A SUMMARY OF ENERGY EFFICIENCY OPPORTUNITIES FOR THE RED CHRIS COMMINUTION CIRCUITS

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Abstract

A comprehensive energy study was carried out for the Red Chris mill, which processes copper-gold ore at a rate of 30,000 tonnes per day (t/d) and is located in Northern British Columbia. The study focused on identifying opportunities for energy conservation in the semi-autogenous grinding (SAG)-ball mill and regrind circuits. Mill surveys were carried out to calibrate mill models, such as those in JKSimMet, for simulation of alternative operating scenarios. Energy benchmarking methods were used for all circuits, including a Vertimill regrind circuit, to evaluate nominal energy performance and compare circuit configurations.

For the SAG and ball mill circuits, considerable flexibility in the material handling system allowed alternative flowsheets to be assessed. Evaluated energy conservation measures included implementation of SAG mill charge monitoring technologies to allow for mill speed reduction, diversion of pebble crusher product to the ball mill circuit, sensor-based sorting of pebble crusher feed, and modification of media sizes.

The regrinding circuit consists of a grate-discharge ball mill and a Vertimill, which is operated with a separating tank. Circuit surveys and energy benchmarking through use of an Eliason laboratory stirred mill test showed that the Vertimill separating tank was ineffective as a size classifier. Overall, the paper presents a summary of energy benchmarking efforts and evaluation of identified energy conservation opportunities.

Keywords

Crushing, grinding, SAG mill, ore sorting, Vertimill, MillSlicer™, separating tank

Introduction

The Red Chris copper/gold mine is located in northwest British Columbia and has been operating since 2012. Energy studies for the SAG-ball mill circuit and regrind/flotation circuits were carried out in 2018/2019 to identify opportunities for energy conservation and improving production performance. A summary of the key findings is presented in this paper.

The SAG and ball mill circuits are responsible for 59% of mine-wide electrical energy consumption, equating to 195 GWh of annual consumption. The regrind and flotation circuits account for 16% of mine-wide electrical energy consumption. Overall, the two studies addressed the majority of Red Chris mine electrical use. A breakdown of energy consumption for each processing area is shown in Figure 1.

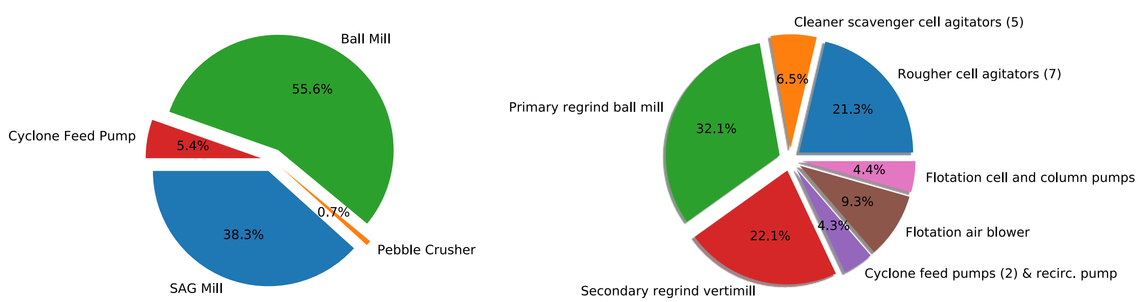

Figure 1 – Proportion of Electrical Energy Used by Main Equipment in the Primary/Secondary and Regrind Circuits

The Red Chris deposit displays characteristics of both alkalic and calc-alkalic porphyry copper deposits (Imperial Metals, 2012). The deposit is mined using conventional open-pit mining methods. At the time of the study, open-pit activities were focused on the Main Zone. Metallurgical tests indicated an average Bond ball mill work index of 14.8 kWh/t for Main Zone material, with a range of 11.5 to 16.6 kWh/t (Imperial Metals, 2012).

DESCRIPTION OF THE SAG AND BALL MILL CIRCUITS

A conventional SAG and ball mill circuit (SABC) is used to treat material at a production rate of 30,000 t/d. The primary crusher product, having an 80% passing size of ~90 mm, is crushed and ground by the circuit to an 80% passing size of ~150 µm, after which it reports to rougher flotation. A diagram of the SAG and ball mill circuit is shown in Figure 2.

