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ENERGY EFFICIENT GRINDING MILLS[1]

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Abstract
The horizontal grinding mills have been existing in mining industry since more than a century and the question on their efficiency is still remains debatable. The instant we think of ball mills, overflow discharge ball mills strikes first and indeed they are the most commonly seen in mining industry. The material transport in overflow ball mills is by displacement compared to the quicker migration of product size fines across the grate due to higher gradient. Quick migration and removal of the finished product leads to rapid change of mill content, minimum over-grinding, lower grinding cost per ton, improved metallurgy in downstream processes etc. Although principally grate discharge mills do have many advantages compared to overflow mills, their application has been quite limited. The efficiency of AG/SAG mills fall between the overflow mills and true grate-discharge (open ended grate) mills due to inherent material transport problems. This paper will look into different factors that influence the grinding efficiency of the horizontal mills – AG/SAG/Ball mills, with the possible solutions to make them more energy efficient using the Turbo Pulp Lifter (TPLTM) technology - an Outotec patented design, developed to ensure good grinding conditions in grate discharge grinding mills..
Key words: Grinding; Regrinding; Ball Mill; AG; SAG; Energy Efficient.

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1 INTRODUCTION

The energy efficiency of a comminution device typically depends on how good the energy is used in breaking of new particles and how best the product size particles are classified and taken out. In other words it can be stated that the most energy efficient breakage system would be the one where the particles leave the energy field as soon as they become smaller than the required product size – a classic example of which is the crushers where free falling gravitational (vertical) material transport exists (Figure 1).

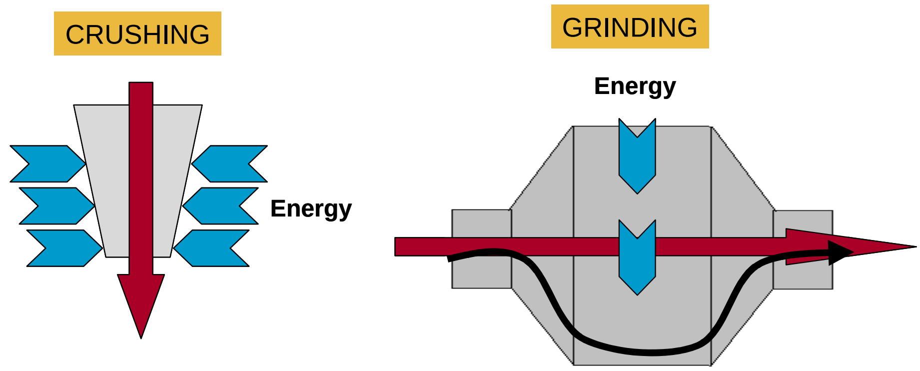

Figure 1. Material transport in crushers and grinding mills.

Contrary to the crushers, the material transport in grinding mills is horizontal and therefore requires a suitable arrangement to remove the product. The grate and pulp lifter arrangement has been introduced in grinding mills to increase the material transport by providing high gradient across the grate. However, extensive research has proved that the material transport across the grinding mill is not straight forward (Figure 3) but it consists of several inherent drawbacks (Figure 2).

