Whitepaper
Mill Optimisation

Increased throughput from liner design initiatives in the Aktogay 40 ft sag mill

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Abstract

The Aktogay Mine is a large open pit mine located in southeastern Kazakhstan in East Kazakhstan province approximately 250 kilometres (km) from the Kazakhstan – China border. Aktogay is KAZ Minerals' second major growth project. The Aktogay orebody consists of an oxide deposit on top of a larger sulphide deposit, the latter containing some valuable molybdenum as a by-product. The Aktogay project has a measured and indicated oxide ore resource of 74 million tonnes (Mt) with a copper grade of 0.37%, and a sulphide ore resource of 1,558 Mt at a copper grade of 0.33%. The sulphide ore extracted from the Aktogay Mine is processed at the concentrator on site with a production life of over 50 years (to be shortened to c.28 years after the construction of the second concentrator, which is underway). The first concentrator was commissioned in late 2016 with a 40 ft diameter x 26 ft long semi-autogenous grinding (SAG) mill and two 28 ft diameter x 44 ft long ball mills supplied through FLSmidth.

The 40 ft SAG mill was supplied with a traditional bi-directional OEM lining system manufactured from chrome molybdenum steel and liners were installed utilising a 4,500 kg RME 7-axis reline machine. Since mill start-up in December 2016, the SAG mill was monitored on a regular basis to determine liner performance and wear patterns to understand the critical areas of the mill lining that were driving maintenance relines. During the first two sets of OEM liners, the tonnes increased from 2,034 t/h to 2,343 t/h, but remained well short of the target name plate 3,102 t/h.

During 2017, through a continuous improvement program, potential improvements to the liner system were identified that could increase mill performance as well as address high wear areas of the liners that were driving liner replacement. A decision was made to investigate and carry out Discrete Element Modelling (DEM) on the benefits of converting the SAG mill to a Uni-directional mill and take advantage of the Bradken Vortex discharge system, whilst customising the feed end of the mill lining to improve wear performance and maximise reline efficiencies. A Uni-directional shell liner design has been initiated for phase two of the transformation to be implemented in 2019.

The SAG mill was relined in April 2018 incorporating the new design enhancements. These initiatives also included a 15% reduction in the quantity of liners installed which delivered an immediate improvement in mill availability. The first three months of operation after installation of the Bradken Vortex discharge system resulted in mill throughput increasing by 28.5% from 2,343 t/h to an average of 3,012 t/h. Further reduced wear and mill uptime benefits are expected to be realised over time as a result of utilising premium materials in the manufacture of certain products during the liner redesign. Introduction of the advanced 3D liner wear monitoring and reporting package is also expected to deliver data that will be used to improve liner profiles and life cycles. The 3D data captured during the highly accurate terrestrial laser mapping process is used to engineer the next generation liner design.

The paper outlines the approach used to identifying and implement design changes used in the optimisation of the Aktogay 40 ft SAG mill lining system and summarises the operational performance improvements realised and the future design initiatives being investigation.

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Keywords

Straight Radial, Bi-directional, Backflow, Super Vortex, Uni-directional, Feed End, Shell, Discharge end, BULLNOSE.

Introduction

KAZ Minerals' Aktogay Mine is the one of two largest copper mines in Kazakhstan and is situated north-east of Almaty city.

The Aktogay mine currently operates one milling train, with the grinding circuit treating around 70,000 t/d (as designed) and comprises a primary 63" x 114" TS Fuller Traylor Gyratory crusher, a primary 40 ft diameter x 26 ft long FLS SAG mill with two secondary 28 ft diameter x 44 ft long FLS Ball mills, High Pressure Grinding Rolls (HPGR), and two XL1100 Raptor pebble crushers. The entire grinding circuit is closed with hydro cyclones with the coarse underflow recirculated back into the grinding circuit and the finer overflow reporting to the flotation circuit giving a product with P80 of 180 µm.

The Aktogay 40 ft FLS manufactured SAG mill has a variable speed drive (VSD) ring motor with a total installed power of 28 megawatts (MW). The mill was lined in late December 2016 with a traditional OEM radial bi-directional liner system manufactured from chrome molybdenum steel and commissioned during the early months of 2017. The first set of OEM liners produced 8.52 Mt through commissioning, with the second OEM set of liners ramping up to 9.96 Mt.

The paper outlines a basic, but simple approach and the benefits of having the key stakeholders collaborate and focused on using advanced methods and technologies to identify and incorporate mill liner design initiatives to maximise the performance of key critical equipment. Here we have shown the benefits focused on the large 40 ft SAG mill at Aktogay to not only optimise the mill lining in the mill, but to achieve the KPI milestones in operating performance, maintenance improvements, reline safety, and future design initiatives.

