IMPACT OF THE STIRRED MILL GRINDING MECHANISM ON GRINDING PERFORMANCE AND MEDIA CONSUMPTION

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ABSTRACT

Nowadays, the demand for a finer grind in minerals processing has set new challenges within the industry. Apart from a finer grind, energy efficiency and reduction of media consumption are also key drivers in optimising comminution technology in today's plants.
Anglo American Platinum and three other mining companies, together with Swiss Tower Mills Minerals and Outotec embarked on a technology comparison program to review what impact the different grinding mechanisms would have on energy consumption, grinding media wear, liner wear, product quality and throughput in the hard rock UFG comminution circuit. This was tested in a tertiary grinding application comparing production size mills in closed and open circuit, as well as, vertical and horizontal mill arrangements.

KEYWORDS

Regrinding, fine grinding, efficiency, vertical mill, stirred media mill, HIGmill^{TM}

INTRODUCTION

Fine grinding has become an important part of the comminution circuit over the last decade. For many mine operators, the additional recoveries or grade quality improvements achieved by finer grinding has been the difference between making a profit or a loss when metal prices are low.
Where 10 years ago mining companies had only one or two technologies or suppliers to select from, today the stirred mill product offering is much more diverse. All major technology providers have stirred mills in their portfolio and promote this technology for greenfields and brownfield plants. This paper attempts to compare the different grinding mechanisms on the market by means of side by side test work in operating plants. The main comparison criteria were:

a) Grinding efficiency (kwh per ton)
b) Grinding media wear
c) Product PSD distribution

The difficulty for such a study is to find operations that have a production size mill and will allow a test mill to be extensively tested alongside it.
Acknowledgements and an extension of gratitude must be made to those plants for providing the opportunity to execute such test work and provide the necessary support.

1. Grinding mechanisms

On the various sites and in different applications we tested the HIGmill^{TM} which is a vertical mill with vane rotors against existing mills which were already installed on site such as:

- vertical mill with helical agitator
- vertical stirred mill with flat discs
- vertical stirred mill with pins (sand mill)
- horizontal stirred mill with flat discs

Table 1. Comparison overview of different grinding mechanisms

Description	**Vertical mill with vane rotors (HIGmill^{TM})**	**Vertical mill with helical agitator**	**Vertical stirred mill with flat discs**	**Vertical stirred mill with pins**	**Horizontal stirred mill with flat discs**
Closed or open circuit	Open	Closed	Open	Open	Open
Grinding media type	Ceramic or Steel	Steel	Ceramic	Ceramic	Ceramic
Grinding media size	Up to 25mm	Up to 38mm	Up to 6mm	Up to 6mm	Up to 6mm
Typical grinding media surface per volume	High	Medium	High	High	High
Grinding media feed	From top or bottom with feed	From top	From bottom with feed	From top	With slurry into feed tank
Retaining of grinding media	Inherent (gravity) no screens	Inherent (gravity) no screens	Inherent (gravity) with screens	Inherent (gravity) with screens	By centrifugal force of internal rotor
tip speed	medium	Low	medium	high	High
Agitator material	Steel	Steel or rubber covered	Poly Urethane	Steel covered with rubber	Rubber
Liner material	Steel	Steel	Poly Urethane	Steel or rubber	Rubber
Grinding chamber pressure	Atmospherics pressure	Atmospherics pressure	Atmospherics pressure	Atmospherics pressure	Under positive pressure
Turndown ratio	High	None	Medium	small	Small with fixed speed motor Medium with optional VFD
Top feed size	>1mm	>1mm	< 1mm	< 1mm	< 1mm
Variable speed	Yes	No	Partly	No	Optional

1.1 Grinding mechanism of a vertical mill with vane rotors

STM/Outotec's HIGmill™ is a "stirred media" grinding mill where the stirred effect is caused by rotating vane grinding discs (rotors) together with stator rings situated on the shell. The shape of the mill offers a small footprint. The general structure and its main components are presented in the Figure 1.

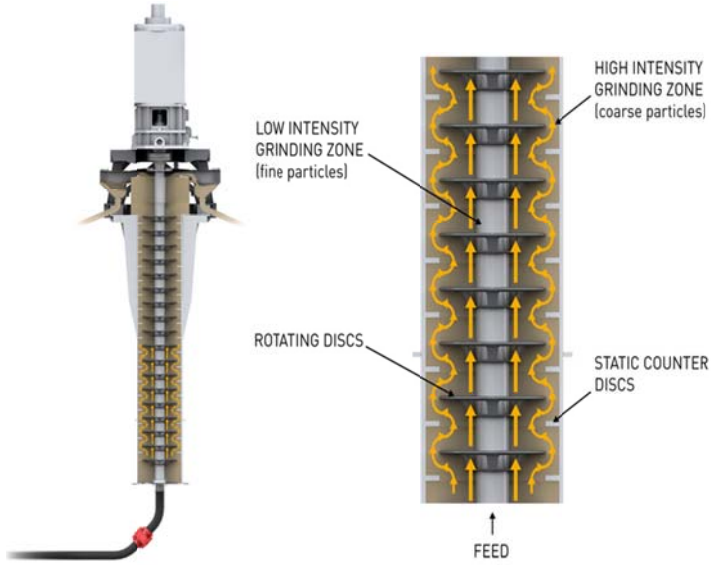

Figure 1. Outotec HIGmill™

Feed is pumped into the mill from the bottom. As the material passes upwards, it passes through all consecutive grinding stages, which are basically separate grinding chambers.