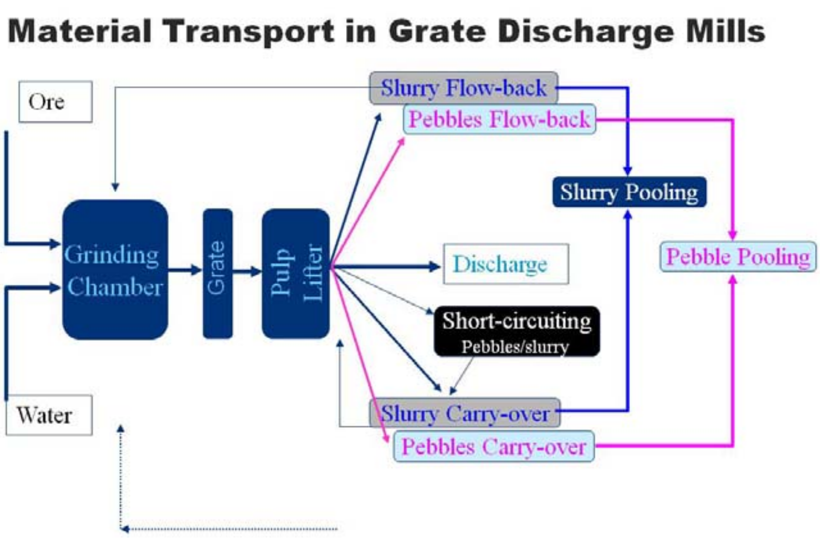

Figure 2. Material transport with conventional pulp lifters in grate discharge mills.

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While the above factors are also inherent to grate discharge ball mills, the presence of large slurry pool (forced) in overflow ball mills can be termed as the most inefficient way of material transport. In early 1900's, several approaches - Marcy mills, peripheral discharge, have been introduced to rapidly discharge the product size particles to attain higher capacity and energy efficiency. However, the relentless increase in mill size has put restrictions on building such mills and are left with the existing grate-pulp lifter discharge and overflow-discharge grinding mills.
While the designing and selection of grinding mills, Outotec does extensive studies to ensure an efficient material transport system, therefore enhancing the energy efficiency and maximizing the capacity of the horizontal grinding mills.
Outotec has developed a new technology[(1)]– Turbo Pulp Lifter (TPL™), for enhancing the grinding efficiency of AG/SAG and Ball mills and therefore saves significant amount of electrical energy while maximizing the mill capacity.
The objective of the TPL™ is to ensure energy efficient grinding by pushing the discharge efficiency of AG/SAG mills towards the crushers and thus allowing the mills to operate at their maximum possible capacity with higher energy efficiency. Latchireddi[(2-4)] has experimentally proved that the material transport in grinding mills with TPL moves towards ideal one as shown in Figure 3.

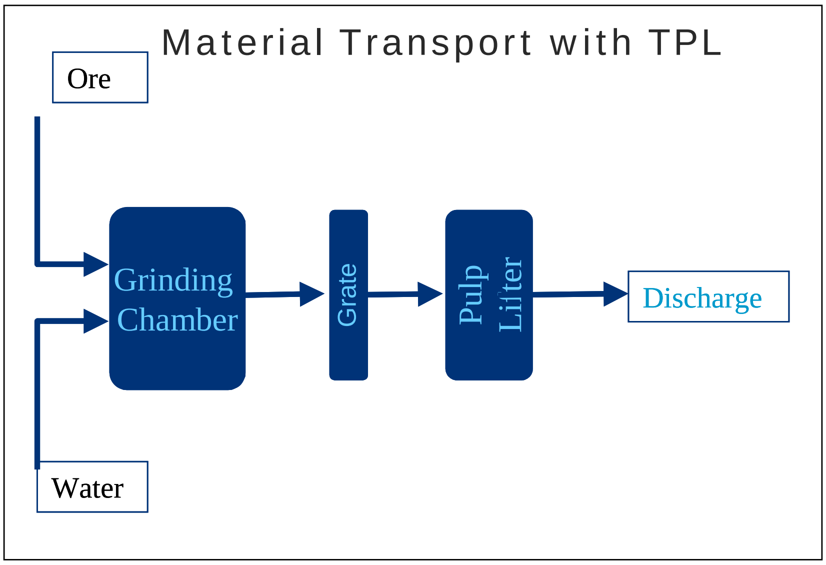

Figure 3. Material transport with Turbo Pulp Lifter -TPL™.

2 ENERGY EFFICIENCY ISSUES IN GRINDING MILLS

The intense research carried out by Latchireddi[(2,5)] over the past few years has explained the principle factors that cause inefficient grinding in different grinding circuits. This is summarized in Table 1 and their relation to energy efficiency of grinding mills are discussed here.