Figure 1 – Aktogay Concentrator and Camp

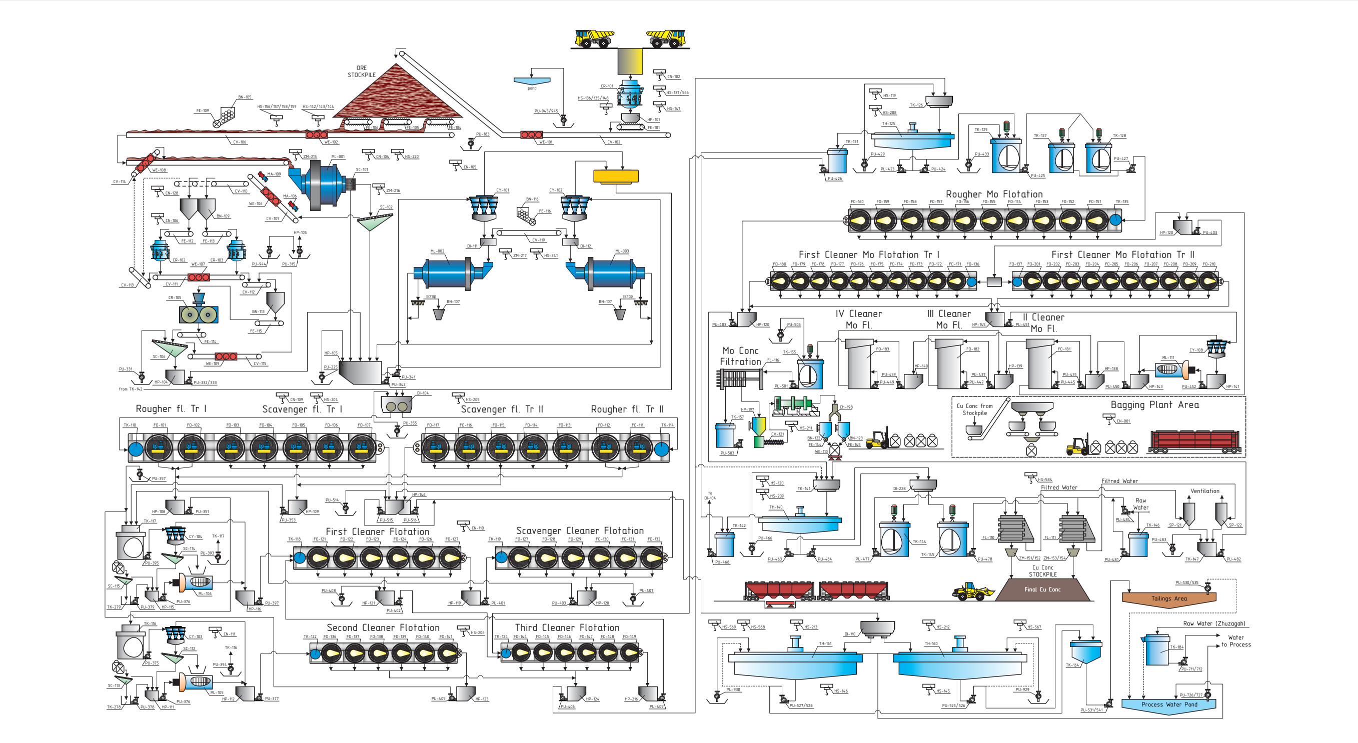

Figure 2 – Aktogay Flowsheet

Table 1 – SAG Mill Operating Data

Data Description	Unit	Design Data
Grinding circuit configuration		SABC
SAG mill circuit		
No. of mills	#	1
SAG mill motor power installed	kW	28,000
Motor type		Gearless
Mill manufacture		FLSmidth
SAG mill dimensions	diameter length	40 ft (12,192 m) 26 ft (7,924 m)
Mill direction		Bi-directional
Mill speed – range	% critical	0-80
Mill speed – nominal	% critical	76
SAG mill specific energy	kWh/t	6.6
Grinding media	Mm	125
Ball loading – expected operating	%	12
Ball loading – maximum process design	%	16
Total charge – expected operating	%	25
Total charge – maximum processing design	%	35
Grate discharge	mm	63
Discharge % solids	wt%	72
SAG mill discharge screening		
Stage 1		trommel
Stage 2		double deck screen

Table 2 – Pre-Sampling Data

Parameter	Unit	Design Criteria	Sampled Collected from Mine Pit on 31-Oct-2017 TOM Laboratory
SG	g/cm3	2.66	2.69
Bulk density	t/m3	1.6	1.58 – 1.76
Abrasion index	g	0.30 (avg.)	0.3184
		0.36 (design)	
Crushing work index	kWh/t	7.69 (avg.)	4.83
		9.60 (design)	
Rod mill work index	kWh/t	22.2 (avg.)	
		24.7 (design)	
Ball mill work index	kWh/t	19.4 (avg.)	17.33
		20.9 (design)	

Background

The 40 ft SAG mill was supplied with a traditional bi-directional OEM lining system manufactured from chrome molybdenum steel with a total of 412 liners per set and a total liner mass of 773,931 kg. All the liners were designed and installed utilising a 4,500 kg 7-axis Russell reline machine. The SAG mill was inspected on a regular basis to monitor the change in liner design and identify wear patterns to gauge the mill performance as the circuit ramped up production over the first set of liners. The first commissioning set of liners were removed during September 2017 producing a total of 8,518,545 tonnes, at its peak average 2,034 t/h. A review of the first set of mill liners quickly identified areas in the liner design that would enhance the wear life of the liner set, increase discharge throughput efficiency, improve the mill reline times, focusing on reducing overall maintenance costs, whilst keeping safety at the forefront of all decisions, ultimately working towards achieving the original target tonnes.