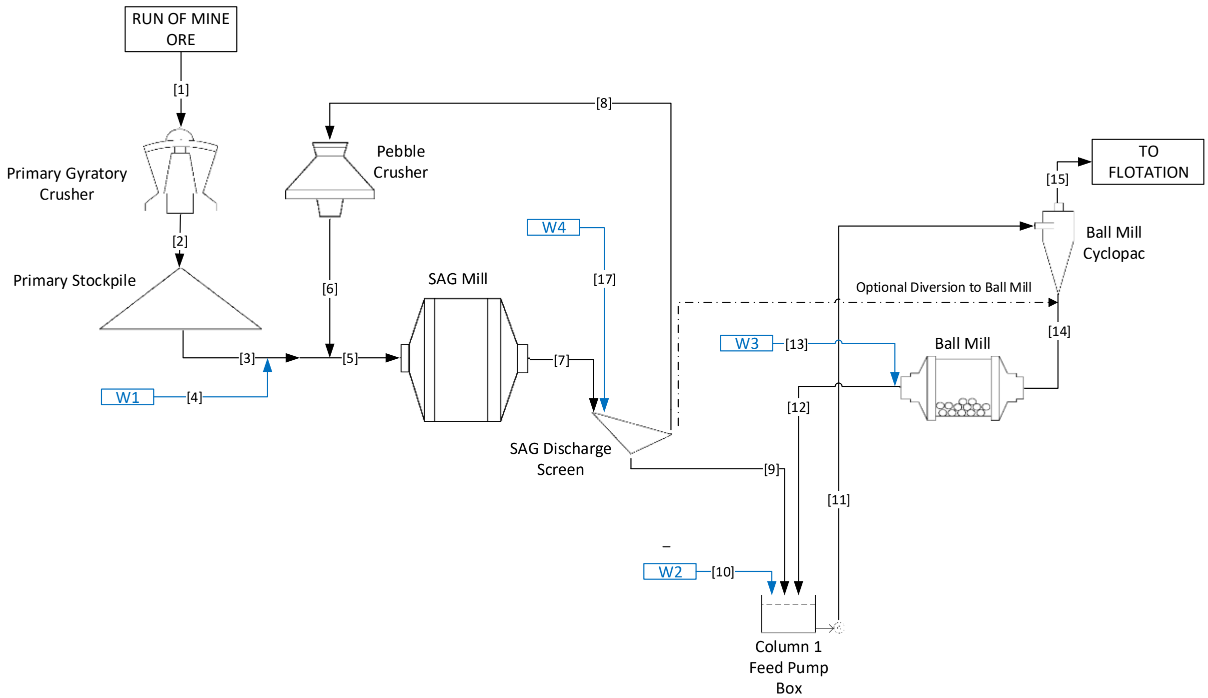

Figure 2 – SAG and Ball Mill Grinding Flowsheet

The SAG mill grinding circuit includes a 34 ft x 15.25 ft SAG mill operated with a 10.5 MW variable speed drivetrain. SAG mill product is screened at ~12 mm; oversize is conveyed to the pebble crushing circuit operating with one HP800 cone crusher. Screen undersize is pumped to the downstream ball mill grinding circuit. Ball mill cyclone overflow is sent to the first stage of rougher flotation.

The 24 ft x 42 ft overflow ball mill is operated with a variable speed drive and has a rated capacity of 13.4 MW. Based on fresh feed and cyclone feed rates from distributed control system (DCS) instrumentation, it is typically operated at circulating load of ~480%. The top size of ball mill make-up media is 3" and typical media loading is 36% by mill volume.

The material handling system provides for considerable flexibility in the circuit. Alternative processing options can be engaged within a 30-minute period and includes diversion of pebble crusher product to the ball mill feed stream.

DESCRIPTION OF THE REGRIND CIRCUITS

The two-stage flowsheet configuration typically used at Red Chris is shown in Figure 3. The first stage of regrinding is carried out by a grate-discharge ball mill, which is charged with 1" grinding media. It is driven by a 2.2 MW fixed-speed drivetrain at 14.6 rpm (69% of critical speed).

The second stage of regrinding is carried out by a VTM-1500 Vertimill, which is top-fed and operates with a separating tank (serves as a size classifier). Tank sinks (coarse particles) are fed to the bottom of the Vertimill and the tank floats (fines) float out of the top of the tank and are pumped back to the Vertimill cyclopac. The screw agitator is driven by a 1.1 MW fixed-speed drivetrain. A dart valve on the separating tank allows for level control and tank isolation.