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Table 1. Inherent factors and transport problems in grinding mills

Circuit	Closed circuit with	Mill discharge	Inherent Factors	Problem
Single stage AG/SAG/ Pebble	Hydrocyclones/ Screens/Sieve-bends	Slurry	Flow-back and Carry-over of slurry	Slurry pooling
Multi stage ABC/SABC	Pebble crusher/screens	Slurry and Solids/pebbles	Flow-back and Carry-over of slurry and pebles	Slurry and Solids pooling

2.1 Flow-Back and Energy Efficiency

Flow-back is the inevitable phenomena associated with the conventional pulp lifter designs – Radial and Curved, applicable to both slurry and solids/pebbles phase. Slurry flow-back is predominant in single stage AG/SAG mills, as they handle large volume of slurry due to the higher circulating loads up to 400%-500%. The geometry of radial and curved pulp lifters allow the slurry to be always in contact with the grate until it is completely discharged, which makes the 'flow-back' process inevitable.
As illustrated in Figure 4, while the gradient across the grate is from the grinding chamber in to the pulp lifter between the toe and shoulder of mill load, the gradient reverses from pulp lifter into grinding chamber, once the pulp lifter crosses the shoulder position. When slurry and pebbles flow down across the grate slots, they get an equal chance to go back into the mill as illustrated in DEM simulation of 36ft SAG mill pulp lifters shown in Figure 4.

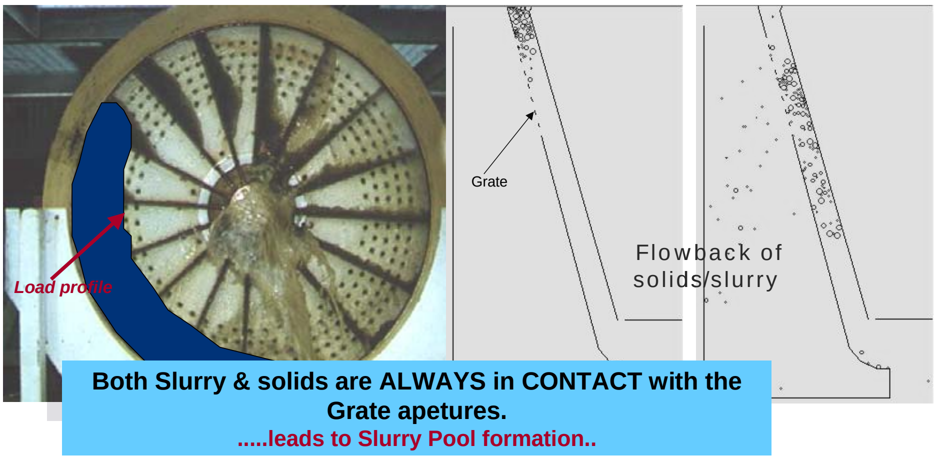

Figure 4. Inherent flow-back process with conventional pulp lifters.

While flow-back of slurry leads to pool formation, flow-back of pebbles increases the quantity of critical size material in the mill. The amount of pebbles passing through the grate increases with the angle of the grate. A DEM simulation of this scenario for a 36-ft diameter SAG mill is shown in Figure 4.

The inefficient usage of energy due to the flow back phenomena are summarised below:

- the amount of energy spent on the product size particles that flow back, after they passed through the grate, contributes to wasteful energy;
- the excess mill power draw due to the higher mill loads caused by the pebbles flow back contributes to wasteful energy;
- the flow back of coarse pebbles also increases the quantity of critical size particles and affects the energy levels available for breakage of coarse particles;
- the mill capacity is curtailed to the extent of flow-back, which has been noted to be anywhere from 10% to 35% based on industrial data.

TPL™ discharge system completely stops the flow-back process and hence saves all the wasteful energy and uses it efficiently in breaking the new particles.

