TECHNOLOGY SELECTION OF STIRRED MILLS FOR ENERGY EFFICIENCY IN PRIMARY AND REGRINDING APPLICATIONS FOR THE PLATINUM INDUSTRY

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Abstract

Stirred milling technologies have firmly established themselves in concentrator circuits as energy-efficient alternatives to tumbling ball mills.

High and continued increases in electricity costs, coupled with the ever-increasing power consumption by primary grinding circuits due to declining head grades of ore-bodies, provides a compelling case for these technologies.

Additionally, the ability to successfully deploy stirred milling in coarse grinding applications extends the range of use in concentrators, thus increasing the opportunity matrix for energy optimization in a flowsheet.

This paper therefore details methodologies and strategies that can be applied to evaluate the optimum stirred milling solution for different concentrator applications. These methods and strategies will focus specifically on the two major stirred mill machine types; namely, gravity-induced (VERTIMILL™ grinding mill and Nippion-Eirich tower mill) and fluidized (SMD, Isamill™, Knelson-Deswik mill, etc.).

Finally, case studies from circuits across industry and laboratory tests will be used to illustrate the energy benefit from the use of stirred mills.

Introduction

Energy efficiency in the production of goods and services is no longer a nice-to-have but a must-win challenge for all of industry. Eskom[1] estimates that the South African mining industry consumes in the region of 15 per cent of all electrical energy produced in the country. A further categorization indicates that the platinum mining sector is second to the gold mining sector and consumes 33 per cent of the said 15 per cent. Generally, processing activities within a concentrator are estimated to consume in the region of 19 per cent of the 15 per cent and about approximately 30 per cent of this energy is used in the comminution (crushing and grinding) of ores.

This then positions comminution as one of the prime areas within a concentrator where energy usage can be optimized or reduced. The focus of this paper, though, will be limited to how stirred milling technologies can be used in concentrator circuits to yield energy savings or optimization. But first, a few challenges facing the mining industry are discussed.

The challenge

One of the biggest challenges facing the mining industry is the ever-declining ore grades, and in some cases this is associated with finely disseminated valuables within the ore matrix. The platinum sector is no exception, as pointed out by Valenta[2] and Rule[3] in papers detailing some of the complexities involved in the processing of UG2 ores. The processing of UG2 ores typically requires multiple stages of grinding punctuated by flotation. This is due mainly to the fine dissemination and association of the platinum group metals (PGMs) with the gangue phases within the ore matrix.

Therefore, for operations to remain profitable huge volumes of ore must be mined and ground to product sizes less than 80 per cent passing 75 µm, which is typical of feed to the various flotation stages in UG2 concentrators. However, the relationship between fine grinding and power consumption is exponential (Figure 1); processing rates also increase power consumption. So, whether the requirement is to grind finer or to increase plant capacity or both, the result will be an unavoidable increase in energy consumption.

The other significant challenge relates to the ever-increasing cost of energy and its security. This is also accompanied by the impact that the generation of energy from fossil fuels has on the environment through the emission of greenhHouse gases (GHGs).

The cumulative effect of the above-mentioned challenges is as follows:

- Decrease in profitability due to high operating costs. Electricity can contribute to up to 15 per cent of the total operating cost
- Significant loss in productivity due to an unreliable supply of electricity, as witnessed in South Africa during 2008
- Loss of reputation or goodwill due to non-compliance with regards to regulatory requirements for good corporate citizenship in terms of GHG emissions. Corporations are now reporting GHG emissions in their annual reports. This will become a standard practice, and if not complied with may impair a corporation’s ability to conduct business
- Potential loss of revenue due to abatement costs related to GHG emissions through instruments such as carbon taxes. In a white paper published for discussion by the South African government in 2010, a carbon tax is advocated over regulatory policy by itself. So, carbon tax might just be a real cost component of operating costs unless the marginal abatement costs are observed by an operator.

If not addressed, the cumulative effect of the above-mentioned challenges is that mining may no longer be as attractive an investment as it has been in the past. Also, the sustainability of current operations into the future will be questionable.