The grinding chamber can be filled with up to 70% of media. Standard ceramic, high density ceramic and steel media have been tested in the HIGmill™ and may be used as required. The grinding media is easily retained in the mill by both the stator rings and the gravity, since the specific weight of the media is much higher than the slurry; therefore no power consuming separator or similar is required to avoid spillage of the beads.

The rotors stir the charge and the grinding takes places between beads by attrition only. Due to the tall vertical mill body arrangement, grinding media is in each grinding chamber evenly distributed in radial direction and the gravitational effect ensures inherent classification of particles. Furthermore the unique concept with the stator rings also eliminates the possibility of short-circuiting the mill. The hydrostatic pressure ensures optimal contact between grinding media and the mineral particles, significantly increasing grinding efficiency. The final product discharges at the top of the mill at open atmosphere. Flow fluctuations to a HIGmill™ can be dampened by maintaining the net energy via control of the mill shaft speed. Product fineness is controlled by maintaining the feed rate, feed density, media level, and shaft speed. The mill offers high power intensity with reduced energy consumption.

The grinding mechanism consists of special castellated rotors (patent pending) with vanes as shown in the figure below. They are used, in order to transfer the energy from the rotors efficiently into the slurry, while at the same time the wear on the rotors is being reduced.

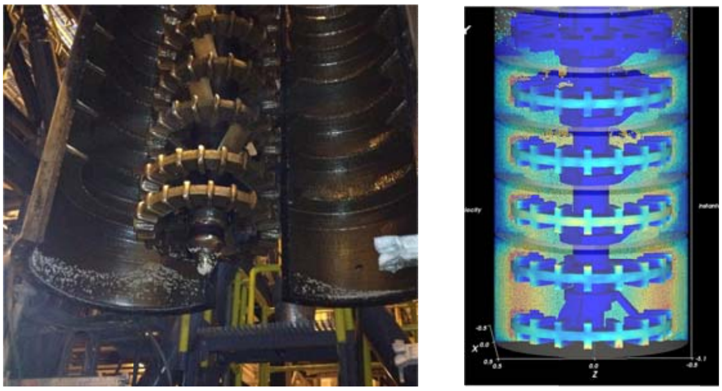

Figure 2. Special shaped vane rotors in the Outotec HIGmill™

1.2 Grinding mechanism of a vertical tower mill with helical agitator

The mill is designed mainly for closed circuit operation with large recirculation loads. The agitator runs at low speeds, with predominantly steel media being used as grinding media.

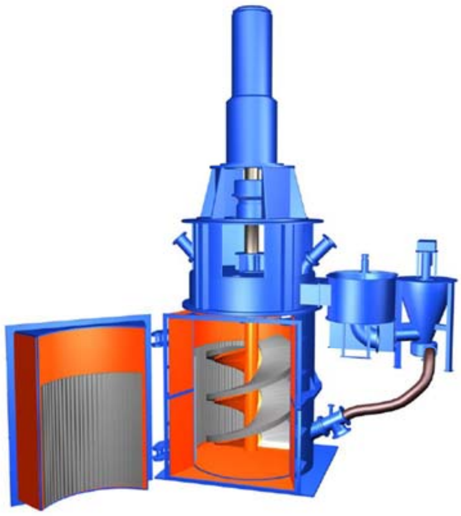

Figure 3. Vertical tower mill with helical agitator (J. Allen, 2009)

1.3 Grinding mechanism of a vertical stirred mill with flat discs

The mill cylinder is a tube with poly ethylene lining. The flat grinding discs are also made from polyurethane. The media filling level is up to 80%, screens prevent the small media to exit the mill with slurry.

Figure 4. Vertical stirred mill with flat discs (P. Radziszewski et al., 2012)

1.4 Grinding mechanism of a vertical stirred mill with pinss

The stirred mill with pins also known as sand mills originate from the clay milling. The unit's sizes are traditionally small. A number of screens prevent the small media to exit the mill with the slurry.

