SAG Mill Operation at Cortez: Evolution of Liner Design from Current to Future Operations

Julius Stieger, Process Superintendent
Dave Plummer, Process Maintenance Planner
Sanjeeva Latchiredi, Chief Process Engineer
Raj K. Rajamani, Professor – Metallurgical Engineering

1Barrick - Cortez Gold Mines
   Star HC66 Box 1250
   Crescent Valley, Nevada 89801
   PH: (775) 468-4400, E-mail: jstieger@barrick.com

2Barrick - Cortez Gold Mines
   Star HC66 Box 1250
   Crescent Valley, Nevada 89801
   PH: (775) 468-4400, E-mail: dplummer@barrick.com

3Outokumpu Technology Inc.
   10771 E Easter Ave. Suite 120
   Centennial Colorado 80112
   PH: (303) 792 3110 x224, E-mail: sanjeeva.latchiredi@outokumpu.com

4University of Utah
   Department of Metallurgical Engineering
   University of Utah
   Salt Lake City, Utah 84112
   PH: (801) 581-3107, E-mail: raj_rajamani@yahoo.com

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ABSTRACT

The Cortez SAG mill liner design was recently modified to improve the mill operating energy efficiency. In addition to the expected benefits, the design change unexpectedly played a significant role of verifying the proposed grinding circuit expansion for the Cortez Hills project as well as illustrating current SAG mill bottlenecks. This paper will discuss the evaluation that addressed operator and maintenance observations, historical PLC data, and “crash stop” observations to calculate charge motion, packing between lifters, and slurry transport through grate and pulp lifters. The performance of the new shell and discharge end liner design will also be discussed as well as their role in the possible grinding circuit expansion.

INTRODUCTION

Cortez Gold Mines commenced operation in 1969 with its Mill #1 rated at a nominal 2,000 tons per day. Mill #1 was a conventional rod mill/ball mill circuit followed by an 8-stage CIP circuit. In the early 1990s the Pipeline deposit was discovered and subsequently Mill #2 was built to process the increased ore volume. Mill #2, commissioned by mid-1997, was a nominal 10,000 tons per day SABC circuit followed by an 8-stage CIL circuit for oxide gold ore. Operating and commissioning details of this plant have been published elsewhere (Powell, 1998). By late 1998, there was not enough ore volume to support both mills so the smaller, higher operating cost Mill #1 was put under its current care-and-maintenance status. A simplified flowsheet of the current mill is shown in Figure 1.

Figure 1: Cortez Gold Mines Mill #2 Flowsheet
The SAG mill is 26’ diameter x 12’3” EGL and powered by 4,500 HP motor driven by a variable speed LCI drive that can control the mill speed from 36% to 80% of critical speed depending on ore type and operational demands. Ball charge is typically 8-12% and is adjusted accordingly after monthly mill inspections. Total mill filling is about 25%. The mill lining originally consisted of rubber plates and “polymet” lifters on the feed and discharge ends as well as rubber plates and cast lifters on the mill shell. The shell lifter pattern was 52 rows of high-low pattern (nominal 7” lift followed by 5” lift above shell plate) built with a 17° face angle. The grate open area was nominal 7% generated from 2.75” x 2.75” square holes. 5” grinding balls are also used. The maximum grinding circuit throughput as dictated by downstream conditions is about 13,500 dry tons per day (560 dtph).

Early in the Mill #2 life the ore had been predominantly ball mill limiting in that the ore basically “blew through” the SAG mill due to its already small size. Regardless of this, budget throughput targets that surpassed the original plant design figures were consistently being met. As such, focus on improving SAG mill performance has been limited except in the areas of liner wear life optimization. As Cortez progressively mined deeper into the pit in 2003 and early 2004 the ore generated a steadily increasing plant operating work index. The ore in turn started swinging towards SAG mill limiting. Slowly budget tons were just barely being met or just falling under targets. Difficulty in meeting targets was also being compounded by shell liner repair downtime induced by the aggressive ore that was also making its presence known in upstream process areas (e.g., crusher linings) via less wear material life.

In mid-2003 Cortez was approached by the University of Utah for participation in a voluntary U.S. Department of Energy (DOE) project. The primary tools that were used in this project were the MillSoft™ and FlowMod™ software packages after the collection of good plant operating data to calibrate the software. In the initial stages of the project it soon became readily apparent that significant opportunities existed to improve on mill operating energy efficiency as well as improve on liner maintenance for improved productivity. Results from this study were also used in the mill expansion feasibility study for the Cortez Hills deposit and helped to concretely identify significant SAG circuit bottlenecks that should be addressed to maximize the current installed circuit as well as the possible future mill expansion to 15,000 tons per day.

