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Unlocking Plant Capability through Targeted Debottlenecking of Arrium's Magnetite Concentrator

C. Stanton[1], M. Mativenga[2], J Gerber[3], C Jenkins[4]

1.
Process Engineer, Arrium Mining, PO Box 21, Whyalla, SA. Email: chris.stanton@arrium.com

2. Process Development Manager, Arrium Mining, PO Box 21, Whyalla, SA. Email: martin.mativenga@arrium.com

3.
Principle Process Engineer, Arrium Mining, PO Box 21, Whyalla, SA. Email: johan.gerber@arrium.com

4.
Senior Process Engineer, Arrium Mining, PO Box 21, Whyalla, SA. Email: Clinton.jenkins@arrium.com

ABSTRACT

In 2014, Arrium completed an optimisation program on its magnetite concentrator, enabling a reduction in the overall cost base of producing concentrate through an increased ability to treat a wider range of ore types, previously considered waste. The development was the culmination of four years of work, conducted in house by Arrium's mining development group. The overall intent of the plant design focused on improving the concentrator's ability to treat a wider range of magnetite ore types. Metallurgical analysis of these feed ore groups outlined a need for more grinding power if production quality was to be maintained and throughput increased. As such, a tertiary grinding circuit was designed which, alongside the rectification of key operational bottlenecks, would allow the plant to continue to produce concentrate at the required specification and rate. The technology chosen for the tertiary grinding application was the XT IsaMill™, which is known for efficient fine grinding when compared to conventional ball milling. The transfer sizes between the existing comminution circuits were coarsened, allowed for the treatment of different ores at the required rates. The optimisation project was successfully completed in February 2014 after a three month commissioning phase. The initial metallurgical testing and engineering of new equipment proved highly successful with all equipment meeting or exceeding design parameters.

INTRODUCTION

Arrium operates a magnetite concentrator at its Iron Duke mine, located 67km south west of the township of Whyalla, South Australia. The concentrator was commissioned in 2007 as part of Project Magnet, a successful initiative to convert the Whyalla pellet plant from hematite feed to magnetite. Operation of the concentrator in subsequent years highlighted several areas of improvement in the original plant design. A project was commenced in 2009 to investigate, design, and construct solutions to optimize the plant. In addition, stockpiles of high silica material previously disregarded presented a business opportunity if made treatable by the upgraded flowsheet. The Magnetite Optimization Project (MOP) represented a body of work consisting of four years' work in plant design, working with an array of highly experienced subject matter experts, to develop, test and construct an upgraded flowsheet for the processing of Arrium's magnetite reserve. This paper will discuss the identification of problem areas, development of key process solutions and finally, the implementation measures that occurred.

ORIGINAL FLOWSHEET

The original Project Magnet flowsheet consisted of two stages of grinding with low intensity magnetic separation following each comminution circuit. Crushed ore (-32mm) was fed to two parallel 1.8MW High Pressure Grinding Rollers (HPGR) in closed circuit with 2.2mm banana deck screens. Undersize from the screens was slurried and pumped to the Rougher Magnetic Separators (RMS). Rougher concentrate was then screened at 0.5mm, with all oversize going back to the HPGR, in an attempt to liberate and reject as much non-magnetic material as possible. Minus 0.5mm was ground down to an 80% passing size (P_{80}) of 38µm within the 7.5MW ball mill. The ball mill was closed out with hydro cyclones, with the overflow gravity discharging to a bank of De-slime Intermediate Magnetic Separators (DIMS). The DIMS concentrate was fed to the Cleaner Magnetic Sseparator (CMS) before passing through a protection screen prior to the slurry storage tanks.

INITIAL CIRCUIT ANALYSIS

In 2009, Arrium began an optimization program on the concentrator plant to improve production rate and reduce cost. An initial review was conducted on plant performance in conjunction with Process Technology and Innovation (Baguley, Jankovic and Valery, 2010). It comprised of metallurgical surveys, assay mass balancing, and historical data analysis. This review provided the following main conclusions:

- The HPGR circuit was power limited at harder ore types; restricting fresh feed due to the recycling load rising beyond conveyor limitations.
- At 0.5mm, the HPGR close out screen size was causing excessive front end recycling load, limiting throughput.
- The ball mill was shown to be overgrinding the heavier magnetics, reducing efficiency.

The existing cyclone feed pumps were operating at the limit of their duty due to the preferred cyclone configuration at the time.

