SAG
2001

MINING AND MINERAL PROCESS ENGINEERING
UNIVERSITY OF BRITISH COLUMBIA
Vancouver, B. C., Canada

The Development and Installation of the Twin Chamber Pulp Lifters at Alcoa

D.Nicoli[1], S.Morrell[2], B.Chapman[1], S.Latchireddi[1]

[1]Alcoa of Australia Limited, WA; [2]JKMRC, QLD, Australia

ABSTRACT

Alcoa operates 9 sag mills at two alumina refineries in Western Australia. All of these mills run as single-stage units in closed circuit with DSM screens and provide a product that is sent directly to the digestion stage of the Bayer process. Historically Alcoa has run its mills at maximum throughput as dictated by the maximum load level that could be achieved without the mills spilling from the feed end trunnion. At maximum throughput mill performance was typified by a large mill inventory of slurry, which caused the formation of a large slurry pool and a depressed power draw. Research at the JKMRC and operational experience at one of the refineries showed that the mills were severely limited in their pulp lifter capacity and that increasing this capacity would improve mill performance. Installing a new concept of pulp lifter, which came out of the JKMRC research program, subsequently increased pulp lifter capacity. This resulted in large gains in throughput and power utilization efficiency. This paper documents the experiences at Alcoa from recognition of the initial problem, the research carried out at the JKMRC, the engineering difficulties that had to be overcome in designing the new concept pulp lifter and the gains that were subsequently made in milling efficiency.

RESEARCH ON CONVENTIONAL PULP LIFTERS

Research at the JKMRC into understanding the performance characteristics of grates and pulp lifters was started in 1993, initially looking at only the grates (Morrell and Stephenson, 1996). This work was accelerated and broadened following slurry transport problems encountered at Leinster (Morrell and Kojovic, 1996) with their single stage AG mill. This resulted in a drastic loss of power and throughput. The loss in power resulted from a large slurry pool building up in the mill – a symptom of the slurry discharge system having insufficient capacity for the required flow rate.

Both laboratory and pilot scale programs were mounted, the pilot scale data being generated from a purpose-built 1m diameter mill. This was fitted with a glass end to view the passage of slurry from the grates into the pulp lifters and out of the mill. A picture of the mill in operation is shown in Figure 1.

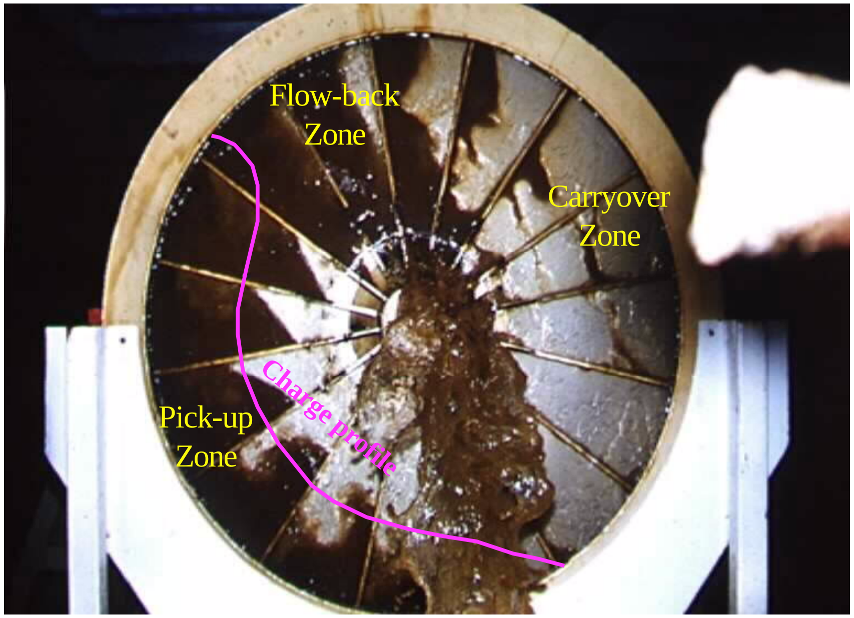

Figure 1: Slurry Discharging from Pulp Lifters

Initial studies indicated that if undersized, the pulp lifters dominated the flow characteristics of the mill. This was discovered to be the result of so-called flow back in which slurry passed from the pulp lifters back into the mill chamber. This can only occur when the pulp lifter reaches the zone where the rock/ball media are no longer pressed up against the grate. This is illustrated in Figure 1 where the charge profile is outlined in purple. This area is known as the pick-up zone and is where slurry flows into the pulp lifters. The flow-back zone can be seen marked above this. A third area is also marked and is called the carry-over zone where in some circumstances (mostly when the mill is run at speeds in the 85-90% of critical range) slurry remains in the pulp lifters and is carried over to the next cycle.

