IMPROVING ENERGY EFFICIENCY VIA OPTIMIZED CHARGE MOTION AND SLURRY FLOW IN PLANT SCALE SAG MILLS

ANNUAL TECHNICAL PROGRESS REPORT

Reporting Period Start Date: 20 July 2005
Reporting Period End Date: 21 July 2006

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March 2007

DOE Award number*: DE-FC26-03NT41786*

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ABSTRACT

A research team from the University of Utah is working to make inroads into saving energy in these SAG mills. In 2003, Industries of the Future Program of the Department of Energy tasked the University of Utah team to build a partnership between the University and the mining industry for the specific purpose of reducing energy consumption in SAG mills. A partnership was formed with Cortez Gold Mines, Kennecott Utah Copper Corporation, Process Engineering Resources Inc. and Outokumpu Technology.

EXECUTIVE SUMMARY

In the current project, Cortez Gold Mines played a key role in facilitating the 26-ft SAG mill at Cortez as a test mill for this study. According to plant personnel, there were a number of unscheduled shut downs to repair broken liners and the mill throughput fluctuated depending on ore type. The University team had two softwares, Millsoft and FlowMod to tackle the problem. Millsoft is capable of simulating the motion of charge in the mill. FlowMod calculates the slurry flow through the grate and pulp lifters. Based on this data the two models were fine-tuned to fit the Cortez SAG will.

In the summer of 2004 a new design of shell lifters were presented to Cortez and in September 2004 these lifters were installed in the SAG mill. By December 2004 Cortez Mines realized that the SAG mill is drawing approximately 236-kW less power than before while maintaining the same level of production.

In the first month there was extreme cycling and operators had to learn more. Now the power consumption is 0.3-1.3 kWh / ton lower than before. The actual SAG mill power draw is 230-370 kW lower. Mill runs 1 rpm lesser in speed on the average. The re-circulation to the cone crusher is reduced by 1-10%, which means more efficient grinding of critical size material is taking place in the mill. All of the savings have resulted in reduction of operating cost be about $0.023-$0.048/ ton.

After completing the shell lifter design, the pulp lifter design was taken up. Through a series of mill surveys and model calculations it was figured that the radial pulp lifter installed on the mill had less than optimum discharge capacity. A number of alternative designs were evaluated. The final choice was the Turbo Pulp Lifter for which Outukumpu Technology, Centennial, Colorado had filed a patent. After installation of the pulp lifter a 22% increase in throughput rate from 344 stph to 421 stph was realized. A 35% decrease in the SAG mill power draw from 3,908 HP to 2,526 HP (2,915 kW to 1,884 kW) was recorded. This equates to a 47% decrease in SAG unit energy consumption from 8.98 kWh/ton to 4.74 kWh/ton. A 11% decrease in SAG mill speed was observed indicating optimized ball strikes. Also, the ball chip generation from the SAG mill was reduced considerably. Further more, a 7% decrease in ball mill power draw from 4,843 HP to 4,491 HP (3,613 kW to 3,350 kW) was observed. This equates to a 24% decrease in ball mill unit energy consumption from 11.13 kWh/ton to 8.43 kWh/ton.

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1. INTRODUCTION

1.1 Evaluation of SAG pulp lifter

The Cortez Gold Mine mill had been fitted with the new design of shell lifters, which has been in operation since September 2004. In the two years it has been in operation it became clear that the mill was not discharging the ground ore slurry efficiently. This was evidenced by a number of observations including the performance of the mill without the pebble crusher. Some mill-entry observations also showed slurry build-up known as pooling.

The new liner design emphasized the now increased importance of the pebble cone crusher in the SAG circuit. Whenever the pebble crusher was bypassed for cleaning or maintenance, an immediate drop in mill throughput on the order of 50-100 stph was noticed. Prior to the shell lifter 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 stph increase of critical size material back into the mill thereby overloading it.

