Gruyere Gold Project Western Australia, part 1 – from design to commissioning

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ABSTRACT

The Gruyere Gold Project was discovered by Gold Road Resources Limited in October 2013 on the Yamarna Belt 200 km east of Laverton in Western Australia. The Feasibility Study for Gruyere, which was completed in October 2016, envisaged a large-scale open pit mine feeding a 7.5 Mtpa processing plant and producing an average of 270 000 ounces of gold a year over an initial 13-year mine life.

A comminution circuit option study was conducted as part of the Feasibility Study, which examined four circuit options. The preliminary option study identified a primary crush SAG-ball circuit with recycle pebble crushing (SABC) and two-stage crush-HPGR-ball mill as the two options to evaluate in detail for the Gruyere Gold project. Ultimately, primary crush-SABC was selected due to its operational robustness and being the more cost-effect solution for the life of the project.

Gruyere Management Pty Ltd (GRM) – a wholly owned subsidiary of Gold Fields, has undertaken detailed reviews of Feasibility Study engineering, procurement and construction which has resulted in a number of improvements and enhancements to the Project. Gold Fields extensive operational experience has directly contributed to these improvements and enhancements, which aim to deliver:

- improved operational ergonomics and maintainability
- advanced process plant control
- increasing throughput beyond design
- more consistent metallurgical recovery.

An Engineering, Procurement and Construction (EPC) contract was executed in June 2017 with commissioning of the project commencing mid-2019.

This paper examines the comminution test work and the subsequent modelling completed during the feasibility study. It also discusses changes to the early design of the project and reasons for driving those improvements, as well as covering commissioning issues in the grinding circuit during the early stages of processing.

INTRODUCTION

Gold Road Resources Limited discovered the Gruyere Gold orebody (the Project) in October 2013 on the Yamarna Belt 200 km east of Laverton in Western Australia. The Gruyere mineral resource has since grown to 148 Mt grading 1.3 g/t for 6.2 Moz of contained gold, making it one of the largest undeveloped gold deposits in Australia.

The Gruyere feasibility study was completed in October 2016. The study envisaged a large-scale open pit mine feeding a 7.5 Mtpa processing plant producing an average of 270 000 oz of gold a year over an initial 13-year mine life.

The gold mineralisation is hosted within a medium-grained quartz monzonite porphyry rock that exhibits moderate to hard competency. A comminution circuit option study was conducted as part of the feasibility study, which examined four circuit options. The preliminary option study identified a primary crush SABC and two-stage crush-HPGR-ball milling as the two options to evaluate in detail.

Ultimately, the primary crush SABC was selected due to its operational robustness and being the more cost-effective solution for the life of the Project. Further consideration was given to the final mill selection in order to maximise operational flexibility while reducing operating costs.

In November 2016, Gold Road entered into a 50:50 Joint Venture with Gold Fields Ltd (Gold Fields), to form the Gruyere Joint Venture (Gruyere JV), managed by Gruyere Management Pty Ltd (GRM) – a wholly owned subsidiary of Gold Fields. GRM has undertaken detailed reviews of feasibility study engineering, procurement, and construction, which has resulted in a number of improvements and enhancements to the Project. Gold Fields' extensive operational experience has directly contributed to these improvements and enhancements, which aim to deliver:

- Improved operational ergonomics and maintainability.
- Advanced process plant control.
- Increasing throughput beyond design.
- More consistent metallurgical recovery.

An engineering, procurement, and construction (EPC) contract was executed in June 2017 with construction and commissioning of the Project planned for early 2019.

In this paper, the authors examine the comminution test work and the subsequent modelling completed during the feasibility study. The authors also discuss changes to the early design of the Project and reasons for driving those improvements, as well as covering commissioning issues in the grinding circuit during the early stages of processing.

ORE CHARACTERISTICS

The Gruyere deposit is located within the Yamarna Terrane of the eastern Yilgarn, Western Australia (200 km east of Laverton and 1000 km north-east of Perth). The deposit occurs on a flexure point of the regional-scale Dorothy Hills shear zone within the Dorothy Hills greenstone belt. Orogenic gold mineralisation is hosted within the steep easterly dipping Gruyere porphyry, a medium-grained quartz monzonite porphyry. The entire Gruyere porphyry is variably altered and gold grade is related to variations in style and intensity of the alteration, structure, veining, and sulphide species. Zones containing higher-grade gold mineralisation above 1.2 g/t gold generally have strong albite, sericite, chlorite, and biotite alteration and are associated with a sulphide assemblage of pyrrhotite, pyrite, arsenopyrite, weak to moderate foliation, common micro-fracturing, and steeply dipping quartz veining.

Ore from two smaller open pit deposits (Attila and Alaric) within trucking distance from the Gruyere plant is planned to be blended with the Gruyere ore. Gold mineralisation at Attila and Alaric comprises steeply dipping shear hosted gold in volcaniclastic sequences, with gold associated with zones of albite, sericite, chlorite, and pyrite mineralisation.

Samples from the mineralised zones were classified into weathered states, Oxide, Transition, Saprock, and Primary ore. From the Gruyere deposit, comminution test work was conducted on 19 Fresh samples, 5 Transition samples, 7 Saprock samples, and 1 Oxide (saprolite) sample. Comminution tests were also undertaken on the 12 Attila and 2 Alaric Fresh samples, as well as a single Oxide sample from Attila.

The plant was designed to treat 100 per cent Gruyere Fresh ore. A summary of the design (85th percentile) and average comminution test work parameters for the Gruyere Fresh ore is given in Table 1.

TABLE 1

Summary of Gruyere Fresh ore comminution test work parameters.

Parameter	Units	Design	Average	St. dev.
Crushing work index (CWi)	kWh/t	21.0	6.0	57.0
Bond rod work index (RWi)	kWh/t	22.0	20.8	0.7
Bond ball work index (BWi)	kWh/t	18.3	17.6	1.3
Abrasion index (Ai)	g	0.53	0.49	0.07
SMC Test work				
ta		0.3	0.36	0.1
A×b		31.5	35.6	5.2
DWi	kWh/m^3	8.5	7.4	1.2

FLOW SHEET SELECTION

A percentile ranking of the Gruyere Fresh ore characteristics against the Orway Mineral Consultants (OMC) test work database (over 9000 samples) is given in Table 2.

TABLE 2

Gruyere Fresh ore ranking against OMC database (percentile).

Parameter	Units	Gruyere design	Gruyere average
Ai	%	84.0	84.9
RWi	%	77.9	75.8
BWi	%	74.0	68.3
A×b	%	11.6	19.4
Uniaxial compressive strength	%	97.9	95.0

The value of A×b is a measure of resistance to impact breakage, in contrast to the DWi, a high value of A×b indicates that an ore is soft whilst a low value means that it is hard. The comparison shows that both the A×b and BWi values for the Gruyere ore are harder than the database average. The BWi is moderate when compared to the A×b, which indicates that SAG milling of this particular ore will not be the most energy efficient comminution circuit option (Scinto, 2015). Ores that exhibit this type of relationship between the A×b and BWi values have higher f_{SAG} values (Siddall, 1996). These ores typically benefit from multistage crush-ball milling circuits to reduce the overall comminution energy consumption (Scinto, 2015). For a project of this size and location, finding the most cost-effective flow sheet typically depends on the magnitude of the difference between the A×b and BWi, and the cost of power over the life of the project (Putland, 2006). Options initially considered for Gruyere were primary crush-SABC, full secondary crush-SABC, secondary crush-HPGR-ball milling, and conventional three stage crush-ball milling. The preliminary studies indicated that the SABC and HPGR-ball milling options should be investigated further.