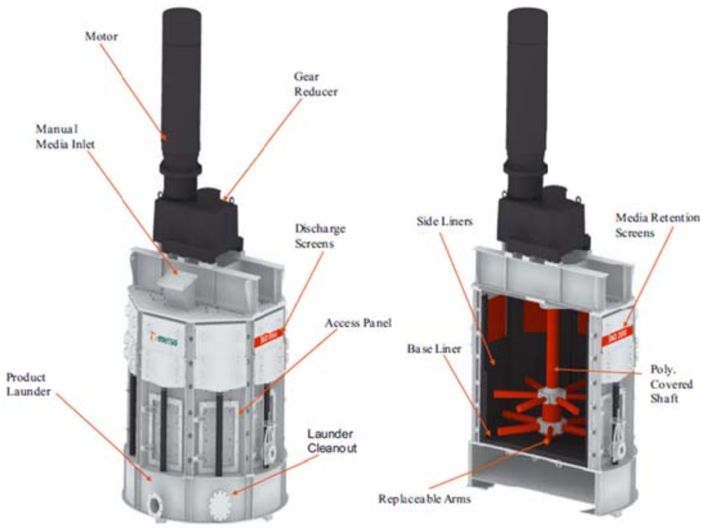

Figure 5. Vertical stirred mill with pins (C. Ntsele et al., 2012)

1.5 Grinding mechanism of a horizontal stirred mill with flat discs

The horizontal stirred mill operates with high power intensities. Inside the shell are rotating flat grinding discs mounted on a shaft which is coupled to a motor and gearbox. The shaft is counter-levelled at the product discharge end. A rotor at the discharge end of mill aims to keep media inside the mill by centrifugal action. The mill shell is a tube with rubber lining and the flat grinding discs are also lined with rubber. The grinding discs agitate the media and slurry which is continuously fed into the feed port.

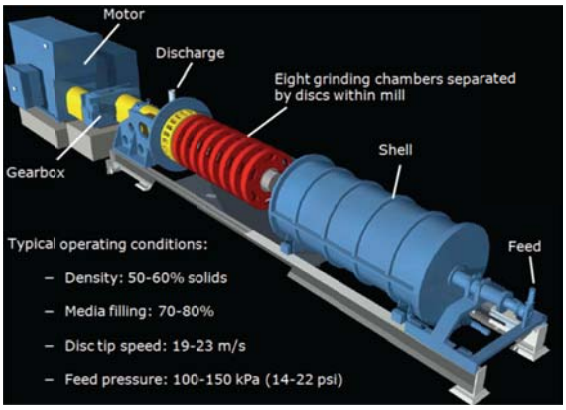

Figure 6. Horizontal stirred mill with flat grinding discs (H. de Waal et al., 2013)

2. Test Locations

2.1 Gold mine in the DRC

Our first test plant was at a Gold Plant in Eastern Congo, the HIG 75/200 production mill was shipped via Mombasa overland to the plant site. The mill was dispatched in April 2015 and arrived on site end of May 2015. The test period was 6 months and the mill was shipped in November 2015 to Johannesburg. Test work conducted was on a gold concentrate and, we benchmarked the installed mills with the rotor mill.

Figure 7. Gold mine in the DRC

2.2 East Rand Gold Tailings Plant

Our 2nd test plant was at a East Rand Gold Tailings Treatment Plant near Johannesburg. The mill arrived on site in January 2016 and test work commenced end of January until end of February 2016. Tests conducted were on gold tailings where we benchmarked the installed mills with the rotor mill.

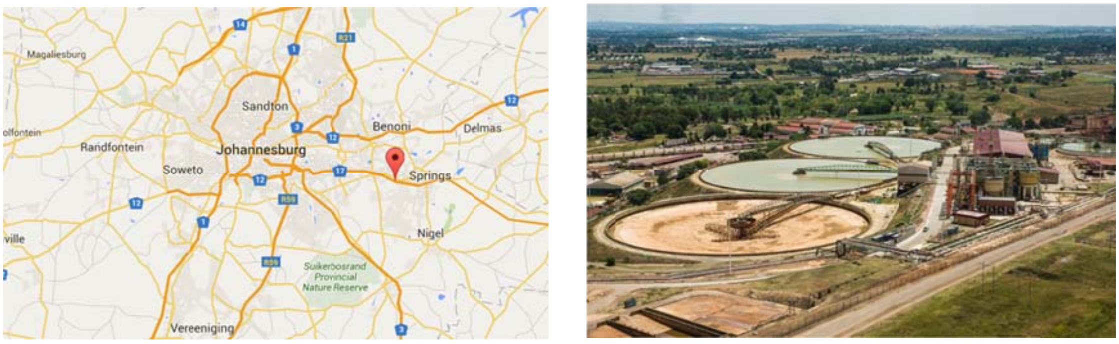

Figure 8. East Rand Gold Tailings Plant

2.3 Platinum Pilot Plant

For many years Anglo American Platinum (AAP) has pioneered the fine grinding option in its platinum concentrators in South Africa. Its optimisation and development test facility, the Divisional Metallurgical Laboratory (DML), comprises a laboratory scale test facility, as well as, a fully equipped pilot plant which situated at the old Frank Concentrator complex in Rustenburg. Over the many decades, AAP has shown devotion in testing and comparing of different concentrator technologies. As part of its continuous drive to stay ahead of the industry standard, AAP was very open to testing a horizontal fine grinding mill with flat discs against a vertical rotor mill. The test material used was a UG2 platinum ore.