Although the pebble crusher applies more energy to the ore thus increasing the product fineness, it was determined that the SAG mill was not discharging the slurry and pebbles efficiently.

1.2 SAG mill is a grinding device as well as a pump

SAG mill is mainly thought of as a grinding mill in which ball charge, mill filling, and mill speed were maximized to ensure maximum throughput. Liner design for the SAG mill is approached more from a wear perspective rather than a metallurgical and hydraulic-flow perspective. However, upon grinding the ore to pebbles and ground pulp the mill has to perform as an efficient pump. The grates and pulp discharger end must be designed for 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 the flow. The actual maximum SAG discharge at Cortez is dictated by the current radial pulp lifter (RPL) design. 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. Figure 17 illustrates this concept.

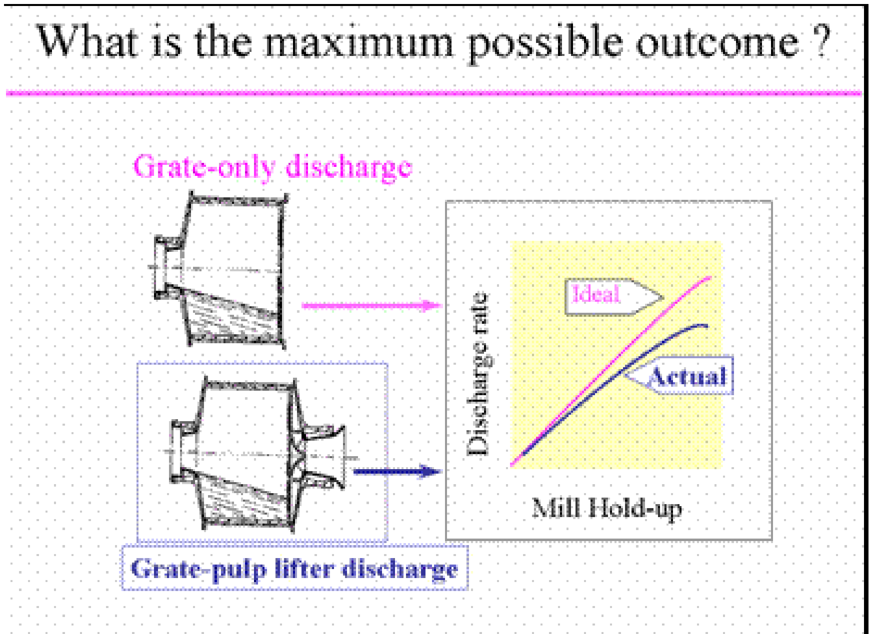

Figure 1: Theoretical Maximum SAG Mill Pulp Discharge Rate

1.3 Pulp Flow Modeling

The computer modeling of the pulp discharger was done using FlowMod™ software, that was developed by Dr. Sanjeeva Latchireddi. The model used the crash-stop/survey data collected on 6/30/04. Table 1 shows the results of model analysis. The results clearly show that at best 12,100 stpd would be realized out of the SAG mill with the current ore type. In other words, the radial pulp lifter is limiting the pebble and pulp flow out of the mill interior.

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

Base Case 6/30/04
@ 95% Availability
@ Pebble Crusher Feed + 21% of Fresh

	Fresh Feed		Pebble Crusher	Total SAG Feed	
	dstph	dtpd	dstph	dstph	dtpd
Actual w/Radial Pulp Lifter	420	9,576	88	508	383
Theoretical Grate Only Discharge	530	12,084	111	641	482
Pulp Removal Efficiency %	---	---	---	---	79%
Max Incremental Gain	110	2,508	23	133	---

1.4 Critical Size Material Flow

The crash stop measurements, ore characteristics and mass flow measurements illustrate critical size (pebble) flow behavior with the RPL design.

Essentially the critical size material was building up in the SAG mill. Especially, with the harder ore the mill rpm had to be set higher to break the ore. However, at higher rpm, the RPL pulp discharger allows slurry to be carried back into the mill, despite being discharged through the grates as shown in Figure 2.