A summary of the predicted power utilisation for the SABC and HPGR ball milling options at the original design grind P_{80} of 106 µm is compared in Table 3.

TABLE 3

Comparative specific energy used in the study phase, kWh/t

Equipment	SABC	HPGR-Ball mill
Primary crushing	0.1	0.1
Secondary crushing	-	0.4
HPGR	-	4.0
SAG mill	11.6	-
Recycle crusher	0.2	-
Ball mill	12.3	13.7
Auxiliary equipment*	2.0	3.7
Total	26.2	21.9

Note: *Conveyors, screens, lube packs etc.

The SABC option had an f_{SAG} value of 1.32. It was accepted during the Pre-Feasibility Study (PFS) stage that a total energy consumption saving of around 16 per cent could be expected for the HPGR option when compared to SABC. When considering maintenance, power, reagents and other operating costs, the SABC option was also higher at A$17.60/t compared to the HPGR option at $17.05/t. The SABC comminution circuit had the lowest predicted project development capital cost at A$313M when compared to the HPGR option at A$363M. Ultimately the overall project economics determined that the operating cost saving was not significant enough to justify the additional capital cost of the HPGR option. It is acknowledged that the HPGR design was conservative as there was no HPGR test work conducted at the time of the study, and there was no additional HPGR benefit was applied to the ball mill specific energy as the supporting data was scarce at the time of the study. The PFS risk assessment indicated that a robust SABC circuit design with low complexity and proven comminution configuration was favoured over the HPGR option. At the time, the HPGR option was seen as complex less mature technology that required higher upfront capital. In the authors opinion, the primary crush-SABC option better suited the junior gold miner's appetite for risk at the time of the study (before the Gruyere JV was formed).

This result is an interesting contrast to the nearby Tropicana Project, also modelled by OMC, which has similar design ore characteristics (A×b of 33.1 and BWi of 18.2 kWh/t) and subsequently has comparable f_{SAG} values (1.3 to 1.4). In that case, the preliminary option study identified the same two comminution circuit options for further analysis; however, the final selection was the HPGR ball circuit (Kock, 2015). A future comparison of the actual operating data from the two projects will give a relatively good energy efficiency comparison between a conventional primary crush SABC circuit and HPGR ball mill circuit. This should ideally occur once the operating data is available from the Gruyere Project when treating fresh ore at design operating conditions.

PROCESS FLOW DESCRIPTION

The circuit is a conventional primary crush – SABC circuit that includes a pre-leach and tailings thickener. A stand-alone gravity circuit is fed from dedicated pumps at the mill discharge hopper. Gravity concentrate is treated via an Inline Leach Reactor (ILR). The elution circuit is a split AARL with acid wash and an optional cold cyanide wash step. A cyanide DETOX circuit was not included.

The Gruyere comminution flow sheet includes primary crushing followed by a coarse ore stockpile (COS). The primary crusher is an FLSmidth TSU 1400 × 2100 gyratory crusher fitted with 600 kW motor. The crusher is designed to achieve a P_{80} of 150 mm to 170 mm and treat 1550 t/h. The coarse ore is reclaimed from the stockpile via three reclaim apron feeders and conveyed to the SAG mill.

The primary crushed feed reports to the SAG mill feed chute. Lime is dosed onto the SAG mill feed conveyor from two lime silos. The SAG mill is a single Outotec 10.97 m (36') diameter × 5.79 m (19') effective grinding length (EGL) mill equipped with a 15 MW dual pinion drive. The SAG mill discharges onto a single 3.6 m × 8.5 m vibrating screen fitted with 8.5 mm aperture screen panels. The screen oversize is conveyed to the pebble crusher storage bin. Pebbles are reclaimed from the bin via two belt feeders, each reporting to a pebble crusher. The pebble crushers are two parallel Metso HP4 cone crushers fitted with 315 kW drives. The pebble crushers are designed to treat 200 t/h each at a closed side setting (CSS) of 13 mm. Crushed pebbles are returned to the SAG mill feed conveyor.

The SAG mill discharge screen undersize reports to the common mill discharge hopper, along with the ball mill discharge and dilution water. This is pumped to the cyclone cluster for classification, which is fitted with 12 × 650 mm hydrocyclones. The cyclone overflow reports to the trash screens followed by the leach feed thickener, while the cyclone underflow reports to the 7.93 m (26') diameter × 10.82 m (35.4') EGL overflow discharge ball mill for further size reduction. The FLSmidth ball mill is equipped with twin 7.5 MW drives, common with the SAG mill drive. The flow sheet includes the ability to bleed part of the cyclone underflow to the SAG mill feed chute, if required. The cyclone overflow P_{80} target is 125 µm.

A portion of the combined mill discharge is bled from the mill discharge hopper via a dedicated set of pumps to the gravity circuit. A baffle in the mill discharge hopper is designed to separate the SAG mill and ball mill discharge, with the gravity feed drawn from the ball mill side to assist in pre-concentration of the gravity feed. The gravity circuit comprises two vibrating screens and four 48" Knelson concentrators. Tailings from the gravity concentrators is combined with the gravity screen oversize and returned to the mill discharge hopper on the SAG mill discharge side of the baffle. The gravity concentrate reports to a Gekko ILR, with pregnant solution reporting to the gold room, and washed leach residue returned to the mill discharge hopper. A block flow diagram of the Gruyere comminution circuit is shown in Figure 1 and an aerial circuit layout in Figure 2.

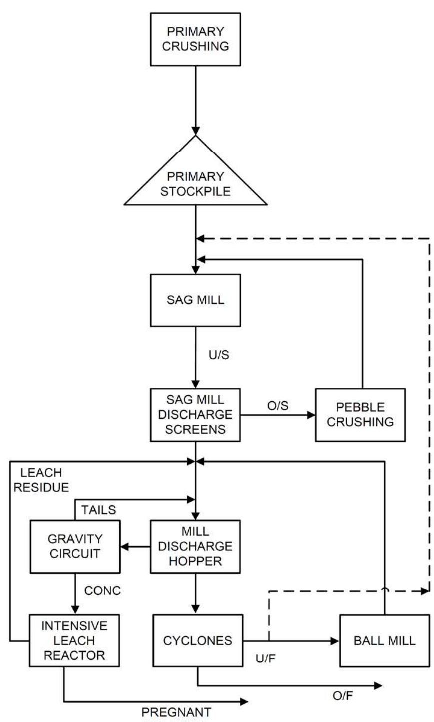

FIG 1 – Gruyere comminution circuit block flow diagram.

FIG 2 – Gruyere plant aerial photograph.

FLOW SHEET DESIGN

Mill selection

The predicted specific energy requirement to achieve the design grind P_{80} of 125 µm was 11.4 kWh/t for the SAG mill and 11.3 kWh/t for the ball mill. Once contingency is added, this resulted in a minimum required installed power of 14.3 MW for the SAG mill and 12.9 MW for the ball mill. In the interest of commonality, 14.3 MW SAG and ball mills were initially selected for the Project.