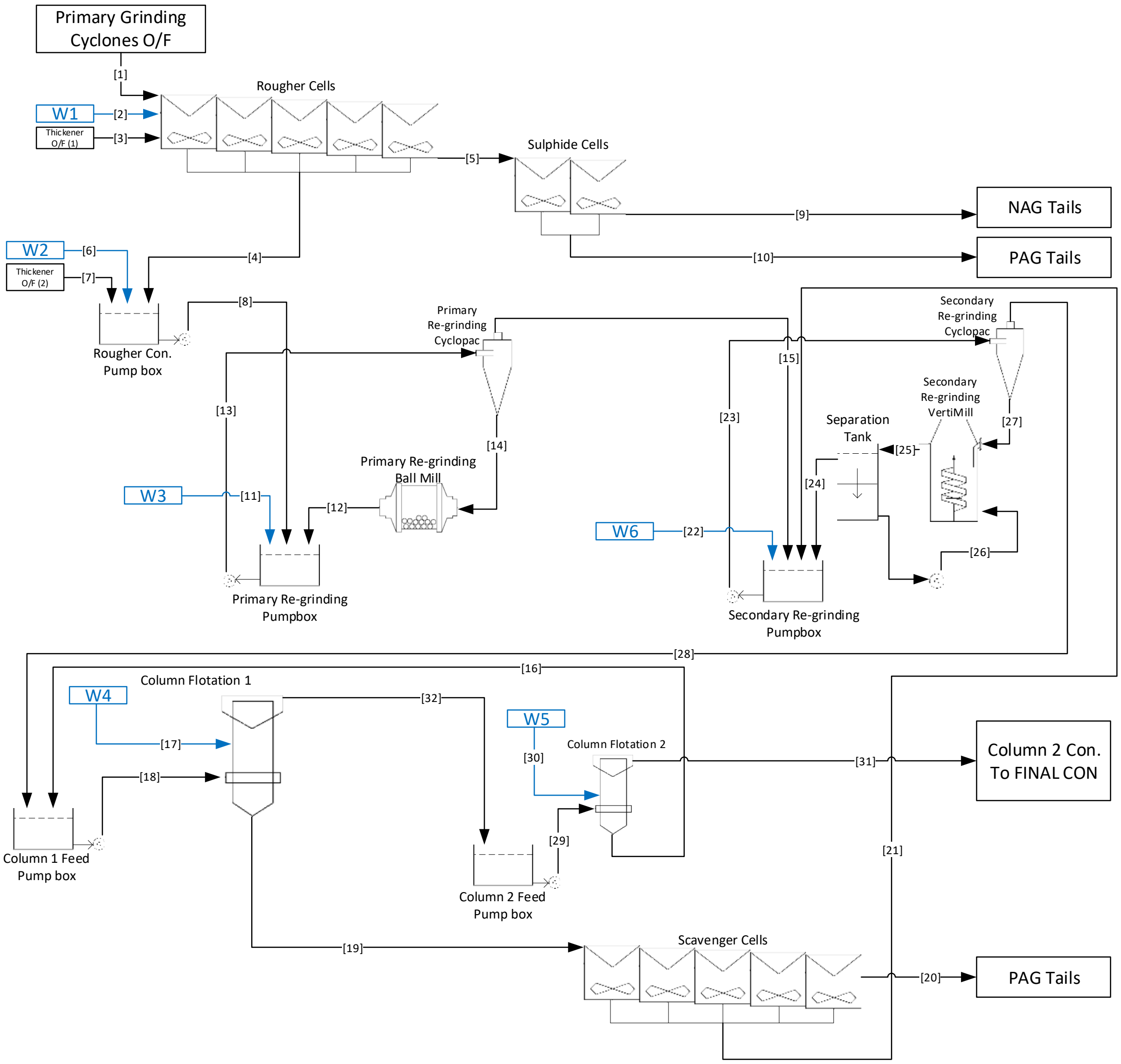

Figure 3 – Flotation and Regrind Flowsheet

Circuit Performance

SAG CIRCUIT PERFORMANCE

Results from the mill survey and metallurgical testing were used to assess energy utilization of the Red Chris SAG and ball mill circuit. The "Morrell method for determining comminution circuit specific energy and assessing energy utilization efficiency of existing circuits," published by the Global Mining Guidelines Group (2016), was applied. The calculations, presented in Table 1, showed that the expected specific energy consumption for the circuit was 13.5 kWh/t, based on the measured ore hardness, feed size, and product size. A specific energy consumption of 14.9 kWh/t was measured for crushing and grinding equipment while accounting for drivetrain losses (as described by the method).