CHANGES TO THE FEED: BUSINESS OPPORTUNITY

During the initial years of processing magnetite, a significant amount of high silica magnetite was stockpiled. This material was not treated through the concentrator due to final product quality concerns that existed at the time.

The Geometallurgy group developed a modified Davis Tube Recovery (DTR) process, with the results able to be translated into expected plant performance utilising a regression model. Laboratory test work conducted on these high silica magnetite stockpiles in 2011-2012 indicated that the material achieved good metallurgical performance when ground to the target 80% passing size of 38µm (P_{80}) of the concentrate. The test work also indicated that due to the increased quartz content, the material was harder than the traditionally dominant carbonate magnetite usually treated by the plant. This material also had a lower mass recovery when compared to the average magnetite feed blend. These two factors together would require an increased capacity in the concentrator grinding circuit to maintain the required final product production rates.

Full scale plant trials were conducted, progressively increasing the ratio of high silica feed to standard feed, ranging from 10% through to 30%. Initial results on the trial date blend showed encouraging results in the concentrate quality that was produced. During subsequent plant trials feeding up to 100% high silica material, it was shown that while the concentrator could achieve the target grind and an acceptable concentrate quality, production was significantly reduced due to lower mass recovery. It was also found that the final product quality was sensitive towards the grind achieved, with any variation from the target grind causing the product quality to fall outside the required levels.

This added impetus to the notion of conducting a major debottlenecking exercise as the most applicable means of increasing production.

EARLY BOTTLENECK IDENTIFICATION

Prior to commencing a design study with an engineering company, Arrium conducted an internal review of the plant bottlenecks identified previously by PTI and other subject matter experts. In order to increase the feed rate beyond the design these key bottlenecks would need to be identified first to save time later on.

HPGR Circuit

At the time of review, the feed conveyors around the HPGR units were running at near maximum capacity. Each HPGR was tasked with reducing 1000tph of -32mm feed material down to below 0.5mm, taking into account the fine recycle from the RMS screens. The plant operators could not physically increase the circuit raw feed rate without exceeding the capacity of the HPGR feed conveyor belts. Prior optimisation work to increase the recycling load was recommended by PTI as a means of increasing the utilisation of installed power (Baguley, Jankovic and Valery, 2010), which should also increase the proportion of fine material being generated by the circuit (Dundar et al, 2009). However, a site review by the HPGR vendor, Koeppern, noted that the amount of fines in the HPGR feed was already well above the original design specification (Gardula, 2010). It was also noted that there was up to 40% -2mm in the HPGR feed, as opposed to the 15% catered for in the origin design calculations. The inability to process more tonnage because of the belt limitations and recycling load was a major conclusion to this stage of the review.

Ball Mill Circuit

From metallurgical surveys and reviews, it was established that the recycling load around the ball mill was industry average at 250%, but that the cyclone feed pumps were operating at their limits. This data led to the conclusion that the mill could be optimized for higher throughput or coarser grind size, and that attention should be instead paid to cyclone pump capacity.

An in house review of the cyclone pump capacities confirmed that both cyclone feed pumps were not adequate for the volumetric duty required to achieve the 38µm grind. The actual static head on the system at the time was 17 metres, as opposed to the original design of 13.8m (Phillips, Westbrook, 2010). This was further compounded by a back pressure of 166kPa, as opposed to the original design of 100kPa. Because of these disparities, the overall static head increase was 9.2m over the design, and the pump could not be expected to reach its design duty rate (Phillips, Westbrook, 2010). From the review, the calculated sustainable volumetric flow rate was $712m^3$/hr, far less than the original mass balance rate of $1114.5m^3$/hr.

For the plant operators, this translated simply into a lack of capacity to control product quality if the feed ore was harder than normal, or an inability to increase feed rate when the opposite was true.

OPTIMISATION APPLIED TO INITIAL SCOPING DESIGN

While optimization of the existing concentrator concluded with PTI at the end of 2011, work had already began within Arrium creating multiple base flowsheets upon which a feasibility study could be developed. These flowsheets would target the bottlenecks identified and include, where possible, proposed remedies based on the best available information at the time. Major changes put forward for engineering design were:

Removal of the RMS screens

This would coarsen the feed 80% passing size (F_{80}) to the ball mill from approximately 300µm to 1400µm. Fresh feed tonnes into the HPGR circuit would also be increased to make up the recycling load.