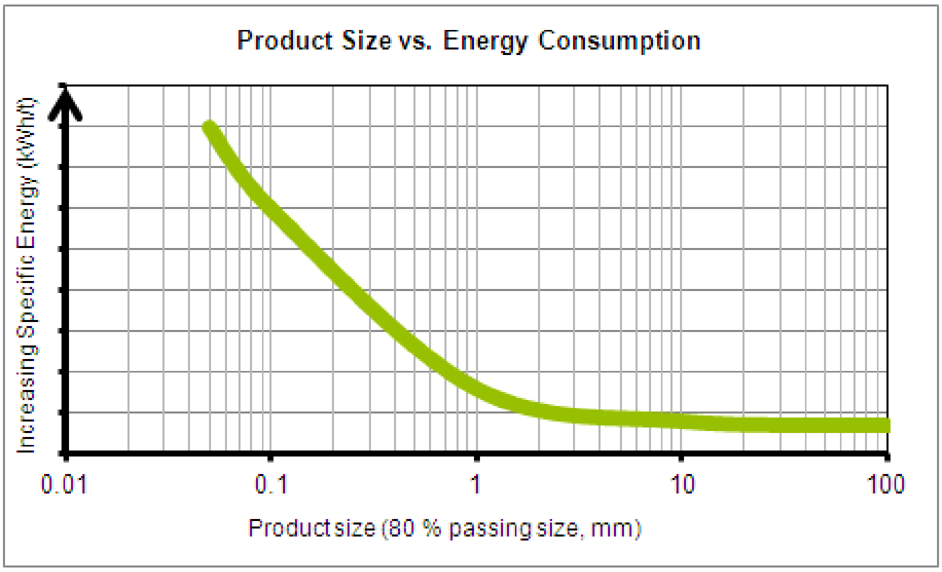

Figure 1-Relationship between grind size and energy consumption

The solution

Part of the solution, which is the focus of this paper, is to implement and expand the use of energy-efficient grinding technologies such as stirred mills in platinum concentrator circuits. In addition to this, further energy gains can result, depending on how this technology is incorporated in a flowsheet. For instance, in some cases a two-stage stirred milling circuit will use energy more efficiently than a single-stage option. Therefore it is vital to evaluate all opportunities that exist in a concentrator circuit where such technologies can be used instead of the energy-inefficient tumbling ball mill.

Stirred milling technologies

Generally, stirred mills can be divided into two categories; namely, gravity-induced and fluidized charge mills. Commercially active brand names for the gravity induced variety are the Metso VERTIMILL™ (VTM™) and the Nippion-Eirich tower mill. The fluidized stirred mill brands are represented by the Metso Stirred Media Detritor (SMD), Isamill™, and the Knelson-Deswik mill.

Metso is in the enviable position of owning both the VTM™ and SMD technologies, and can therefore evaluate the efficacy of each technology on a case–by-case basis.

Stirred mills are in general applied to fine and ultra-fine grinding applications. For the purposes of this paper, grinds of up to 75 µm are regarded as conventional, between 75 and 30 µm as regrind, below that and up to 10 µm as fine grinding, and finally below 10 µm as ultra-fine grinding. Coarse feeds are defined as streams that contain particles of up 6 mm.

Operating principle – gravity-induced stirred mills

Gravity-induced mills are in the main slow-speed stirred mills that use high-density media such as steel balls as the grinding charge. The screw rotates slowly such that the ball charge and slurry are not fluidized, but settle under gravity. The screw action pulls the ball charge up the centre of the mill, and the charge eventually cascades over the edge of the screw, creating a general downward flow pattern at the mill perimeter. This pattern of flow, coupled with the low velocities involved, ensures that the grinding media and particles stay in contact with one another, thus enabling the efficient transfer of the drive energy into attrition and abrasion breakage throughout the charge. Figure 2 shows the flow pattern of the grinding media within the VTM™. The yellow – green zone is indicative of the grinding zone within the mill, which is dominated by abrasion and attrition forces.