Figure 3 – Aktogay Grinding Circuit

Table 3 – OEM Liner Set Detail Summary

Part Description	Material	Qty.	Total Mass (kg)
Feed end liners	CrMo	60	100,968
Shell liners	CrMo	180	390,540
Discharge end liners	CrMo	172	272,423
Total		412	773,931

Figure 4 – OEM Liner Set General Assembly

Issues Identified – OEM Liner Design

As is a common practice, the OEM mill is usually installed with a low cost, basic engineered liner design to get a new mill up and running for the initial warranty period. Lessons learnt can vastly improve a new mill installation as seen with the following examples. Issues can be eliminated using good first-up design practices and by investing early in an enhanced liner design to achieve good production tonnes as soon as the mill started up.

The following issues were identified relating to the OEM liner design which were leading to operational maintenance issues, and the inability to reach the desired name plate throughput tonnes.

1. High wear rates on the Feed End of the mill dictating the reline schedule

With limited knowledge of the wear rates during a new start-up of the mill and the ore being treated, it was quickly apparent that the Feed End middle liner and Feed End outer liner were wearing across the middle joint line from the eye of the operating charge volume. This led to both parts being changed out together leaving good wear material remaining on the inner edge of the Feed End middle liner and outer edge of the Feed End outer liner. The high concentrated wear zone on the joint of the two liners determined the reline date over the other liners in the mill and also the duration of the reline time. The high wear zone was monitored closely over monthly intervals to capture the accurate wear data between periods and recorded with an average rate of 20.41 mm/Mt of wear at end of life. The data was then fed into the design data in the next generation of liner design, as detailed in the Methodology.

Figure 5 – Feed End Liners showing High Wear Zone

2. Difficulty removing worn shell liners with no knock-in-holes available

The original OEM shell liner design was installed with four rings of double-wide shell liners along the length of the mill with a total quantity of 120 liners per set. The initial profile was a Hi/Lo liner design running parallel in thickness for the full length, consisting of thirty rows per ring, with thirty corner liners in each end of the mill. The double wide shell liner design with the maximum part unit mass of 3,286 kg was developed to reduce the quantity of liners to install in the mill whilst keeping within the safe lifting capacity of the 4.5T RME reline machine. It was quickly found during the first reline, the double-wide shell liners used all the bolt holes in the mill shell with no knock-in holes to assist with liner removal, adding considerable delays to the reline time in removing the first row of liners.

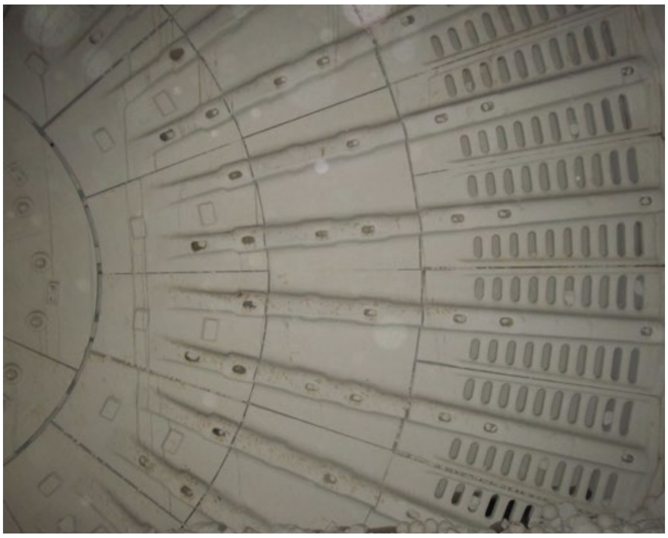

Figure 6 – Radial Discharge End Grate Design

3. High concentrated wear in the outer back corners of the Discharge End Outer pulp lifters

Nearing the end of life for the first set of discharge grates it was apparent that there was premature wear in the outer back corners of the Discharge End Outer pulp lifters (refer to Figure 7). The local concentrated wear zone was caused by back flow of coarse material not exiting the mill during each revolution. This phenomenon is typical of radial discharge grate mills with larger grate apertures. The high wear zone pattern in the back corners of the outer pulp lifters is a consequence of the Discharge Cone design during the final discharge of product, where the coarse material is restricted in time to exit from the mill and gets trapped by the long vane in the discharge cone during the rotation and flows back down the pulp cavity.

Figure 7 – High Concentrated Wear in the Discharge End Outer Pulp Lifter

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Methodology

A team was developed, to bring together the key stake holders and focus on the key drivers that would achieve the target outcome of 3,102 t/h.

- Maintenance teams
- Operations, processing, and metallurgy
- Mill liner supplier
- Mill reline company
- Mill reline machine manufacturer.

Collaboration between the parties enabled a structured approach to ensure each of the stake holders' key objectives are achieved in the most efficient, safe, and cost-effective manner. As each of the actions were developed, a risk review was undertaken to make sure each step didn't have an adverse effect in achieving the final goal or compromise key critical equipment.