At the time of the mill tender, a partially built 10.97 m (36') diameter × 5.79 m (19') 15.4 MW Outotec SAG mill became available. This mill was available for a comparable price to that offered for a new 14.3 MW by the same vendor, the additional civil and services upgrades required to accommodate the larger SAG mill was predicted to add approximately A$2M to the capital cost of the Project. Further complicating the decision was the ball mill selection, which following the formation of the joint venture with Gold Fields, resulted in an FLSmidth mill being reassigned from another Gold Fields Project. This ball mill has 15 MW of installed power. A cancelled 10.97 m (36') × 5.3 m (17.5') EGL 15 MW SAG mill order was also being considered from another vendor. All of the tendered mills were assessed, and it was found that the two-foot difference in the SAG mill EGL was significant. The key findings were as follows:

- The shorter EGL mill required operation at 13 per cent ball charge to achieve the design pinion power draw, while the longer mill achieve the same the same power draw at 9 per cent ball charge (assuming 25 per cent total load in both cases).
- While both mills had more than the estimated installed power requirement of 14.3 MW, the longer mill could draw the full installed power at a lower ball charge. This results in the additional contingency being available at more sustainable operating conditions.
- Operating the SAG mill at above 13 per cent ball charge may prove to be problematic from a load stability point of view, particularly for the harder ore types of the Gruyere deposit. Higher ball charge levels result in a flatter power curve, making the mill more susceptible to overloading. It is likely that operating at lower ball charges will be beneficial when treating harder ore.

- Operating at the lower ball charge also resulted in a reduced media consumption rate. It was estimated that a saving of A$1.15 million per annum could be expected from the longer EGL mill by operating at the lower ball charge.

Ultimately, the longer Outotec SAG mill was selected for the Project. The motor design was revised to match that of the FLSmidth ball mill, such that both mills have common twin 7.5 MW low-speed synchronous motors equipped with variable voltage variable frequency (VVVF) speed control drives.

Main design changes

At the time the Gruyere joint venture was formed in November 2016, the Gruyere Project had already passed the feasibility study stage and was in the final stages tendering the EPC contract. The Gruyere Project team together with operation and mechanical leads from Gold Fields Australia carried out design reviews to improve the operability and enhance long-term success of the Project. These included:

- FLS crusher sizing and apron feeder capacity changes.
- Drive in cleanout for the ROM primary crusher pocket.
- Crusher and COS tunnel access for cleaning and maintenance.
- Grinding area layout – addition of mill ramp for access, Russell Mineral Equipment (RME) chute handlers replacing winch/cables.
- Additional reline space.
- Addition of cyclone underflow partial bypass line for SAG mill.
- Additional tramp metal removal on the recycle pebble crusher conveyor.
- Dual access around conveyor systems with dedicated maintenance and splicing bays.
- Additional standby equipment, trash and carbon safety screens, air compressors.
- Gravity area design with screens, batch concentrators, and leach reactor offset, preventing spillage on equipment at levels below.
- Fully decked leach and carbon-in-leach (CIL) circuit with dedicated central piping system.
- Additional instrumentation for thickener and leach systems control.

Process control system

The Gruyere feasibility study included a review between a programmable logic controller/supervisory control and data acquisition (PLC/SCADA) process control system and a distributed control system (DCS). Due to the tight integration, reliability and its life cycle cost-effectiveness, the Yokogawa DCS was chosen. It would deliver a good and robust level of regulatory control of the plant and like any process control system would however require constant monitoring of control room operators to adjust the process parameters to maintain plant operations. Operator response to constantly varying process variables is commonly delayed and not consistent, resulting in underutilisation, downtime, and/or damage to equipment.

Gold Fields Limited has had a technical collaboration with Manta Controls since 2005 and uses the Manta Cube system under licence at several operations to provide throughput, recovery, and reagent optimisation. The Manta Cube system utilises advanced control fundamentals including constraint control, feed forward control, expert system control, gain scheduling, object-oriented control, model predictive, decoupling control, and new optimisation process control technology that has been developed by Manta Controls. As an example, the Gruyere SAG Cube utilises key drivers, such as feed rate, mill speed, feed density to control the SAG mill weight and other constraints such as mill power draw and impact sound.

The Manta Cube systems including the Feed Cube, SAG Cube, Ball Mill Cube, Cyclone Pressure Cube, the pre-Leach Thickener Cube with Manta Sub (Submarine), the Cyanide Leach Cube and the Tails Thickener Cube with Sub were seamlessly integrated into the plant Yokogawa DCS installed by Manta Controls and engineered during the design and construction phase so that they were available once care, custody, and control of the plant is transferred from the EPC contractor to the company. By fast tracking the historical method of justifying installation of advanced process control systems over a period of years after start-up, installing proven advanced process control technology enabled the Gruyere Project to achieve circuit stability and improve ramp-up rates from day one

Debottleneck study

OMC was commissioned to assist with the identification of possible bottlenecks at the Gruyere plant based on the current design and equipment selection. The study assumed that there is sufficient ore delivery to the primary crusher to meet plant feed requirements. The original mill design was based on the 85th percentile ore characteristics to warrant that nameplate throughput can be consistently achieved. To evaluate potential restrictions throughout the rest of the plant, a review was conducted utilising the 25th percentile ore characteristics (providing higher throughputs for the milling circuit) on Fresh ore only (Table 4).

TABLE 4

Throughput modelling at 25th percentile ore parameters.

Parameter	Unit	Design grind	Relaxed grind
Ore parameters			
BWi A×b Ore SG	kWh/t	17.0 36.1 2.69	17.0 36.1 2.69
Feed rate	t/h	1222	1290
Primary feed size, F_{80}	mm	124	124
Product size, P_{80}	μm	125	140
Pebble crushing	% feed t/h	14.3 175	15.2 196
SAG mill specific energy Ball mill specific energy Total specific energy f_{SAG}	kWh/t kWh/t kWh/t -	10.50 9.76 20.30 1.28	10.23 9.25 19.53 1.28
SAG mill pinion power required BM pinion power required	kW kW	12 825 11 927	13 199 11 931

Under the modelled conditions, a throughput of 1222 t/h is anticipated while maintaining the grind size at a P_{80} of 125 μm. With the softer ore, the ball mill becomes the limiting unit process. If the grind is allowed to coarsen to a P_{80} of 140 μm, a throughput up to1290 t/h is possible, at which point the SAG mill becomes the limit. For this evaluation,1222 t/h was used as a sustainable basis with commentary on maximum capacity.

The review identified the maximum sustainable capacities of the mills by modelling under operating conditions considered sustainable under good supervision and control. While the equipment is not fully utilised, there is limited margin between nominal and maximum conditions. All major processing equipment (conveyors, screens, pumping and piping, tanks etc) were then evaluated based on these calculated throughputs to assess that there was sufficient capacity at each processing stage.

The key areas highlighted as potential capacity restrictions at higher throughput rates were:

- Primary and recycle crusher power draw operating at close to the installed power and instantaneous spikes could result in larger OSS/CSS or material bypassing the crusher.

- Both the leach feed and tailings thickeners are a limitation at the design flux rates of 1.0 t/m^{2}h. However, test work has confirmed flux rates of up to 1.5 t/m^{2}h on Fresh ore are achievable.
- Leach residence time reduced to about 18.5 hours and there was a predicted inability of the 6 t/d oxygen plant to supply at a rate of 0.22 kg/t of ore.
- Trash screen solids and flow rate capacity of the two duty units limit throughput; however, a third 'standby' unit has been included in design for ease of cleaning and maintenance while providing additional capacity when required.

The capacity limitations in these areas are expected to be overcome with relatively minor capital and operational adjustments, which leaves the mill as the true plant bottleneck. The OMC review confirmed that under the current Amec Foster Wheeler Civmec Joint Venture (ACJV) design and with the selected equipment, there were no foreseeable bottlenecks or risks to achieving the nameplate 7.5 Mtpa capacity. The review provided confidence in the ability of the circuit to increase annual throughput to 8.2 Mtpa capacity. An updated mine plan was announced in December 2018 increasing average annual production to 300 000 oz, up from 270 000 oz/a as per the 2016 feasibility study.