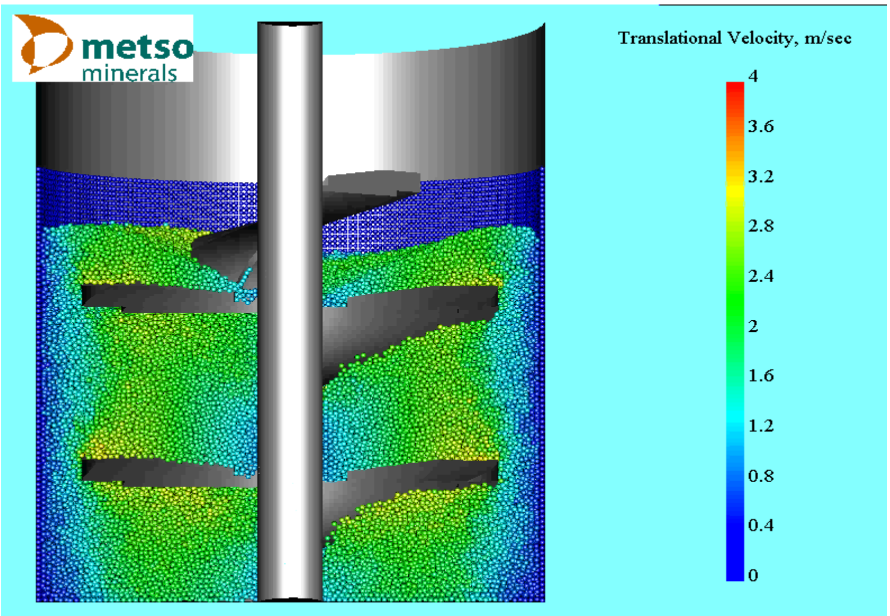

Figure 2-VTM™ grinding action

The mill itself essentially comprises of a stationary vertical grinding vessel housing a centrally-located rotating double helical screw shaft. The shaft is suspended externally to the mill by a slow-speed coupling which connects the screw to the mill's drive train (motor and reducer), Figure 3 refers. Auxiliary equipment such as the separating tank and recycle pump completes the VTM™ system. A VTM™ circuit is almost always in reverse closed circuit with an external classifier such as a cyclone, as depicted by Figure 4.

