Process optimization using real time tracking of coarse material in individual cyclone overflow streams

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ABSTRACT

The purpose of a mineral comminution circuit with a ball mill running in closed-loop with a hydrocyclone classification cluster is to feed the downstream process with the target particle size. Maintaining the optimal particle size in the flotation feed can significantly improve plant cash flow. In particular, reducing the amount of coarse material is often a major challenge. Existing instrumentation to provide particle size measurement is considered standard equipment in most modern concentrator plants. However, availability is often very low, mainly owing to high maintenance requirements of the analyser and associated sampling system.

CiDRA Minerals Processing has developed two novel and robust technologies that address this challenge by providing high reliability and very low maintenance systems for on-line measurement of coarse material in the overflow of individual hydrocyclones. The first system is non-invasive and measures pebbles and rocks greater than 6 mm. This paper focuses on the second system, which is a ruggedized wetted sensor design with no moving parts and provides a real-time trend of the desired target grind size parameter, such as percentage above 150 micron.

Both systems have simple robust designs and measure in the primary overflow stream of the individual hydrocyclone. Individual hydrocyclone measurement enables identification of poor performing hydrocyclones in addition to providing a representative measurement of the whole hydrocyclone cluster. The systems do not require sampling and associated sample transfer piping circuits that are prone to plugging, thus avoiding high maintenance requirements.

The wetted sensor will be described in detail along with its implementation in a robust control scheme in a major copper concentrator in North America. Plant data shows very high availability, achieved with

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very low maintenance, has enabled improved process control, thereby maintaining throughput and ball mill target power while reducing grind size.

INTRODUCTION

Rio Tinto Kennecott's Bingham Canyon deposit in Salt Lake City, UT, USA, is a copper porphyry orebody with a fairly uniform distribution of sulfide mineralization, predominantly chalcopyrite. Typical copper head grade ranges from 0.4 to 0.6 percent and the orebody also contains molybdenum, gold and silver. Rio Tinto Kennecott's concentrator is a SAG mill, ball mill and pebble crushing (SABC) circuit with four grinding lines to treat an average throughput of approximately 168 kt/d. Wemco mechanically agitated cells are used for rougher-scavenger duty and the rougher concentrate is treated by column flotation to produce a bulk concentrate. The bulk concentrate is further processed in a molybdenum flotation circuit to produce a molybdenum concentrate, as a saleable product, and a copper concentrate for the downstream smelter.

In a minerals processing concentrator, valuable mineral recovery is strongly linked to the particle size distribution of the material produced in the grinding circuit and delivered to the flotation circuit.

Through an industry partnership Rio Tinto Kennecott and CiDRA developed a novel technology for the measurement of particle size in individual hydrocyclone overflow pipes.

GRIND CIRCUIT CONTROL

One of the key challenges facing today's large concentrators is to maximize throughput while maintaining valuable mineral recovery. As ore grades drop, throughput rates must increase to maintain production targets. Furthermore, the reliance on fewer milling circuits to lower capital costs has resulted in an increased sensitivity to changes in ore type and feed rates. The sooner operators detect these changes, the smaller the process disturbance and performance impact will be (Jones and Pena, 1999).

Often times the resulting process disturbance is a particle size excursion in the hydrocyclone overflow stream. The disturbance could be particles slightly above the optimum size for recovery. In the extreme case, the disturbance could be pebbles or rocks reporting to downstream flotation.

The particle size of the product stream from the grinding circuit is a critical key performance indicator (KPI) because it is directly linked to mineral recovery, plant grinding efficiency and overall plant throughput. In order to control grind size, it must be measured. Key requirements of a useful measurement include:

- real-time feedback
- accurate and repeatable signals
- high availability
- low maintenance

Historically, concentrators have relied on various methods for particle size measurement and control. Examples include:

- particle size estimation based on the ore type, historical performance and plant conditions
- 'soft sensors' that are real-time empirical implementations of the above

- particle size measurement by sieving a composite flotation feed sample
- hand sampling of the cyclone overflow stream to spot check the process performance
- control strategies based on a hydrocyclone model, virtual sensor or the use of cyclone overflow percent solids as a proxy for particle size

All the above have worked to some degree but typically result in slow or intermittent data updates and perform poorly over the long term. Ideally, the particle size measurement of the cyclone overflow stream should enable a grinding circuit control scheme to be sustainable over the long term and allow throughput-particle size trade-off decisions to be made. This conceptual idea is represented visually on a chart of particle size vs. throughput (**Figure 1 – Particle Size vs. Throughput**). With control enabled there could be a shift in the operating line allowing for a particle size reduction at constant throughput or a throughput increase at constant particle size.

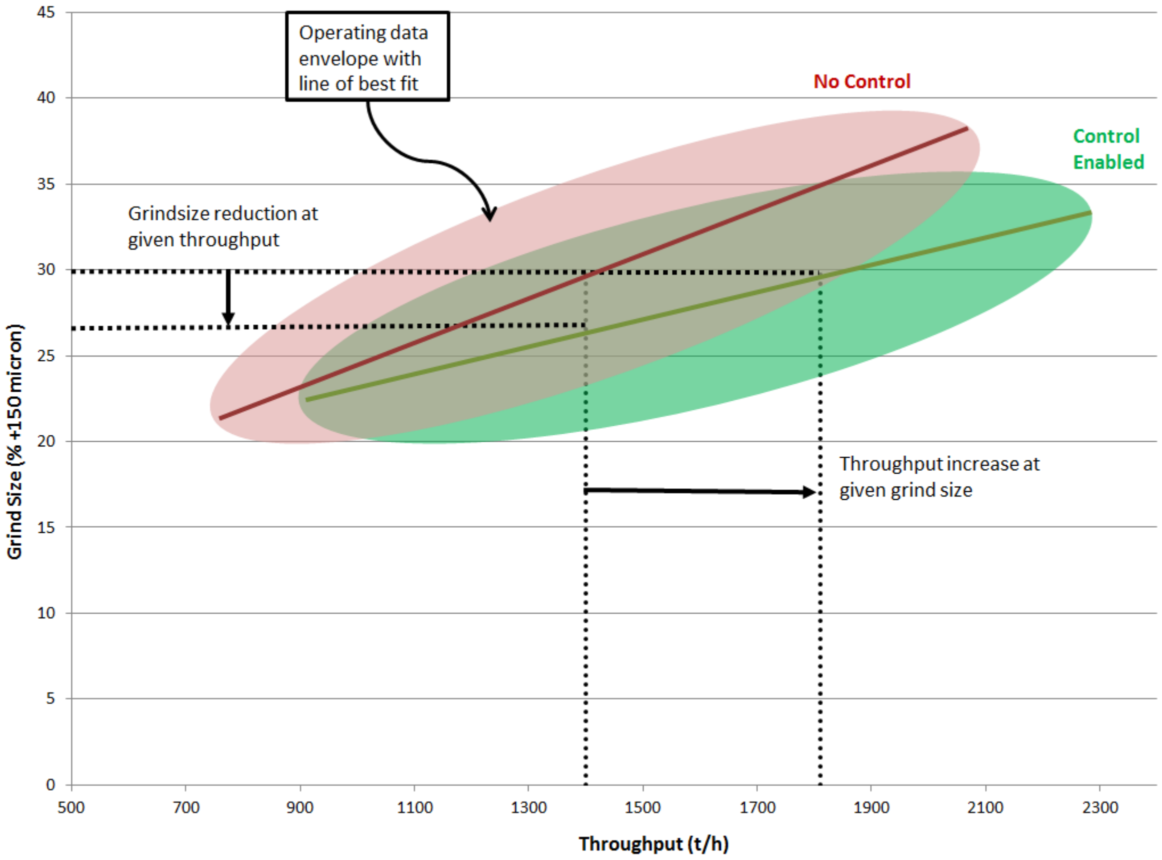

Figure 1 – Particle Size vs. Throughput

CONTROL DEVELOPMENT

The Rio Tinto Kennecott concentrator uses an Emerson Delta V distributed control system (DCS) for its regulatory process control. The Metso-Cisa Expert system is used for the advanced process control in the grinding circuit.

The CYCLONEtrac Particle Size Tracking (PST) system was initially installed at Rio Tinto Kennecott on one of the cyclone clusters only. A sampling campaign was undertaken to validate the performance of the system where CiDRA and Rio Tinto Kennecott personnel worked closely to manipulate the hydrocyclone and grind circuit operating conditions over a range of grind sizes. During the validation campaign more than 130 samples were collected from individual hydrocyclone overflow streams. Sieve analysis was performed on the samples and the results compared to the output of the PST system. The particular particle size distribution feature of interest at Rio Tinto Kennecott is the percent of material over 150 micron (100 mesh). The valuable mineral recovery drops significantly for grind size that is greater than 150 micron. As such, the PST system was tailored to provide a direct real-time indication of the percent by weight of the stream that is over 150 micron. Full PST system details have been published previously by O'Keefe *et al* (2014).