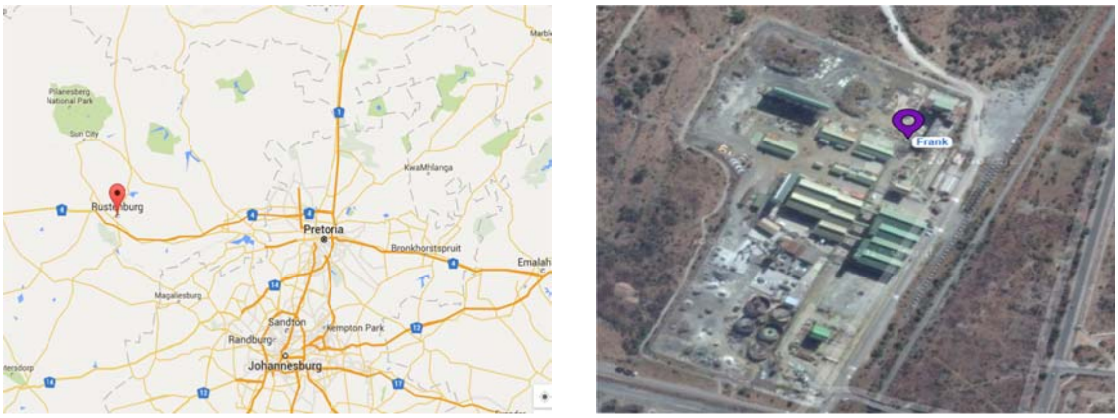

Figure 9. Anglo's platinum pilot plant at Rustenburg

2.4 Platinum Production Plant

In today's economic environment with platinum prices below 1000 USD, tailings regrinding to liberate PGMs is becoming common in the industry. On a plant near Pilanesburg, we were able to do comparative testing between the rotor mill and a vertical stirred mill with pins. The test work is still ongoing and more comparison data will be available by the end of April 2016.

Figure 10. Platinum production plant

3. Test setup

The test setup in all plants were similar. The mill feed for the test mill was taken from the same feed as the existing mills. The same grinding media used was the same as that used in the existing mills.

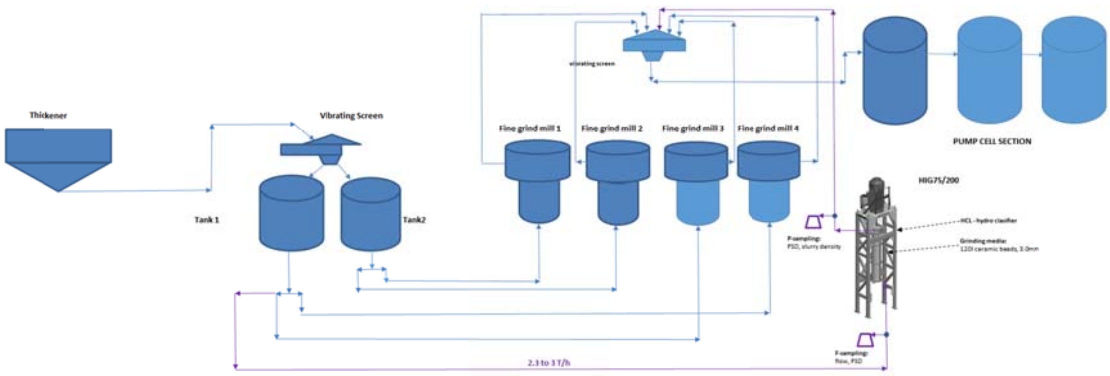

Figure 11. Typical test setup

It is noted there were some challenges experienced during the different tests as follows.:

- For some sites, it was difficult to get the same media for the test mill as that used in the operating mills.
- The location and type of sampling points is very important to ensure the same feed material is used.
- It is important that feed and product samples of the mills are taken at the same time.

4. Test results

4.1 Gold mine in the DRC

In the DRC we conducted two sets of tests, one with fine feed and one with coarser feed against a vertical stirred mill with flat discs.

a) Milling with fine feed (full stream). Results are presented in Table 2.

Table 2. Results fine feed test

Description	HIGmill™	Existing vertical stirred mill with flat discs	Comments
F80	25 um	25 um	
P80 target 1	15 um	15 um	
SGE to reach 15 micron	13,4 kWh/t	25 kWh/t	
Media consumption target 1	120 gram / ton	290 gram / ton	

b) Milling with coarse feed (cyclone underflow). Results are presented in Table 3.