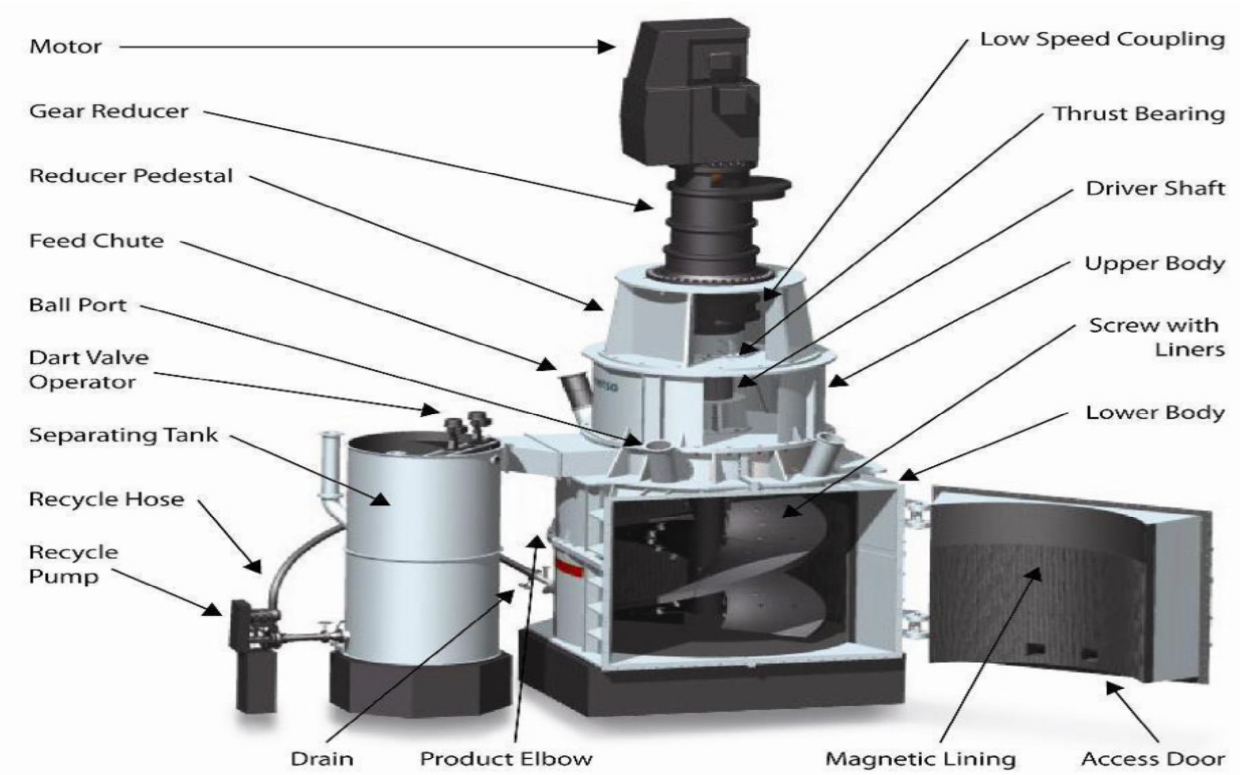

Figure 3-Schematic of the Metso Vertimill™

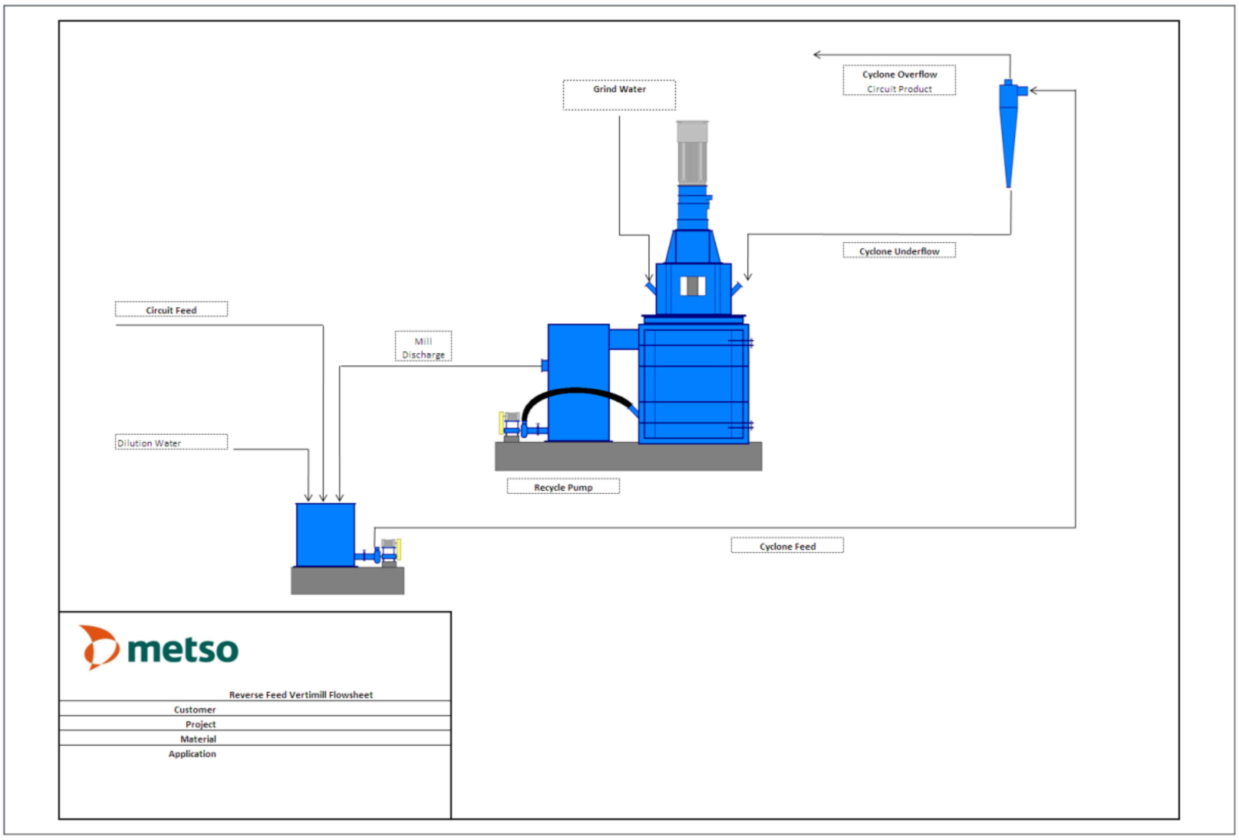

Figure 4-Typical Vertimill™ circuit in a reverse closed circuit mode

The VTM™ is fed from the top. As the feed enters the grinding chamber, the downward movement of the feed material into the grinding zone is influenced by the upward velocity created by the recycle pump. The combination of this uprising velocity and the mill's vertical arrangement contributes to the removal of a fraction of fine particles before they enter the grinding zone, thus reducing overgrinding. The ground particles, together with fine particles removed from the mill feed will, under the influence of the upward velocity, exit the mill to an external coarse separator. A change in the rotational direction of the slurry when it transitions from the mill to the separating tank causes laminar flow, which facilitates the settling of the coarser material in the separating tank. The coarse portion of the mill overflow is recycled back into the bottom of the mill through a variable-speed pump. The benefit of the recycle system is that it can reduce the cyclone circulating load by allowing the mill to preferentially grind the coarse material. Also, the upward velocity within the mill can be controlled by the recycle pump such that overgrinding is minimized. A combination of the force of gravity acting on the high-density media, the low intensity agitation action, and the vertical configuration of the mill contributes towards the ability of the mill to keep the grinding charge within the mill.