Following the validation of the PST output, raw data from the cyclones was collected for a period of five months. The data collected was used to correlate the response of the PST system to key plant variables (e.g. SAG throughput, cyclone feed density, cyclone feed flow, cyclone operating pressure etc.) The results of the correlation analysis are shown in Figure 2 – Pearson correlation coefficient between plant variables and PST system cyclone average

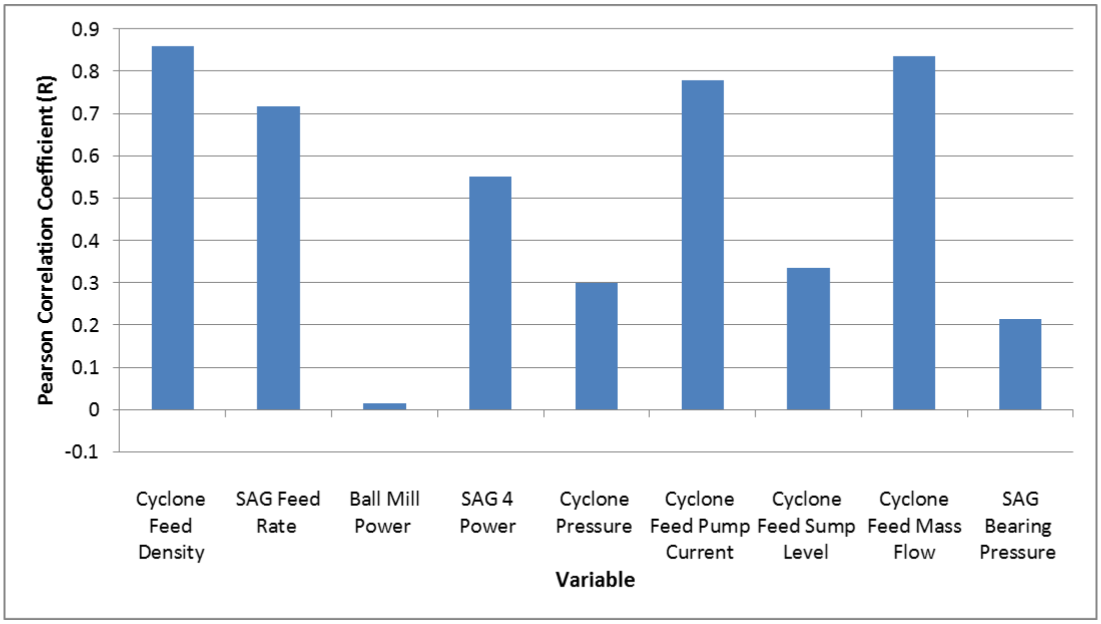

Figure 2 – Pearson correlation coefficient between plant variables and PST system cyclone average

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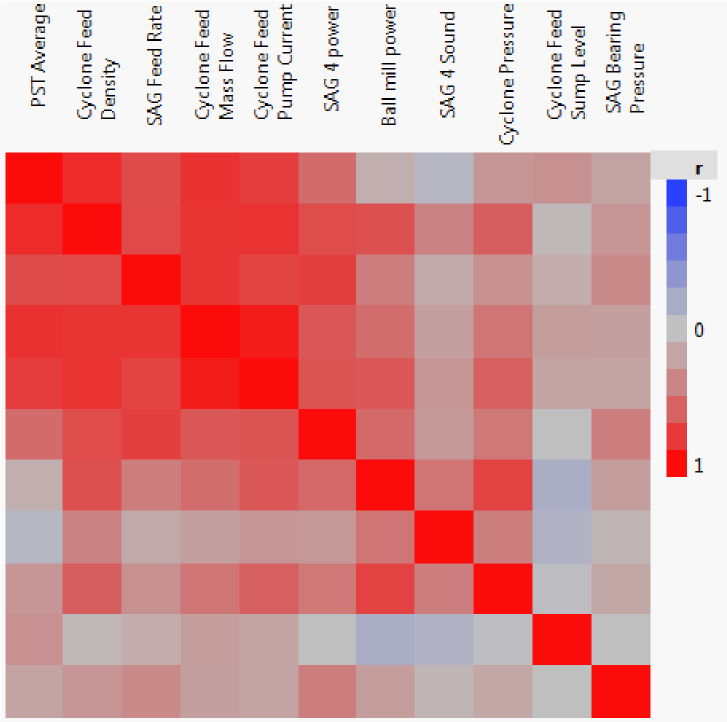

Figure 3 - Cross correlation between circuit variables

Based on the system response the variables with the highest correlation were cyclone feed density, cyclone feed mass flow and SAG feed rate. These variables are not independent as shown in the colour map chart of the cross correlations (Figure 3 - Cross correlation between circuit variables. The cyclone feed nuclear density meters had recently undergone a significant calibration effort and a multiple constraint PID control scheme had already been implemented on the DCS to allow the operators to target a cyclone feed density set point. However, determination of the optimum target cyclone feed density requires onerous operator attention and objective interpretation of the actual grinding conditions.

The PST system provides a particle size measurement for individual cyclones, providing the benefit of identifying poorly classifying cyclones and effectively a full stream measurement without a sampling system. This does however present a difficulty for control purposes since it does not represent a single input single output (SISO) process. Therefore a single change on the grinding circuit (e.g. change in water addition) results in multiple changes on the cyclone cluster; not all of which may be similarly correlated.

Furthermore, as cyclones in the cluster are switched ON/OFF values for overflow particle size may appear or disappear. An *average* and a *median* value of all cyclones in service were the options considered. Statistical analysis of calibration data indicated that the *median* value of all (good) cyclones in service offered the most accurate value. Therefore the decision was made to initially use the median PST value of all operating cyclones for the particle size loop. Intuitively this would also avoid the impact of potential outliers, since one poor performing cycling should not dictate the circuit control.

The availability of a robust online particle size measurement allowed the development of a particle size controller which adjusts the required cyclone feed density to approach target particle size. This allowed the operator to enter a desired particle size set point.

In parallel to the PST control development, a team had been formed at the Concentrator to optimize the grinding efficiency by utilizing more of the installed grinding circuit power (SAG mill plus ball mill).

The goal for the ball mills was to hold power within limits (92 to 95 percent of grind out power) to avoid historic excursions of under loading and overloading of the ball mills. The grind control proved to be an important enabler for this project as demonstrated in Figure 4 - Particle Size Control on Ball Mill 8(O'Keefe *et al*, 2014). The chart shows a 12 hour period where the control room operator was manipulating the target particle size set point on one ball mill line to achieve the desired ball mill power. By taking advantage of the excess capacity in the ball mill, as indicated by above target power draw, the circuit saw an approximate 30 percent reduction in percent over 150 micron with little impact on the SAG mill feed rate.

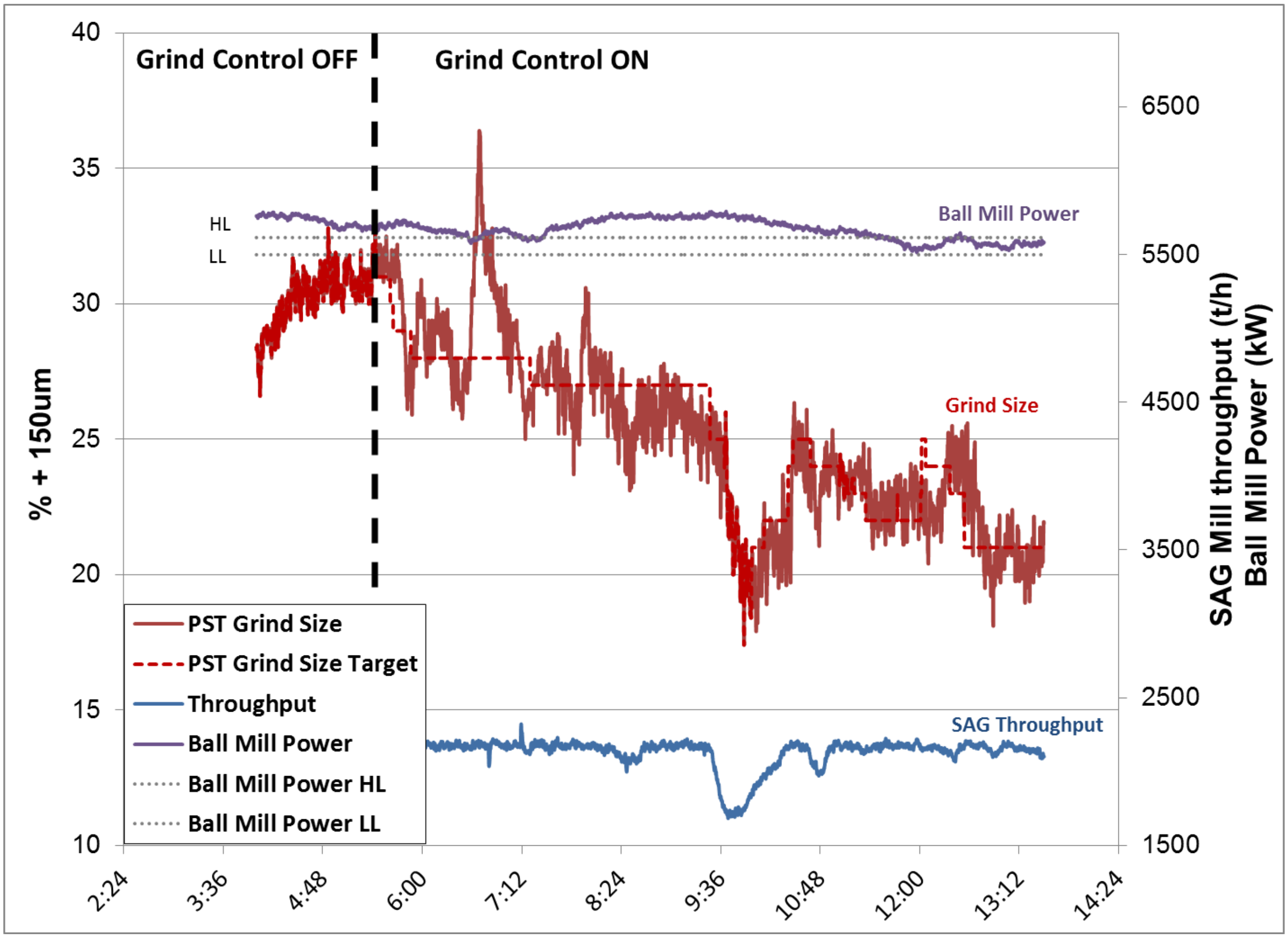

Figure 4 - Particle Size Control on Ball Mill 8

Following on from successful trials like the one shown in Figure 4 - Particle Size Control on Ball Mill 8, a multivariable control scheme was developed which adjusted target particle size acceptable limits (20 to 35 percent above 150micron) to achieve power draw within a target range (92 to 95 percent) of grind-out power. The control scheme included constraints such as cyclone feed mass flow high limits (indication of the recirculating load) and limits on the cyclone feed sump level which would impact the dilution water addition.