Table 3. Results coarse feed test

Description	HIGmill™	Existing vertical stirred mill with flat discs	Comments
F80	60 to 70 micron	60 to 70 micron	
P80 target 1	29 micron	29 micron	
P80 target 2	15 micron	15 micron	
SGE to reach target 1	9,2 kWh/t	18 kWh/t	
SGE to reach target 2	35,7 kWh/t	Could not be reached	Not possible for existing mill
Media consumption target 1	78 gram per ton	Not measured	
Media consumption target 2	252 gram per ton	Not measured	Not possible for existing mill

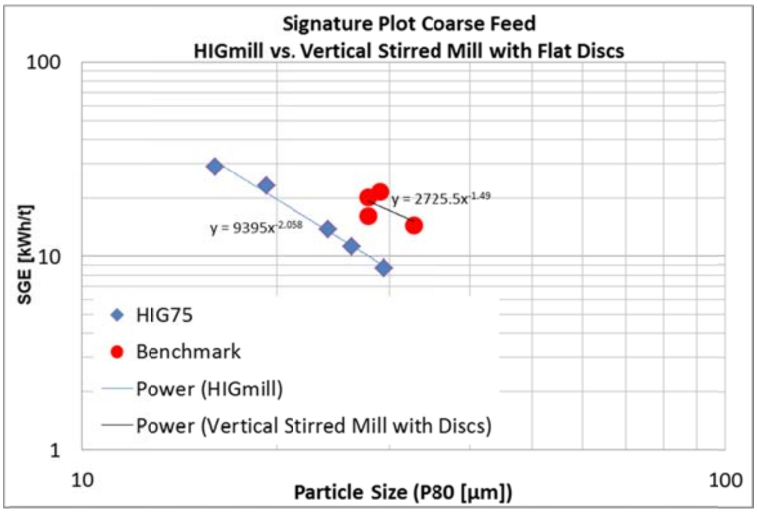

Figure 12. Signature plot coarse feed

4.2 East Rand Gold Tailings Plant

On the East Rand Tailings Plant we conducted a side by side test with the existing fine grinding mills that are vertical stirred mills with flat discs. Results are presented in Table 4.

Table 4. Results East Rand Gold Tailings Plant

Description	HIGmill™	Existing vertical stirred mill with flat discs	Comments
F80	40 um	40 um	
P80 target 1	28 um	28 um	
P80 target 2	22 um	Could not be reached	
P80 target 3	17 um	Could not be reached	
SGE to reach 28 micron	4,2 kWh/t	8.6 kWh/t	Benchmark test
SGE to reach 22 micron	11.2 kWh/t	Could not be reached	Target 2 not possible for existing mill
SGE to reach 17 micron	31,9 kWh/t	Could not be reached	Target 3 not possible for existing mill

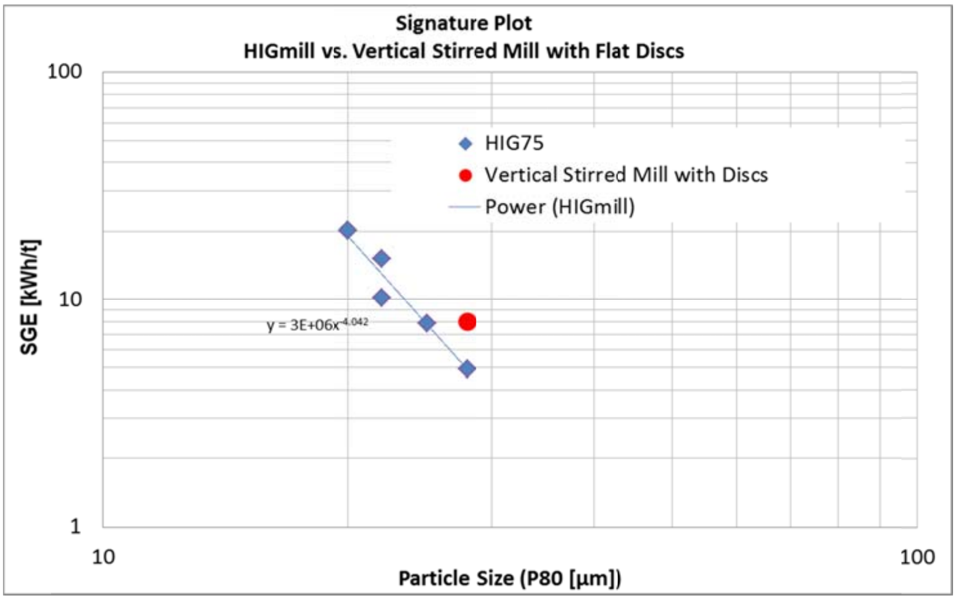

Figure 13. Signature plot East Rand Gold Tailings Plant

4.3 Platinum Pilot Plant 1

In the AAP's DML Pilot Plant the HIG mill was compared to the operation of a pilot scale horizontal fine grinding mill. UG2 ore was used in the tests. The Pilot Plant's secondary milling circuit product formed the feed to the tertiary mills with a slurry SG of 1.4 t/m^3. The horizontal stirred mill was operated at its optimized conditions with a 70% media filling degree. The HIGmill was not optimized at the time of the tests but had a media filling degree of 60%. Results are shown in Table 5.