The operating conditions of the VTM™ are very similar to those of the conventional ball mill in the sense that the percentage solids of the feed should be kept in the range of between 65 to 75 per cent by mass. The power draw of the mill is directly linked to the mass of balls within the mill. The distinct advantage that the VTM™ has over the conventional ball mill is its ability to use media smaller than 25 mm more effectively. Also, the VTM™ has a turn-down ratio of up 10 per cent before grinding performance suffers, and this is particularly useful in times when for whatever reason nameplate capacity cannot be maintained.

Operating principle – fluidized-media stirred mills

In contrast to the gravity-induced stirred mills, the fluidized mill type uses high rotational speeds of either impellers or discs to cause the suspension and complete mixing of the grinding media and slurry particles. The fluidization compels the slurry particles and grinding media to remain in contact with each other, and the resulting relative motion induces size reduction of the slurry particles by abrasion and attrition grinding. Figure 5 shows the characteristic charge profile of the Metso SMD. The Isamill™ also falls under this category of mills; its orientation is, however, horizontal.

Figure 5-Fluidised mill charge within the pilot-scale SMD

The Metso SMD consists essentially of an octagonal body that supports a suspended multi-armed impeller shaft and the drive system. The impeller shaft is driven by an electric motor through a helical gear reducer. Wedge-wire profile polyutherene screens located at the top half of the mill body retains the ball charge within the mill while allowing the ground product to exit the mill. Figure 6 shows the internals of the SMD and the various mill components.

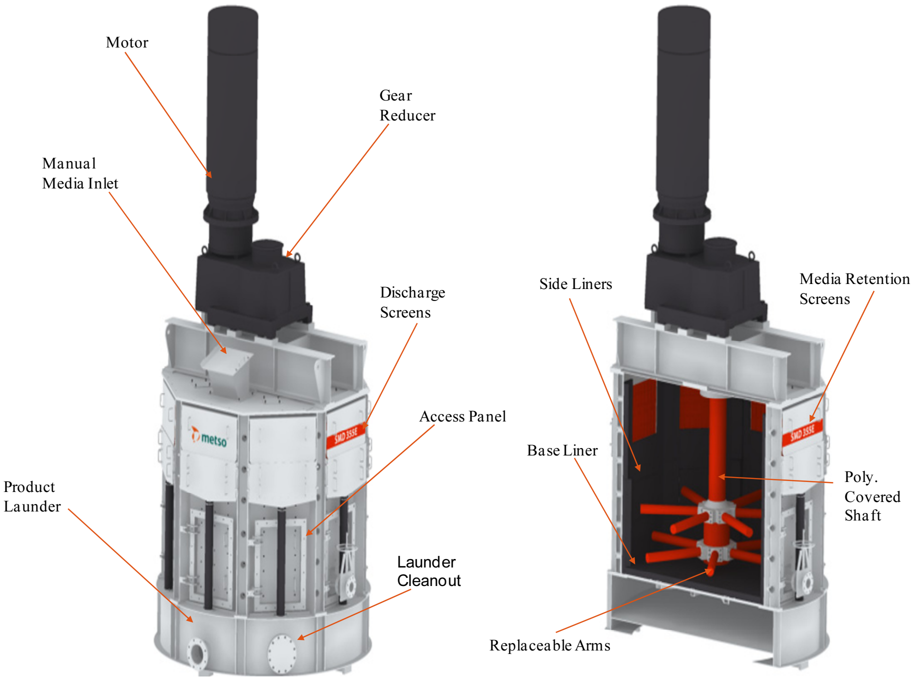

Figure 6-General view and cut out view of the Metso SMD

The slurry feed is introduced through an inlet nozzle located at the top of the mill and directed into the grinding zone of the mill. The media is also charged through the top of the mill, either through a manual port or a pneumatic charging system.