CONSTRUCTION AND COMMISSIONING

The construction of the Gruyere processing plant commenced in the first quarter of 2018 with commissioning completed and handover to operations occurring in the third quarter of 2019. A timeline of key events for the project is presented in Figure 3.

FIG 3 – Gruyere project timeline.

SAG mill grate apertures

During early stages of design, it was proposed that the SAG mill grates would have a 25 mm aperture; however, this was decreased to an 18 mm aperture during final engineering and purchasing. Initial start-up was based on 100 per cent Oxide ore feed and the SAG running without pebble crushing. Modelling conducted by Outotec indicated that:

- A full set of 32 × 18 mm grates provided 5.7 per cent open area, which was suitable for Oxide ore at 70 per cent solids w/w pulp density.
- Flow rates of 1354 m^3/h at 25 per cent mill load and 70 per cent of critical speed (Nc) is equivalent to 1600 t/h, far exceeding design of 1100 t/h.

It is expected that the circuit will operate at lower mill speeds to maintain sufficient mill load to prevent liner damage and grate peening from ball impacts. As the ore gets harder and the plant commences processing Transitional ore, it is expected that 7 per cent open area would be considered with 20 mm to 25 mm apertures. This can then be supplemented with pebble ports as the plant processes Fresh ore. To maintain flexibility and the ability to react to changing conditions, additional sets of 25 mm aperture and 45 mm aperture grates were ordered and mobilised to site prior to commissioning.

Grinding media first fills

The SAG mill is designed to operate with a top ball size of 125 mm. The ball mill is designed to operate with a top ball size of 65 mm. Mill datasheets were provided to Moly-Cop to review the initial grinding media size recommendations, ball charge estimates, and wear rate estimates using the Moly-Cop Tools™ software.

The EPC requested an initial SAG charge of a 105 mm top size ball before transitioning to 125 mm as ore competency increases with higher proportions of Transitional and Fresh ore processed. The initial 63 t charge is approximately 2.5 per cent by volume and consists of 80 mm diameter balls to minimise the risk of liner damage by an operational mistake. The remainder of the first fill consists of 126 t of larger 94 mm and 105 mm balls was planned to be added as required for make-up to approximately 7.8 per cent by volume.

For Oxide ore, the review recommended a ball mill media top size of 55 mm increasing to 65 mm as the operation begins treating Fresh ore. The initial 441 t charge is approximately 20 per cent by volume, which is expected to be enough to allow the mill to grind reasonably efficiently. To improve the early grinding efficiency the initial charge was made by combining 25 mm, 38 mm, and 50 mm balls to emulate a seasoned charge, see Table 5. The remainder of the 378 t first fill 50 mm and 65 mm balls were stored in the grinding media bunkers and were planned to be added opportunistically over a span of two to three weeks after the introduction of ore.

Actual graded charge quantities differed from the supplier recommendations after taking into consideration standard bulk haulage quantities that could be delivered remotely to site. Table 5 details the recommended and actual graded charges for both mills.

TABLE 5

Initial charge recommendations.

Ball size (mm)	SAG mill %				Ball mill			
	Recommended		Actual		Recommended		Actual	
	(%)	(t)	(%)	(t)	(%)	(t)	(%)	(t)
125	-	-	-	-	-	-	-	-
105	27	54	33.3	63	-	-	-	-
94	41.5	83	33.3	63	-	-	-	-
80	31.5	63	33.3	63	-	-	-	-
65	-	-	-	-	41	336	23.1	189
50	-	-	-	-	44	360	30.7	252
38	-	-	-	-	15	123	30.7	252
25	-	-	-	-		-	15.4	126

Start-up strategy

During the design reviews, provision was made in the grinding circuit flow sheet to divert part of the cyclone underflow stream into the SAG mill via a bypass line, whilst operating the two mills at the same time. The bypass system exists as a variable knife gate valve and V-notch overflow weir built into the cyclone underflow launder with a 500 mm pipe returning to the SAG feed chute. The partial bypass was primarily included for future optimisation of the grinding circuit. To prepare for all eventualities and construction delays, two options were considered for initial commissioning of the grinding circuit:

1. Commissioning of the SAG and ball mills at the same time in semi-autogenous ball (SAB) mode.
2. Commissioning of the SAG mill ahead of the ball mill in single-stage (SS) SAG operation mode.

SAB mode advantages

- No variations or modifications required to plant flow sheet (to bypass, isolate unused lines etc). For example, SS SAG operation requires return of the cyclone underflow to the SAG mill rather than to the ball mill, requiring installation of a blanking flange on the ball mill feed line.
- SAB operation is inherently easier to control and operate compared to SS SAG operation and produces a more consistent final product size (P_{80}).
- All equipment will be operated as per the original design intentions and specifications and a faster ramp-up to achieve full plant capacity is expected.

SAB mode disadvantages

- If the SAG mill installation is completed ahead of the ball mill, commissioning of the grinding circuit will have to await completion of the ball mill.
- Commissioning and initial testing of the mill motors at the same time may be difficult in terms of specialist commissioning resources, specifically ABB personnel from Switzerland.

SS SAG mode advantages

- More efficient allocation of specialist vendor commissioning resources (ABB).
- More focused team efforts (both commissioning and GRM operations personnel) on getting the SAG mill and its ancillaries commissioned and operational.
- Earlier commencement of ore through the plant with a gentler ramp up in filling CIL tanks and thickeners and establishment of production procedures.

SS SAG mode disadvantages

- Lower than design throughput levels are expected through the SS SAG mill circuit.
- Settling of solid particles may occur downstream if the slurry flow rates are too low or grind size is too coarse.

For single stage operation on commissioning ore, the following conditions were considered likely:

- Milling speed of 60 per cent Nc
- Ball charge of 10 per cent volume
- Operating mill load of 25 per cent volume
- Pulp density of 65 per cent solids w/w
- Circulating load of 200 per cent to 300 per cent.

These conditions were modelled to establish the likely new feed solids rate that is possible when considering the grate flow restriction in single stage operation.

The power of the SAG mill indicated a capacity of 878 t/h; however, the grate geometry is predicted to restrict the expected throughput rate to between 428 t/h and 570 t/h depending on the circulating load. Key items that were considered during SS SAG operation included:

- Stability of the SAG mill charge weight, rock to ball ratio, power draw, and speed.
- Final product sizing without the ball mill to prevent downstream sanding in early commissioning stages.
- Reliable charge weight from the Outotec SAG mill hydrostatic bearing load measurement system.
- Capacity of the cyclone underflow bypass line to handle the SS SAG recirculation flow rates, which at a design rate of 2500 m^3/h was deemed sufficient.

Ultimately the process plant was commissioned on first ore operating in SS SAG configuration. The decision being driven by the requirement to ensure production targets were achieved and the advantage of a steady ramp up of the thickener and carbon-in-leach circuit. Of the key points identified during the risk assessment on operating in SS SAG mode, achieving the target grind size of 125 µm whilst processing oxide material with low ball and rock charge was most problematic.

Despite the graded charge loaded into the SAG mill and reduced top size ball of 105 mm, shift composites indicated a grind P_{80} between 150 µm and 200 µm with the top size exceeding 600 µm. This led to grit and slurry spillage from the cyclone overflow trash screens at throughput rates over 500 t/h. Further optimisation of the SAG operating conditions utilising lower speeds, higher charge levels and bypassing the recycle pebble crushers aided in minimising the coarse grit until the Ball mill was commissioned. The hydrostatic bearing load measurement system proved reliable allowing charge weight to be controlled via mill speed and no noticeable downstream issues occurred in either the pre-leach or tails thickener and carbon-in-leach circuit related to the coarse particle sizing.