2.2 Slurry Pool and Energy Efficiency

The fraction of slurry that is flown back into the grinding chamber, ultimately leads to slurry pool formation near the toe of the charge as depicted in Figure 5. The presence of the slurry pool absorbs significant fraction of impact energy causing poor coarse particle breakage. Presence of slurry pool also leads to poor attrition action, as the probability of particles draining into the slurry pool increases due to drag force, thus causing poor fine particle breakage. Both poor impact and poor attrition leads to overall lower breakage rates and therefore limits the mill capacity.

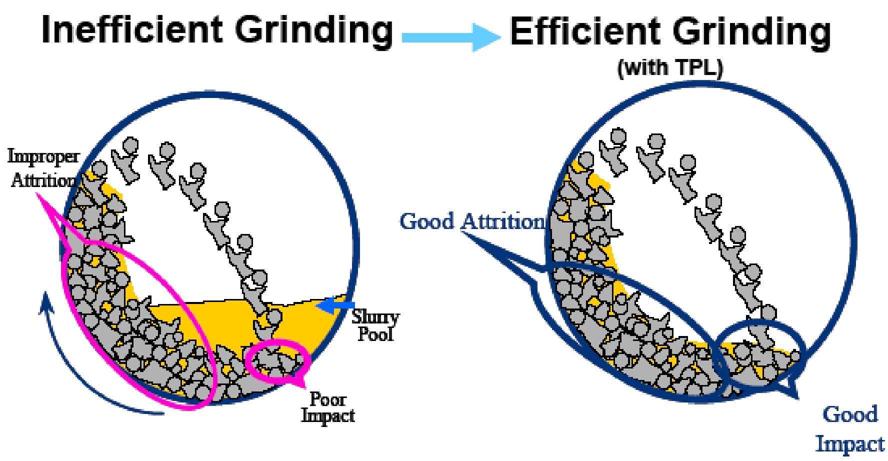

Figure 5. Inefficient grinding to efficient grinding with TPL™.

TPL™ discharge system stops slurry pool formation and provides good grinding conditions where all the available energy is used for efficient breakage of particles. In absence of slurry pool, the smaller particles are confined to stay inside the active charge and forced to attrition breakage. Combining both good impact and good attrition process leads to higher breakage rates and hence higher throughput.

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2.3 Inefficient Discharge

When grinding mill rotates in clock-wise direction, the pulp lifter essentially has the possibility to discharge its contents starting from 9'O clock and complete latest by 3'O clock position. If the contents are not emptied by 3'O clock position, then the leftover slurry/solids get carried over inside the pulp lifter.
A snapshot of the discharge of slurry from single stage sag mill operating (*pre ad post TPL installation*) is shown in Figure 6, where the pre-TPL discharge shows a narrow space between 1.30 and 3'O clock position. it is quite reasonable to assume in Figure 6 that a significant fraction of slurry (74% solids) must be left inside the pulp lifter, as the time is not enough for complete discharge. The leftover slurry ultimately flows back through the grate into the grinding chamber and become part of slurry pool.
However, with TPL^{TM} discharge system, the available time for discharge of pulp lifter contents increased significantly, providing ample time for complete discharge.