To check the ball mill capacity, a simulation of the ball mill performance at the optimised conditions was carried out, and only through significant variance in the design parameters did the model predicted power requirement exceed the installed capacity. An internal report outlined that with the original design 80% particle passing size (F_{80}) of 416µm and product 80% passing size of (P_{80}) of 38µm, the calculated installed grinding power ranges from 5800kW to 7250kW. In essence, there was more than enough installed power to achieve the original grinding requirements, yet as the resultant mill grinding efficiency was lower than anticipated the mill represented a bottleneck on the plant. A paper written by Partyka outlined the limitations of ball milling when fine grinding, noting that below 20 to 30µm, they become inefficient (Partyka, Yan, 2007). Of particular interest, the paper also showed a worldwide trend against using ball mills in a regrind application with similar parameters to Arrium’s operation (Table 1).

This hypothesis was later re-iterated with ongoing design work with Amec. The ongoing feasibility study also pointed out the inefficiency within the mill could be attributed to its very fine grinding duty and wide reduction ratio (Lilford, Nofal, 2012). As such, the tonnage and grind reduction ratio required at Arrium’s concentrator was not conducive for any increase in throughput, and the design focused on coarsening the mill and increasing grinding efficiency.

Installation of a new grinding mill

To cater for the throughput increase and coarsened product from the ball mill, an additional grinding circuit was required. For the size range being considered (-100µm), stirred milling technology was deemed appropriate for consideration. The two possible mill configurations considered suitable for the duty were the Metso VertiMill and XT IsaMill^{TM}. The early steps involved in the data collection for the decision making were:

1. Visit to Arrium by Metso and Xstrata engineers,
2. Bench-scale testwork on each technology – samples were sent to independent laboratories for grinding testwork with both technologies. This included multiple tests with the XT M4 lab scale IsaMill,
3. Communication and visits to reference sites – a number of reference sites were visited, including Ernest Henry Mine in Queensland and McArthur River Mine in the Northern Territory.
4. Advice sought from independent subject matter experts,
5. Literature review of laboratory mill technology, focusing on the grinding performance and successful scale-up.
6. Construction lead time of equipment, and what auxiliary capital is required (for example, cyclones).

Criteria from the data collection, such as capital and operational expenditure, lead times, and risk were weighed in a selection workshop. From this, the XT IsaMill^{TM} was chosen as the preferred technology to move into feasibility design. For the duty, a single 3MW M10,000 IsaMill^{TM} was required. By the start of 2011, Arrium commenced a feasibility study into the new plant design, with Amec selected as engineering partner.

FEASIBILITY – CONFIRMING ASSUMPTIONS

With the scoping study concluded, the feasibility phase of design aimed to provide a revised flowsheet and capital estimate to +/-25% accuracy.

Flowsheet Simulation Model

In order to mitigate the risk of the flowsheet changes and new equipment, a JKSimMet model was developed simulating the proposed changes on the plant. In order to fulfil this task an extensive metallurgical survey of the concentrator was conducted, including obtaining a bulk sample of the RMS feed. The bulk sample would be processed by the selected lab on bench scale equipment as per the proposed flowsheet steps, including the IsaMill stage. Bond work indices were also conducted on the nominated size range to verify the mill power required. As a final measure for risk mitigation, three separate plant surveys were conducted on different dates to ensure some variance in feed mineralogy. Three bulk samples were in turn submitted for analysis to the laboratory to run through the testwork program independently.

To ensure adequate model comparison against the actual industrial sized concentrator, the metallurgical surveys sampled every major unit of operations within the plant. All samples generated from the lab scale and full scale surveys were subject to identical analytical tests to ensure comparative data. As the M4 IsaMill was situated at ALS Perth, this laboratory was selected to conduct the majority of the analytical work, with the aid of vendors for specific equipment tests.

Results Analysis

The flowsheet simulation program successfully verified many of the assumptions carried through the feasibility study. The model and the final flowsheet design were in turn updated ensuring the rigour of third party review was continued. It was concluded from the testwork program that the results substantiated the flow sheet selection, successfully mitigating a significant portion of the process risks. In turn, an independent third party review conducted by PTI (Baguley, Jankovic, 2012) outlined no major issues or problems with the flowsheet.

A high level comparison of the grinding transfer point changes between the original plant and that at the end of feasibility is shown below in figure 1.