Figure 8 – Schematic of Key Stakeholders

Discussion

Liner Design Initiatives

The focus of the new proposed liner design was to implement practical liner design enhancements that would drive the SAG mill performance to Aktogay's target of 3,102 t/h. The key criteria identified were to maximise the mill availability, improve the mill discharge efficiency of the mill and ensure safety was kept at the forefront of all design initiatives.

To maximise the mill availability, the focus was to limit the number of liners that required change out during each of the normal mid-term relines. This moved the attention to the liner design initiatives to cover the areas of high wear and minimise the number of liners in the mill to improve safe installation, thus reducing the time and movements within the mill and around the mill deck during the reline process. Less movements of liners leads to improved safety.

The approach was to focus on the areas of the mill that would provide sound payback in both mill performance and mill availability during the first liner change and also keeping in mind using up the existing stock of liners to prevent redundant liner material being wasted. The focus was addressing the high wear on the Feed End of the mill that was driving the reline schedule and secondly looking at improving the discharge efficiency of the mill to increase throughput tonnes. The redesign of the shell liners to their optimum profile was considered more valuable in the second stage of the liner design program, to best fit the impact, the changes have on the Feed end and Discharge end redesign in wear and charge movement within the mill.

The team focused its efforts to ensure the timing to finalise the new design and obtain customer sign off still allowed for delivery of product for installation after the initial two sets of OEM liners were installed.

The Stage 1 liner design initiatives achieved a reduction of liners from 412 in the OEM liner design to 358 in the new enhanced Stage 1 re-design, whilst maintaining a similar overall weight for the mill set of 773.9 T for the OEM design versus 771.2 T for the re-design by using composite materials in the Discharge Cone design.

Table 4 – Stage 1 Liner Set Detail Summary

Part Description	Material	Qty.	Total Mass (kg)
Feed end liners	CrMo	60	125,556
Shell liners	CrMo	180	390,510
Discharge end liners	CrMo & Composite	118	255,163
Total		358	771,229

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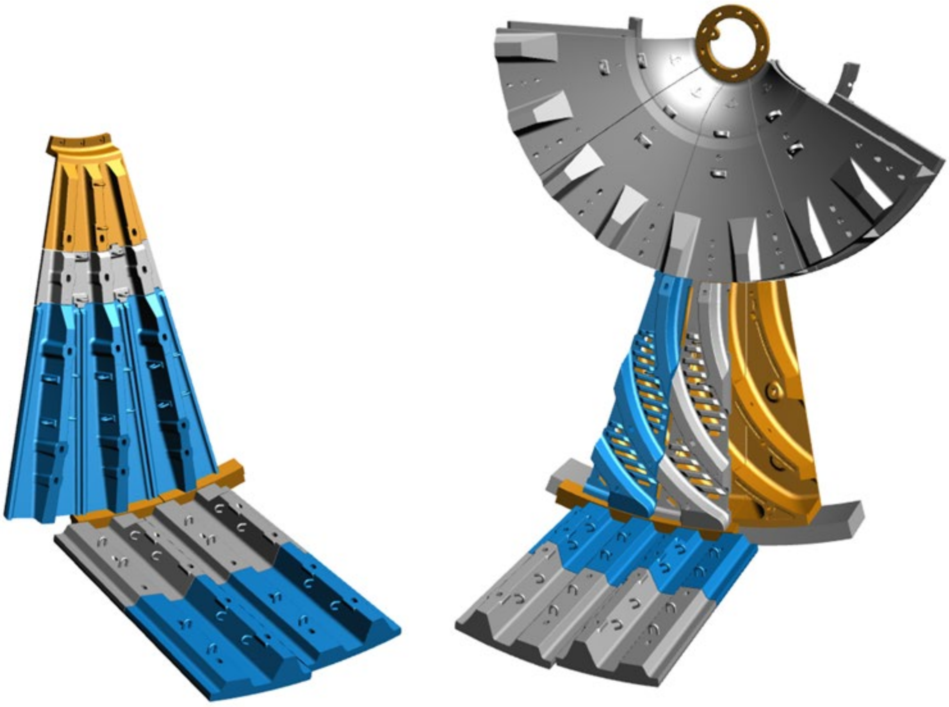

Figure 9 – Stage 1 Liner General Assembly

Feed End Liner Design Initiatives – To Improve Wear Life Performance and Reline Efficiency

To address the high wear on the feed end of the mill, the wear data captured through 3D scanning was used to provide the optimum use of distributing the wear material and ensuring a single liner could be designed to cover the full charge kidney, both the DEM and scan wear data confirmed the analysis (refer to Figure 10, marked in red). The middle joint line between the Feed End middle and Feed End outer liner was repositioned higher up the mill to locate it outside the charge mass. The main integral lifter bar was increased in size and repositioned to cover the high wear zones measured through the 3D scanning process. This provided a one-piece Feed End outer liner that would receive all the high wear during the grinding process and eliminate the need to replace twelve Feed End middle liners during the normal mid-term reline, saving considerable reline time and improving mill availability.