CURRENT OPERATION

The average monthly throughput and grind size achieved since commissioning is presented in Figure 4. The mill utilisation, defined as the actual run time of the mill, is presented in Figure 5. Material processed during the ramp up period consisted of oxide and transitional ore from Run-of-mine (ROM) stockpiles and the design targets shown correspond to the transitional ore. Ramp up of the Gruyere processing plant commenced in the second quarter of 2019 in SS SAG mode and continued until the ball mill was brought online two months later. The circuit transitioned to SABC mode however the recycle crushers were not required due to the soft ore characteristics at the time. Throughput increased as availability and utilisation improved across the circuit with design tonnes being achieved in the first five months of operation.

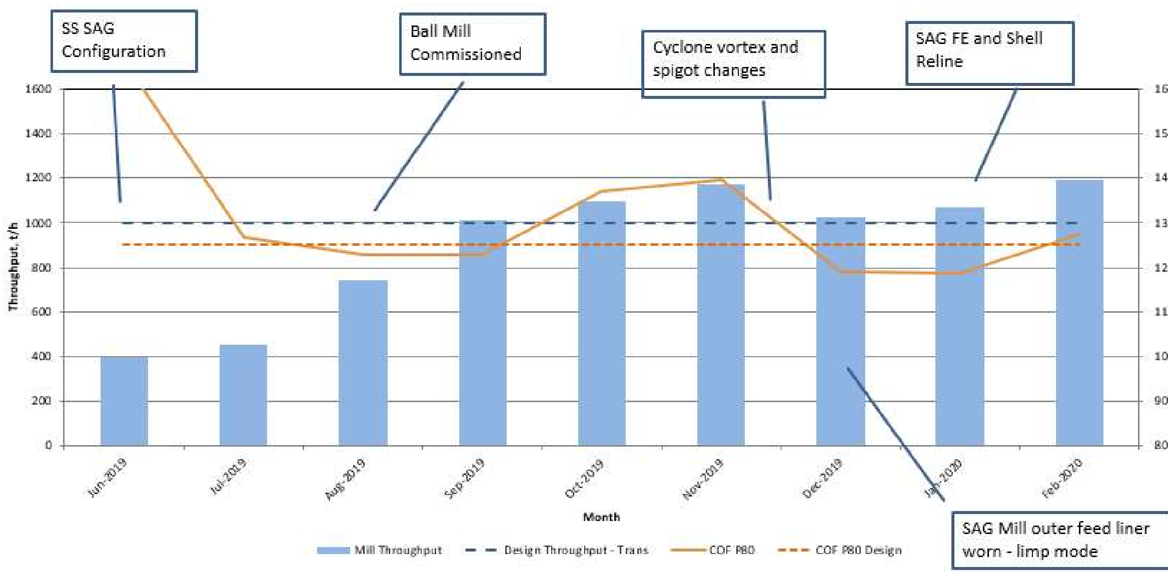

FIG 4 – Mill throughput and cyclone overflow (COF) P_{80}.

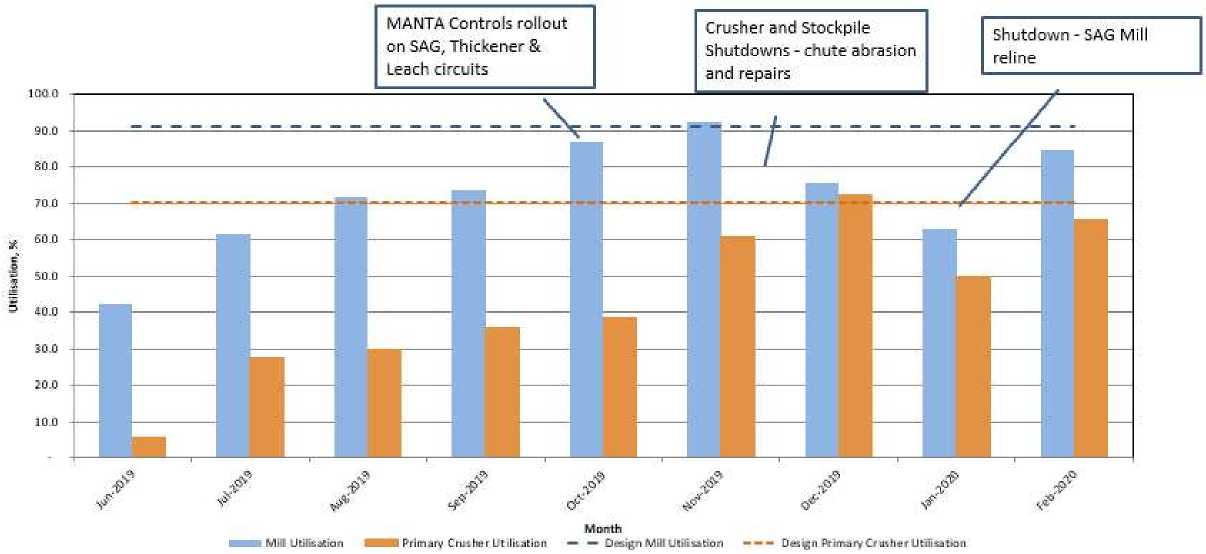

FIG 5 – Circuit utilisation.

Circuit stability was affected by limited process control loops being in place at the time of commissioning. Key circuits that required monitoring and manual adjustment by the process technician included

- SAG feed tonnes to stockpile apron feeder control.
- SAG power and load to variable speed control.
- Cyclone feed pump to level, pressure or density control.
- Thickener bed level, pressure, underflow density and mass flow control.
- Tailings discharge hopper level and mass flow control.

In effect much of the plant was operated manually by the control room technician during an ongoing commissioning period with at times stressful background distractions and constant radio communications. Priority was placed on resolving this with the EPC contractor working closely with Gruyere's internal and external resources. The commitment from GJV to install the MANTA Controls system during the project stage allowed the project schedule for this work to be brought forward without the usual one to two year process of justifying and executing process control upgrades once the circuit was stable and operational. Within the first six months of commissioning the key SAG, Ball, Thickener and Leach circuits were all operating under the Manta Controls Cube system leading to immediate throughput benefits whilst meeting downstream operating targets for grind size, density and reagent control.

In the early stages of commissioning the ball mill, two main issues arose. Firstly, when throughput exceeded 1200 t/h cyclone overflow (COF) P_{80} exceeded the design target of 125 µm with daily composites averaging 150 µm. The second issue involved low cyclone underflow/ball mill feed density (<55 per cent solids w/w) causing low power draw from the ball mill and excessive slurry spillage from the feed chute retainer ring as shown in Figure 6. While throughput was exceeding design, circuit stability and performance was suboptimal. A series of cyclone spigot and vortex finder trials were completed with the vortex finder being reduced from 320 mm to 280 mm and the spigots being progressively reduced from 190 mm to 180 mm, 170 mm and finally 160 mm. These changes increased the ball mill density to the target range >70 per cent solids w/w and as well as reducing the COF P_{80} back to design of 125 µm and maximising gold recovery. The ability to quickly resolve the poor classification issue was assisted by purchasing alternate vortex and spigot sizes prior to commissioning for trialling as well expediting the desired size ranges from the supplier.

FIG 6 – Excessive Ball mill feed spillage.