The above control scheme was implemented on the Expert (supervisory) System which sends appropriate set-points to the underlying DCS based controllers; including the previously mentioned cyclone feed density controller. This architecture (Figure 5 - Ball mill circuit control architecture follows the principles of hierarchical control scheme design whereby high level systems determine operating set-points for lower level controllers. A simplified version of the Expert control scheme was implemented on the DCS contingent on a loss of communication to the Expert system.

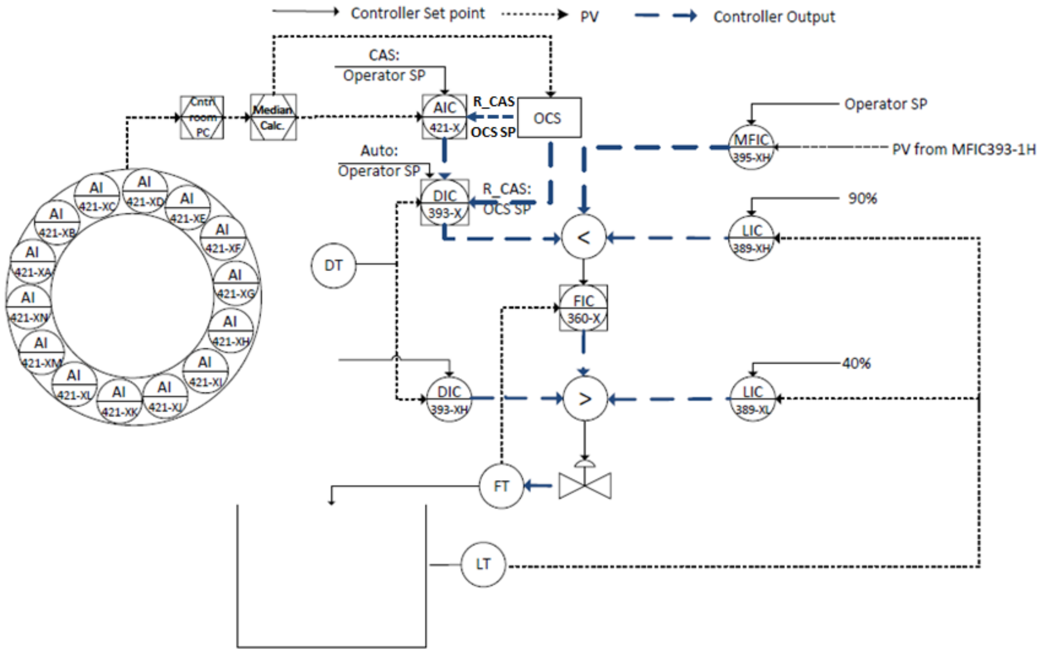

Figure 5 - Ball mill circuit control architecture

RESULTS AND DISCUSSION

As previously described, one ball mill line was used to develop and trial the new control logic. Once the development was complete, the changes were applied to the seven remaining ball mill lines in the concentrator. Figure Figure 6 - Control Scheme Utilization shows the control utilization from January 1 to June 1, 2014. It can be seen that by May, the utilization across all lines was above 80 percent.

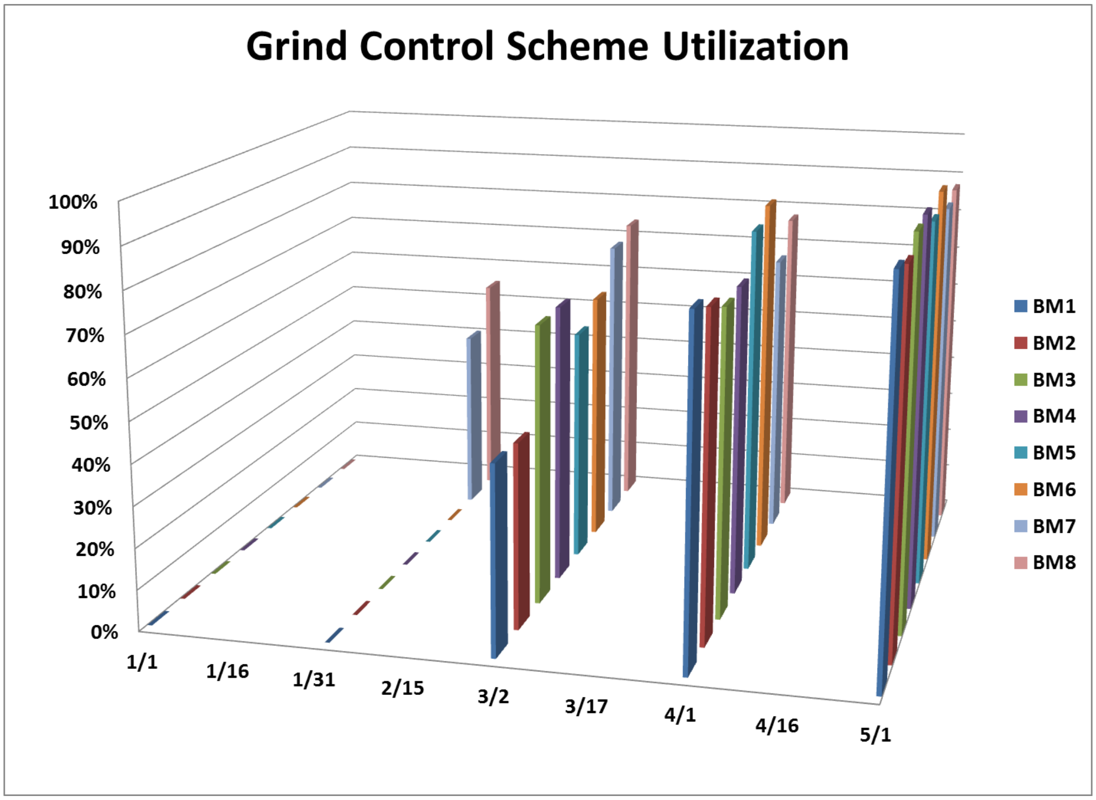

Figure 6 - Control Scheme Utilization

Due to the success of the implementation and rapid adoption no official ON/OFF testing was completed during the control development. Therefore, the five month period from Jan 1 to June 1, 2014 was analysed to assess the impact of the new control scheme. Figure 6 - Control Scheme Utilizationshows that this time period is roughly split in half, when the control was utilized and when it wasn't.

Particle Size vs. Throughput

The plant control strategy is not to hold a constant particle size product from the cyclones but to keep within an acceptable range (20 to 35 percent above 150 micron). Therefore analysing the control impact is more complex than identifying a specific particle size distribution or variance. By looking at the relationship between throughput and particle size, the performance by control mode of each milling circuit can be examined. Figures through Figure 14 - Ball Mill 8 Particle Size vs. Throughput by Control Modeshow the PST signal vs. throughput by control mode. The data used was a 1hr average and the data was filtered to include:

- SAG throughput greater than 900 t/h
- ball mill power above 3500 kW
- PST values greater than nine percent over 150 micron

The SAG throughput and ball mill power filtering is to remove abnormal operating conditions such as start-up and shutdown and/or severe upstream/downstream constraints. The PST value filter is due to the noise floor on the sensor when the cyclones are running with water only.