The extent of flow-back varies considerably and is dictated by the ratio of grate flow capacity to pulp lifter volume. If the pulp lifter volume is relatively small in relation to the grate flow capacity flow-back will be high. This response is illustrated in Figure 2 where the results from a series of pilot tests are shown.

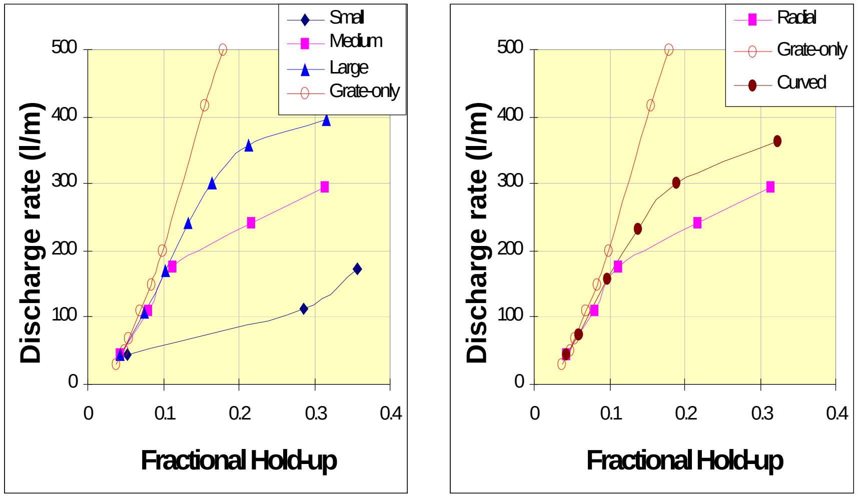

Figure 2: Effect of pulp lifter size (left)and design (right)

The data relate the discharge rate (volumetric flow) out of the mill to the hold-up (slurry level) inside the mill. The most effective discharge system is one, which results in the least amount of hold-up for a given flow. In this respect a grate-only system (i.e. no pulp lifters) will be the best. In Figure 2, therefore, the response of grate-pulp lifter assemblies is compared with the grate-only response. It is quite clear from Figure 2(a) that as the pulp lifter volume (indicated by small, medium and large in the graph) decreases the grate-pulp lifter assembly becomes worse and worse (i.e. it deviates further and further from the grate-only line). Design is also important as illustrated where a radial and curved design of equal volume is compared. The curved unit is seen to be better than the radial one.

The improvement that larger pulp lifters make is due to the fact that for a given flow rate the slurry level is lower in a larger pulp lifter. This results in fewer holes in the grate being submerged and therefore available for flow in the flow-back zone. In the case of the curved pulp lifter flow-back

is also reduced but in this case it is the result of its design causing slurry to flow down the pulp lifters to the mill exit earlier than in the case of the radial design. As a result, when the pulp lifter reaches the flow-back zone slurry has already begun exiting the mill leaving less in the pulp lifter to flow back into the mill.

The data collected in these programs were used to develop a mathematical model to help design and size grates and pulp lifters to avoid capacity limitations. The data also showed convincingly that flow-back can be a major problem with conventional pulp lifters and if removed could greatly improve pulp lifter discharge capacity.

CONCEPTION OF A NEW DESIGN

On the assumption that flow-back is the principal cause of pulp lifter inefficiency a new design was sought which eliminated this aspect of performance. The idea, which was developed, was to incorporate two interconnecting chambers in the pulp lifter, one of which was isolated from the grate and one, which was next to the grate. This design gave rise to the description "Twin Chamber Pulp Lifter" (TCPL). The chamber next to the grate allowed flow from the grate to be transmitted through it to the second (collection) chamber. As the second chamber was isolated from the grate flow back could not occur. A schematic of the design is shown in Figure 3.