**SAG MILL CRASH STOPS**

After the project was approved baseline data collection was required in the form of SAG mill “crash stops”. In a crash stop the SAG mill is operated under steady-state conditions and then stopped as if the power plug was pulled. After mill lock-out and confined space procedures are satisfied researchers enter the mill discharge trunnion and take measurements and pictures of mill filling, ball load, slurry pooling, and liner wear observations. The mill is then restarted and then can continue under normal operation or be ground out for further ball charge and liner measurements. Cortez management was initially apprehensive about doing crash stops due to the downtime required. This was a valid concern, but the project team at the same time felt that a snapshot of our SAG operating under steady state conditions was necessary for the project success. After some negotiating, approval was granted, the Safety, Electrical, Mill Maintenance,
and Mill Operation departments were coordinated, and the first crash stop was done just prior to a scheduled mill shutdown to minimize downtime.

**Crash Stop #1 – October 8, 2003**

Please refer to Figure 2. This crash stop was done on moderately ball mill limiting ore that typically averaged 460 dry tph. The picture does suggest some slurry pooling as well as some packing between lifters. The measured mill filling was 25% with a 10% ball load. The lifters also showed some peening due to ball overthrow beyond the charge toe onto the unprotected shell lifters. This crash stop was interesting, but not the “smoking gun” we were looking for.

![Figure 2: SAG Mill Crash Stop on 10/8/2003](image)

**Crash Stop #2 – March 3, 2004**

Please refer to Figures 3-5. This crash stop was done on severely SAG mill limiting ore that typically averaged 360-390 dry tph. In comparison, the worst case SAG mill limiting ore type throughput is 8,160 dry tons per day (340 dtph). The picture shows extensive lifter packing and slurry pooling. Also clearly visible are extensive lifter peening and cracked/missing lifters.
Figure 3: SAG Mill Limited Ore Lifter Packing on 3/3/2003

Figure 4: Lifter Peening From Ball Charge Overthrow
Crash Stop #3 – June 30, 2004

The reader is asked to refer to Figures 6-7. The purpose of this crash stop was to collect circuit data to aid in the Cortez Hills project’s proposed mill expansion feasibility study. A full grind circuit survey, including feed belt cut, crash stop, and grind-out were done to gather all relevant data. The data served to validate parameters used in future computer simulations as well as provide another data point in the DOE project. The moderately SAG mill limiting ore throughput was 420 dtph.
Initial Review of Crash Stop Results

It is very obvious that the crash stops point out many things:

- The lifter spacing is too close such that they pack with ore and the effective lift and mill volume is reduced. This would suggest that less of the available mill power can be used for grinding.
- The lifter face angle is too steep such that high mill speeds required for harder ore result in balls overthrowing the toe of the charge and striking the unprotected mill shell liners. This would suggest that a portion of the applied mill power is wasted turning the mill faster to grind the harder ore as well as the subsequent unnecessary and costly liner breakage and mill downtime.
- The mill is not adequately discharging the ground slurry and/or returning it back into the mill. This means that the mill volume is taken up by material that is already product sized.
- The pooling could lower the energy of ball-to-charge impacts and therefore waste a portion of the applied mill power by “grinding water” and/or re-grinding product sized ore.

It was then decided to pursue computer simulations of these results as well as solutions to prevent these observations from occurring.

Computer Simulation of Crash Stop Results

The crash stop measurements, liner profiles, operator observations, and recorded PLC data were then inputted into a drawing software package as well as the MillSoft™ software. The software outputs are depicted in Figures 8-10. The figures illustrate that with packed lifters, the worst
case lift is 2” with the concurrent reduction in effective mill diameter of 4”. In addition, the MillSoft™ simulation shows that the media hits the unprotected shell with a 17° face angle lifter at mill speeds required to process the harder ore.