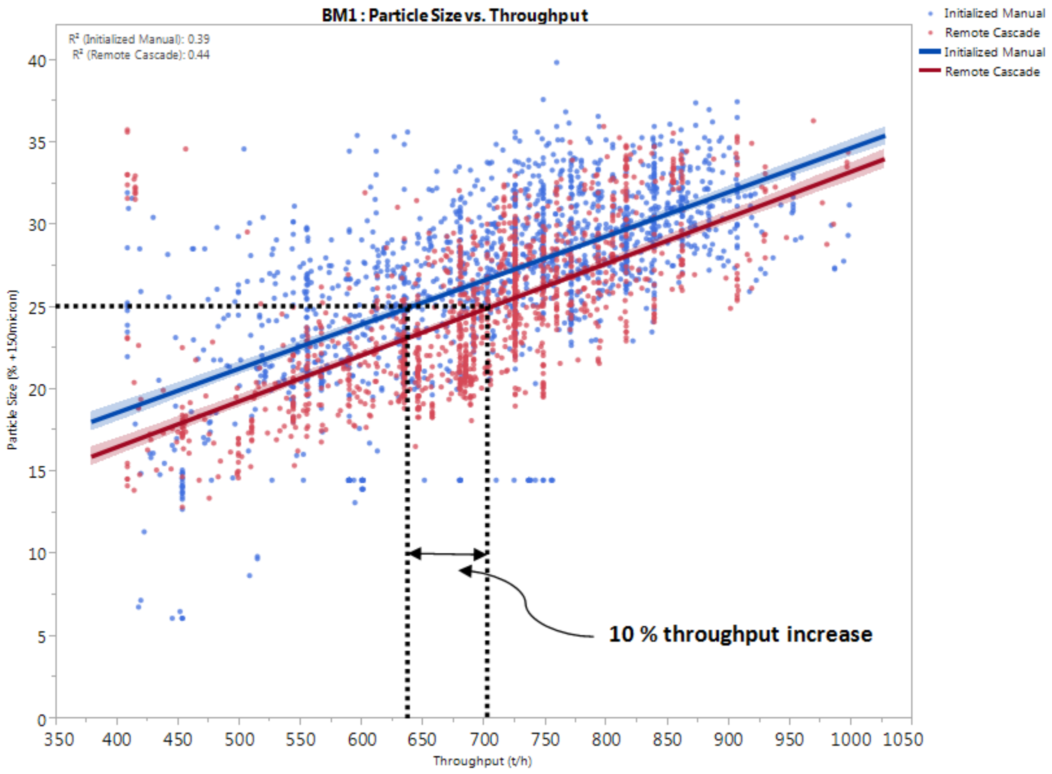

Figure 7 - Ball Mill 1 Particle Size vs. Throughput by Control Mode

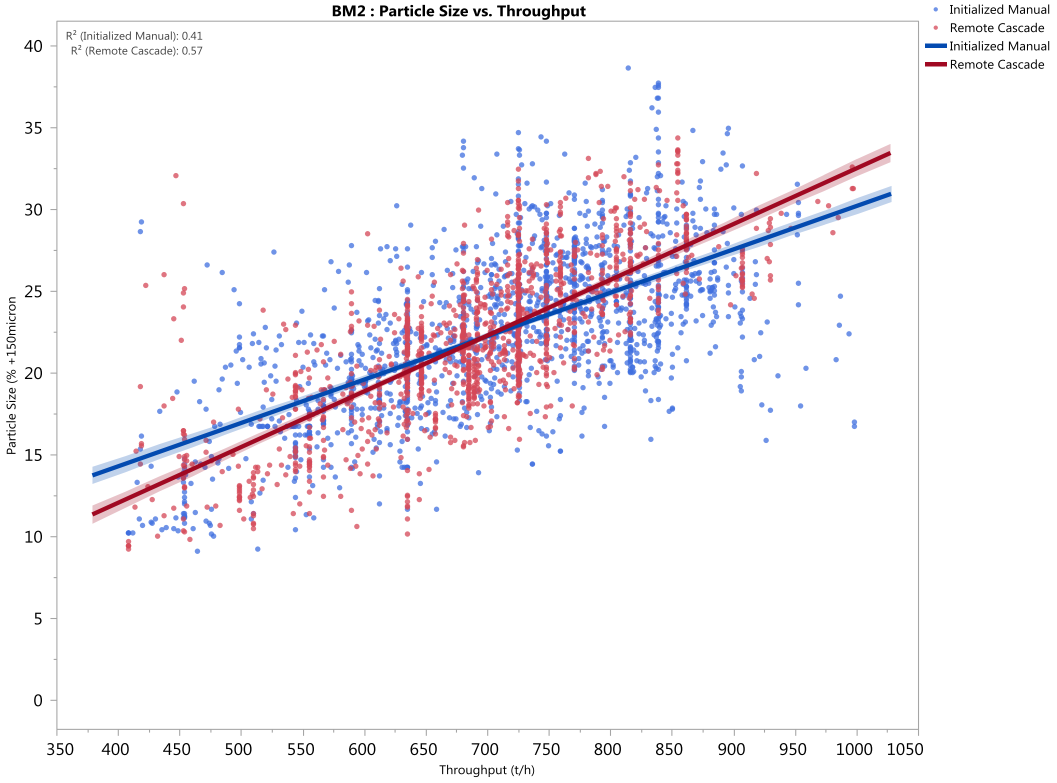

Figure 8 - Ball Mill 2 Particle Size vs. Throughput by Control Mode

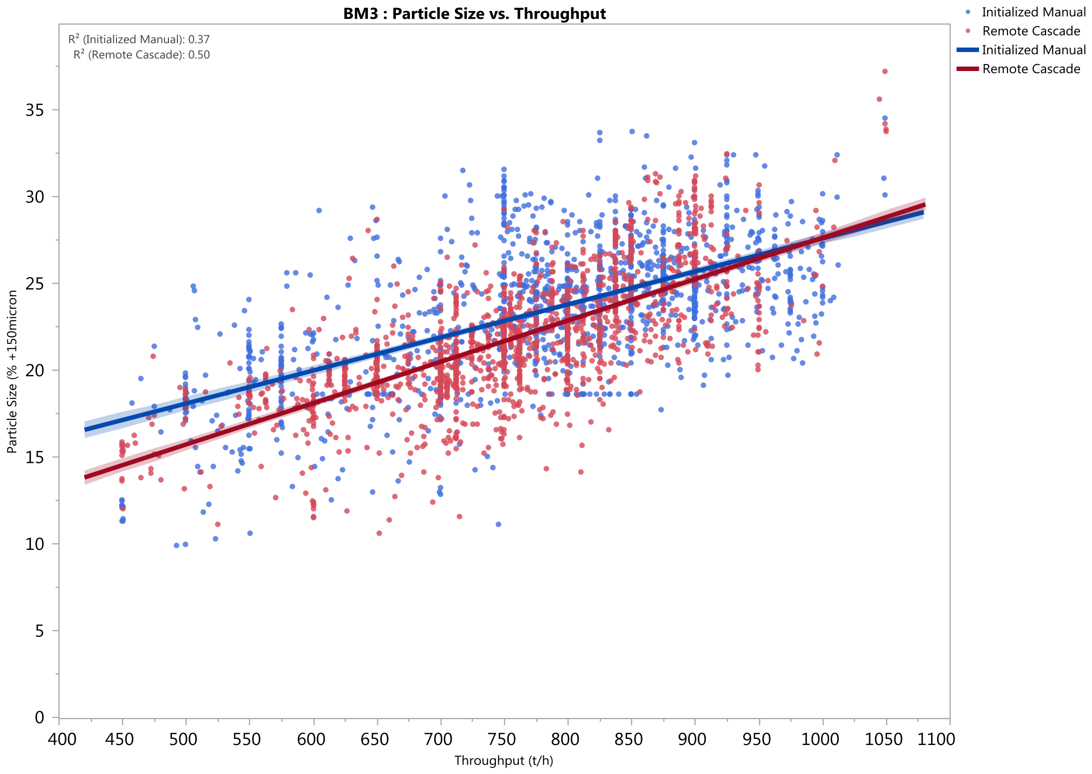

Figure 9 - Ball Mill 3 Particle Size vs. Throughput by Control Mode

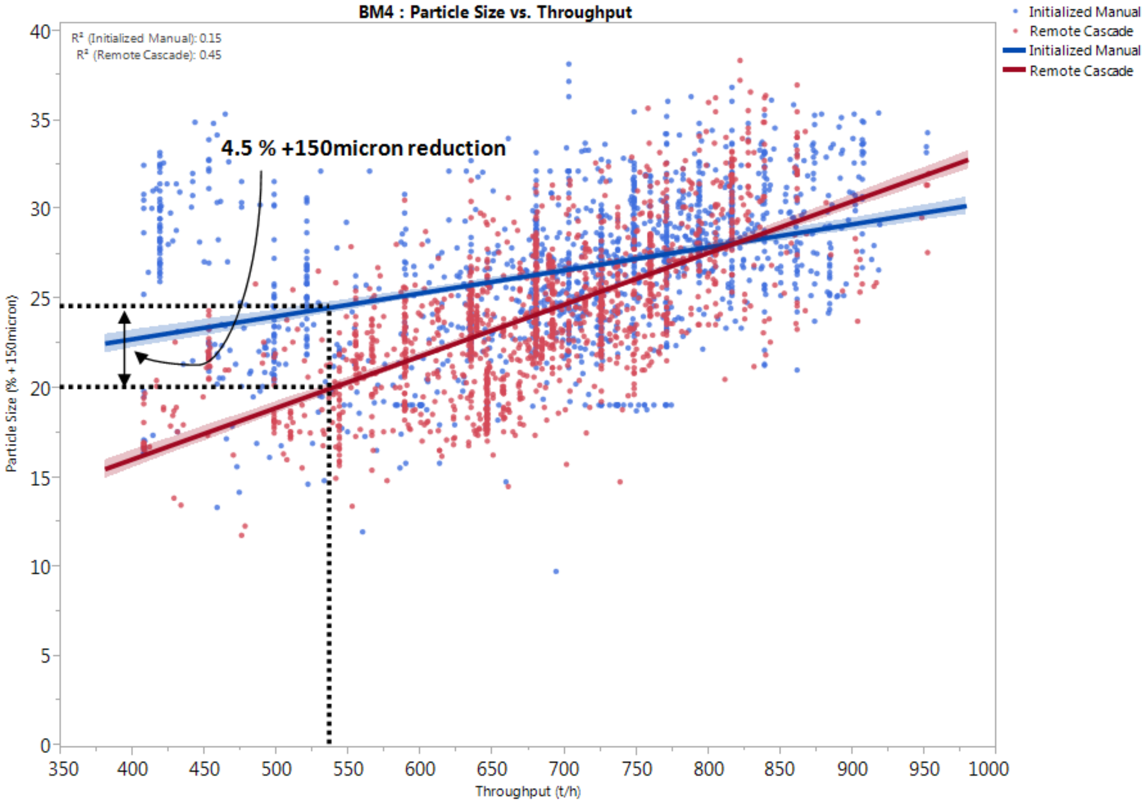

Figure 10 - Ball Mill 4 Particle Size vs. Throughput by Control Mode

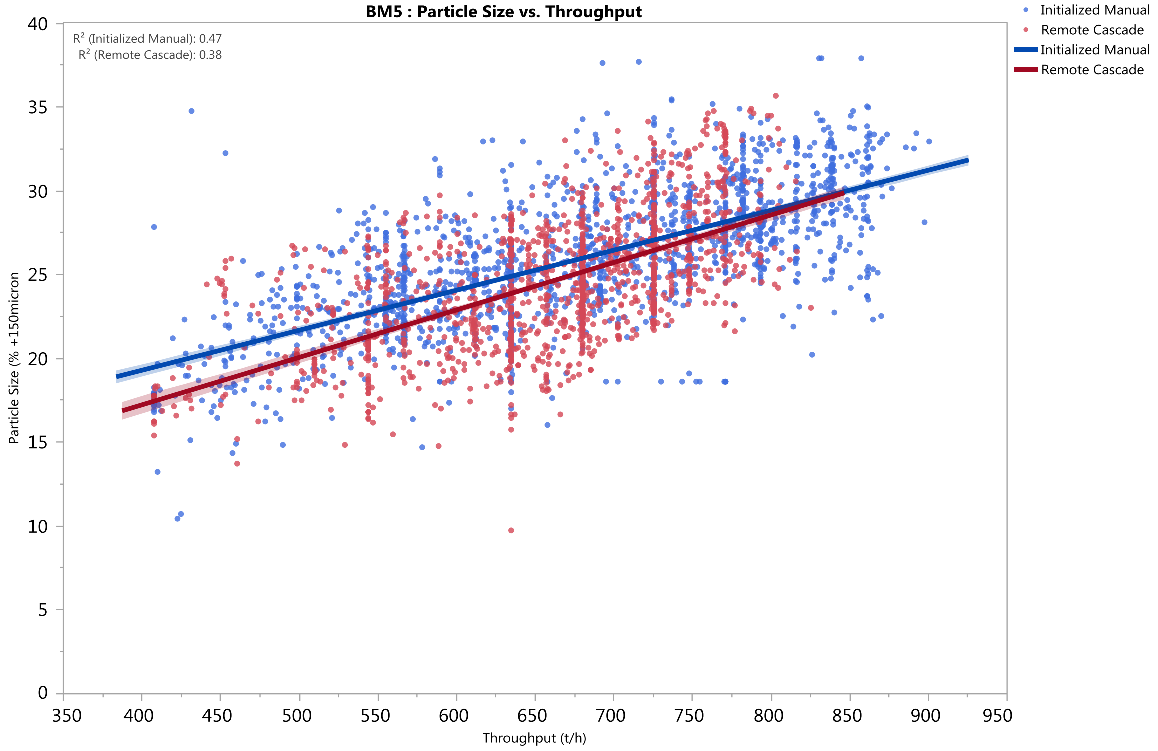

Figure 11 - Ball Mill 5 Particle Size vs. Throughput by Control Mode

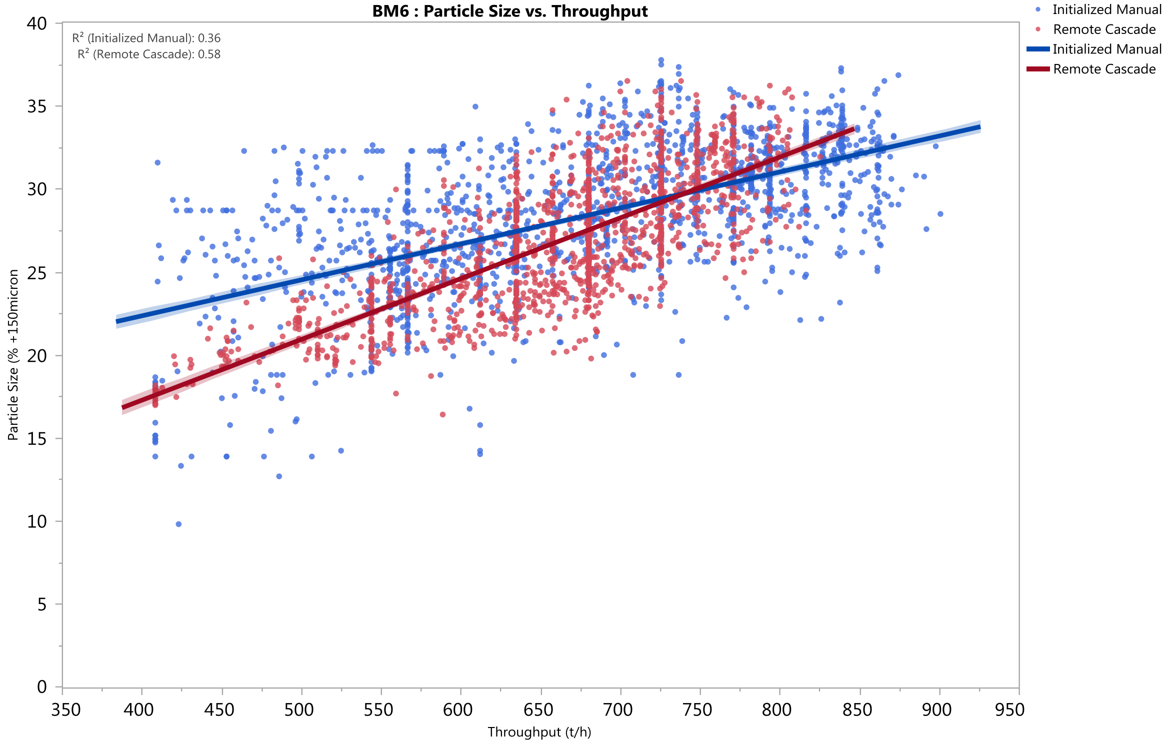

Figure 12 - Ball Mill 6 Particle Size vs. Throughput by Control Mode

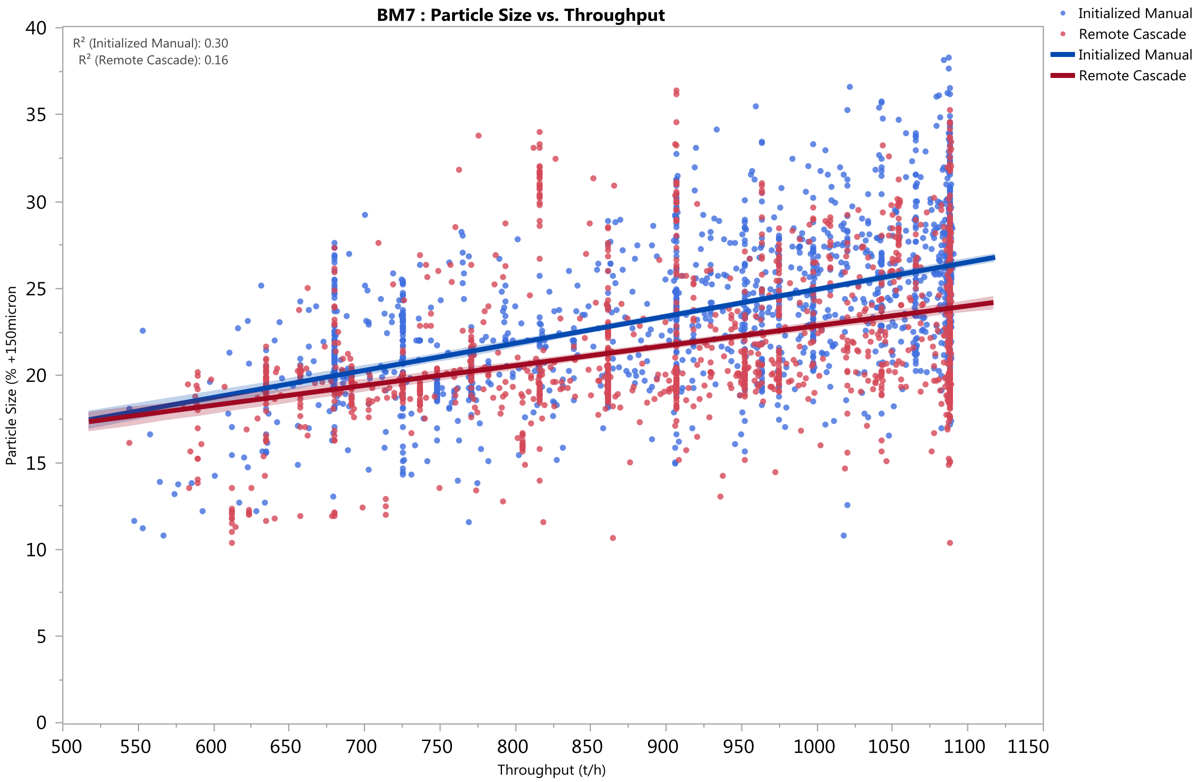

Figure 13 - Ball Mill 7 Particle Size vs. Throughput by Control Mode

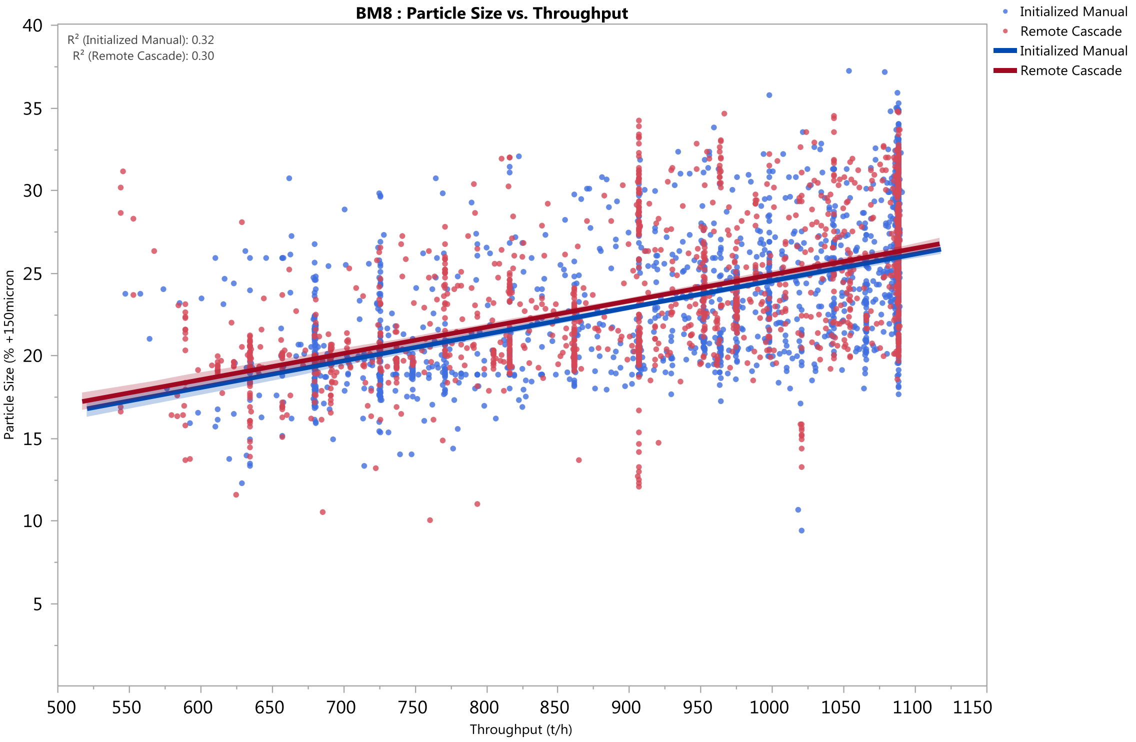

Figure 14 - Ball Mill 8 Particle Size vs. Throughput by Control Mode

The charts show that there has been a shift in the particle size-throughput operating line from control OFF to control ON. In general, this represents the ability to achieve a higher throughput at a given particle size (range), or a lower particle size (range) at a given throughput. In addition to the shift in operating lines, the