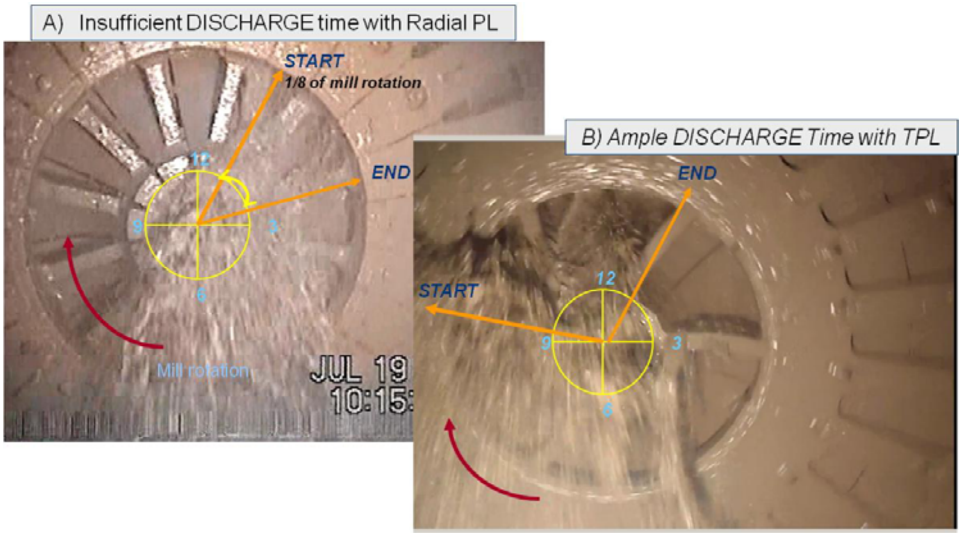

Figure 6. Inefficient to efficient discharge with TPL.

2.4 Effect of Carry-Over on Grinding Efficiency

Carry-over is a strong function of mill speed and slurry viscosity. Similar to the differential flow behavior of water and sand in open channel river streams, the slurry fraction and pebbles follow different flow pattern inside pulp lifter. The fraction of slurry that is carried-over in pulp lifter ultimately flows back into the grinding chamber and leads to slurry pool formation. However, only part of the solid particles flow back through the grate and majority of them stay inside the pulp lifter chamber as shown in Figure 7, where both DEM simulation and actual picture are shown.

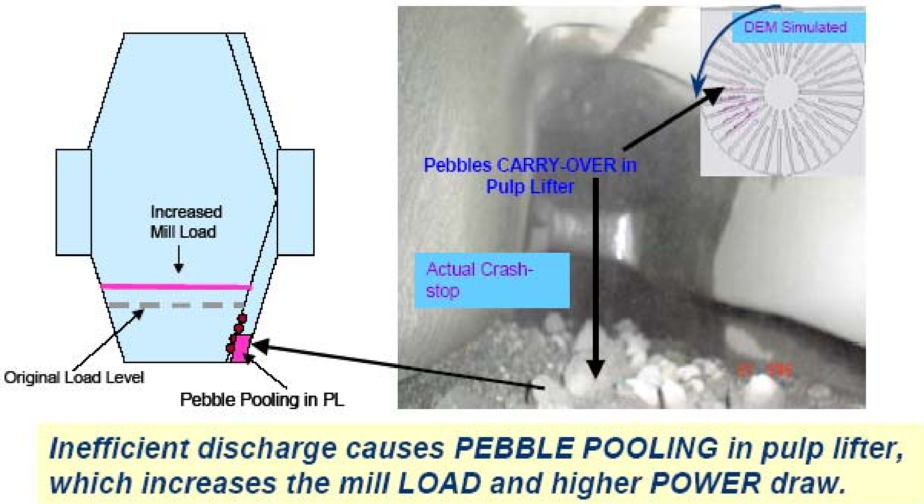

Figure 7. Effect of pebbles carry-over on mill load.

By the time a pulp lifter reaches 6 O'Clock position, the pebbles remained in pulp lifter reach the bottom and exert resistance to flow through the outer few rows of grate slots. However, to maintain the overall discharge rate using the remaining slots, the load level automatically raises to a level sufficient enough to exert the required pressure head. The increased mill load draws extra power as well as decreases the grinding efficiency by reducing the drop height and ball to rock ratio, which affects impact energy.

The internal dimensions of TPL are designed using modeling and simulations to make sure all the particles that are passed through the grate, are discharged out of pulp lifter and stop pebble pooling in pulp lifters and unwanted raise in mill load. The drop in mill load at the same throughput could be significantly high and so does the magnitude of electrical energy savings.