Table 5. Results Anglo Platinum

Description	HIG Mill	Horizontal stirred mill with flat discs	Comments
F80	100 micron	100 micron	
P80 target 1	53 micron	53 micron	
SGE to reach 53 micron	10.48	16.4	
Media consumption per ton	-	-	Not measured (Kings ZR400 3.5mm media used)

The PSDs were analysed using a laser analyser called the Malvern Mastersizer 2000. Figure 14 confirms the similar feed PSDs with the respective product PSDs of the two mills.

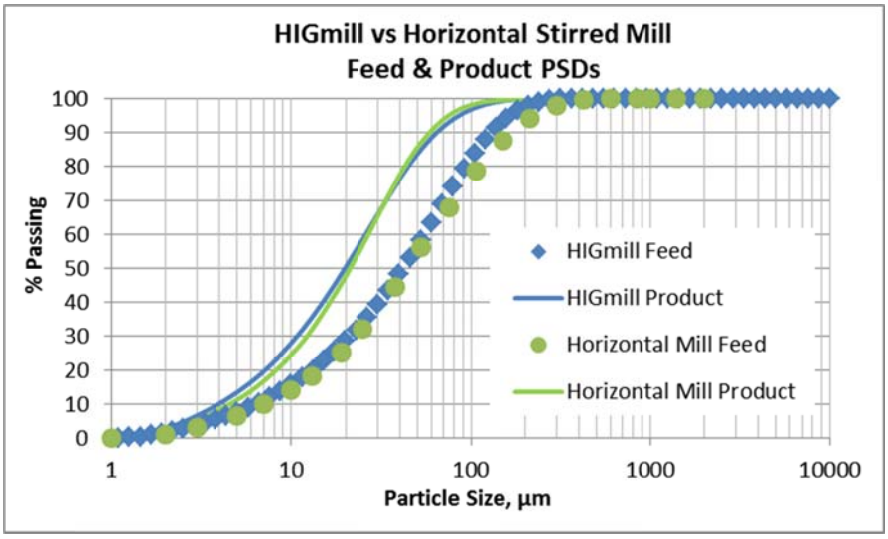

Figure 14. PSDs of the feed and product of both mills

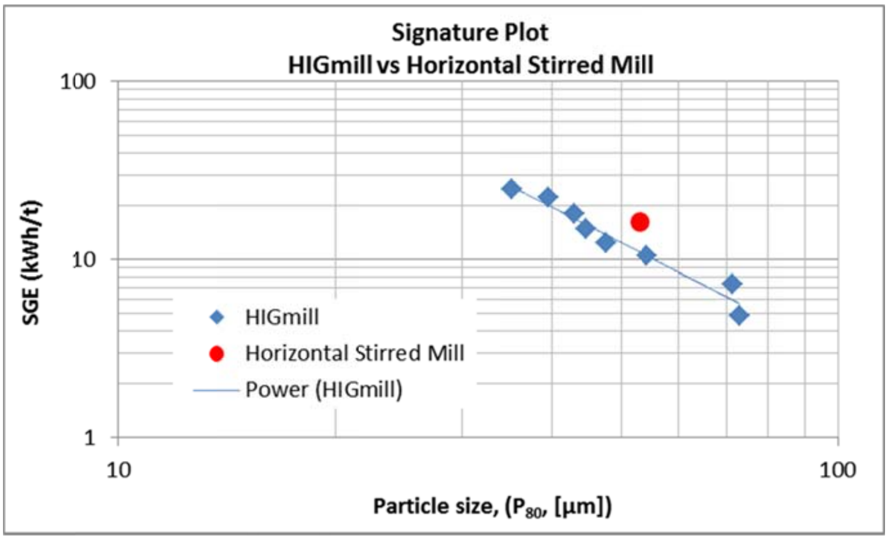

Figure 15. Signature plot of the HIG mill vs Horizontal Stirred mill

Figure 15 illustrates the signature plot of the HIG mill with a comparison benchmark of the horizontal stirred mill. The energy saving using the HIGmill™ translates to 36.13% to reduce a F_{80} of 100µm to obtain a P_{80} of 53µm.

4.3 Platinum pilot plant 2

In the Pilanesberg region in South Africa we were able to run the HIGmill™ side by side with a vertical stirred mill with spokes. The test work was done in a pilot plant where tailings where run through the fine grind mill. The tests where done on scalped and un-scalped feed. The energy consumption and the media consumption of the fine grinding can have an impact and make a project feasible or unfeasible. The test work is still ongoing and the media consumption will be measured. Results are shown in Table 6 and 7.