Figure 8: New Lifter Set with Packing
(Rajamani and Latchireddi, 2003)

Figure 9: Worn Lifter Set with Packing
(Rajamani and Latchireddi, 2003)
SHELL LINER DESIGN CHANGE

The above crash stops and subsequent computer modeling told Cortez that we needed to act now before our downtime, mill throughput, and unit energy consumption further deteriorated. We therefore approached the project in these regards. Numerous computer simulations, discussions with local and our sister site Granny Smith and Porgera SAG plants, as well as a thorough literature review drove us to a design eliminating ½ the lifter rows and replacing them with shell plates to minimize the packing and maximize lift and mill volume. In addition, we chose to optimize the lifter face angle for optimum ball trajectory at high mill speeds as well as increase the lifter height for wear life. Metallurgists familiar with SAG plants will know that these types of changes and subsequent operating successes have been numerous documented elsewhere so the writer will not discuss the theory here. Figures 11-13 show the computer simulation trials at 28°, 32°, and 35° face angles, respectively.
Figure 11: Charge Motion Analysis of 28° Face Angle Lifters

Figure 12: Charge Motion Analysis of 32° Face Angle Lifters
The 32° lifter was the starting point of optimized ball strikes at high mill speeds. In the end, however, we decided to be conservative, to try to maximize wear life, and settled on a 28° face angle lifter with the belief that a 28° lifter will quickly wear to a 32° lifter. Lift height was also set at 9” above the 4” shell plate. Figures 14-15 shows the final design settled upon.

It is also important to note that we did investigate the “polymet” style shell liner design, but decided against it. It was felt that the rubber would flex and take away from the impact energy – energy that we were trying hard to focus on doing useful work. Further, our research indicated that for high throughput plants with aggressive ore that cast liners were the preferred option for wear and performance.
LINER DESIGN CHANGE CONSIDERATIONS

Concurrent to this major liner design change, there were many questions in the background that needed to be resolved before the design could be implemented.

**How would we safely handle the heavier cast liners?**

The issue was that while the new design had 33% less pieces, each piece now weighed up to 2.5 times more than the old design. The maximum weight to be encountered was 2,000 lbs. We
reviewed our current liner handler and decided to send it back to the manufacturer to get it upgraded and professionally recertified from 3,000 lbs capacity to 4,000 lbs capacity. In addition, we held numerous pre-installation meetings involving the mill maintenance, operations, safety, and management departments as well as the liner manufacturer to break down the liner change step-by-step to ensure adequate equipment and procedures were available. In addition, local and our sister SAG plants were consulted in regards to their liner change-out practices. With all of the above covered, we felt fairly confident that we would safely handle the upcoming design change.

**What would the cast liners do to the workplace noise?**

The issue was the cast liners would operate noisier than the old design rubber plate-cast lifter combination. We consulted other plants about this and they all responded that it was a non-issue to them because of already established hearing protection policies and that the sound was not obnoxious provided that the mill was operated properly. We left this issue there, but still conducted before and after noise surveys and found that the noise only increased up to 2%.

**What effect would the heavier cast liner weight have on the mill shell and mill motor?**

Another issue was that the new shell liner design at 41 extra tons would cause undue stress to our mill shell as well as mill motor. We consulted with our mill designer who confirmed that our mill was designed for considerably more shell weight. Calculations were also done that showed only about 100 extra HP was required to start the mill in order to overcome bearing pressure friction after which the “flywheel effect” soon takes over. After the change we were also pleasantly surprised to find that the mill starts up under a full load noticeably easier than the previous design undoubtedly due to this effect.

**Could the existing inching drive handle the increased mill weight?**

The issue of an inadequate inching drive stemmed from our ball mill inching drive experience where we found that its performance was severely hindered with a fully charged and/or frozen charge ball mill. We again consulted other SAG plants and discovered that this was also a non-issue in regards to a SAG mill because of the large diameter causing a counterweight effect balanced by charge. They further advised that the mill would be most unbalanced when ½ the liner installation was complete such that jogging the mill into place would be difficult as compared to inching it into place. In the end we found that our SAG inching drive did work hardest at this point, but nowhere near the difficulty the ball mill inching drive had on the ball mill under similar circumstances.

**How would our operating practice change with the new liners and how long would the learning curve be?**

The concern was that the expensive set of new liners would be damaged upon start-up due to operator unfamiliarity running with new mill speed and bearing pressure targets that would be undefined until we actually started running the mill. The resolution was to discuss these
concerns with all the operators beforehand and then practice conservatism on mill speed and aggressiveness on mill bearing pressure upon new liner commissioning. In addition, the operators were given explicit instructions to run the mill under their control rather than Expert System control to learn the new operating regime.