Table 1 – Morrell Calculations for Assessing Energy Utilization

Morrell Method for Determining Comminution Circuit Specific Energy		Unit	Value
Ore Properties	Fresh feed rate (solids)	t/h	1,358
	Fresh feed size, F_{80}	Mm	89
	Final product size, P_{80}	µm	168
	A x b		66.7 x 0.72 (48)
	DWi	kWh/m^3	5.80
	BBWi (150 µm closing screen)	kWh/mt	13.55
	BBWi, net product	g/revolution	1.70
SAG Mill	Measured power draw at VFD input	kW	9,001
	Power draw at pinion	kW	8,214
Pebble Crusher	Throughput, dry	t/h	204.3
	Pebble crusher feed, F_{80}	mm	60.2
	Pebble crusher product, P_{80}	mm	18.6
	Survey power draw	kW	167
	No load power	kW	~75
Ball Mill	Survey power draw at VFD input	kW	13,055
	Power draw at pinion	kW	11,914
SMC Calculations	Coarse particle tumbling specific energy, W_a	kWh/t	8.21
	Fine particle tumbling specific energy, W_b	kWh/t	5.15
	Pebble crushing specific energy, W_c	kWh/t of fresh feed	0.12
	Total Predicted Specific Energy	**kWh/t**	**13.48**
Red Chris Performance	**Red Chris Specific Energy**	**kWh/t**	**14.89**

BALL MILL CIRCUIT PERFORMANCE

The efficiency of the ball mill circuit was evaluated using a method published as "Determining the Bond Efficiency of industrial grinding circuits" by the Global Mining Guidelines Group (2016). Results presented in Table 2 show that the Red Chris ball mill circuit was operating at 88% of the energy efficiency of a standard Bond circuit. It is important to note that cases have been reported where the Wi efficiency ratio exceeds 100%, i.e., circuit performance has a higher efficiency than the Bond standard. The Wi efficiency ratio is a useful metric that can be referenced when carrying out future surveys to gauge changes in circuit performance.

Table 2 – Bond Efficiency Calculations for Assessing Ball Mill Circuit Efficiency

Parameter	Unit	Value
Fresh feed rate (solids)	t/h	1,358
Screen undersize, F_{80}	µm	2,453
Final product size, P_{80}	µm	168
Measured power draw	kW	13055
Assumed drivetrain efficiency at VFD input	kW	0.913
Power draw at pinion	kW	11914
Bond ball mill work index, Wi	kWh/t	13.55
Operating work index, Wi_{oACT}	kWh/t	15.40
Wi Efficiency Ratio	**%**	**88.0**

REGRIND CIRCUIT PERFORMANCE

The Eliason test mill at ALS Metallurgy was used to benchmark the grinding performance of the regrind ball mill and Vertimill. The Eliason mill measures an internal diameter of 4" and a height of 6" and has an impeller with a series of rings at various positions down a central shaft (similar to an engine camshaft) (Johnston, 2014). The impellor is mounted in a drill press that runs at 1,700 rpm. A power meter is used to measure the power draw during testing and when the mill is empty so that the net specific energy consumption can be determined for each test run.

Rougher flotation concentrate samples, representing the fresh feed to the regrind circuits, was used for Eliason testing with 2.2 mm diameter media. Splits of 100 grams (solids) were processed at different processing times to determine the specific energy versus product size (P_{80}) curve for each sample (also referred to as a signature plot). The Eliason test proved to be a useful benchmark for gauging the performance of the regrind circuits, as it incorporated feed size, product size, and the hardness associated with each grinding duty.

The Vertimill specific energy consumption was 1.5 to 2.2 times more than the Eliason mill for the same grinding duty, depending on the grinding configuration used. Table 3 shows the Vertimill circuit survey results for the different configurations operated.

Pease (2010) published a summary of tower mill operations showing that for P_{80} product sizes of approximately 30 µm to 33 µm, operations were reporting operating work indices of ~25 to ~42 kWh/t. This is in line with the Red Chris Vertimill operating work indices of 31 to 43 kWh/t.

The Vertimill media load was measured to confirm that the Vertimill draw was appropriate. Based on the media bulk density and charge height (measured using a sinker and line being fed through the media filling pipe), the load was estimated at 123 tonnes. The power draw at the time of measurement was 1019 kW. This is consistent with a power curve from Hasan (2016) showing that Vertimill power draw (kW) is approximately equal to the media load in tonnes divided by 0.122, which would predict a power draw of 1008 kW for the media load used.