By design, the SMD power intensity is high enough to achieve efficient grinding while limiting wear of the elastomeric mill internals. The large surface area of the mill allows for easy heat dissipation and obviates the requirement of a mill cooling system.

In operation, the mill can accommodate a wide range of feed slurry solids, ranging between 30 – 60 per cent by mass, with the optimum somewhere between 50 and 55 per cent. Although the mill has the ability to operate outside of this optimal range, grinding performance may suffer as a result.

The SMD in the main uses ceramic balls as grinding media. The top size of the ball diameter depends on the top size of the feed material and the targeted product size. Proper selection of the media size as driven by both feed and product size is pivotal to the optimum operation of the mill in terms of effective power usage and product size distribution. The power draw of the mill is controlled through the amount of media within the mill, and as media is consumed during grinding so must it be replenished at the same rate so as to maintain the optimum grinding power.

The SMD can be configured to operate in open or closed circuit. The vast majority, though, are operated in an open-circuit configuration, typically fed by a thickener underflow so as meet the feed density requirement. Where there is no existing thickener and capital is a constraint, cyclones can be used to fulfil the feed density requirement. In instances where it has been established that the entire feed stream will benefit from the attrition action of the mill, then dewatering cyclones must be used ahead of the mill. Figure 7 shows a SMD circuit operating in a pre-classified open-circuit mode.

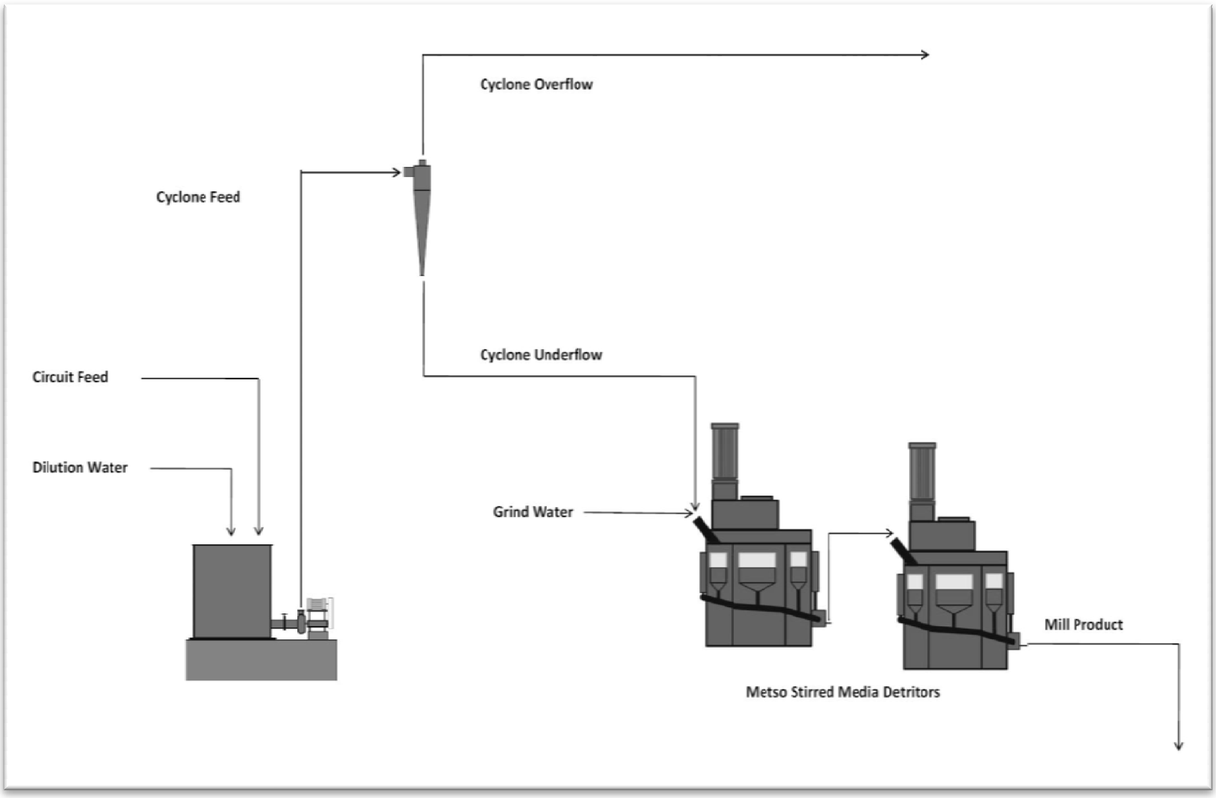

Figure 7-Metso SMD in a pre-classified open circuit arrangement

What makes stirred mills energy-efficient?