**SHELL LINER DESIGN CHANGE OPERATING RESULTS**

We would assume that the new design encountered numerous different ore types over its life similar to the previous design’s life such that we could come to some valid conclusions. Without extensive work index and mineralogy data, the derived conclusions focus on what the operating data clearly tells us:

- **Similar mill throughput.** Before the change we averaged 411 dtph and after the change we averaged 419 dtph on the first shell liner set. On the second shell liner set we averaged 400 dtph. Essentially the throughput has been similar due to our ore variability.

- **Overall reduced unit energy consumption on both mills.** On average the plant operating work index decreased by 1.2 kWh/ton milled over 2 sets of the new shell liner design. The SAG power draw has been reduced 94-262 kW (126-351 HP) with the new shell liner design. This was due to the SAG grinding more efficiently with optimized ball strikes and feeding a better product to the ball mill circuit, while yielding essentially the same average throughput before and after the design change.

- **Increased use of the mill volume for grinding.** Lifter packing throughout the new shell liner design life has disappeared thereby allowing the use of the entire mill diameter for grinding. Slurry pooling, however, has not been eliminated. Please refer to Figure 16.

![Figure 16: No Lifter Packing with New Shell Liner Design](image)

- **Virtually eliminated downtime from broken shell liner bolts for the first time in Mill #2 history.** Since the new design install we have had no downtime due to shell liner bolt problems.
• **Increased grinding of critical size material in the SAG.** Our SAG now began to perform like a secondary crusher and grinding mill like a SAG mill was conceptually intended to do from its early beginnings. We started the new design on essentially the same ore type as the old design and immediately noticed less pebbles being recycled to the pebble crusher, but the cyclone feed circuit recirculating load increased with a slight decrease in grinding circuit product size that was still within metallurgical guidelines. This suggested more grinding of critical sized SAG material with the subsequent increase in particle size of typical ball mill feed.

• **Increased liner life.** Measurements and calculations done on both old and new liner designs reveal that the liner wear life has improved 47% to 57 kgs/day steel loss from the previous design’s 84 kgs/day (Rajamani and Latchireddi, 2005).

**EXPOSING THE INEFFICIENT SAG PULP DISCHARGER**

At the same time the new shell design was commissioned Cortez Gold Mine announced its major Cortez Hills gold discovery. A feasibility study team was soon assembled to investigate various process options to handle the Cortez Hills ore. The front runners were keeping the current mill flowsheet versus expanding the mill capacity by 50% to nominal 15,000 stpd. In the early stages of the study it became apparent from operator, peer reviewer, and metallurgical concerns that the SAG would not be able to handle 15,000 stpd fresh feed let alone the +17,000 stpd operating days that would need to occur to make up the nominal 15,000 stpd requirement.

In parallel to the above, the new liner design emphasized the now increased importance of the pebble cone crusher in the SAG circuit compared to the old design to cause the efficient size reduction of critical size material. Whenever the pebble crusher was bypassed for cleaning or maintenance, we noticed an immediate drop in mill throughput on the order of 50-100 stph. Previous to the design change the pebble crusher had at most a 25 stph effect on mill throughput and often sat idle over all ore types. The initial thought was that when the pebble crusher was online, the SAG mill was very efficient in grinding the critical size material in the mill due to the crushed pebbles being discharged from the mill on their next pass through it. When the pebble crusher was bypassed, the effect was almost an immediate 80-100 tph increase of critical size material back into the mill thereby overloading it. This is what was partially occurring, but with the aid of our consultants we soon found that it was primarily due to the inherent weakness of the SAG pulp discharger design.

**Imagine the SAG Mill as a Pump**

Initially, conventional wisdom told us to think of the SAG mill as just another grinding mill in which ball charge, mill filling, and mill speed were maximized to ensure maximum throughput. Liner design for the SAG was also approached more from a wear perspective rather than a metallurgical and hydraulic-flow perspective. Our University of Utah partners immediately encouraged us to think of the SAG as more of a pump in which the grates and pulp discharger end (“impeller”) were designed to allow for optimizing slurry density, mill speed, and mill filling ensuring maximum slurry discharge out of the mill with minimal recirculation of product sized material.
The theoretical maximum SAG discharge is dictated by a “grate-only” (GO) configuration in which the mill is open on the discharge end with no trunnion. The end is covered with grates without lifters. The maximum flow then becomes a fluid dynamics problem in which head pressure on the inside grates dictate flow. The actual maximum SAG discharge is dictated by the current SAG configuration, which is a radial pulp lifter (RPL) design in our case. The comparison between actual and theoretical gives the pulp removal efficiency so therefore the maximum efficiency is realized by making the current design as close as possible to GO. Please refer to Figure 17.