Installation of TPL in 2006 in 26ftx12.5ft SAG mill at Cortez Gold Mines has proved the importance of good material transportation and its impact on energy efficiency and capacity. The pre and post performance results in terms of improved plant availability and liner wear are well discussed by Latchireddi(5) and Steiger et al.(6)

2.5 Overflow Vs Grate Discharge Ball Mills

Majority of the present day ball mills are overflow discharge type and the grate discharge ball mills are opted only in special circumstances such as to minimize fines generation. In author's view, the reason for the limited application of grate discharge ball mills in wet grinding could be the presence of all the inherent material transport issues discussed in previous section, which limits the realization of complete benefits of the true grate discharge arrangement.

The typical cross-section of the slurry profile in overflow grinding mills is shown in Figure 8. The constant presence of large body of slurry pool in overflow mills causes reduced ball impacts due to cushioning. Since both fines and coarse particles migrate at the same rate in overflow mills, the grinding balls expend energy on particles already sufficiently fine enough thus resulting in 'wasteful grinding'.

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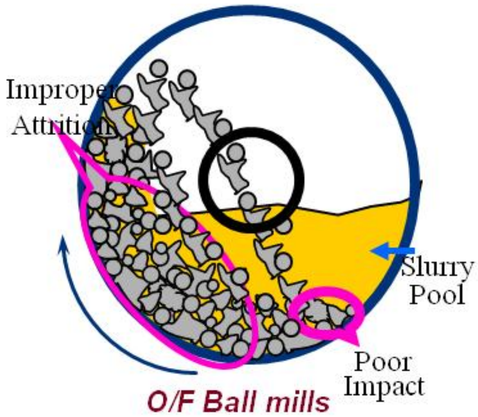

Figure 8. Slurry profile in overflow ball mills.

In absence of large slurry pool, all the particles have to pass through the grinding media and are subjected to breakage without escaping into slurry pool. Grate discharge arrangement with TPL allows quick discharge of the finished material resulting in maximizing the 'good grinding' in breaking the oversize particles, thus minimizing the 'wasteful grinding' in further reducing particles already fine enough for the finished product.
The advantages of the true grate discharge mechanism (with TPL) in ball mills are listed below:

- more effective utilization of ball action;
- allows quick migration and removal of the finished product;
- enables to grind with highest Energy Efficiency;
- provides flexibility on controlling mill product size;
- allows max ball load and hence the power utilization;
- can take coarser feed size;
- improve classification efficiency.

The application of TPL technology in ball mills is in progress and the results are expected towards the end of this year. However, to illustrate the magnitude of the benefits, the data published by Mokken et al.(7) in terms of comparison of grate discharge mills (with conventional pan/pulp lifters) and true grate discharge mills (End/peripheral discharge) mills is shown in Figure 9.