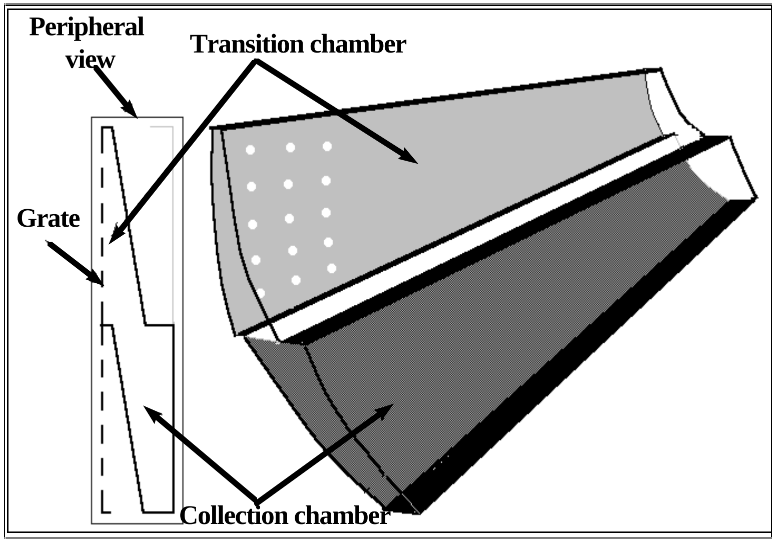

Figure 3: Schematic of Twin Chamber Pulp Lifter

CONCEPT TO REALITY - MECHANICAL DESIGN AND MANUFACTURE

Alcoa Wagerup had been experiencing difficulties commissioning a new SAG mill and pooling and slurry transport was identified as the main cause of loss of throughput. In addition, it was known that existing mills experienced large pooling and there was an opportunity to rectify these issues with this new concept.

Alcoa chose to proceed with design and development of the twin chamber pulp lifters for one of their mills at the Wagerup refinery.

One of the main challenges presented in development of the Twin Chamber Pulp Lifter was the issue of turning the conceptual idea into a product for installation into appropriate mills.

Although simple in concept, mill operators and researchers were familiar with the current operation and geometry of pulp lifters and to visualize the new concept was difficult. The researcher was presented new barriers to try to modify people's perception and used paper models to try to convey the concept to fellow researchers and designers. This issue of understanding was to become more important as the project continued. It was critical for all parties involved to understand the issues of flow-back through grates and the pitfalls of the current radial pulp lifters.

Other realizations were that the depth of the existing radial pulp lifter cavity in the Wagerup mill could not accommodate a Twin Chamber Pulp Lifter concept and so this required increasing the pulp lifter depth and shortening the mill grinding length and liners to suit.

Additionally, an allowance had to be made to hold and allow alignment of the new pulp lifters whilst installation was taking place. It was recognized that the bolting arrangement would require to be modified to prevent crushing of the pulp lifters once the discharge grates and lifters were installed.

Great importance was placed on demonstrating the new concept to show how a new design could be fitted to the mill to resolve these issues. A wide variety of personnel needed to be educated on the potential of the Twin Chamber Pulp Lifter. At this point it was decided that conceptual sketches were required to be turned into engineering drawings from which a scale model was manufactured so that this education process could be undertaken and the idea sold. This scale model proved invaluable in terms of checking fitting issues and to allow an installation plan to be made. A photo of this is shown in Figure 4 on the next page.