Figure 17: Theoretical Maximum SAG Mill Pulp Discharge Rate
(Latchireddi and Rajamani, 2005)

Pulp Flow Modeling

Our University of Utah partners then conducted computer modeling of our pulp discharger using their powerful FlowMod™ software using our 6/30/04 survey data. After several iterations we were left with the results in Table 1. The results clearly show that at best 12,100 stpd would be realized out of our SAG with the current “420 tph ore” and therefore we will fall short of the nominal 15,000 stpd goal.

Table 1: Results of FlowMod™ Simulations on 6/30/04 Ore

<table>
<thead>
<tr>
<th></th>
<th>Fresh Feed</th>
<th>Pebble Crusher</th>
<th>Total SAG Feed</th>
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<tbody>
<tr>
<td></td>
<td>estph</td>
<td>estph</td>
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<tr>
<td>Actual w/ Radial Pulp Lifter</td>
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<td>9,576</td>
<td>80</td>
</tr>
<tr>
<td>Theoretical Grate Only Discharge</td>
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<td>12,084</td>
<td>111</td>
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<tr>
<td>Pulp Removal Efficiency %</td>
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<tr>
<td>Max Incremental Gain</td>
<td>110</td>
<td>2,508</td>
<td>23</td>
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Critical Size Material Flow

Using crash stop measurements as well as ore characteristic and mass flow measurements our University of Utah partners were also able to illustrate what was happening with our critical size (pebble) material with the RPL design.

- Essentially the critical size material was building up in our SAG mill because as the mill was run faster to grind the harder ore the RPL pulp discharger design would allow for material to come back into the mill after going through the grates (Figure 18). For example, this observation was also documented with pictures from the Cadia Hill mine (Figure 19 - Hart et al., 2001).

![Figure 18: Pulp Discharge Profile with Radial Pulp Lifters (Latchireddi and Rajamani, 2005)](image1)

- As the mill turns faster the critical size material then builds up even more on the interior mill circumference. Our grate design in turn was not optimized with holes towards the outer circumference of the grate since the OEM rubber discharger design prevented this.
As much as 12 inches of the outer mill radius was not used for pebble and pulp discharge (Figure 20).

![Figure 20: Unavailable Mill Diameter for Pulp and Pebble Discharge at Cortez](image)

- Eventually the critical size material and slurry flow-back as well as subsequent slurry pooling built up so much, but not to the levels of traditional mill overloads, such that the mill power decreased due to ball-on-slurry instead of ball-on-rock impacts (Figure 21).

![Figure 21: Impact of Slurry Pooling on Grinding Efficiency (Rajamani and Latchireddi, 2004)](image)

- This critical size material overload was further compounded when the pebble crusher was bypassed such that the power draw decrease and load increase happened quicker - often within 5 minutes. The only remedy was to cut throughput by as much as 100-150 tph (Figure 22). The subsequent drawback in addition to throughput reductions is cycling introduced to the downstream mill circuits (Figure 23).
• The critical size recirculation calculated at 31% also explained the impact wear observed on the non-lifting side of the pulp lifter as well as on the rubber filler rings on the periphery of the mill discharge end. Minor impact wear on the Cortez SAG shell due to pebble flow-back is shown in Figure 24.
Optimized SAG Discharge End Design

The goal of the next design phase was to address our pulp lifters, pulp discharger, and grate open area orientation for optimum efficiency and flow. With the aforementioned knowledge we decided to pursue with Latchireddi’s 2nd generation of pulp lifters called Turbo Pulp Lifters (TPL™), developed specifically for AG/SAG mills with pebble circuits for efficient mill discharge (Latchireddi, 2005). The theory behind and successes of Latchireddi’s first version called the TCPL design (Latchireddi and Morrell, 1997) are well documented (Nicoli et al., 2001).