The Feed End middle liner was reduced in size from 2,338 kg to 1,126 kg and the Feed End outer was increased from 1,569 kg to 2,658 kg. The liner mass in the Feed End of the mill increased by 24,588 kg to achieve the extra wear life performance, but this was offset with a decrease of 27,260 kg from the Discharge End liner design. The feed end outer liners remained at 36 liners per set, which allows for three liners to be installed at every inch of the mill leaving one liner gap above for safe relining and easy bolt access from both internal and external to the mill. The design and manufacturing of double wide liners was looked at but would prevent efficient relining per relining inches from both access and internal build processes.

The revision to the liner profile and the additional wear material incorporated into the liner design allowed the feed end outer liners to achieve increased target tonnes from 48,382 t/d to 67,648 t/d during the period.

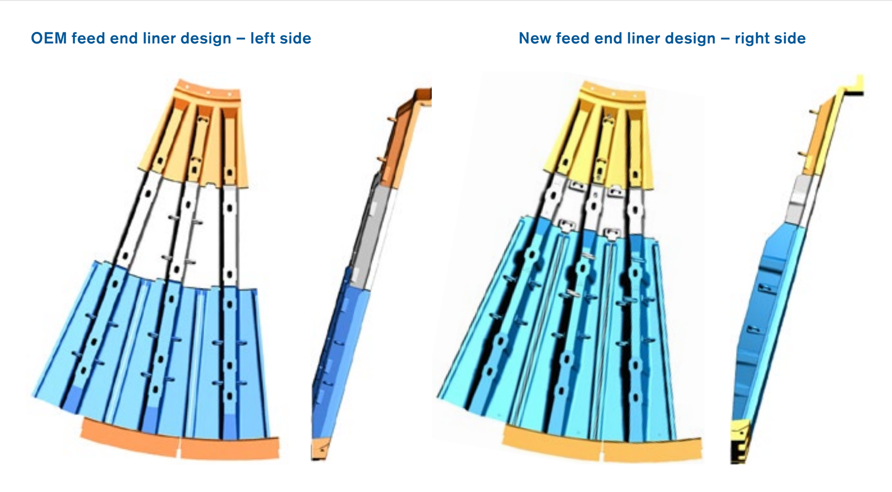

Figure 10 – Stage 1 Feed End Re-design Comparison

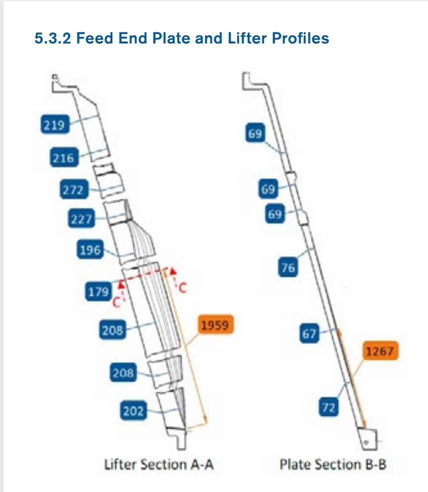

Figure 11 – New Feed End Outer Liner Wear Profile

Discharge End Liner Design Initiatives – To Improve Mill Performance and Reline Efficiency

The discharge end of the mill received the biggest overhaul to the design, and this was driven to achieve the KPI target of 3,102 t/h. The focus was to eliminate the lost production efficiency in the return backflow in the discharge pulp lifters that was confirmed through the wear data from the first set of OEM liners. The discharge design was converted from a straight radial Uni-directional mill to a single Bi-directional Super Vortex discharge end system to assist and improve mill discharge. The new design of the Vortex discharge end system reduced the quantity of liners in the discharge end of the mill from 172 in the OEM set, to 118 liners in the NEW Stage 1 liner design. A new composite BULLNOSE discharge cone reduced the overall liner mass in the discharge end of the mill by 27,260 kg, which allowed for the additional wear material to be used in Feed End high wear zones.

The Super Vortex discharge end grates and pulp lifters were designed around the existing radial drilling pattern on the discharge head. The Super Vortex curve allowed for a single piece liner on the discharge end to cover the full charge mass, and thus improving the relining efficiency during the mid-term relines by eighteen liners. The 63 mm grate slot apertures were maintained from the OEM liner design to the new Super Vortex grate, to maintain the discharge recycle size, but the overall grate opening was increased by the one-piece Super Vortex grate design by 21%.

The design of the Super Vortex curve was simulated through DEM software to analyse the discharge flow characteristics against the current straight radial design. The DEM results showed a vast improved flow dynamic with minimal backflow present at each revolution. The Super Vortex curve encourages early partial movement of the coarse product and continues the rate of movement along its full Vortex curve to final discharge. This can be seen through the following captured frames highlighting the rate of particle flow at the same comparative stage in both liner designs. The DEM software was carried out using particle flow with no slurry present in the simulation, refer to Figure 12 and Figure 13.

The installation of the Super Vortex discharge end design has seen the discharge efficiency in the mill improve considerable by 28.5% to the target 3,012 t/h of new feed and further benefits were achieved with extended wear life in the Discharge Vortex pulp lifters.