Table 6. Results fine feed test classified feed stream

Description	HIGmill™	**Existing vertical stirred mill with pins**
F80	80 micron	80 micron
P80 target	44 micron	44 micron
SGE to reach 44 micron	14 kWh/t	28 kWh/t

Table 7. Full feed stream

Description	HIGmill™	**Existing vertical stirred mill with pins**
F80	80 micron	80 micron
P80 target	44 micron	44 micron
SGE to reach 44 micron	6 kWh/t	16 kWh/t

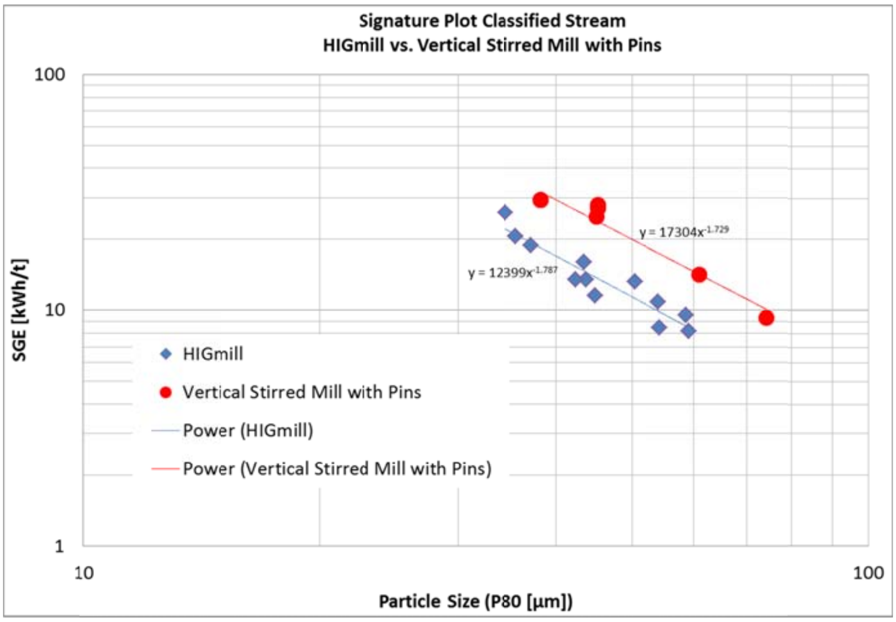

Figure 16. Signature plot classified feed stream

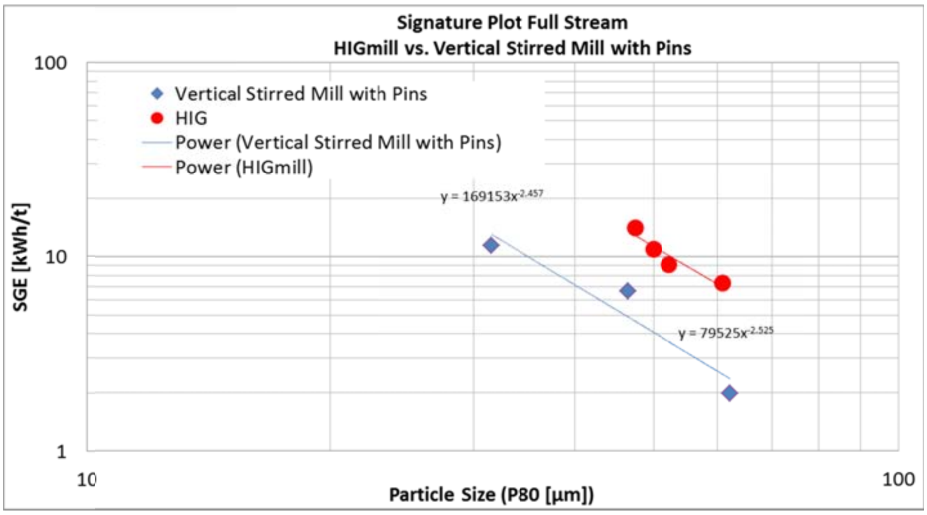

Figure 17. Signature plot full feed stream

5. Discussion

5.1 Gold mine in the DRC

The two comparison tests between the vertical rotor mill (HIGmill^{TM}) and the existing mill (vertical stirred mill with discs) in the DRC have shown several interesting points:

- The vertical rotor mill (HIGmill^{TM}) needed much less energy on both fine and coarse feed tests

- Although the same grinding media has been used in both mills, it was observed that the grinding media consumption (gram/ton) in the HIGmill^{TM} was significant lower (almost 30%). This implicates a direct linear relation between the SGE (kWh/t) and the grinding media consumption (gram/ton). Refer to Table 8.