The next steps were then the engineering design in conjunction with the preparation of an internal AFE to document the project’s progress. Through discussions with our Alcoa contacts as well as thorough trending and understanding of the SAG mill dynamics during difficult ore conditions, the AFE justification was based on 3-months payback with the conservative assumptions of:

- Minimum throughput gains on the order of 1% on the hard, blocky ores.
- A concurrent reduction in unit grinding circuit energy consumption of 0.1 kWh/ton due to reduced regrinding of product sized ore.
- Less throughput sensitivity and cycling whenever the pebble crusher is bypassed for operational maintenance. At least 50% (50 tph) of the cycling should be eliminated over every 1.5 hour period per operating day based on analysis of current mill trends.
- Increasing the shutdown interval between a complete discharge end liner changes by 1 year to every 4-5 years, as well as allowing for more even discharge end liner wear to correspond with other liner jobs.
Not assumed was the possibility of less throughput sensitivity and cycling whenever the mill coarse ore feed stockpile was low and/or being pushed, such as when the primary crusher was down for maintenance (12 hours minimum scheduled every 2 weeks). This typically resulted in a feed rate reduction by as much as 100 tph due to the feeding of harder, blocky coarse ore pushed into the apron feeders from the stockpile perimeter.

The design phase progressed relatively smoothly through the last half of 2005 with approved drawings of the Turbo Pulp Lifter (TPL™) issued for casting in early January 2006, at the same time the AFE was approved by Cortez management.

**INSTALLATION OF THE TURBO PULP LIFTER**

The target date for the TPL™ installation was mid-June 2006 when a one week major mill maintenance shutdown was planned. In the meantime, the same safety discussions mentioned earlier in this paper that took place prior to the installation of the cast shell lifters and plates were reviewed. The TPL™ castings arrived on-site late May 2006 and were then assembled on the ground for maintenance and operations personnel to visualize its installation and operation. This step proved to be the most crucial as, “seeing is truly believing” and enabled everyone to have 100% complete buy-in to this project.

The overall TPL™ installation took about 4.5 days. This included 12 hours for drilling the SAG discharge head for 16 holes to complete the bolt circle pattern, where there were previously tapped holes. No TPL™ liners were installed during the drilling in order to maintain precise drilling conditions. Please refer to Figures 25-27 for snapshots of the TPL™ installation.

![TPL™ Laid Out on Ground for Pre-Installation Review](image)
Initial Mill Start-up on the TPL™ Design

After the TPL™ installation we started milling the same ore that we processed immediately prior to the shutdown. This ore was also the most troublesome due to its hard, blocky nature that was compounded by being pushed into the feeders due to a primary crusher shutdown that ultimately induced circuit cycling with the old SAG discharge end design. We immediately noticed with similar before and after mill ball charge levels as well as with operators not yet familiar with the new TPL™ design:

- 22% increase in throughput rate from 344 wstph to 421 wstph
- 35% decrease in the SAG mill power draw from 3,908 HP to 2,526 HP (2,915 kW to 1,884 kW). This equates to a 47% decrease in SAG unit energy consumption from 8.98 kWh/ton to 4.74 kWh/ton.
- 11% decrease in SAG mill speed (11.5 rpm to 10.3 rpm) indicating optimized ball strikes with the concurrent observation of reduced large ball chip scrap generation.
• 50% increase in pebble discharge rate
• 7% decrease in ball mill power draw from 4,843 HP to 4,491 HP (3,613 kW to 3,350 kW). This equates to a 24% decrease in ball mill unit energy consumption from 11.13 kWh/ton to 8.43 kWh/ton.
• Ball mill circuit load increased due to the higher throughput with the concurrent decrease in grind size from 78% - 200 mesh to 69% - 200 mesh. This is still well within our operating grind target of >62% - 200 mesh. Note that historically our ball mill power draw drops as the mill starts to work from the increase in circulating load.

Assuming a similar ore type over a 30 day month with current electrical costs, operating performance, and mill run-time, we can calculate improvements on a monthly basis of:

• 742,320 kWh or $67,000 SAG mill electrical savings
• 181,786 kWh or $17,100 ball mill electrical savings
• 77 stph or 4,000 ozs of incremental gold production. This translates to $2.4M incremental revenue increase per month at $600 gold.