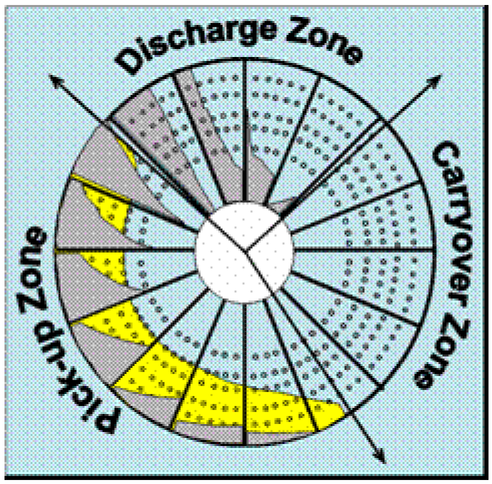

Figure 2: Pulp Discharge Profile with Radial Pulp Lifters

As the mill turns faster the critical size material then builds up even more on the interior mill circumference. The existing grate was not designed for slots towards the outer circumference. As shown in Figure 3, 12 inches of the outer mill radius was not used for pebble and pulp discharge.

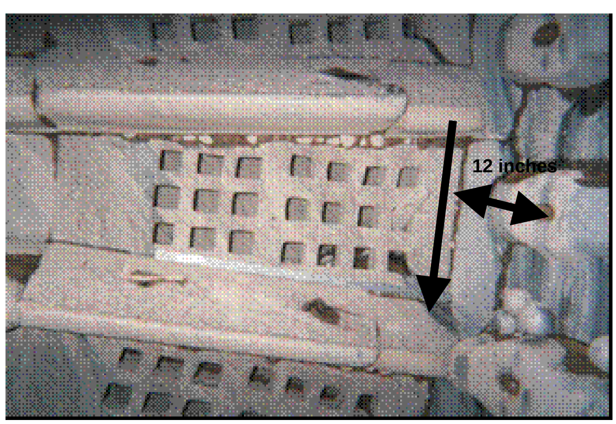

Figure 3: Unavailable Mill Diameter for Pulp and Pebble Discharge at Cortez

Hence, the lack of removal of critical size pebbles and slurry flow-back led to slurry pooling. But the level of pooling was not to the levels of traditional mill overloads. Slurry pooling causes a reduction in power draw of the mill.

The critical size material overload was further compounded when the pebble crusher was bypassed. In the SAG mill 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 stph. A sample of operating data shown in Figure 4 illustrates the reduction in throughput due to pebble crusher shut down. The subsequent drawback in addition to throughput reductions is cycling introduced in SAG throughput which in turn affects downstream mill circuits (Figure 5).