Table 5 – Discharge Grate Open Area Comparison

Discharge Grate Open Area	m2	Qty.	Total m2
DE straight radial outer grate – 63 mm slots	0.2436	36	8.880
DE Super Vortex grate – 63 mm slots	0.2952	36	10.626
			121%

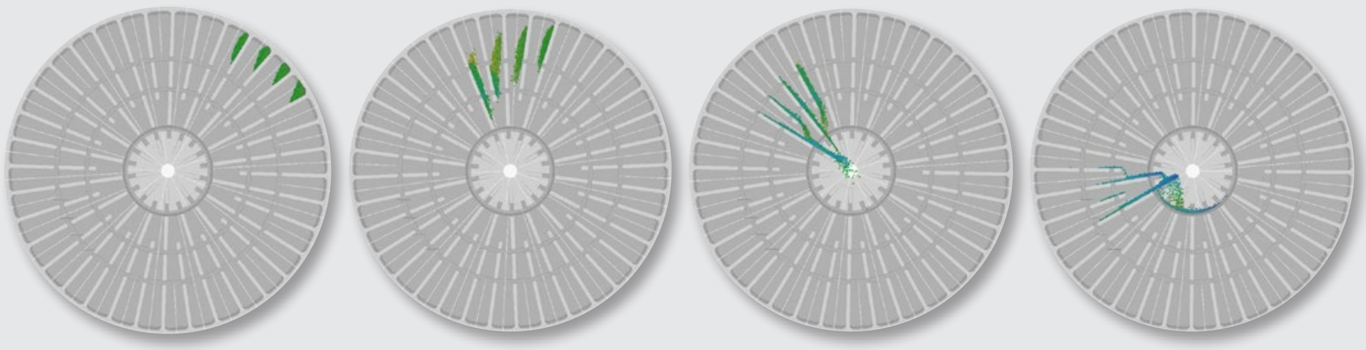

Figure 12 – DEM Results for the Straight Radial Discharge Design

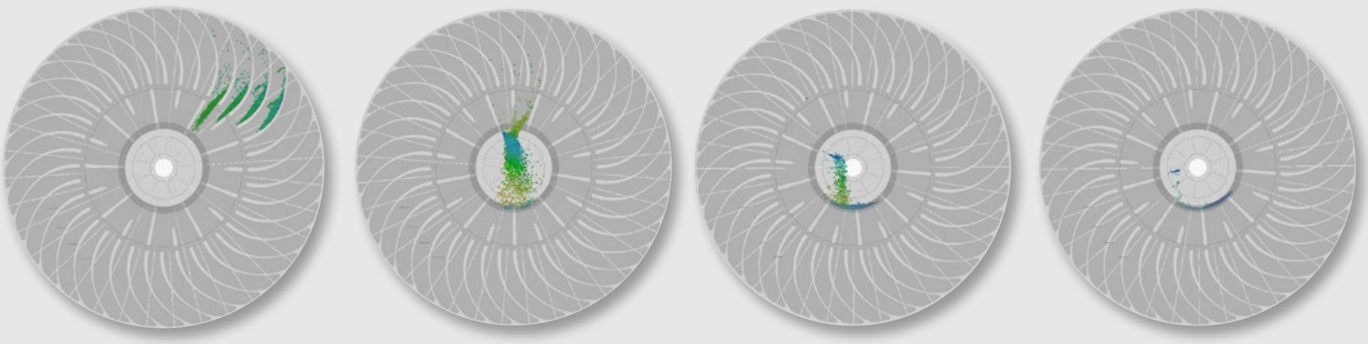

Figure 13 – DEM Results for the Super Vortex Discharge Design

The original discharge cone system was replaced with a new BULLNOSE discharge cone system. The new composite BULLNOSE reduced the cone assembly from 28 pieces in the OEM design to 10 pieces in the BULLNOSE design. The overall liner mass per assembly was further reduced from 58,035 kg in the OEM steel design to 27,607 kg in the BULLNOSE with the use of composite wear materials, a total saving of 30,428 kg in assembled liner mass. The BULLNOSE is manufactured with high wear resistant white-iron material to combat the high wear zones and rubber composite top and bottom plates to reduce overall liner mass in non-critical areas of flow.

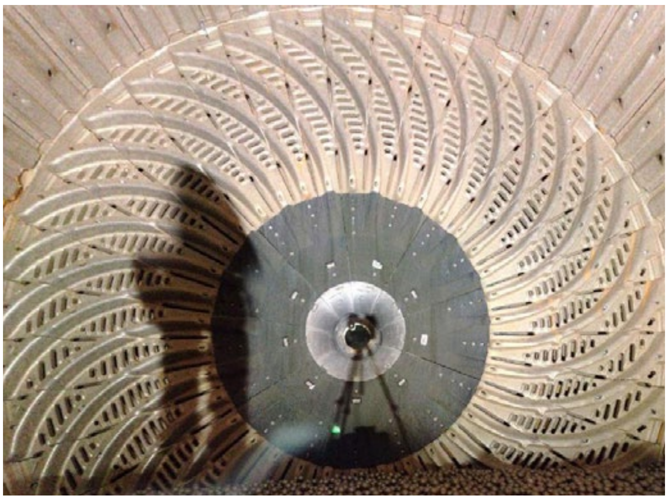

Figure 14 – The Super Vortex Discharge System

Results

The following graphs indicate the performance measured from the radial OEM system to the Super Vortex system of operation.

The transition between the two liner designs has seen early performance indicators achieved, whereas generally new installed liners demonstrate inefficiencies early as dimensions of lifters and grates are still to be optimized until wear patterns develop for optimal operation.