FINAL DESIGN AND CONSTRUCTION

Leighton Contractors (LCPL) and GR Engineering Services (GRES) were selected as final design and construction engineering partners. A final review of flowsheet and testwork results were conducted by GRES, with a few key changes made. These included modifications to the final screening plant, including reducing the complexity from two stages to one, and installing Derrick StackSizer™ screens for greater efficiency. Another notable change to the design was the recycle of the oversize from the screening plant back into the process, as opposed to sending it to tail. Construction commenced in 2013, with LCPL working in conjunction with Arrium's Major Capital Development Group. All brownfield construction was completed within the monthly 24 hour production shutdowns leading into November, upon which a 10 day production halt enabled the completion of all tie-ins and pre-commissioning activities.

THE FINAL FLOWSHEET

The magnetite optimization project targeted multiple areas of the existing plant to install additional capacity, and while this paper focused primarily on the grinding circuits, there were numerous other upgrades that were included and not discussed. Figure 2 is a depiction of the improved flowsheet as constructed and commissioned in 2013.

COMMISSIONING

Transitioning the project from design to construction, commissioning, and finally to plant handover was managed through the use of risk management and coordination tools. During the risk management process, all risks associated with the project were classified, ranked and prioritized with timed action plans and performance monitoring processes put in place (figure 3).

The transition and coordination steps involved bringing all stakeholders together to review construction progress and map out when the different phases of commissioning would commence. The overall goal was to ensure the plant was handed over to the operational owner as soon as possible.

A Management Operating System (MOS) was put in place to ensure all stakeholders were able to attend and give input into the required progress review meetings. The project progressed into process commissioning by mid November 2013, with performance acceptance tests successfully concluded in mid-December, 2013. By the beginning of January, the plant was formally handed over to operations and the ramp up continued.

During the first two months from commissioning, process optimization was undertaken to bring the plant to design production rates. The work included optimisation of the IsaMill™ wear components to maximise throughput and grind. Plant surveys and sampling campaigns were conducted to validate the mass balance and design assumptions. Classification (ball mill cyclones and screening) optimisation was also performed to achieve the required concentrate grade. The optimisation work under taken resulted in the process operating at above 10% of the design throughput prior to concluding the commissioning phase.

The performance monitoring system put in place to transition from construction to project handover was done successfully, with seamless transition between the different phases of the project delivery model. This success also led into an above target ramp up process after commissioning, shown in figure 4.

RESULTS

Measurement of plant capability post commissioning was demonstrated by the newfound ability to process lower feed magnetic content ores while maintaining production rate. The following parameters have been assessed since commissioning:

- The removal of the RMS screens resulted in a 98% reduction in HPGR recycling load, resulted in an increase of up to 25% in fresh feed rates, depending on the feed magnetic content,
- The de-constraining of the ball mill circuit and installation of the IsaMill has allowed for the processing of the coarser HPGR product, while maintaining design throughput rate and maintaining final grind of 38µm.
- Average concentrate pumping rate has been increased by 6% on the previous financial year, however 15% additional throughput has been demonstrated on higher mass recovery material.
- Finally, the plant has been successfully treating feed blended with 30% silica material successfully since commissioning. This was not achievable prior to the project completion.

CONCLUSIONS

The targeted de-bottlenecking of the magnetite concentrator has achieved its overall goals. The desired feed changes have been incorporated into the production budget and the plant is more than able to maintain grade and throughput.

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FIGURE CAPTIONS

FIG 1 Grinding transfer point comparison between old and new plants

FIG 2 – Revised flowsheet, as constructed

FIG 3 – Risk Management Process

FIG 4 – Ramp Up Curve

TABLE CAPTIONS

TABLE 1: Examples of fine grinding ball mills (Partyka, Yan, 2007).