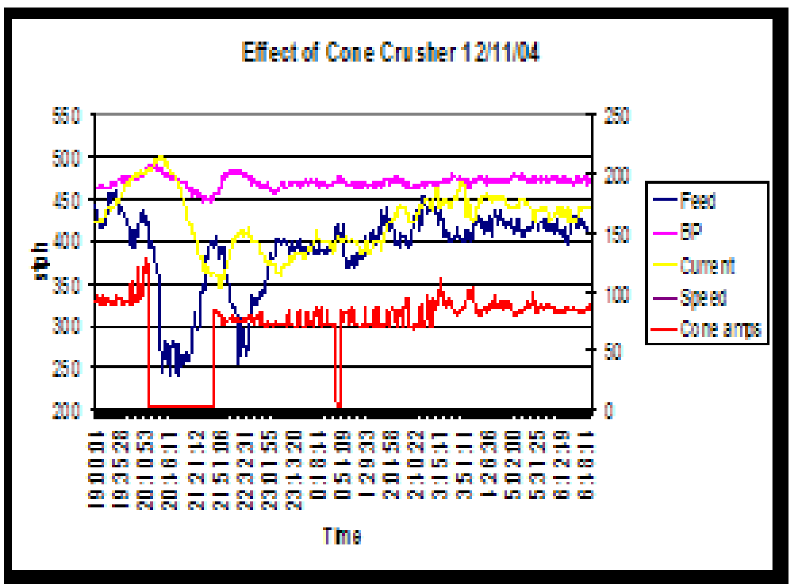

Figure 4: Effect of Pebble Crusher Bypass on Cortez SAG Performance

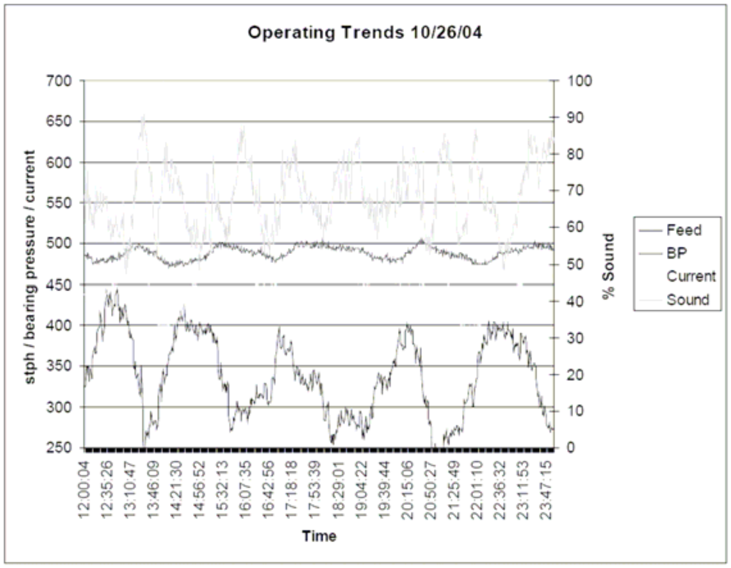

Figure 5: Cortez SAG Circuit Cycling Induced by Pebble Flow-back

The critical size recirculation within the pulp lifter was calculated to be 31%. In fact, 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 confirmed the theoretical calculation. Minor impact wear on the Cortez SAG shell due to pebble flow-back is shown in Figure 6.