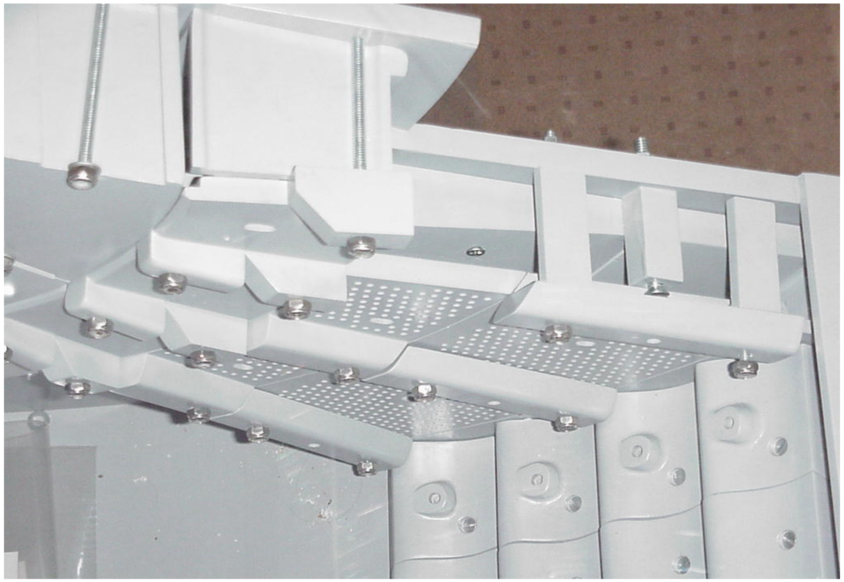

Figure 4: Scale Model of Components

This process was instrumental in allowing progression of the pulp lifters into a production mill, as it decreased the risk and answered many questions raised by parties involved.

At the time of conception, it was not known how effective the new design would be because the design had never been built. Given that pooling problems were evident on the operational Alcoa mill, it was also unknown as to what geometry of new pulp lifter would be required to remove the existing pool formation as the research being undertaken was aimed at improving the assessment of slurry transport through pulp lifters.

Some basic design concepts were used to ensure the pulp lifter capacity was not under designed. The area of cross section for fluid flow was designed to match or exceed the area for flow associated with the grate apertures. This allowed the flow area to be accumulated so that the final throat or outlet of the pulp lifter was able to approximate the grate area available. In order to not over design and result in an excessively deep pulp lifter (which would result in excess loss of mill length), simulations of the mill operating without a pool were performed. This allowed estimation of charge volume and shape so that approximate flow area through the grates could be determined and used.

In addition, the design of the pulp lifter was made so that it could be installed on other mills in operation. This allowed a minimum of rework in design and drafting. Only modifications to account for different directions of rotation were required to enable retrofit to other mills at the same site.

A thorough design review was undertaken before fabrication proceeded. This process involved business center management, engineering, and production and maintenance teams. Considerable attention was given to the reline issues in handling different design components, of different weight and geometry. This allowed minor design improvements to be made for allowance for slinging components and also allowed revision and checking of component weights and numbers. Some simplification of existing components was possible to reduce component numbers.

Based on previous experiences with miss fitting components on radial pulp lifter change outs, it was agreed to cast the components as a trial set with acknowledgment that a final design change would be required for permanent installations. This allowed the pulp lifters to be designed to fit without removal of the belly liners. This would allow a standard change out time to be maintained as per normal radial pulp lifters. To countermeasure any design or fabrication errors, a steel rather than a white iron was chosen for construction so that machining of the components could be performed to allow appropriate final fitting if required without excessive time delays on the mill.

PILOT TESTING

During the period of design and manufacturing, progression was being made on pilot testing of the pulp lifters at the JKMRC.

Pilot testing of the design confirmed its superior performance when compared to conventional designs of the same capacity. This result is illustrated in Figure 5 at the top of the next page.

The indicated improvement in performance that the TCPL concept showed provided a higher impetus for the full-scale trial at the Wagerup refinery.

TRIAL DESIGN, INSTALLATION AND TESTING

In order to obtain a fair assessment of the effect of the TCPL in the mill, it was necessary to plan, coordinate and execute a controlled trial.

The objective was to assess the design difference of the TCPL over the radial pulp lifter geometry. This was not completely possible due to conflicting operational requirements.