Table 3 – Comparison of Regrind Performance for Two-stage Operation

Configuration and Survey ID	Unit	Two-Stage #2 (Base-case)	Two-Stage #1	Two-Stage #3, No-Sep. Tank
Feed Properties				
Specific gravity		3.52	3.71	3.47
Rougher mass pull	t/h	128	135	115
Vertimill fresh feed	t/h	157	166	140
Vertimill circuit fresh feed	F_{80} µm	41	39	41
Vertimill circuit final product	P_{80} µm	33	33	30
Vertimill power draw	kW	917	956	1,119
Vertimill specific energy	kW/t	5.8	5.8	8.0
Operating work index	kW/t	32.5	43.0	31.3
Required lab mill (Eliason) energy	kW/t	3.7	3.22	5.0
Ratio of Vertimill to Eliason mill energy*	%	146	167	151

Note: *Lab mill specific energy was calculated for the equivalent circuit product size using the Eliason test. Actual rougher concentrate from each survey was used as test feed

Energy Efficiency Opportunities

MILLSLICER™

In 2017, Minpraxis Solutions carried out an initial study for the SAG mill. Review of operational data showed that the variable speed system on the SAG mill was rarely used due to operators being concerned about the SAG mill overloading. A recommendation of the study was to implement a system for online monitoring of mill charge levels. The MillSlicer™ system, developed by Digital Control Lab, was chosen for implementation. It uses vibration sensors mounted on the mill shell and both inlet and discharge bearing housing. The system was installed and commissioned in July 2018. A screenshot of MillSlicer™ outputs being observed by operators is shown in Figure 4.

Key outputs of the MillSlicer™ system are:

- The angle of mill charge (red line in the rotational energy plot)
- Impact energy on the shell (blue line in the rotational energy plot)
- Liner damage level (LDL) – a metric that represents the total energy absorbed by the shell liners
- Inlet, shell, and outlet fill levels. Changes in these values can be used to infer a mill filling or mill emptying condition. Reported fill levels are relative to the fill level used during calibration.