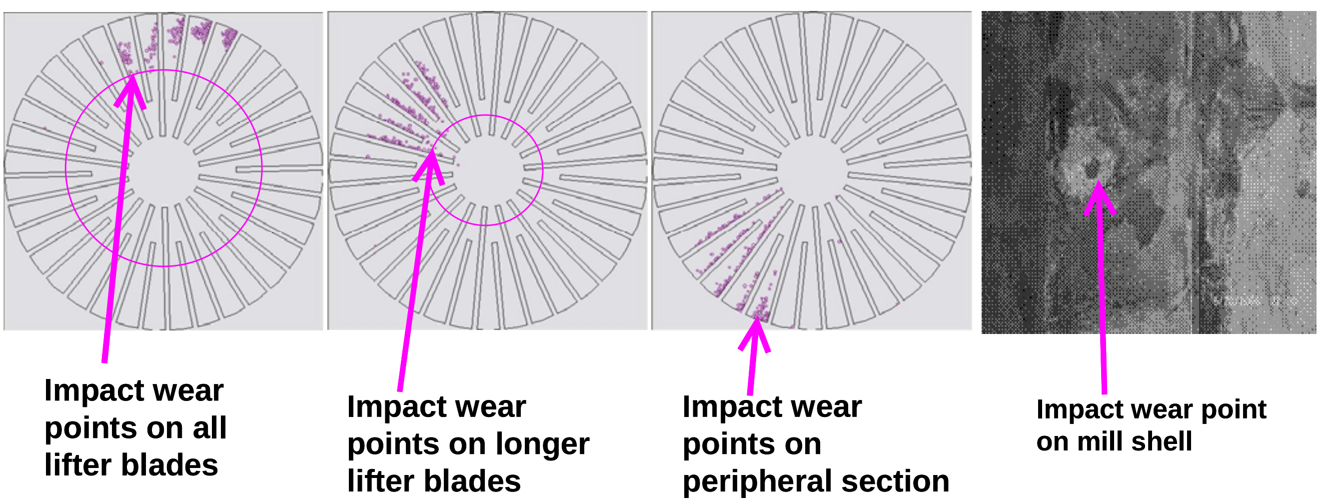

Figure 6: FlowMod™ Predicted RPL Wear Points Minor Impact Wear on Cortez SAG Shell from Pebble Flow-back

1.5 Optimized SAG Discharge End Design

The goal of the next phase of the project was to address the pulp lifters and grate open area for optimum efficiency and flow. With the aforementioned knowledge, Cortez Gold Mines decided to pursue 2nd generation of pulp lifters called Turbo Pulp Lifters (TPL™), for which Outokumpu Technology, Colorado had filed for a patent. This lifter, which is a variation of twin-chamber pulp lifter was developed specifically for AG/SAG mills with pebble circuits for efficient mill discharge (Latchireddi, 2005). The theory behind and successes of the first version called the TCPL design (Latchireddi and Morrell, 1997) are well documented (Nicoli et al., 2001).

The new design was slated to achieve the following minimum objectives:

- 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..
- 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.

2. INSTALLATION OF THE TURBO PULP LIFTER

Norcast Engineering Company manufactured the pulp lifter designed by Outokumpu Technology. The target date for the TPL™ installation was mid-June 2006. 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. Snapshots of the TPL™ are shown in Figures 7 and 8.

Figure 7: TPL™ Laid Out on Ground for Pre-Installation Review

Figure 8: TPL™ Grates on Left. OEM Grates on Right

2.1 Initial Mill Start-up on the TPL™ Design

After the TPL™ installation the SAG mill was started with the same ore that was processed immediately prior to the shutdown. This ore was also the most troublesome due to its hard, blocky nature. Following is a list observations made immediately after start up with TPL™ pulp lifter.:

- 22% increase in throughput rate from 344 stph to 421 stph.
- 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. Also, the ball chip generation from the SAG mill was reduced considerably.
- 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 meshes to 69% - 200 mesh. This is still well within the operating grind target of greater than 62% - 200 mesh.

Assuming a similar ore type over a 30-day month with current electrical costs, operating performance, and mill run-time, the calculated improvements on a monthly basis are:

- 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 ounces of incremental gold production. This translates to $2.4M incremental revenue increase per month at $600 gold.

2.2 Operating with the TPL™ Design

Aside from the above improvements Cortez Gold Mines realized the following gains:

The SAG mill is significantly steadier mill as opposed to the past cyclical trends. The operators can make 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 9).

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 10).

Steadier SAG ball consumption rates due to the optimized ball strikes and slower mill speed. Cortez is expecting liner life to also increase as a result of the slower mill speeds (Figure 11).