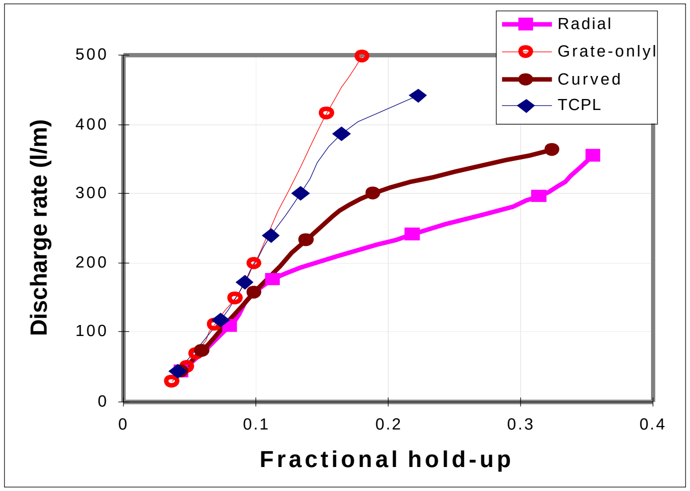

Figure 5: Comparison between TCPL and conventional pulp lifters

Because of the period between shutting down the mill for installation and restarting, concern was raised as to the effects of different ore type on the outcome of the tests. Performing the TCPL installation during consumption of a single stockpile alleviated this. The Wagerup refinery employs bauxite stockpiles for blending of mined ore. Primary crushed ore is stacked in a furrow arrangement longitudinally along a 270,000t stockpile. The stockpile is then reclaimed with a bucket wheel reclaimer across the face. Reclaimed ore is fed to a 2000t mill feed bin that was kept full to minimize size segregation during the mill surveys and trials. The pre and post installation testing and mill surveys were performed using the same blended ore body.

Belly liners and feed end liners were not removed during the installation. This allowed the same mill diameter and ball trajectory to be maintained in the pre and post testing. This was possible due to the wrap around design of the pulp lifters and grates.

The same process equipment (screens, pumps, instruments etc) was employed to perform the trials to minimize introduced variability.

Unfortunately, due to the inability to refit worn components into the mill, it was not possible to refit the original discharge grates into the mill. As a result, the open area associated with the pre- installation tests (14.7% total, 4.2% pegged) was much larger than that associated with the post-installation testing (8.2% total, 0.3% pegged). Discussions were held to investigate casting of a trial grate to allow area to be maintained, but this would have led to other operational issues and requirement for a further mill shutdown in the near future. A comparison of the pre and post installation grate conditions can be seen in Figure 6.

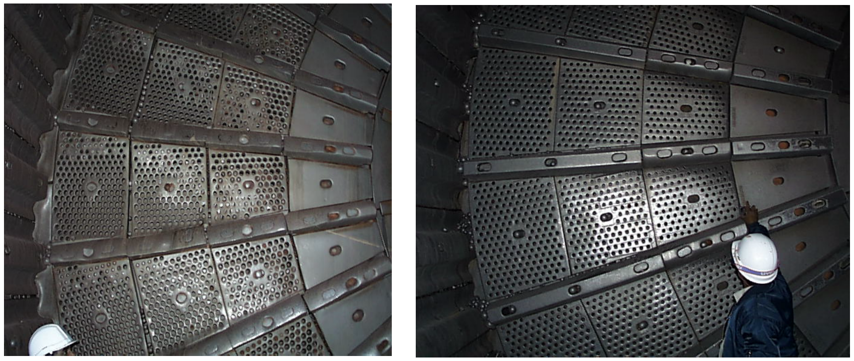

Figure 6: Discharge Grate Comparison Pre(left) & Post(right) Trials

As mentioned earlier, the volume of the original pulp lifter was modified. This had a two-fold effect. The first is an increase in pulp transport due to higher volume alone. The installed TCPL was approximately 90% wider than the radial pulp lifter. The second is a reduced grinding mill chamber. The grinding mill chamber in the trial was reduced by 5% by installation of the wider pulp lifters.

In order to gain an understanding of the changes in charge composition between the pre and post installation, a fixed feed rate test was performed.

Pre installation, the mill was operated to determine the peak throughput of the mill. This was determined by allowing the mill to spill from the feed end. The feed end of the mill corresponds to 34% of the mill volume when at rest and charge is horizontal. Operating volume during a spill condition has been estimated (from volume spilled) in excess of 40%. The mill feed rate was then reduced slightly to avoid a continuous spill condition and brought to an equilibrium power, density and recycle flow. The mill circuit was then surveyed and crash stopped to determine operating charge level and other parameters. This also allowed mill feed conveyor sampling to be performed for ore characterization and sizing. A mill grind out and water flush followed. This allowed vessel entry and measurement of mill internal dimensions such as grate pegging, mill diameter and length and ball charge and size distribution for modeling purposes.