Operating with the TPL™ Design

For the following discussion the reader is asked to refer to Figures 28-32. As of writing this paper, we now have almost 90 days of experience with running the TPL™ design. Our ore has clearly changed somewhat to a softer ore with more clay, but it is still blocky. Despite this, we are still realizing considerable power savings as compared to historical data on similar high throughput ore. Despite having minimal detailed pre-TPL™ operational data on this ore type with confidence, we can still say that the throughput enhancements exist, but the magnitude is unknown. This is due to the following:

• Our pre-TPL™ high throughput ore was all clay with low amounts of rock, whereas the current ore has significantly more rocks. In fact, in July 2006 we established an all-time throughput record for the SAG mill at 522 dry tons per hour, which was only limited by the tailings pumping capacity. The previous throughput record was 514 dtph in February 2003.
• We can now process nominal 440-450 dtph throughput rates while the coarse ore stockpile is at low levels and/or is being pushed into the feeders. Prior to the TPL™ installation we were at best 380 tph due to the all coarse and rocky material being pushed in from the pile outskirts.
• We can now process nominal 420 dtph whenever the pebble crushe rin feed magnet is down for repairs hence requiring the pebble crusher to be bypassed. Previous to the TPL™ installation we only managed 330-350 dtph under similar conditions.
• Daily comments received from the operators are typical of, “we could never run steady and with confidence like this before with the old design for fear of the SAG mill getting quickly out of control.”

Aside from the above improvements we have noticed:
• Significantly steadier mill trends as opposed to the previous cyclical trends. The operators can now make their small changes in a steady manner without worrying about quick negative circuit responses, whereas big step changes had to be done previous to the TPL™ installation.

• The TPL™ resulted in a 3.1 kWh/ton milled reduction in plant operating work index compared to the OEM pulp discharger combined with the new shell liner design (Figure 28).

• The plant operating work index has decreased by a nominal 3.6 kWh/ton compared to the OEM shell liner and OEM pulp discharger design (Figure 28).

• While the SAG unit power consumption has decreased, some of the required breakage energy has to be absorbed somewhere to comply with the laws of physics. In our case we have seen evidence of this in the pebble crusher circuit. The pebble crusher current draw has increased by about 10 amps with about a 20 tph increase in pebble discharge rate. This translates to about 0.4 kWh/ton increase in pebble crusher work input, which is still markedly less than the SAG mill unit power consumption decrease. This would further reinforce previous beliefs that ore over-grinding due to recirculation back into the SAG was occurring before the design change.

• There is a greater emphasis on the pebble crusher to maximize mill throughput due to the increased rate and particle size of pebble discharge from the SAG. The crusher circuit has to be used efficiently to enable the pebbles to pass into the ball mill circuit after the second trip through the SAG mill.

• The renewed importance of prudent and careful utilization of SAG speeds to maximize mill production. Increase speeds too quickly and the mill quickly empties and/or overloads the pebble crusher thereby requiring it to be bypassed. This in turn re-introduces coarse size material to the SAG. In turn, the material that had a difficult time being ground the first time through, passes through the mill again with the concurrent waste in applied energy. For example, now a 0.1 rpm change in SAG speed equates to a 20 tph change in pebble discharge rate. Prior to the TPL™, we required a 1.0 rpm change to get the same result.

• steadier SAG ball consumption rates due to the optimized ball strikes and slower mill speed. We are expecting liner life to also increase as a result of the slower mill speeds (Figure 30).

• Grinding circuit P80 stabilized after the TPL™ installation (Figure 31). We suspect this is due to a more consistently sized product from the SAG mill circuit due to the TPL™ installation.

• Ball mill power draw appears more stable after the TPL™ installation (Figure 32). We also suspect this is due to a more consistently sized product from the SAG mill circuit due to the TPL™ installation.
Figure 28: SAG Mill Circuit Power Trend

Figure 29: SAG Mill Circuit Operating Trend
Figure 30: SAG Mill Circuit Speed Trend

Figure 31: Ball Mill Circuit P80 Trend
CONCLUSION

We are now very pleased with the SAG mill performance. All expectations were surpassed and as of now the plant bottlenecks have shifted towards the downstream CCD thickeners, cyanide destruction circuit, and tailings unit operations. The next step is to optimize the particle size to the pebble crusher so as to not to overload it. With the new design we switched to slots from square holes, while retaining the same minimum hole dimension of 2.75 inches. This was to provide similar before and after comparisons of the RPL to TPL™ designs. We are now finding that with the new discharge end design, pebble discharge rate can overwhelm the pebble crusher such that it has to be repeatedly bypassed if the operators are not careful in balancing the mill speed to the CSS of the pebble crusher. Further, as the grates wear the pebble throughput will only increase and could ultimately hinder plant throughput. As such, we will be modeling different grate slot configurations and dimensions to balance the pebble throughput against the SAG grinding power that is still available for grinding.

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