FIGURES

FIG 1 – Grinding transfer point comparison between old and new plants

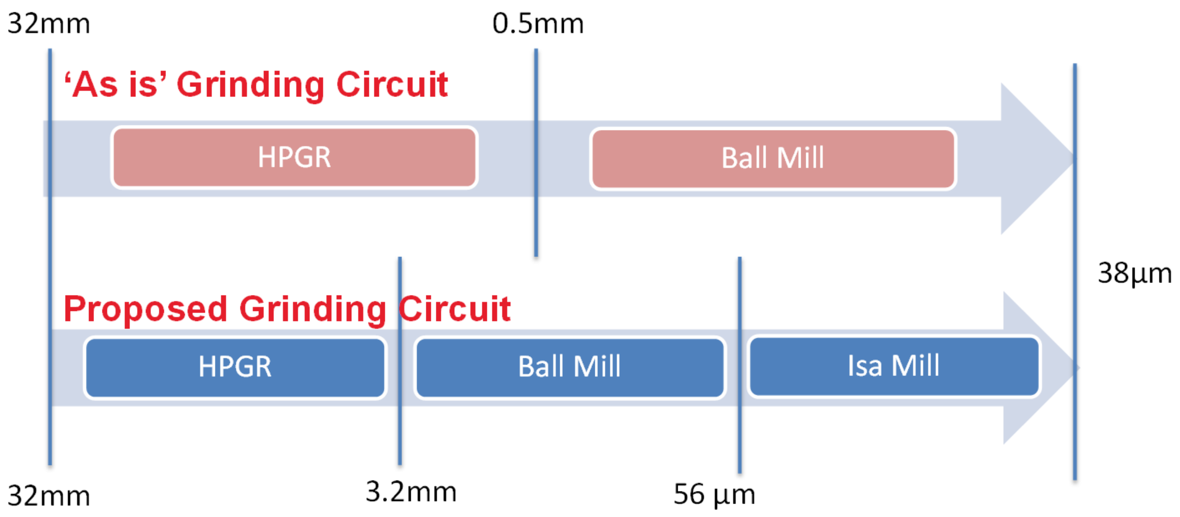


FIG 2 – Revised flowsheet, as constructed.