Post installation, the mill was immediately brought online and the same feed conditions (bauxite ore and liquor rates) set and circuit configuration

applied to the mill. The mill was allowed to equilibrate for several hours to an equilibrium power, density and recirculating flow and then the circuit was crash stopped.

This allowed for a true comparison of the effects of improved pulp transport through the mill.

In addition to this, the mill was then operated at several higher throughputs up to and including an operating charge just below spill point (to allow determination of the effect of TCPL's at the same operating load). The same methodology of spilling the mill was employed to determine if the mill was at full loading and then the feed reduced to operate at a stable condition just below the maximum loading.

ASSESSING THE IMPACTS

A comparison of the total charge volume (at same ball charge of 12.4% by volume and 390tph feed) can be seen in Figure 7. Again it should be noted that the charge photograph of the pre TCPL installation does not include the volume of slurry lost from the front of the mill due to spillage of charge. It was estimated that the total operating charge was approximately 40%. The pre installation rock and ball charge was estimated at 32% and the post installation charge at 15% for 390tph operation.

Figure 7: Crash Stop Charge Pre (left) and Post (right) Installation at 390tph

The effect of the improved removal of pulp from the mill can be seen in the sizing data, as shown in Table 1 on the next page, obtained from the mill surveys at 390tph before and after the installation of the TCPL's. It is evident that the DSM feed and oversize is much finer for the TCPL survey than the Radial Pulp lifter survey and this has resulted in a slightly finer product grind also.

Table 1: The Effect on Particle Size Distributions

	F_{80} (mm)	
Stream	**RPL 390 wet tph**	**TCPL 390wet tph**
DSM Feed	1.968	1.328
DSM Oversize	4.165	3.459
DSM Undersize	0.249	0.246

Simulation of the mill employing JKSIMMET software for the Radial and Twin Chamber Pulp Lifter cases at 390tph confirmed the expectation in change in breakage rates due to removal of the slurry pool. These differences are depicted in Figure 8 below. This indicates an increase in breakage across all size ranges.

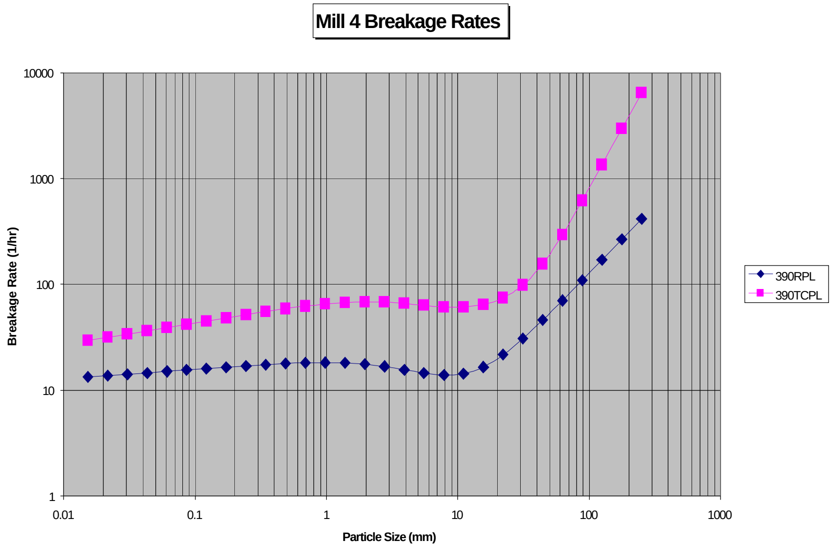

Figure 8: Simulated Breakage Rates at 390tph for Radial and Twin Chamber Pulp Lifter Surveys

Further increases in mill throughput were possible as a result of the low operating charge in the mill. The mill was increased in increments until full load was observed (spilling) and 2 surveys at 425 and 450tph throughput were carried out for further data collection. The crash stop loads at these operating throughputs are shown in Figure 9. The mill operation at 450tph represented the maximum throughput achievable at peak load without overloading the mill (power or spilling). The total operating charge for this feed rate was measured at 27%.