data is also less variable as indicated by the higher correlations on the lines of best fit, suggesting the process is more stable and in control. The three exceptions are ball mills 5, 7 and 8. Ball mill 5 is likely due to the larger distribution of data points across the throughput range in the control ON state. Ball mill 8 R squared values of 0.32 (OFF) and 0.30 (ON) are very close which is due to ball mill 8 being the test mill for the control development. The reason the control modes do not show this is because it was tested manually using an operator in staged in the control room. Also, for both ball mills 7 and 8 the correlations are low which is being driven by the large number of points at maximum throughput.

In the case of ball mills 3, 4, 5 and 6 operating line shift is more apparent at the lower throughputs. This could be explained by the control strategy taking advantage of the excess capacity in the ball mills at lower throughput and ensuring the ball mill power is maintained in the target range. Historically, in lower throughput scenarios (i.e. ore limited) a lower particle size product would be assumed, yet there may still be capacity to grind more efficiently.

The new control strategy has demonstrated up to a four and a half percent over 150 micron absolute decrease (equivalent to ~30 micron reduction in P80) in particle size at same throughput (Figure Figure 10 - Ball Mill 4 Particle Size vs. Throughput by Control Mode For the same particle size a difference in throughput of 10 percent has been demonstrated (Figure Figure 7 - Ball Mill 1 Particle Size vs. Throughput by Control Mode).

Energy Consumption

The new strategy has demonstrated up to a 0.95 kwh/t reduction in specific energy consumption at the same particle size (Figure Figure 15 - Ball Mill 1 Particle Size vs. Specific Energy by Control Mode). If sustained over all ball mills, based on plant throughput and availability this could lead to over 450MWh/yr. savings in power consumption. The mechanism for this improvement is the prevention of under loading to ensure the energy consumed is being used for size reduction of the ore. Figures Figure 15 - Ball Mill 1 Particle Size vs. Specific Energy by Control Mode through Figure 22 - Ball Mill 8 Particle Size vs. Specific Energy by Control Mode show the specific energy consumption (kWh/t of fresh feed) and the PST particle size by control mode for the period January 1, 2014 to June 1, 2014.