The initial 820 t graded charge loaded into the 7.92 m (26’) diameter × 10.79 m (35.4’) EGL ball mill equated to 33 per cent ball charge volume. The mill speed was progressively increased from 80 per cent to 95 per cent motor speed (where 100 per cent motor speed is 76 per cent Nc) whilst final commissioning of the ball mill motors was completed. Being a dual pinion drive, alignment and temperature monitoring of the geared mill was critical. In early October the ball mill achieved close to full power draw at 14 MW and 100 per cent Nc_{80} with regular mill inspections and laser scans indicating a charge volume of 32 per cent and grinding media addition rate stabilising at 0.44 g/t. The 7.92 m (26’) diameter × 10.79 m (35.4’) EGL SAG mill grinding media top size was increased from 105 mm to 125 mm to coincide with the commissioned of the ball mill and the progression from oxide to transitional ore being treated. The ball charge was steadily increased from the initial charge of 8 per cent to a design target of 13 per cent ball load through regular inspections and laser scans. Power draw increased from a range of 5–7 MW during SS SAG mode to a maximum power draw of 11–13.5 MW in SABC mode. Media addition to the SAG mill has since stabilised at a rate of 0.26 g/t when processing transition ore.

Tables 6 and 7 present a summary of the key operating data from when the circuit was running in SABC mode and SS SAG mode respectively.

TABLE 6

Key operating parameters – SABC mode.

Parameter	Units	SAB	Standard deviation
Primary crushing			
-Throughput	t/h	1835	297
-Power draw	kW	259	28
-Specific energy	kWh/t	0.15	0.04
-Auxiliary specific energy	kWh/t		
-Overall utilisation	%	62.5	-
SAG Mill			
-Throughput	t/h	1128	168
-Power draw	kW	10 181	1870
-Specific energy	kWh/t	8.8	0.9
-Auxiliary specific energy	kWh/t		
-Overall utilisation	%	75.6	-
Ball mill			
-Throughput	t/h	1128	168
-Power draw	kW	13 762	607
-Specific energy	kWh/t	11.8	0.9
-Auxiliary specific energy	kWh/t		
-Overall utilisation	%	75.6	-
-Cyclone O/F P_{80}	µm	121	10
Total specific energy	**kWh/t**	**20.6**	**1.4**

TABLE 7

Key operating parameters – SS SAG mode.

Parameter	Units	SS SAG	Standard deviation
Primary crushing			
-Throughput	t/h	1579	256
-Power draw	kW	251	23
-Specific energy	kWh/t	0.16	0.05
-Auxiliary specific energy	kWh/t		
-Overall utilisation	%	57.7	-
SAG Mill			
-Throughput	t/h	402	136
-Power draw	kW	5608	1623
-Specific energy	kWh/t	12.9	1.5
-Auxiliary specific energy	kWh/t		
-Overall utilisation	%	51.8	-
-Cyclone O/F P_{80}	µm	144	18.2
Total specific energy	**kWh/t**	**13.1**	**1.5**

The specific energy consumption was lower in SS SAG mode, however a higher fraction of the feed was Oxide during this period. A circuit survey was conducted in December 2019 as part of an optimisation study conducted by OMC. There were three main goals of the survey:

1. Provide a baseline set of operating conditions for the circuit.
2. Evaluate the efficiency of the circuit and identify opportunities for optimisation.
3. Begin the process of learning how to survey the circuit. Developing the survey plans, training the site metallurgists, modifying the sample points and purchasing required sampling equipment.

It is the opinion of the author that the third point is almost more important than the first two, no two comminution circuits are the same and every new operation must start somewhere.

Samples were tested for moisture content, percent solids and particle size distribution at the on-site Gold Fields laboratory. The SAG mill fresh feed sample was packaged and dispatched to ALS Metallurgy's Perth laboratory for testing of a suit of comminution tests including SG, RWi, BWi, Ai and SMC. The comminution test work results were still pending at the time of writing this paper. Historical test work results were used to produce a fitted model in JKSimMet and to determine the energy efficiency of the circuit. The fitted JK SimMet model output is presented in Figures 7 and 8. The energy comparison summary in Table 8.

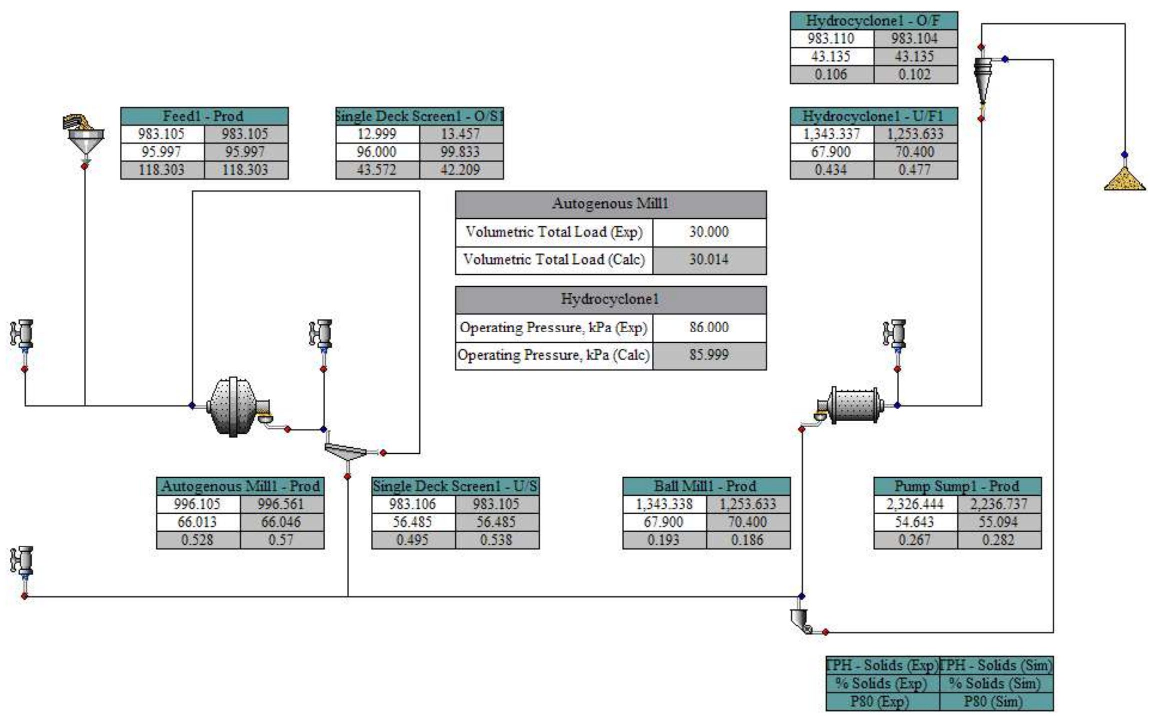

FIG 7 – Fitted JKSimMet model – December 2019 survey.