Figure 9: Crash Stop Charges at 425 (left) and 450tph (right)

Obvious differences are the lack of pool formation in the mill at all operating loads tested. In all inspections of the charge after installation of the TCPL's, the slurry was just covering the rock and ball media in the mill. In the crash stop of the radial pulp lifter, a pool of greater than 11% of mill volume was estimated from lost contents (5% measured from retained contents).

A summary of the main operational differences are given below in Table 2 on the next page.

Other observations on differences in performance included a large reduction of lump material on the trommel screens after the crash stops of the mill at 390tph. The inspection of the trommel after crash stop with the TCPL confirmed a much lower proportion of lump material on the trommel. This is partly due to the lower grate aperture size but also due to the improved breakage within the mill and generation of less lump material through the grate.

CONVERSION OF OTHER MILLS

Due to the success observed with the trial. The trial design has since been removed from the mill and replaced with a permanent design. The outer row pulp lifter has been removed and replaced with a pulp lifter that does not overlap the belly lifters. Improvements to the material of construction to allow longer life have been made and a decrease in the number of components of the discharge end was possible to facilitate reline time.

Table 2: Summary of Operational Differences

Variable	Units	Radial Pulp Lifter	Twin Chamber Pulp Lifter	Twin Chamber Pulp Lifter
Throughput	wet tph	390	390	450
Gross Power	kW	2400	2450	2550
Power Usage	kWh/t	6.15	6.28	5.67
Total Load	% Vol	40	15	27
Ball Load	%Vol	12.4	12.4	12.4
Rock and Slurry Load	% Vol	32	8	20
Mill EGL	m	3.66	3.48	3.48
Mill Diameter	m	7.73	7.73	7.73
Mill Speed	$\%N_c$	70	70	70
Total Area	%	14.7	8.2	8.2
Pegged Area	%	4.2	0.3	0.3
Effective Area	%	10.5	7.9	7.9
Hole Size	mm	26.8	18.5	18.5
Pulp Lifter Depth	mm	150	285	285

CONVERSION OF OTHER MILLS

Due to the success observed with the trial. The trial design has since been removed from the mill and replaced with a permanent design. The outer row pulp lifter has been removed and replaced with a pulp lifter that does not overlap the belly lifters. Improvements to the material of construction to allow longer life have been made and a decrease in the number of components of the discharge end was possible to facilitate reline time.

The permanent design has been retrofitted to mill 5 at Alcoa's Wagerup refinery. This mill is of identical size to mill 4 but is rotating in the opposite direction. Similar performance has been replicated on this mill.

The feasibility of transferring this technology to other mills at Alcoa refineries has also progressed. Full mill surveys of the 2 types of SAG mills installed at Alcoa's Pinjarra refinery was completed. Pinjarra operates 2 types of SAG mills of smaller geometry to the Wagerup Mills. The AC mills are flat ended and the ICAL mills have conical feed and discharge ends. The ICAL mills also had much lower grate open area (approximately 4%) than any of the other mills.

Crash stops and surveys of these mills revealed that the AC mills operate with a total charge of 29% of which 7% is due to slurry pool. The ICAL mill surveyed revealed an operating charge of 17% of which there was no pool observed.

Design and installation of the TCPL's was progressed for one AC mill. During this process it was determined that design improvements could be made on all discharge end assemblies in order to save reline time and improve liner life and maintenance costs. The modified designs of the ICAL mills incorporated the TCPL's for a conical ended mill to allow for testing. In addition, due to the elimination of flow back due to the design of the TCPL, it was decided to install a second row of grates on the ICAL mill and increase open area. The design for the conical mill proved more difficult for two reasons. The first being that the original radial pulp lifters were not located directly behind the discharge grate but were offset by half a discharge grate. This required modification due to the need to have the grate directly in front of the pulp lifter to allow maximum slurry transport and minimal interference to flow. Secondly, because of the conical nature of the discharge end, the slurry passage ways are reduced in cross sectional area from the outside of the mill to the center trunnion. This requires that all internal obstructions are removed and modifications were required to open up the slurry flow path.

Since installation on the AC mill, throughput has been increased by approximately 20% and power consumption has decreased by approximately 20% (on kWh/t basis) even though the extent of pooling in the Pinjarra mill was not as severe as that in the Wagerup mill. Improvements have justified expenditure to install the TCPL in all other AC mills at Pinjarra.