As can be seen in the graphs below, all key parameters for mill operation increased during this transition. Both speed and power draw increased significantly, which allowed the additional throughputs to be achieved. In 2017 the operation at Aktogay was inconsistent with numerous factors effecting availability and overall stability, but the averages indicate that the change in design has influenced a positive change.

In terms of speed, the average has maintained during this period. As can be seen in the figure 16, the period under the radial system was quite erratic with a higher standard deviation. Additional contributing factors with secondary equipment unavailability is also responsible for this. However, as seen under the Vortex arrangement the speed profile has maintained.

In terms of power draw, an increase of 4.5 MW was experienced between liner sets, which is significant. Over this whole period the SAG specific energy was measured at 7.25 kWh/t. When this additional power draw is applied it equates to an additional 550 t/h increase in throughput.

Figure 15 – SAG Mill Performance

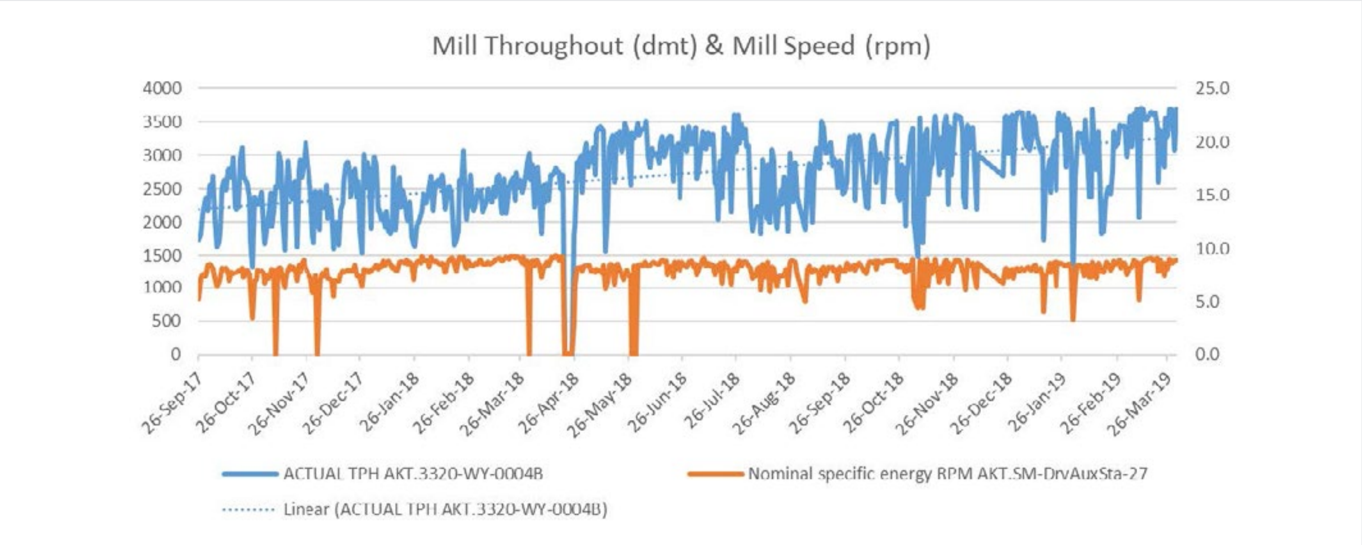

Figure 16 – SAG Mill Throughput and Mill Speed

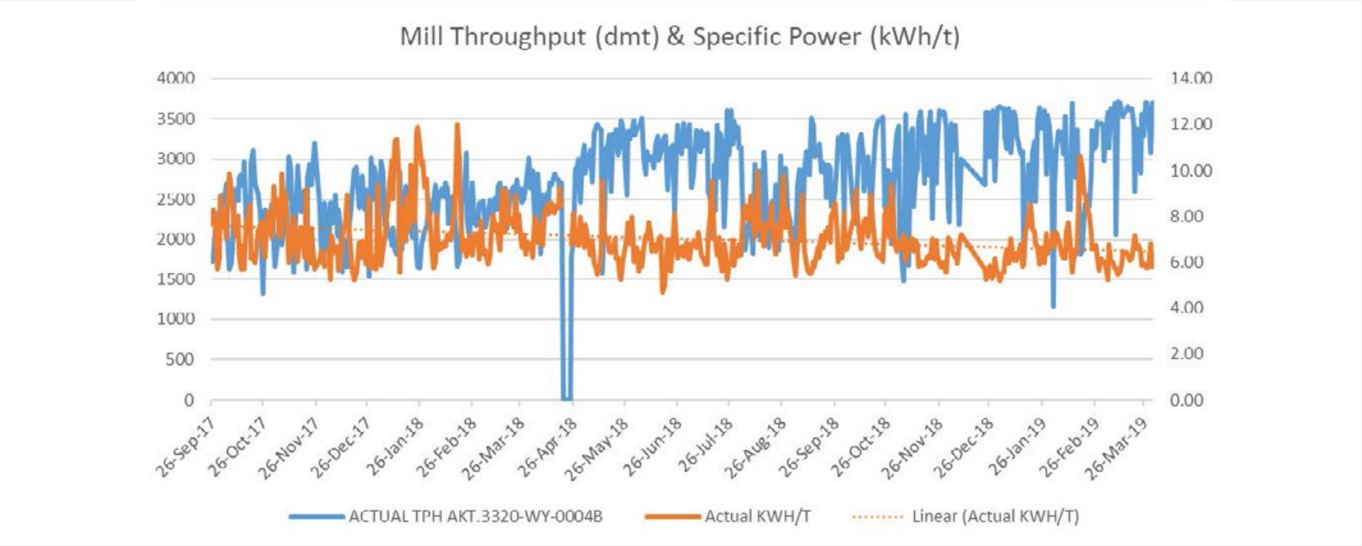

Figure 17 – SAG Mill Throughput and Specific Power kWh/t

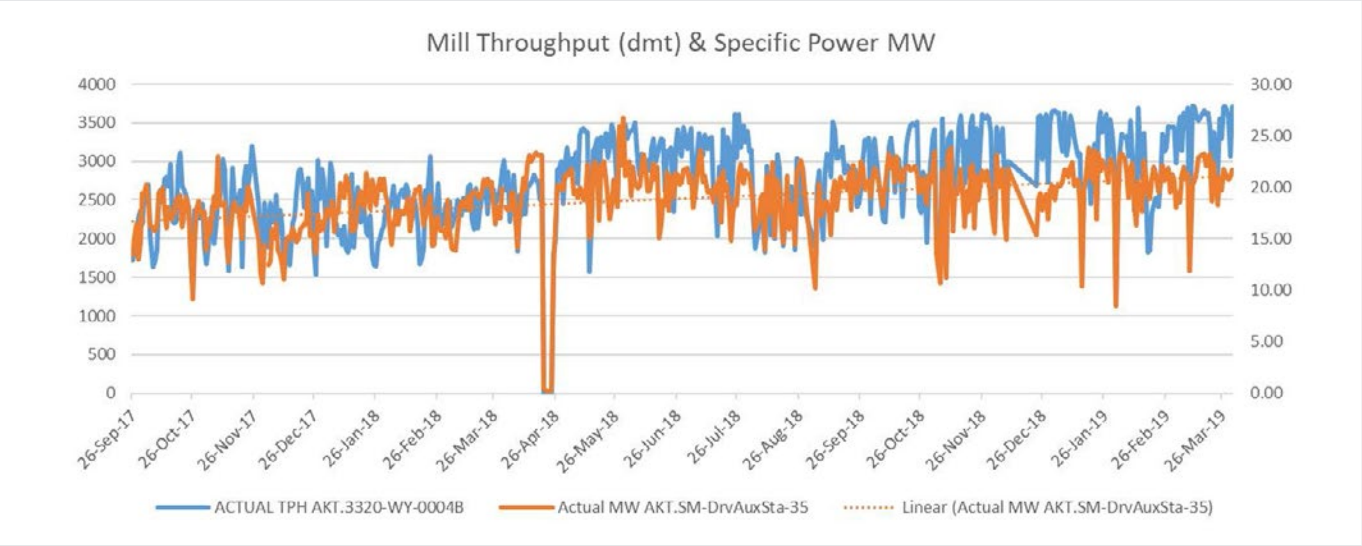

Figure 18 – SAG Mill Throughput and Specific Power

Conclusions

The transition from the OEM radial Bi-directional liner design to the Uni-directional Super Vortex liner design has been a success at KAZ Minerals' Aktogay operation.

The continual improvements made to the operation and the initiatives presented through the new liner design has seen Aktogay achieve their target mill throughput performance of 3,102 t/h. The collaborative approach has delivered improvements in performance across all key indicators whilst operating in a safe environment.