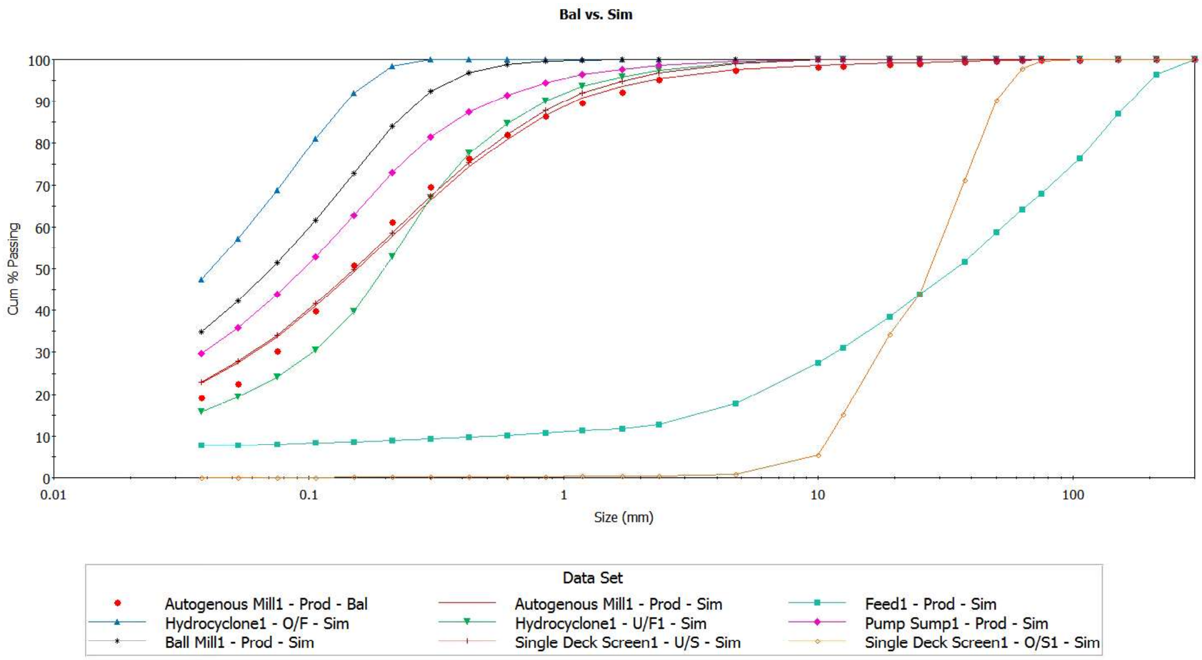

FIG 8 – Fitted particle size distributions – December 2019 survey.

TABLE 8

Power utilisation analysis – December 2019 survey.

Parameter	**Unit**	**SAB survey 1**	**SABC design characteristics**
Feed rate	t/h	984	1370
Primary feed size, F_{80}	mm	121	121
Product size, P_{80}	μm	113	113
Pebble generation	% Feed	1.1	7.9
	t/h	13	108
SAG mill specific energy	kWh/t	11.9	9.9
Ball mill specific energy	kWh/t	13.7	9.8
Pebble crusher specific energy	kWh/t	0.0	0.1
Total specific energy	kWh/t	25.7	19.8
f_{SAG}		1.07	1.22
SAG mill pinion power	kW	11 739	13 594
BM pinion power	kW	13 513	13 536

The key findings of the survey were as follows:

- The circuit is operating below expected efficiency for the given ore type and circuit configuration, (with pebble crushers off-line). The survey specific energy consumption was 25.7 kWh/t, compared to the design value of 19.8 kWh/t. The energy consumption has increased further from that shown in Table 6 for the two-stage circuit. This is unexpected given that the design ore is expected to be more competent than the ore treated at the time of the survey. This suggests that the circuit is performing inefficiently. The performance will be reviewed once the comminution test work results are received, however this only expected to make the outcome worse, given the feed is predicted to be softer than design.

- Based on the current circuit performance, pebble crushing is not recommended and should remain off-line. At the higher throughput rate, the pebble crushers will however be required to assist management of the SAG load.
- The main sources of inefficiency are believed to stem from operating at below optimal milling density, and poor operation of the classification circuit. The SAG mill was operating at 66 per cent solids w/w, while the ball mill was at 68 per cent solids w/w. It is recommended that a constant flow cyclone control philosophy is implemented to improve the stability of the circuit, giving better control over the water balance.
- The inferred ore characteristics indicate a much higher BWi than previously tested for either the Transitional or Oxide material. This may be indicating circuit inefficiencies associated with either over grinding, the low recirculating load, low ball milling densities or potential issues with the measured feed/product PSDs. Similarly, for the current softer feed blend, a ball mill ball top size of 50 mm may be beneficial.
- Modelling of the circuit found that by increasing the recirculating load to 250 per cent (from 137 per cent currently) is expected to yield a throughput increase and operation closer to the 1370 t/h, indicated from the original design test work data, at the current feed blend (from the current 984 t/h observed during the survey). It is recommended that the vortex finder size is reduced from 290 mm to 230 mm and operating pressure increased to 120 kPa to help facilitate this in conjunction with adopting the constant flow pressure control philosophy.

This first survey also gave an opportunity to assess and refine the survey procedure and cutter requirements for the Gruyere circuit. Another survey is proposed following the transition to more competent ore.

LINER WEAR

As is the case with most commissioning exercises, extra attention is paid to monitoring the internal conditions of the respective SAG and ball mills checking for items such liner wear or damage, rock and ball charge conditions and conditions of grates. This was the case for the Gruyere circuit with internal mill inspection occurring during planned and opportune downtime events. Liner suppliers were requested to conduct full laser scans of the SAG and ball mill liners with inspections occurring in August, October (see Figure 9) and again in December (see Figure 10). These first surveys provided the critical liner wear profile information required to estimate the reline times. Initial reports from the August and October inspections indicated an expected reline would be required in March 2020 and a planned scan during a December shutdown expected to confirm this. Unfortunately, the December laser scan combined with visual inspections, indicated that the feed end outer lifters and feed end shell lifters had already progressed past the expected wear profile and were providing minimal lift or shell plate protection.

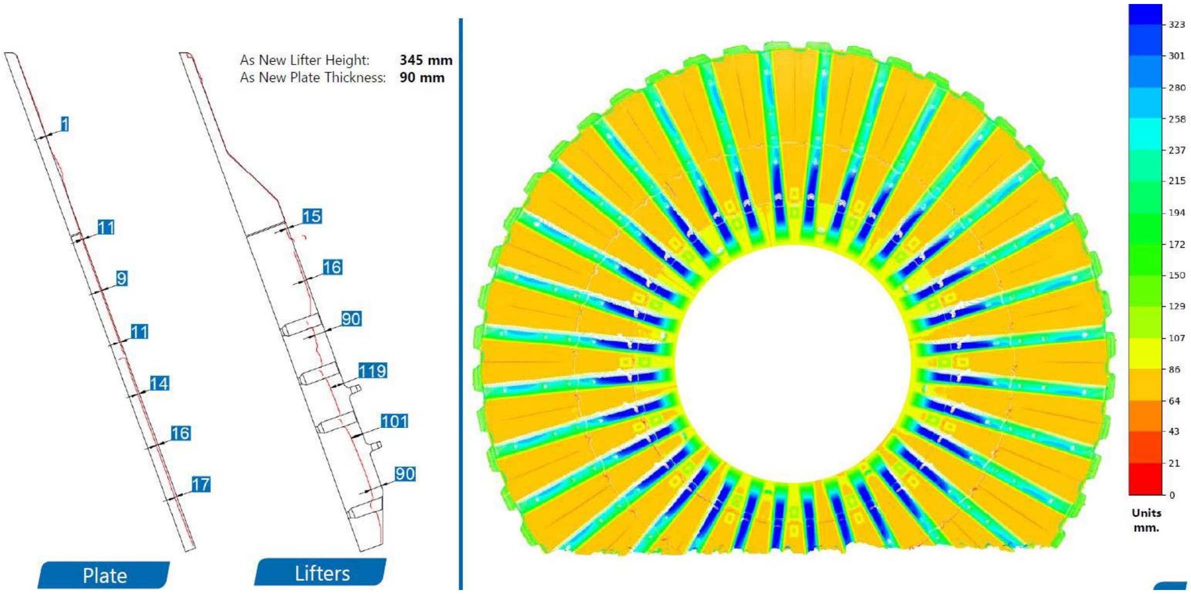

FIG 9 – SAG feed end liners – October 2019 scan.