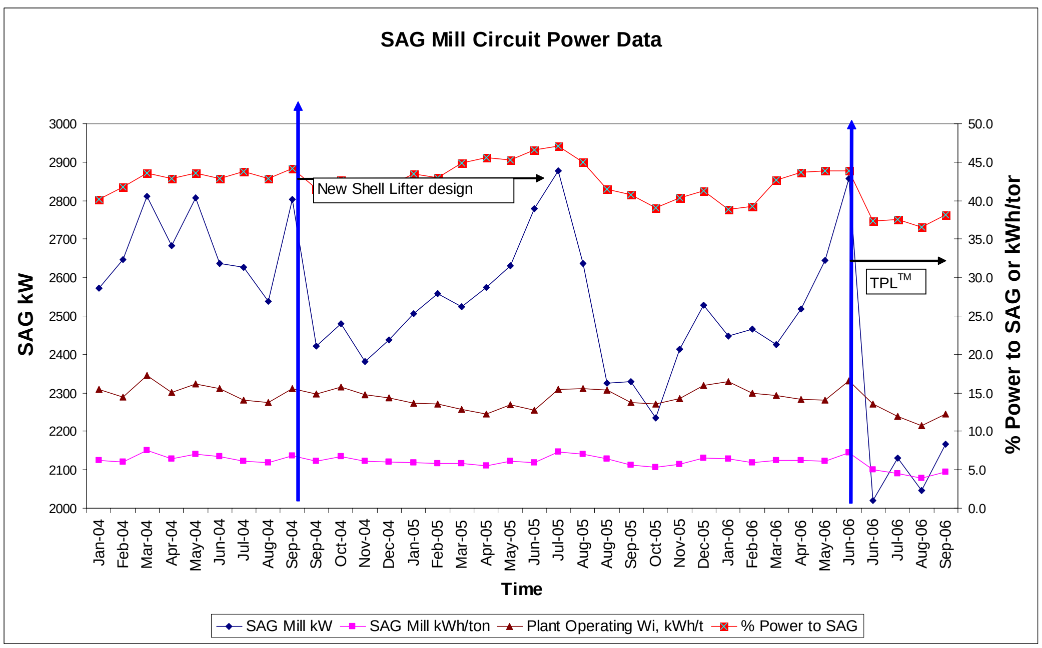

Figure 9: SAG Mill Circuit Power Trend

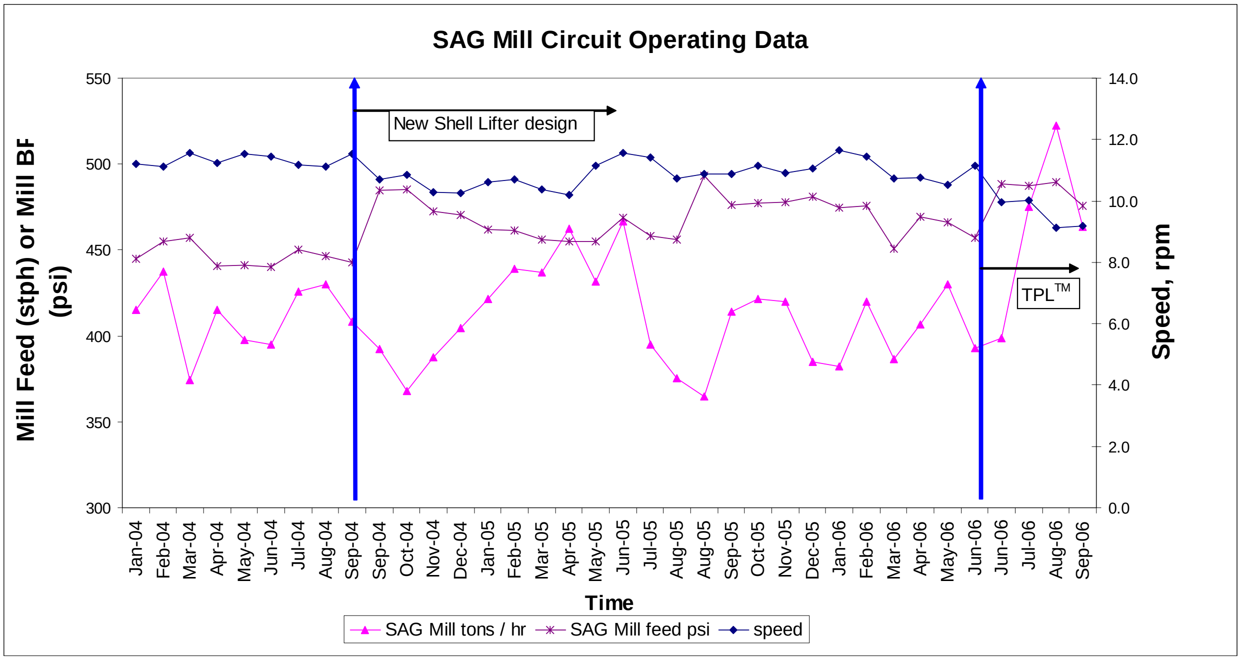

Figure 10: SAG Mill Circuit Operating Trend

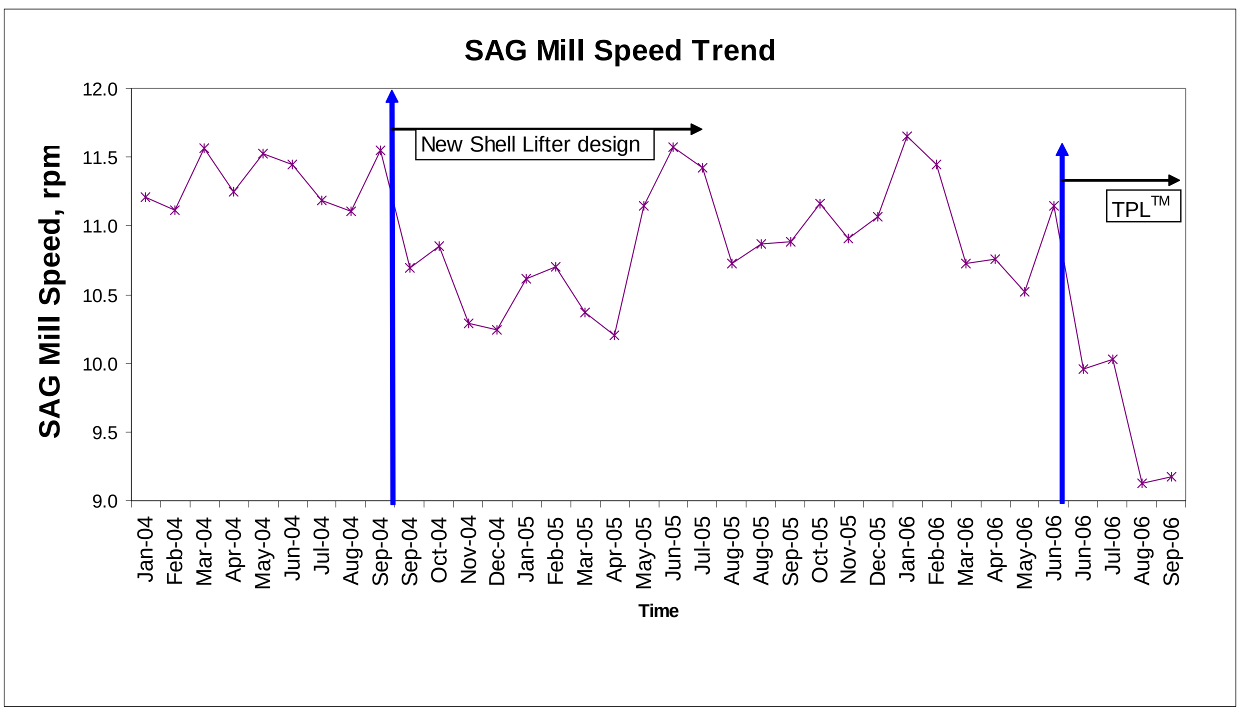

Figure 11: SAG Mill Circuit Speed Trend

3. CONCLUSION

The design of shell lifters and pulp lifters far exceeded expectations. Based on data collected over 90 days after pulp lifter installation, it is projected that Cortez Gold Mines would save 742,320 kWh or $67,000 in SAG mill electrical savings. In the ball milling circuit a saving of 181,786 kWh or $17,100 electrical savings. The increased production of 77 stph translates to 4,000 ounces of incremental gold production. This amounts to $2.4M incremental revenue increase per month at a gold price of $600 per ounce.

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