ISSN 2176-3135

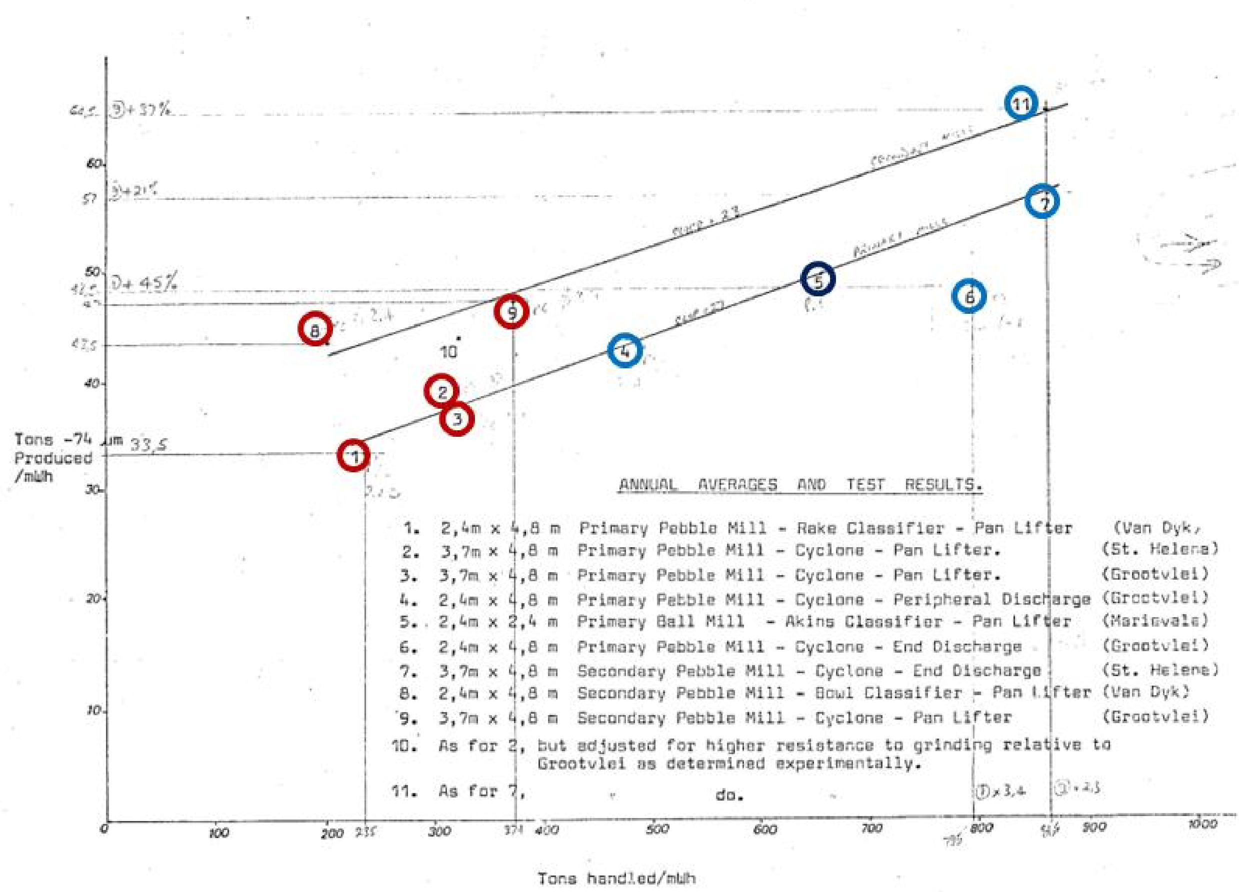

Figure 9. Performance of the mills with pan/pulp lifters and end/peripheral discharge.

3 TURBO PULP LIFTER (TPL^{TM})

It is imperative from the above facts that efficient material transport is an important issue to optimize the energy efficiency of grinding mills.

The TPL ensures the best grinding conditions by allowing the product size particles migrate faster through the discharge grate. The TPL^{TM} does not necessitate re-drilling of the mill head for retrofitting. From outside, the TPL^{TM} appears exactly like the conventional radial pulp lifter. However, the internal design is entirely different. While keeping the concept, the internal design changes to suite the existing mill configuration to ensure the ideal material transportation.

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Elimination of material transport problems using TPL™ will bring the following process benefits:

- maximizes the classification and breakage rates by improving the material transport;
- significantly increases energy efficiency by reducing the energy consumption (proven upto +20%);
- allows the mill to operate at its maximum possible capacity (proven upto +20%).
- ensures the mill gives true response for any changes in ore characteristics or process parameters;
- operator friendly - allows the mill to operate smooth and steady;
- significantly improves wear life;
- improves performance of cyclones and energy efficiency of ball mills.

4 CONCLUSIONS

The optimal performance of grinding mills (AG/SAG/ball) is the key to a successful plant operation. Grinding mills with conventional pulp lifter designs suffer from inherent material transport problems that reduce energy efficiency and limits mill capacity. The Turbo Pulp Lifter (TPL™) ensures best grinding conditions by stopping internal re-circulation of product size particles in AG/SAG/Ball mills leading to significant electrical energy savings and capacity improvements.

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