The successful installation in the Aktogay 40 ft SAG mill has seen outstanding results in both mill performance and reline improvements to-date. The installation of the Stage 1 liner design has resulted in 30 less liners per mill set being installed during mid-term relines and a total of 54 liners for a full reline. The reduction in liners per set contributes to providing a safe reline environment with the less movement of parts in and around the mill deck and during relining. The reduction in liners for the mid-term reline provided an estimated additional 7.5 hours mill availability and run time.

Figure 19 – The New Stage 1 Liner Designed Installed in April 2018

Stage 2 Liner Design Initiatives

Stage 2 liner design initiatives have progressed and are due to be installed in 2019, which will deliver further benefits in mill relining efficiencies, safe relining practices and increased mill availability annually.

The Shell liner design has been converted to a standard height profile with two liners along the full length of the mill. The liner profile has been customised to suit the single directional milling with new improved face angles matched to the operating charge parameters and the more component ore being treated. The two-piece shell liner design allows for additional knock-in holes to assist with liner removal and a 25% reduction in liner bolts.

The Feed End outer liners and Discharge End outer grates have been revised in-line with the new shell installation, to eliminate all the loose corner liners in the mill. This provides a 33.3% reduction in liners for a complete shell reline when corner liners require changing. This provides a safer working environment for the mill reline team during the reline practice, removing all loose steel items in the mill that are not retained by liner bolts.

The above initiatives will improve the overall mill availability, providing an additional 15 hours of operation.

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