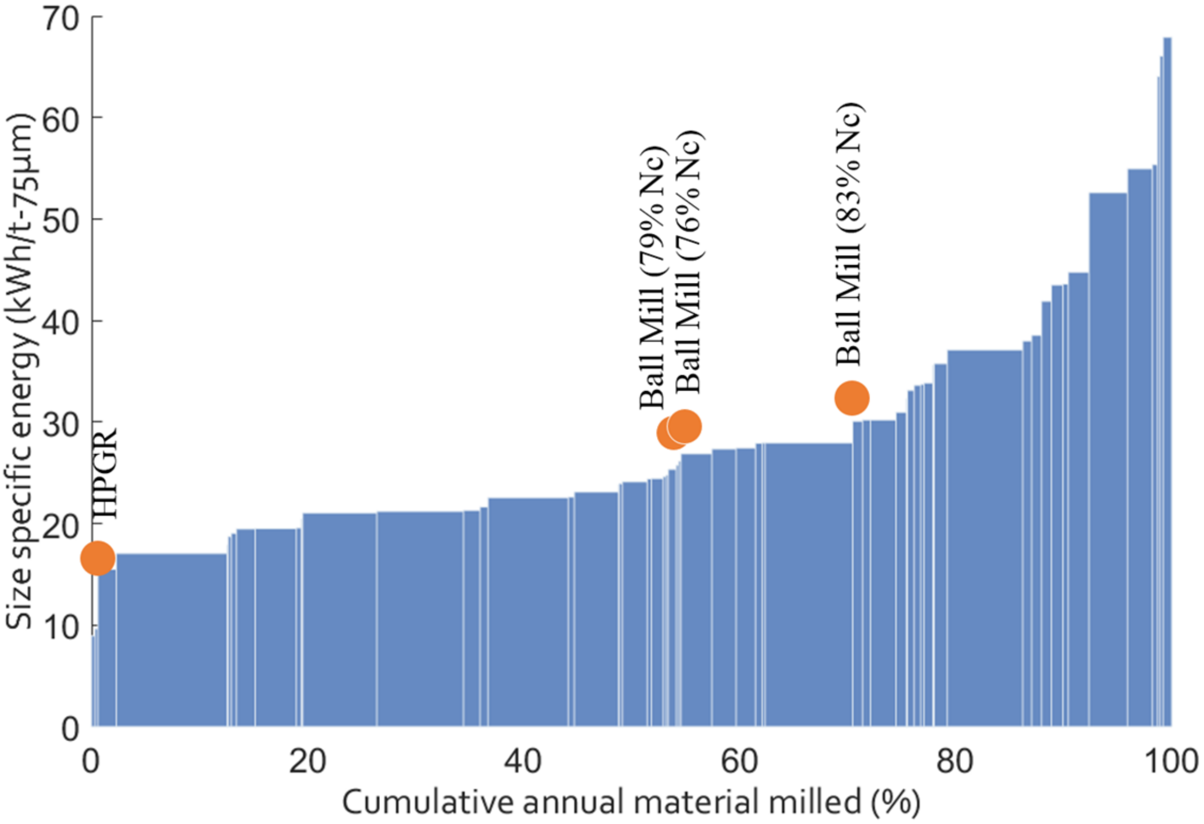


Figure 7 SSE intensity energy curve with 2016 survey results

COMBINATION OF RECENT ADVANCES

Since 2015, Tropicana has increased throughput by 20% from 760 to 930 t/h by implementing several process improvements. A significant proportion of the capacity expansion was realised by optimising the HPGR circuit operation. The HPGR screen aperture was decreased from 4 mm to 2.5 mm which increased the proportion of comminution that occurred in the HPGR in comparison to the ball mill. The HPGR speed was increased, which led to a smaller operating gap between the rolls. The HPGR screen oversize conveyor (CV9) and the conveyor that feeds the HPGR feed bin (CV5) were also upgraded in response to the increased circulating load. The amount of HPGR product removed to the deferred stockpile (fines stacking) has increased from 40 t/h to 150 t/h. The increased circulating load, roll speed and feed moisture content resulted in an increased wear rate of the HPGR rolls surface. But this was more than compensated for by the resulting increase in mill availability from a design of 91.3% to being on track to achieve 96% mill runtime (annualised). The most recent change is the removal of the SER drive from the ball mill, reducing the mill speed to 76% critical. The combination of these changes has resulted in a significant increase in both the hourly and monthly throughput treated at Tropicana (Figure 8). Unfortunately, ore characterisation data was not available over this time, therefore changes in competence cannot be eliminated for causing the throughput increase.

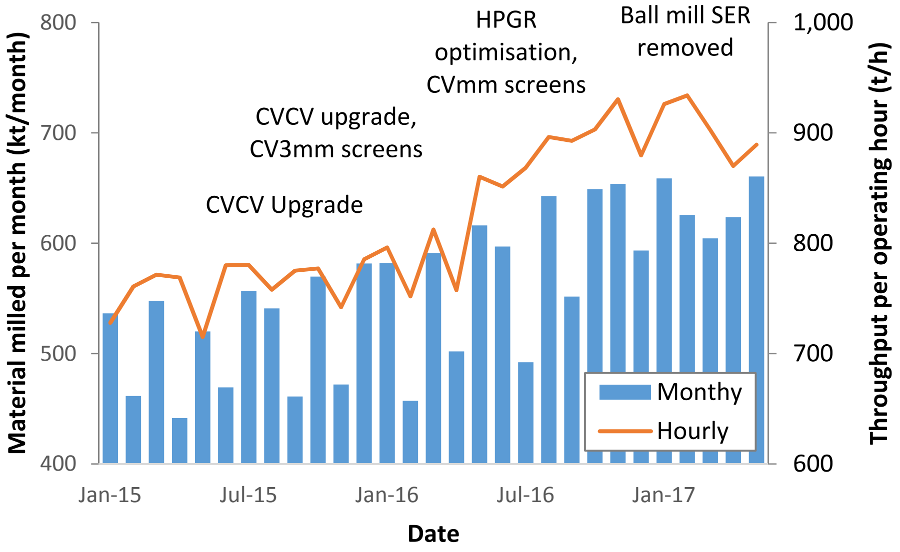


Figure 8 Hourly and monthly throughput operating data from the Tropicana milling circuit from January 2015 to May 2017.

CONCLUSIONS

The design of the Tropicana comminution circuit was driven by the need to reduce operating costs due to the especially high power price for this project. The first survey of the plant was conducted in 2015 and when the efficiency (assessed in terms of SSE75) of the operating HPGR circuit was similar to the small-scale test work and circuit design. The efficiency of the ball mill was found to increase by 10% when the rotational speed was decreased due to improved trajectories and motor efficiency. The HPGR screen aperture was decreased to the practical minimum size (2 mm), thus increasing the circulating load and the work done by the HPGR. In response, the conveyors were upgraded and the HPGR speed was increased. The result of these changes was a significant increase in the energy efficiency of the HPGR. The energy efficiency and utilisation of the ball mills was increased by decommissioning the SER drive, decreasing the mill speed and increasing the fines stacking rate. Between 2015 and 2017 the throughput of the circuit increased by 20% as the HPGR circuit and ball mill operation were further optimised.

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