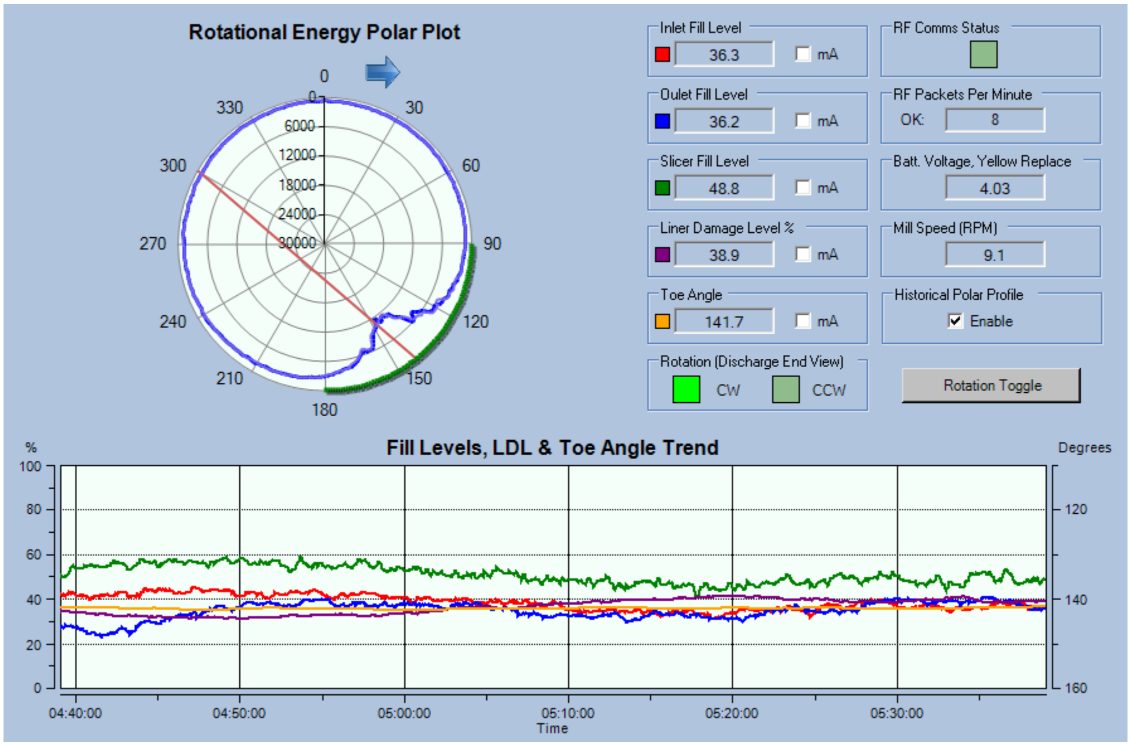

Figure 4 – Operator Display of MillSlicer™ Outputs

Soon after commissioning, mill operators reported at least one instance where the MillSlicer™ system had prevented a mill overload. By observing the vibration levels and toe angle at the shell, it is clear whether media is impacting the charge or shell liners. To improve operator confidence in adjusting mill speed, fragmentation cameras are being considered for the mill feed conveyor.

DIVERSION OF CRUSHED PEBBLES TO THE BALL MILL CIRCUIT

The impact of diverting crushed pebbles from the SAG circuit to the ball mill circuit using the existing material handling system was investigated using fitted JKSimMet models.

A similar circuit configuration, where crushed pebbles were sent to the ball mill, was used at the Edna May configuration (Dance et al., 2014). Trials following modification of the material handling system (for diversion of crushed-pebbles to the ball mill) showed that approximately 10% improvements in throughput were achieved at the expense of a coarser ball mill cyclone overflow size and ball mill circuit stability (which was later resolved).

For the Red Chris simulations, the influence of ore hardness was also incorporated by simulating circuit performance with ore that was 30% softer and 30% harder than the material sampled during the survey and treated as nominal ore. For SAG milling, A and b numbers were modified proportionally to provide Drop Weight Index (DWi) values, an additive parameter, that were ±30% of the nominal ore. A similar approach was used for the Bond ball mill work index. For all simulations, the target P_{80} grind size of 168 µm was maintained.

Results from simulations were consistent for all three hardness scenarios. Improvements in fresh feed throughput and overall circuit power were negligible (<2%); Full diversion of pebbles reduced pebble circulation by 14%.

The existing diverter in the material handling system can be engaged within 30 minutes. Upgrading to fast acting (~30 seconds) diverter was estimated to cost approximately $100,000. A fast-acting system would allow for additional control over the SAG-ball mill circuit. Engagement/disengagement would occur when the SAG mill volume is increasing (as indicated by MillSlicer™) and the pebble circuit is close to its maximum 350 t/h throughput rate.

PEBBLE SORTING

A scoping level pebble-sorting study was carried out using a static X-ray Fluorescence (XRF) unit. Assay results did not indicate a difference in grade between pebbles and fresh feed. Results showed that 50% of pebbles could be rejected while achieving 80% copper recovery. The preliminary cost calculations showed that losses in copper and gold in the sorting plant would outweigh the throughput and operating expenditure (OPEX) benefits of the rejected pebble stream.

BALL MILL MEDIA SIZE

The greatest improvement in energy performance was associated with reducing the size of ball mill make-up media from 3" to 2.5". By changing the size of make-up media, ball mill power draw was estimated to reduce by approximately 21% through slowing down of the mill (with the existing variable-frequency drive [VFD]) while maintaining grind size. The improvement is greater than the error of ±10% associated with the simulation method. Similar improvements in energy performance were found when simulating ores that were 30% softer and 30% harder than the nominal ore that was collected during the survey. The reduction in media size is also supported by media sizing guidelines of Bond (1958) and Azzaroni/Molycop (Giblett and Putland, 2019). Both equations refer to mill speed, mill hardness, mill diameter, feed size, and the specific gravity of feed.

The results of the full circuit simulations for 30% softer and 30% harder ore were used to compare the current media size to the recommended sizes resulting from the equations of Bond and Azzaroni/Molycop. Figure 5 shows that for all cases, the current media size of 3" is larger than the recommended size of both equations. As a third method, ball mill media size was varied within the JKSimMet package to identify the media size that provided the best ball mill energy performance. Within JKSimMet, 2" media provided the best results for the three ore types simulated.

Based on the comparison shown in Figure 5, trials using a make-up ball size of 2.5" were recommended. Currently, ~20% of ball mill media is composed of recycled SAG mill media. It is expected that ball mill energy performance will still improve if newly sourced media is switched to a size of 2" or 2.5" and use of recovered 3" media continues.