Immediately after installation on the ICAL mill at Pinjarra, no increase in throughput was observed. However, it was found that the ball charge in the mill was lower than normal and after rectifying to target, reduced power consumption (kWh/t basis) on this mill was observed in the order of 20%. Throughput has been increased by 5% over other ICAL mills and power consumption is still in the order of 20% less. More investigations are continuing to understand these benefits. It is planned to install the TCPL's in all ICAL mills at Pinjarra.

OPERATIONAL EXPERIENCE

Operational differences were quick to be observed. As throughput was increased on the mill, it was evident that the typical power response of a mill was being observed. Historically, power draw would not decrease when the mill was overloaded at Wagerup. This was attributed to the mill being full due to a slurry pool rather than solid media and so a full (overflowing) mill prevented the peak power to be achieved on the mill unless large lump material was being fed to the mill or ball charge was too high. In addition, the typical response achieved when feed was taken off was an increase in power draw due to removal of slurry pool and then a decrease in power draw as rock was depleted from the mill.

After installation of the TCPL's at Wagerup a loss in power draw could be observed if feed rate was too high followed by spillage of the mill from the feed end. In these instances, the spillage consisted of dry rock rather than a pool and power draw would behave differently in different situations. Sometimes the power would increase if feed was stopped and sometimes it would decrease if feed were stopped. This is an indication that depending on ore type there may still be pooling occurring in the Wagerup mill.

The change in operating dynamics of the mill did take operations personnel time to get accustomed to. Over the following several months and with different ore bodies being presented to the mill, it was possible to increase mill throughput further at Wagerup. Over a 12-month operating period, the mill has averaged 470 tph and has achieved operating peaks as high as 520tph for 1 week duration's. Gross Power consumption (on kWh/t basis) has dropped by approximately 15-20% over this period as throughput has increased.

Following installation of the TCPL's in both the Wagerup and Pinjarra mills, it was evident that noise emanating from the mill was generally higher. Heavy peening of grates was observed on the Wagerup mills with hole apertures originally 20mm being reduced to 15mm. This did not seem to affect mill throughput and may provide further opportunities.

The Pinjarra AC mills (and the Wagerup mill to a smaller degree) indicated over throwing of balls ahead of the toe of the charge. The mill always sounded empty, even when full power was being drawn and reduction in ball charge to increase rock charge would result in loss of throughput. Subsequent modeling of the liners and their influence on the outer trajectory of balls indicated that they were over throwing the toe of the charge and impacting on liners. This was not evident before the installation of the TCPL's as the slurry pool was dampening the noise from this phenomenon and indicating that correct throw was being achieved.

CONCLUSIONS

Pilot and full scale testing of the impacts of the Twin Chamber Pulp Lifter has confirmed that it provides more efficient transport than other conventional pulp lifters, the difference increasing with higher mill hold up.

Conversion of the concept to working designs has been performed successfully for both flat ended and conical ended SAG mills of differing rotation direction and geometry.

The elimination of slurry pool by installation of the TCPL's in both the Wagerup and Pinjarra SAG mills has allowed throughput to be increased by approximately 20% with a similar reduction in power consumption on a kWh/t basis.

There are indications that the TCPL installed on a non pooling mill at Pinjarra is providing significant reduction in power consumption (20% lower kWh/t) and minor throughput increases but the reasons are not fully understood at this stage.

Reduction of the slurry pool in the Alcoa mills has identified further milling inefficiencies that were being hidden by such operation.

ACKNOWLEDGEMENTS

The AMIRA P9L project and associated sponsors for continued support of research into this area of mill operation.

C.Soh (Alcoa) for driving the process of development and installation for the Alcoa mills.

REFERENCES

MORRELL, S. & STEPHENSON, I. 1996. Slurry discharge capacity of autogenous and semi-autogenous mills and the effect of grate design. Int Jnrl Mineral Processing, Vol 46, pp53-72.

MORRELL, S. & KOJOVIC, T. 1996. The influence of slurry transport on the power draw of autogenous and semi-autogenous mills. Proc SAG'96, Vancouver, Vol 1 pp373-389.