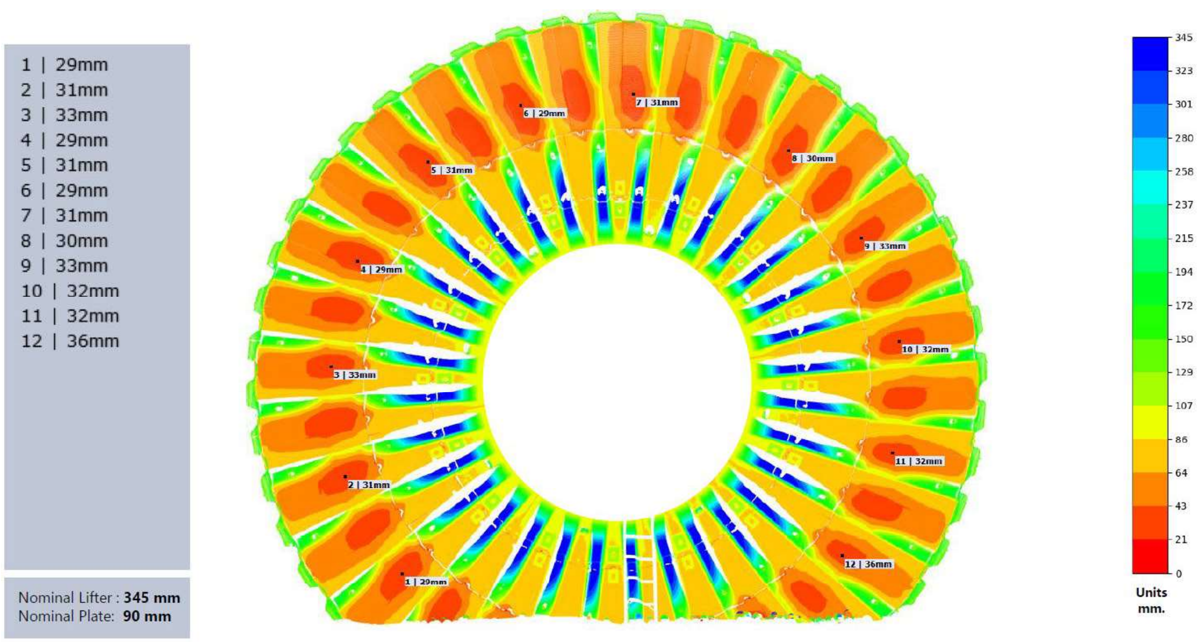

FIG 10 – SAG feed end liners – December 2019 scan.

A SAG reline was unable to be organised until January and the decision was made to proceed at a reduced throughput rate until this time whilst monitoring closely for signs of liner wear such as leaking bolts. Fortunately, during the project construction and commissioning period a full set of SAG liners had already been purchased and stored on-site. This enabled the reline to occur at the earliest opportunity (within four weeks) and avoid being exposed to a typical supplier delivery time of 16–20 weeks for mill liners, thus minimising the impact on the business.

It was suspected that the liners may have worn prematurely due to a manufacturing fault and in January a selection of worn liners were dispatched for independent metallurgical examination to determine the failure mechanism and any contributing factors to the premature failure. Results from the testing concluded that the liners showed material properties consistent with that typically expected for such an operation, therefore the liners were satisfactory for their intended use. It was recommended that due to the satisfactory liner material and shorter predicted life, a review of the liner material specification and design for the SAG mill be undertaken. While the first set of spare liners were a like for like replication of the original profiles, liner design changes have already been implemented to reduce the likely hood of premature wear.

Using the existing Gold Fields St Ives SAG mill liner design as a starting point, the following short-term improvements are underway in time for the next reline expected in mid-2020:

- Feed end Outer and Middle Liners combined as one (saving 16 pcs to install and remove), plus the addition of White Iron Inserts into the Lifter section, to provide improved wear resistance, rather than increase the lifter height and therefore the amount of extra weight needed.
- Feed End and Middle Shelli Liners lifter height and plate thickness increased in the high wear zone, as shown in scan results.
- Rubber Filler Rings added for handling safety, plus provides weight savings over the steel items.

Improvements are being made to the next design iteration to assist in reducing relines times and further reduce overall set weight for the next shell liner change out expected in late 2020. This includes:

- Shell Liners have been changed to a single row to allow more lifter rows to be installed per inch (turn) of the mill. Refiners found that they could only install one row of the double chord shell liners as the reach was too high, whereas they can install three rows of the single chord liners which should save inching the mill eight times. The mill is currently inched 24 times per reline.
- Pulp Lifters converted to the traditional Single Direction Big Curve (Pump design), more suited to higher pebble extraction rates. Discrete Element Modelling (DEM) is underway for comparing the current Turbo Pulp Lifters to Big Curve.
- Centre Dischargers converted to a modular composite design, same as Gold Fields St Ives operation.

CONCLUSIONS AND LESSONS LEARNT

Gruyere was discovered in October 2013 and six years later the project had been successfully designed, constructed and commissioned achieving commercial production in October 2019. Gruyere is currently operating at throughput rates significantly exceeding the design throughput and is at the beginning of the 13-year life-of-mine journey of continuous improvement. As the operation stabilises and the Gruyere open pit deepens into transitional and fresh ore types there will be an opportunity to review the mechanical and operational costs of the crushing and grinding circuits. This information will provide a unique opportunity to revisit the internal SABC versus HPGR trade-off study as well as an external comparison with the existing Tropicana operation.

Identifying during the project phase and implementing the MANTA Controls system in conjunction with the EPC has provided the operations with a seamless transition to supervisory control of the SAG and ball mills, cyclones, thickeners and leaching circuits within the first six months of operation. Conducting internal and external design reviews of the entire circuit identified potential bottlenecks early in the project life cycle and while not everything can be addressed, design changes that were implemented have assisted in improving the operability and reliability of the plant.

An important lesson that has been reinforced at the Gruyere operation is the ability of the site to react quickly during commissioning by being well prepared and utilising the operational experience of Gold Fields and Gruyere Project. Ensuring that critical spares have been purchased, ordered and mobilised to site prior to commissioning can mean the difference between a rapid ramp up or continuous delays. Purchase of a full spare set of liners for the SAG and ball mills prior to commissioning minimised the impact of accelerated wear on the SAG mill and alternate sets of discharge grates and cyclone parts enabled for quick optimisation of the circuit.

The Gold Fields St Ives comminution circuit consists of a 10.97 m (36’) SAG mill operating in closed circuit, this experience proved invaluable when commissioning the Gruyere project in SS SAG mode before transitioning to SABC which allowed for a smooth and controlled ramp up of the thickener and leaching circuits at lower volumetric flow rates. It is important to work closely with comminution consultants that have a broad knowledge across the industry and can provide guidance on various scenarios for the client. It is also important to have the confidence to decide what direction to take using the best information available at the time. Then act quickly on that decision. It is for these reasons that by utilising the existing operational and mechanical knowledge from the Gold Fields sites and personnel there has been a rapid ramp up of production at Gruyere.

At the time of this paper, preparations were already well underway to ensure there was a smooth transition to increasing quantities of fresh ore. We can now say after the 2020 COVID-19 delay to the release of the paper that the circuit is now processing up to 1400 t/h on transitional material after optimisation and removal of some downstream bottlenecks. Furthermore, it is averaging around 1080 t/h, on design hardness ore, comfortable exceeding the design capacity of 938 t/h. The grinding circuit was recently surveyed on the hard fresh material and this information will form the basis of a future paper covering the full ramp up and optimisation at Gruyere.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support and contribution of the Gold Fields Gruyere operations and maintenance teams.

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