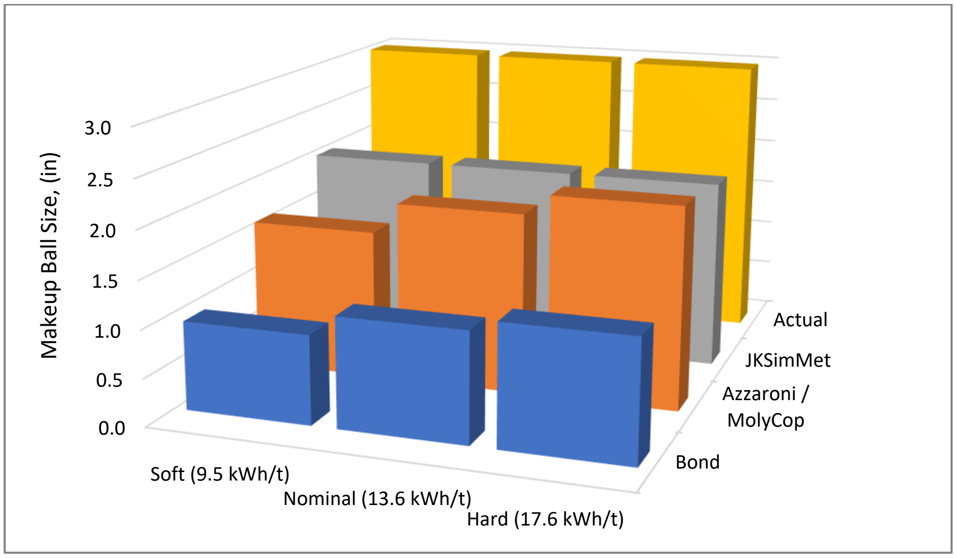

Figure 5 – Recommended Make-Up Ball Sizes Based on Methods Used for Three Different Ore Hardnesses

To compare ball milling efficiency for different media sizes, the ball mill performance of five different operations was compared to the ratio of the media size used and the recommended media size from the Azzaroni calculation method (see Figure 6). Additional survey data would help clarify the usefulness of the media sizing method. The comparison does show that there is potential for improving Red Chris ball mill performance by more than 10% (in terms of operating work index).

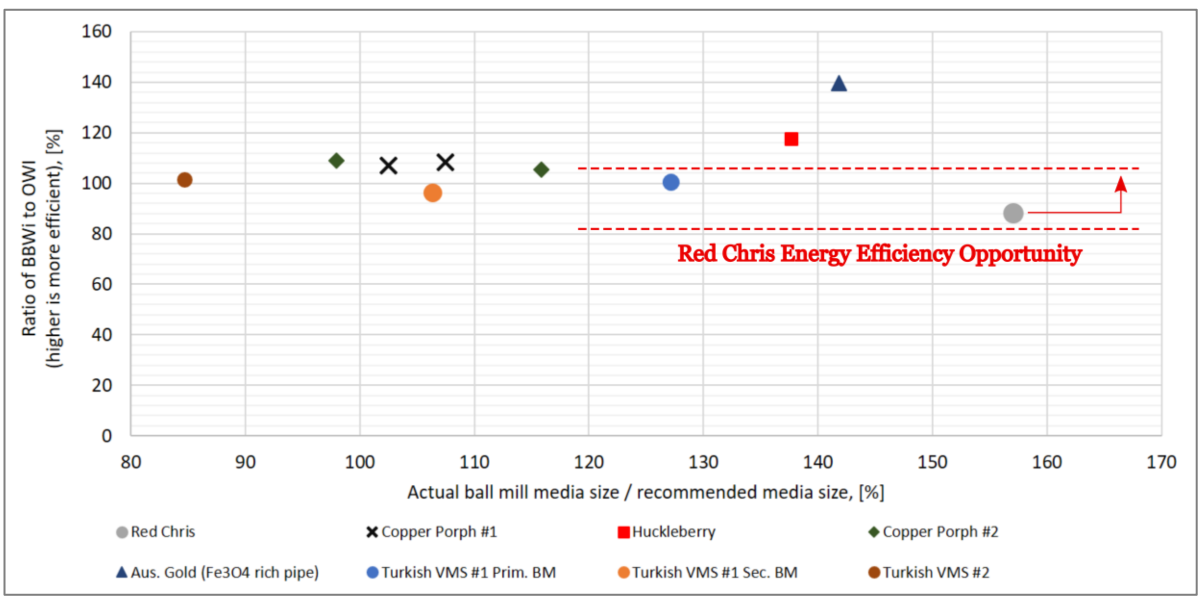

Figure 6 – Work Index Efficiency Ratio (BBWi/OWi) and the Actual Ball Mill Media Size Divided by the Recommended Media Size Based on Azzaroni's Equation

VERTIMILL

Surveys of the Vertimill circuit indicated that the separating tank was not working effectively as a size classifier; size distributions of the coarse and fines streams were almost identical for three circuit surveys. Similar results were found at another Canadian copper-gold regrind application. Napier-Munn (1996) reported that the separating tank installed with most tower mills is unnecessary and can be removed, with a consequent savings in pumping costs. Figure 7 shows the VTM-1500 Vertimill and the separating tank.