Table 8. Grinding media consumption gold mine in the DRC

	F80 25 µm, P80 15 µm		F80 60-70 µm, P80 29 µm		F80 60-70 µm, P80 15 µm	
	HIGmill^{TM}	Existing mill	HIGmill^{TM}	Existing mill	HIGmill^{TM}	Existing mill
SGE (kWh/t)	13,4	25,0	9.2	18,0	35,7	Could not be reached
Consumption (gram/t)	120	290	78	Not measured	252	Could not be reached
Consumption (gram/kWh)	***8.96***	***11.60***	***8.49***	Not measured	***7.06***	Could not be reached

- Apparently the HIGmill^{TM} grinding mechanism results into a more efficient transfer of energy into the slurry, as where for the existing mill much more energy goes into the undesirable grinding of the grinding media.
- With the coarse feed (F80 of 60 – 70 µm), the HIGmill^{TM} was able to reach the second target level (P80 of 15 µm) within one grinding step using a SGE of 35,7 kWh/t. However the existing mill was not able to reach target level in one grinding step, as the mill reached its limits before reaching the P80 target.

5.2 East Rand Gold Tailings Plant

The two comparison tests between the vertical rotor mill (HIGmill^{TM}) and the existing mill (vertical stirred mill with flat discs) in South Africa have also shown several interesting points:

- The HIGmill^{TM} was easily able to reach in one grinding step the three P80 target levels of 28 µm, 22 µm and 17 µm. However the existing mill was only able to reach the first P80 target level of 28 µm. The two finer target levels were not possible with the existing mill in one step, as the mill has reached its limits before reaching the P80 targets.
- Again the vertical rotor mill (HIGmill^{TM}) needed much less energy to reach the P80 target.

5.3 Platinum Pilot Plant 1

This direct comparison test between a pilot HIGmill^{TM} and a pilot horizontal stirred mill resulted into a large grinding efficiency gain for the HIGmill^{TM} of 36% (10.48 kWh/t for the HIGmill^{TM} versus 16.4 kWh/t for the horizontal stirred mill). The same type and size grinding media has been used in both mills for these tests. It has also been noted that the PSD curves of both mill types are basically overlapping and that there is no short circuiting occurring.

5.4 Platinum Pilot Plant 2

This direct comparison test between a pilot HIGmill^{TM} and the vertical stirred mill with spokes resulted into an substantial grinding energy reduction for the HIGmill^{TM} for classified stream 46% (14kWh/t for the

HIGmill^{TM} versus 28 kWh/t) and for the unclassified stream 63% (6 kWh/t for the HIGmill^{TM} versus 16 kWh/t) for the vertical stirred mill with pins. Again, the same type and size grinding media has been used in both mills for these tests.
Presently the testwork is ongoing on a larger scale to also compare grinding media consumption and PSD curves together with recovery improvements.

CONCLUSIONS

The HIGmill^{TM} fine grinding technology has been tested against the vertical stirred mill with flat discs, the horizontal stirred mill with flat discs and the vertical stirred mill with pins. In all these tests the unique HIGmill technology resulted into the lowest energy consumption. To be able to explain these huge energy savings, there must be several major differentiators in the HIGmill^{TM} technology:

- Vertical arrangement with feed from bottom: use of gravity (hydrostatic pressure) to ensure very good contact between the feed particles and the grinding media
- Vertical arrangement: the grinding discs have to agitate the grinding media in a horizontal radial direction only, not lifting media, thus maximising the energy input from media to slurry. As where with a horizontal design, in addition to agitating the media, the grinding discs also need to continuously lift the bed of media from the bottom of the grinding chamber which wastes energy working against gravity.
- An even grinding media distribution in radial direction is essential. This is an inherent feature of a vertical mill design, as where in a horizontal mill there will always be more grinding media at the bottom than on top. Evidence of uneven media distribution in a horizontal mill is that most wear happens on the bottom half of the grinding chamber.
- Special shaped rotors (patent pending) ensure an even grinding media distribution in radial direction is essential resulting into a truly efficient energy transfer, while at the same time the disc wear is being minimized.
- The exclusive concept with the stator rings result into a grinding mill with truly several grinding chambers and into an efficient inherent classification
- The stator rings avoid the possibility of short-circuiting the mill even a high volume flow.
- The vertical arrangement combined with the stator rings ensures that the grinding media is easily retained in the mill; there is no requirement for a power consuming separator and/or screens at the discharge side

Furthermore the test comparison with the vertical stirred mill with flat discs showed clearly that the grinding media consumption of the HIGmill^{TM} is significantly lower. The HIGmill^{TM} is transferring the motor energy efficiently into the grinding of the mineral particles in the feed slurry; the vertical rotor mill however seems to transfer much more energy into the grinding of the grinding media and could not reach the finer P80 targets at all.

The comparison test of the HIGmill^{TM} with a vertical mill with helical agitator will start later this year and will be part of a follow up paper.

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