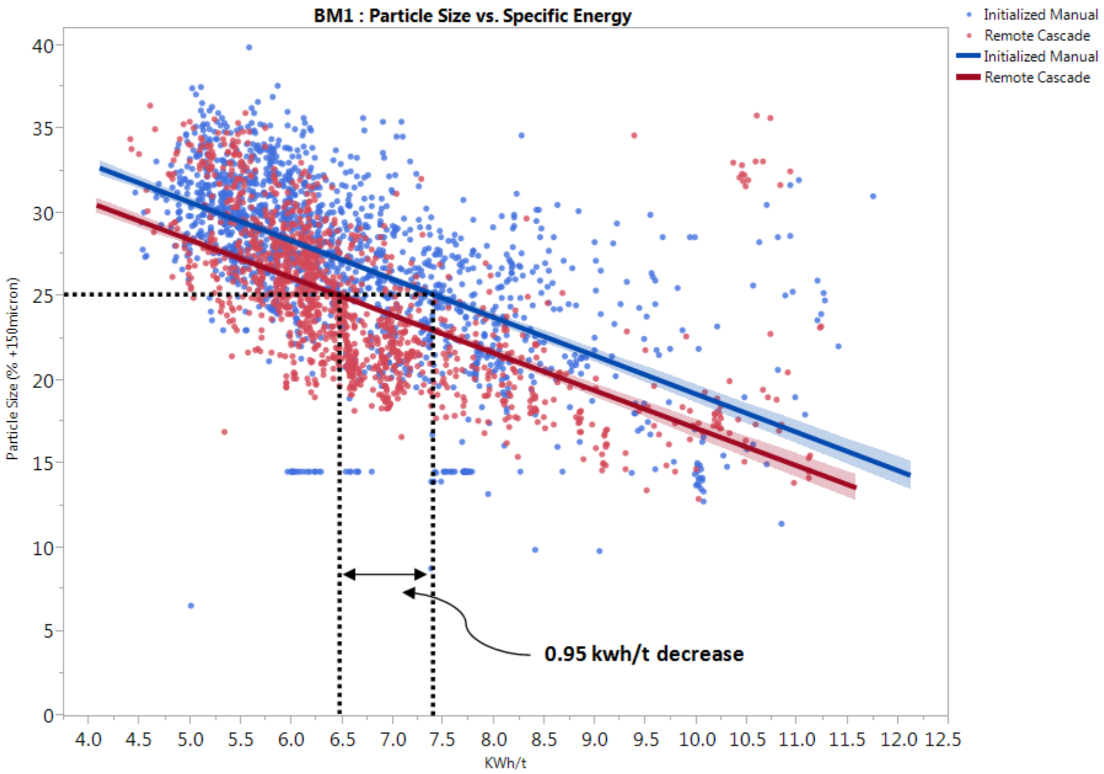

Figure 15 - Ball Mill 1 Particle Size vs. Specific Energy by Control Mode

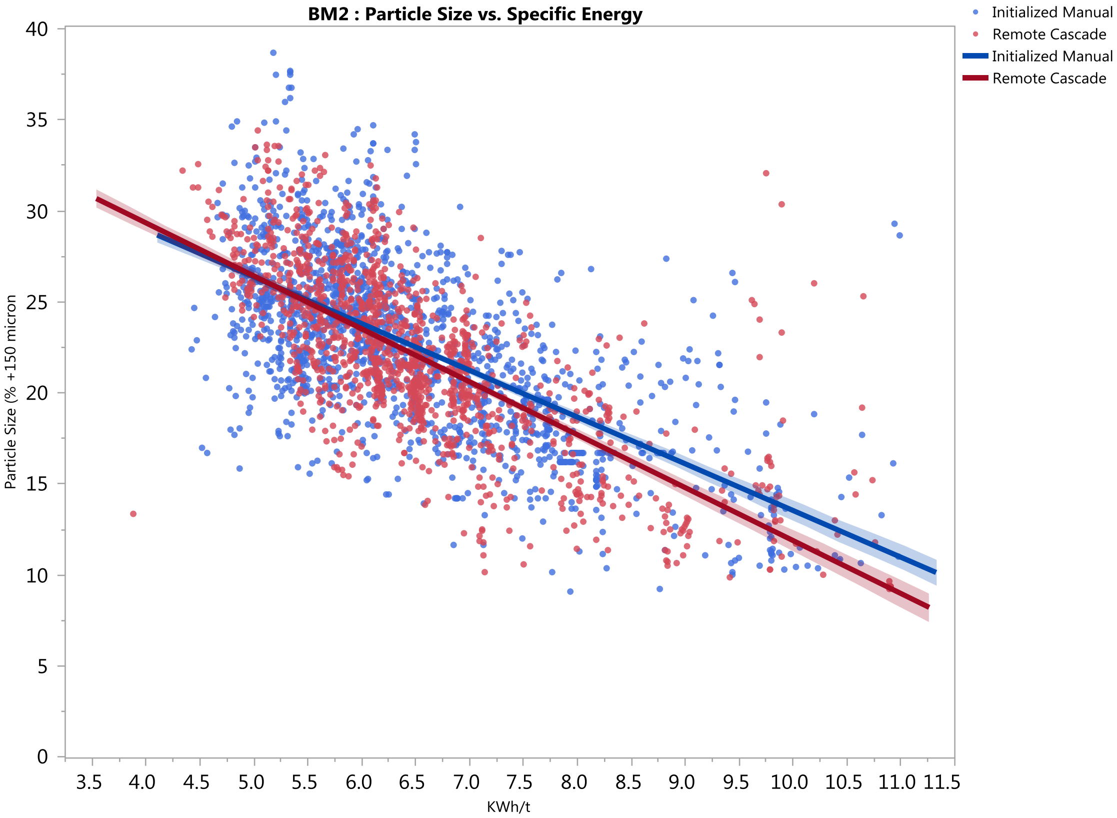

Figure 16 - Ball Mill 2 Particle Size vs. Specific Energy by Control Mode

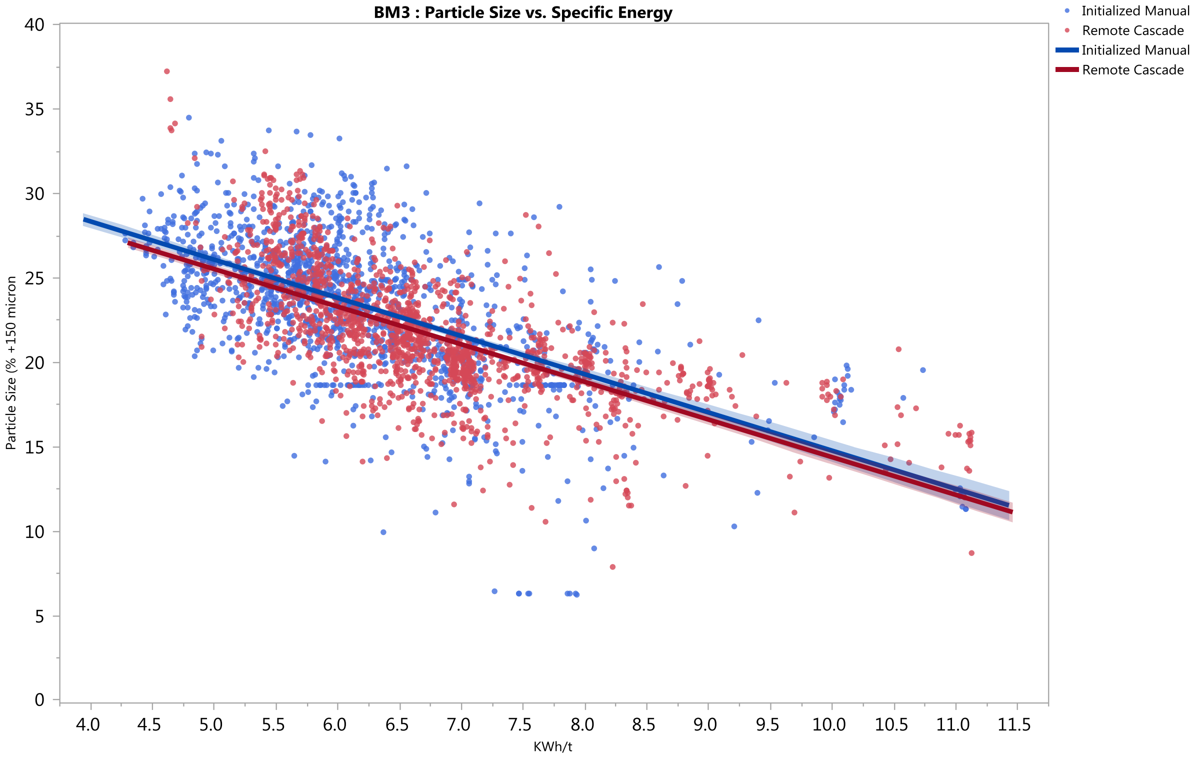

Figure 17 - Ball Mill 3 Particle Size vs. Specific Energy by Control Mode

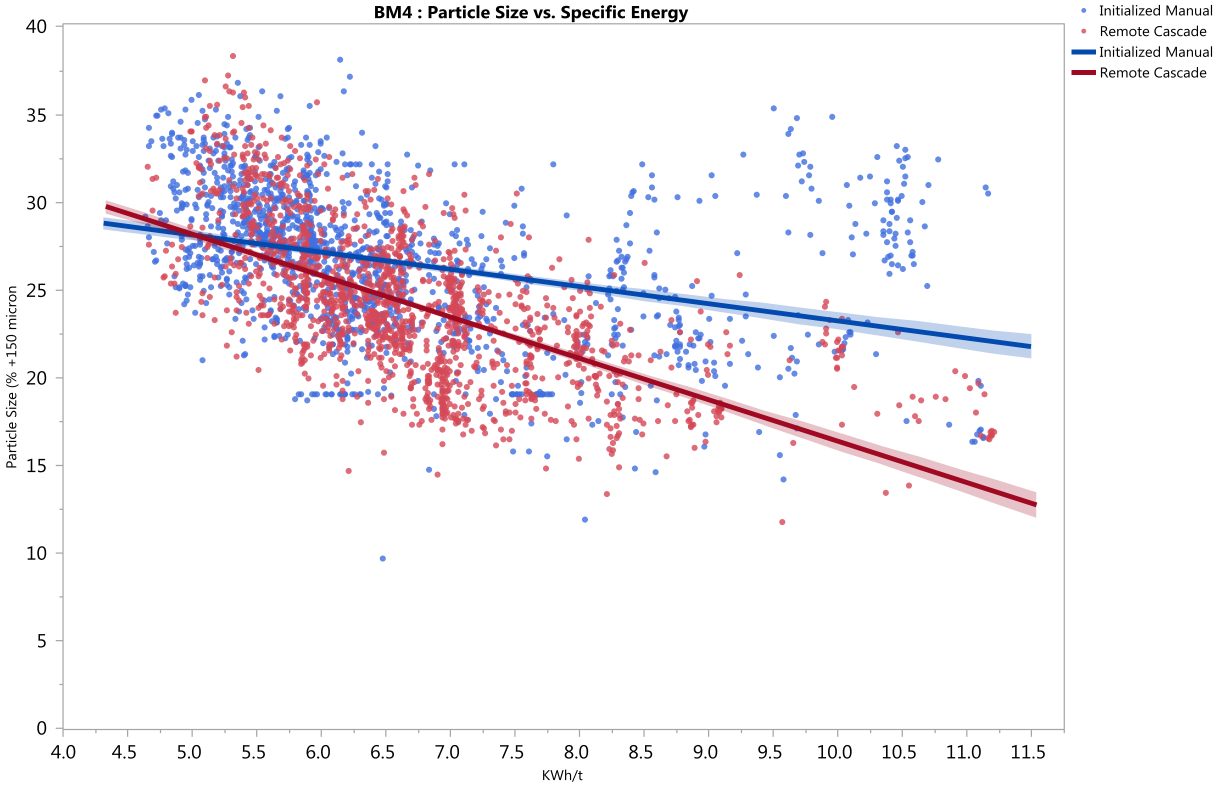

Figure 18 - Ball Mill 4 Particle Size vs. Specific Energy by Control Mode

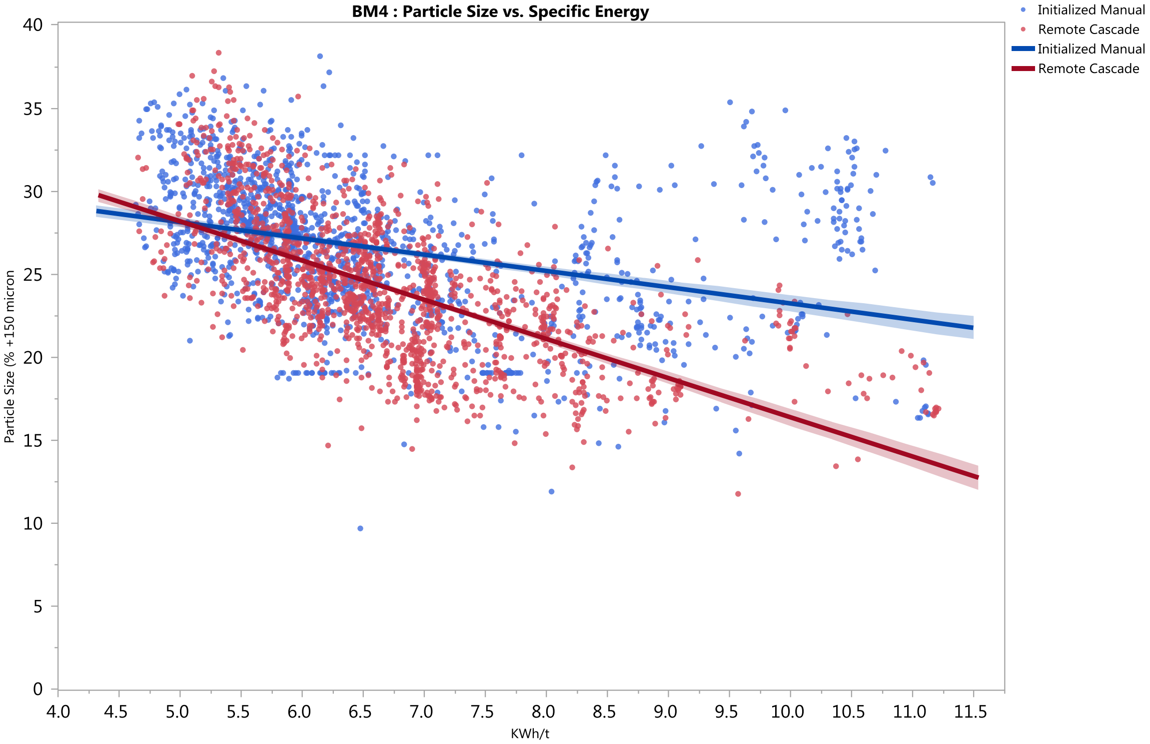

Figure 19 - Ball Mill 5 Particle Size vs. Specific Energy by Control Mode

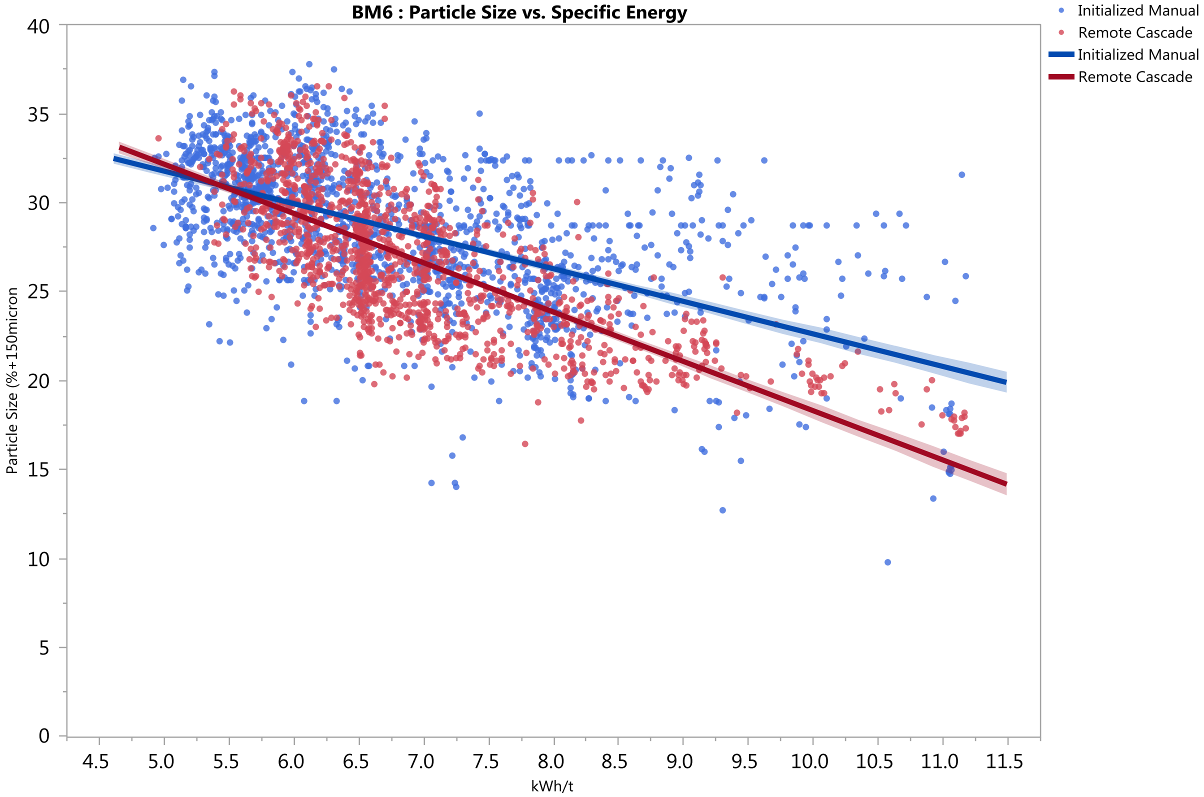

Figure 20 - Ball Mill 6 Particle Size vs. Specific Energy by Control Mode

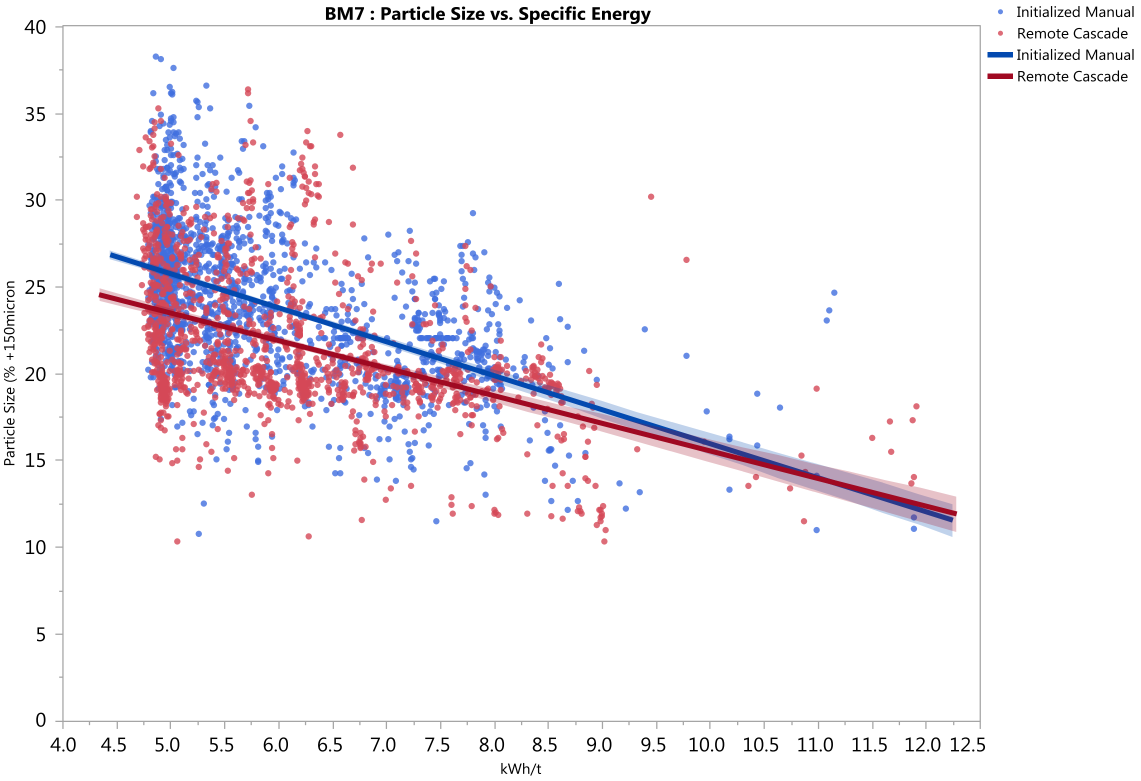

Figure 21 - Ball Mill 7 Particle Size vs. Specific Energy by Control Mode

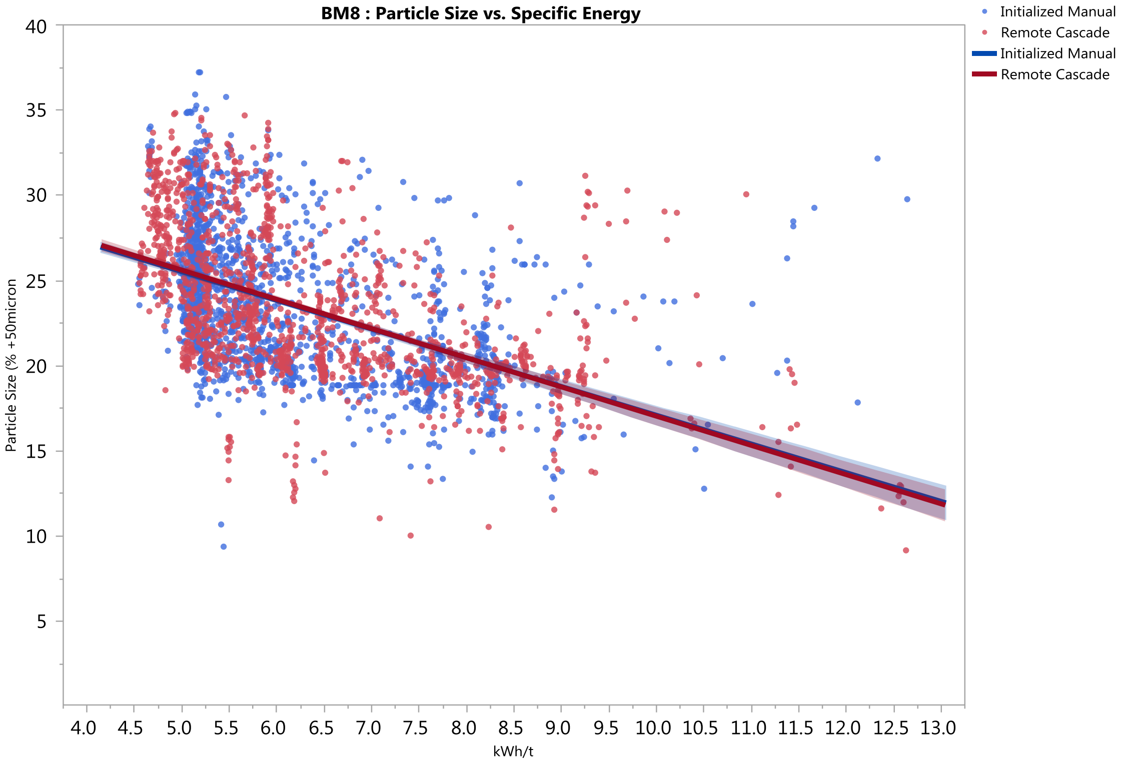

Figure 22 - Ball Mill 8 Particle Size vs. Specific Energy by Control Mode

CONCLUSIONS

Rio Tinto Kennecott has implemented a new control strategy in the ball mill circuit using new particle size measurement technology. The strategy was developed over a 3 months period and adopted rapidly by the operations staff. The hierarchical nature of the control scheme design, as well as incorporation of automatic constraint controls had resulted in 80 to 90 percent utilization of the control scheme. Plant data has shown the following performance improvements:

- 10 percent higher throughput at the same particle size
- four and a half percent over 150 micron lower particle size at same throughput
- 0.95 kwh/t reduction in specific energy consumption at the same particle size

ACKNOWLEDGEMENTS

The CiDRA/Rio Tinto Kennecott development team acknowledges the cooperation of concentrator operations team during the development, deployment, and operational phases of this work. The rapid adoption was key to capturing immediate value to the business. The joint development team would also like to thank the concentrator management for their constant support throughout the project. This support is critical to establishing a solution that will bring long term sustainable value capture for the business.

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