Figure 7 – Vertimill and Separating Tank

Classification within the separating tank is assumed to rely on an adequate slurry flow speed to send larger (and faster settling particles)to the sides of the tank while finer (and slower settling particles) report to the inlet of the fine discharge pipe, which is located at the upper-centre section of the tank (shown in Figure 7, right picture). During mill surveys it was found that material was building up at the edges of the separating tank and reducing its effective volume. This was reported as an ongoing issue by mill operations. Similar material build-up was found for the other mentioned regrind applications.

An additional Vertimill survey was carried out with the separating tank isolated (through the closure of a dart valve). To compare the energy performance of the circuit with and without the separating tank, the actual Vertimill specific energy consumption was divided by the specific energy required by the Eliason stirred mill to generate the same product size (using the rougher concentrate that was sampled for each survey). Without the separating tank engaged, the ratio of Vertimill to lab mill specific energy was 151%, while 146 and 167% were observed for the two other surveys where the separating tank was operating. The results confirmed that the separating tank can be switched off without affecting circuit operation.

Since completion of the study, the Vertimill has been operated with the separating tank isolated. No adverse consequences in circuit performance have been observed by operators. This has also freed up maintenance time associated with cleaning of the separating tank and servicing of the recirculation pump.

Seeing as the Vertimill is currently operated in top-fed configuration, the grinding of coarser components now relies on coarser particles settling into the grinding zone of the Vertimill. Further improvements in Vertimill grinding efficiency are expected by changing to a bottom-fed configuration. Palianandy et al. (2019) carried out a similar modification at the Karara mill, where a top-fed tower mill operating with a separating tank was switched to a bottom feed configuration with the disengagement of the separating tank. Palaniandy et al. (2019) reported that the operating work index and size specific energy consumption improved as a result of the modification.

Trials with smaller media (than the current ¾" media) may also yield improvements in circuit efficiency. Metso, the Vertimill supplier, advised that finer media can be used; however, the percent solids of mill feed (cyclone underflow) may need to be lowered to a range of 50% to 60% to avoid the loss of media to the discharge. Survey results showed that the percent solids of cyclone underflow ranged from 64% to 67% solids when the regrind circuit was operated in a two-stage configuration. During trials, the ejection of media would need to be monitored and water addition to the cyclone feed pump box adjusted if necessary.

Discussion and Conclusions

The Red Chris energy performance studies were successful in identifying opportunities for improving both energy and operational performance of the Red Chris mill. In particular, the MillSlicer™ system has been useful for averting SAG mill overload incidents and could be tied into the control system for mill speed control.

The Morrell method for determining comminution circuit specific energy was found to be an effective tool for energy benchmarking of the SAG and ball mill circuit. Bond efficiency calculations were convenient for tracking improvements in ball mill circuit performance. It is envisaged that both methods will be used in the future for gauging improvements in mill performance.

The performance of the Vertimill circuit was successfully measured using the Eliason stirred mill test for a range of configurations. Results of the regrind benchmarking method provided operators with the confidence to isolate the separating tank. Should the Vertimill be converted from a top-fed to a bottom-fed configuration, energy evaluation with the Eliason test can be used to evaluate the change in circuit performance.

The greatest improvements in energy performance were associated with a reduction of the ball mill media size from 3" to 2.5". Simulations indicated that ball mill power draw can be reduced by approximately 21% if the media change is carried out and the ball mill is slowed down to maintain the current grind size. Alternatively, improvements in energy performance can be utilized in the form of increasing production rates and/or improving final grind sizes. A comparison of ball mill performance for Red Chris and other operations confirmed that there is scope for improving ball mill energy performance.

Simulations for the case where crushed pebbles are diverted to the ball mill circuit did not indicate that overall energy performance can be improved.

The current regrind product size targets are attainable with current Vertimill configuration. However, should Red Chris be looking to expand the cleaning circuit and increase mass pulls, improvements in regrind efficiency will be particularly important for maintaining target grind sizes.

Acknowledgements

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