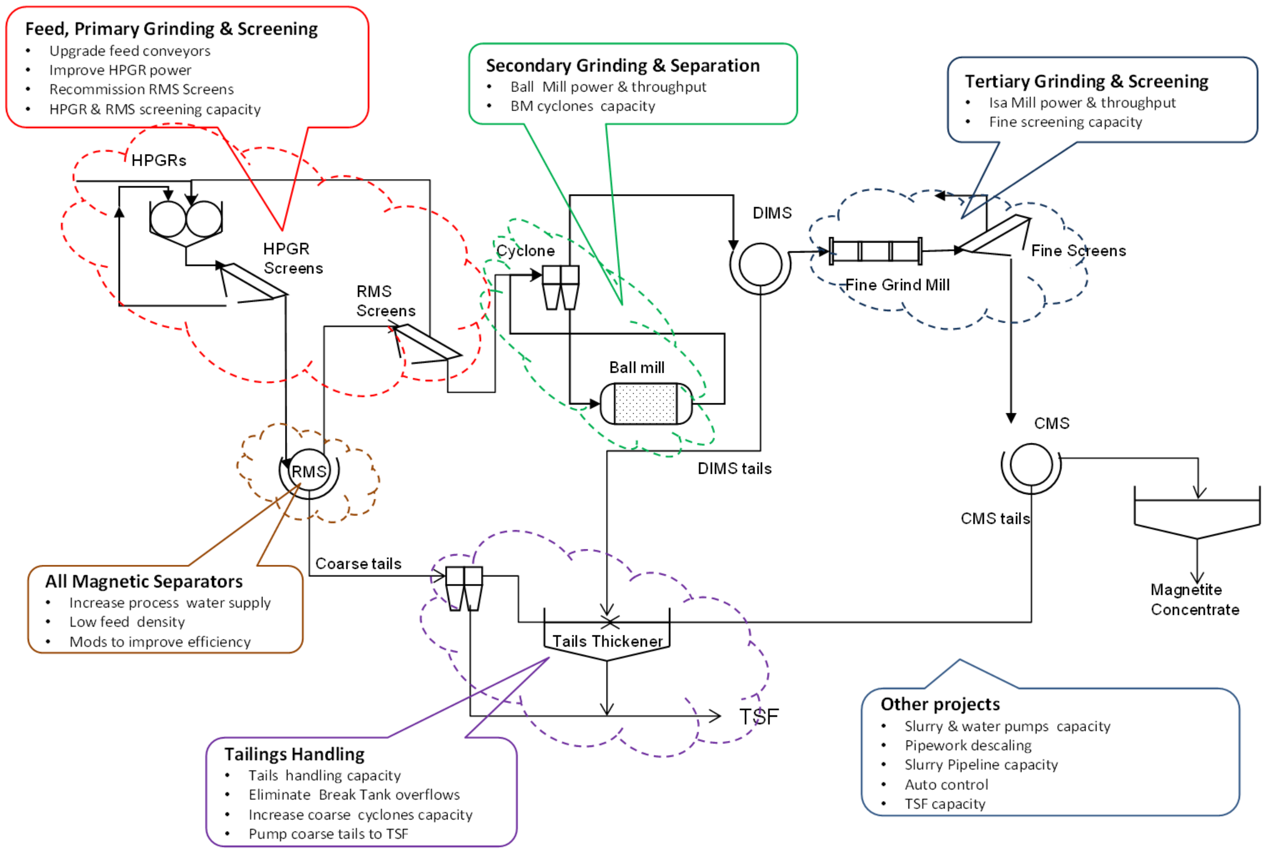
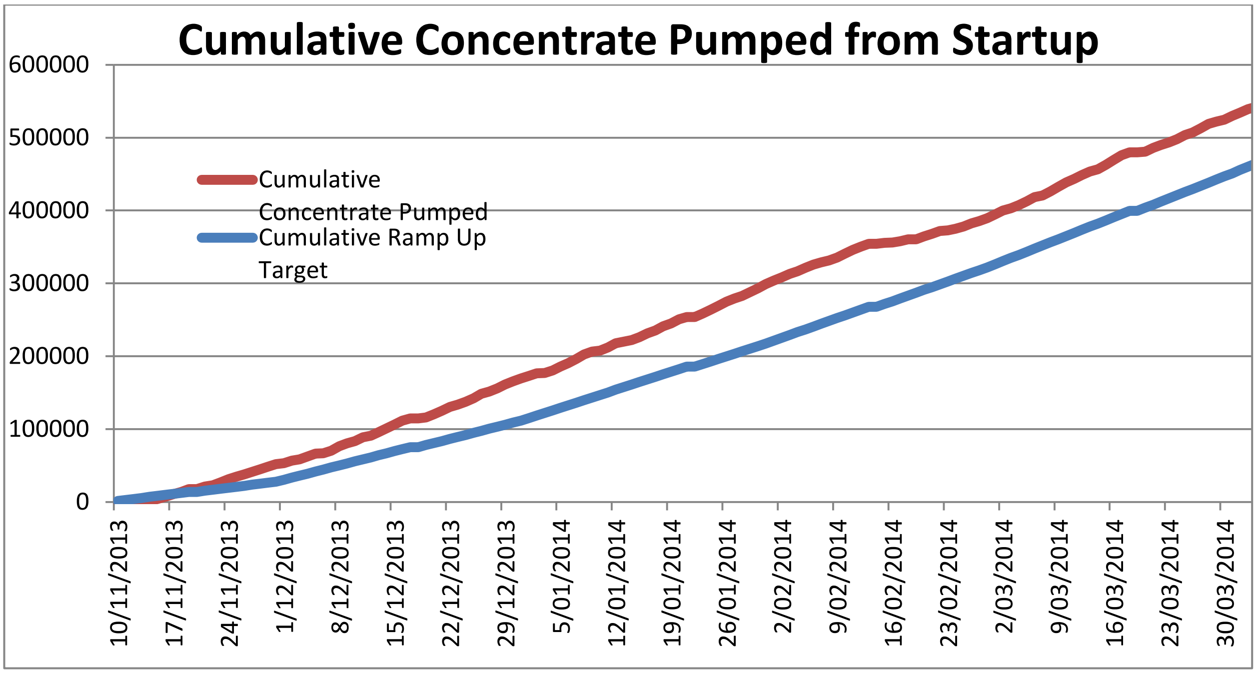


FIG 3 – Risk Management Process.

FIG 4 – Ramp Up Curve.



TABLES

TABLE 1: Examples of fine grinding ball mills (Partyka, Yan, 2007).

	Particle Size		**Mill Dimensions**	
Site	**Feed Size µm**	**Product Size µm**	**Dia (m)**	**Length (m)**
Pajingo Gold	200	38	3.66	4.18
Germano Iron Ore	120	32	5.18	10.36
Savage River	140	43	3.9	8.8
Macraes		20	3	8.2
Pena Colorada	125	38	5	10.67
Beaconsfield		20	1.83	2.44
Tritton Copper	45	30	2	3.4
Brunswick Mining	30	25	3.2	4
Porgera Gold	106	30	3.05	4.27
Arrium	**500**	**38**	**6.1**	**11**