It is now well documented that in the regime of regrind, fine, and ultrafine grinding, the use of the conventional tumbling ball mill (hereafter referred to as ball mill) is uneconomical in terms of energy usage. In the quest to be more energy efficient, the mining industry looked to other industries such as the industrial minerals sector for solutions. The industrial minerals sector has long had success with energy-efficient fine and ultrafine grinding. This is where all of the commercially active stirred mills in the mining industry originate from.

Over time, these were tested and adjusted to meet the harsh operating conditions consistent with the hard-rock mining environment without compromising their energy-efficiency advantage.

Stirred mills were always designed with energy efficiency in mind, and here are some of the reasons that make them effective over ball mills:

- *Stationary shell design* – Contrary to ball mills, whereby several tons of the mill shell and ball charge requires rotation and lifting, with stirred mills energy is expended only to move the ball charge, and therefore the energy that would otherwise have been used to rotate the mill shell is saved. This is further evidenced by the quieter mill operation, indicating that less energy is lost to the generation of noise
- *Grinding media size* – Matching the grinding media size to the target product has been shown to favour the effective use of energy by grinding mills. This is aptly demonstrated by Figure 8 after Davey[4]. In this example, it is shown for instance that, if a grind of 10 µm is sought, the most effective ball top size is 5 mm diameter, since with this ball size the mill will consume the least amount of energy compared to when bigger ball sizes are used.

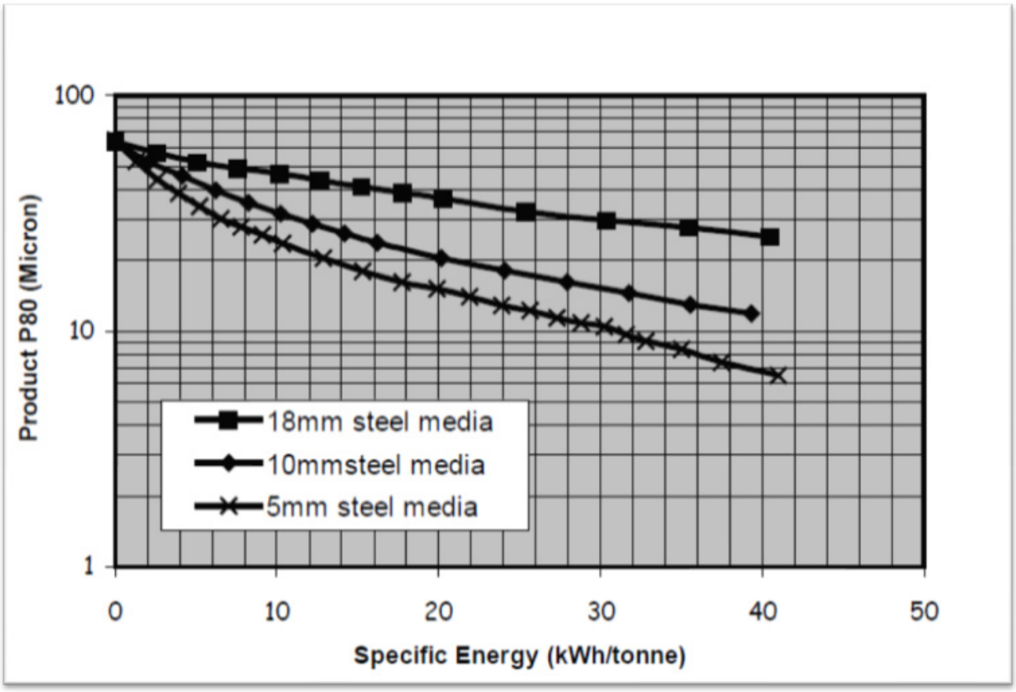

Figure 8-Relationship between media top size and specific energy consumption

The energy consumption profile of a conventional ball mill, on the other hand, deteriorates when such small media is used in the mill. Figure 9, after Brissette[5], shows the comparative energy profile of a vertical mill *versus* a conventional ball mill using a 5 mm top ball size. It can therefore be concluded that for fine grinding, stirred mills are more efficient than ball mills, since they have the ability to use small-size media effectively, in part due to the inherent mill design and the associated operating principles

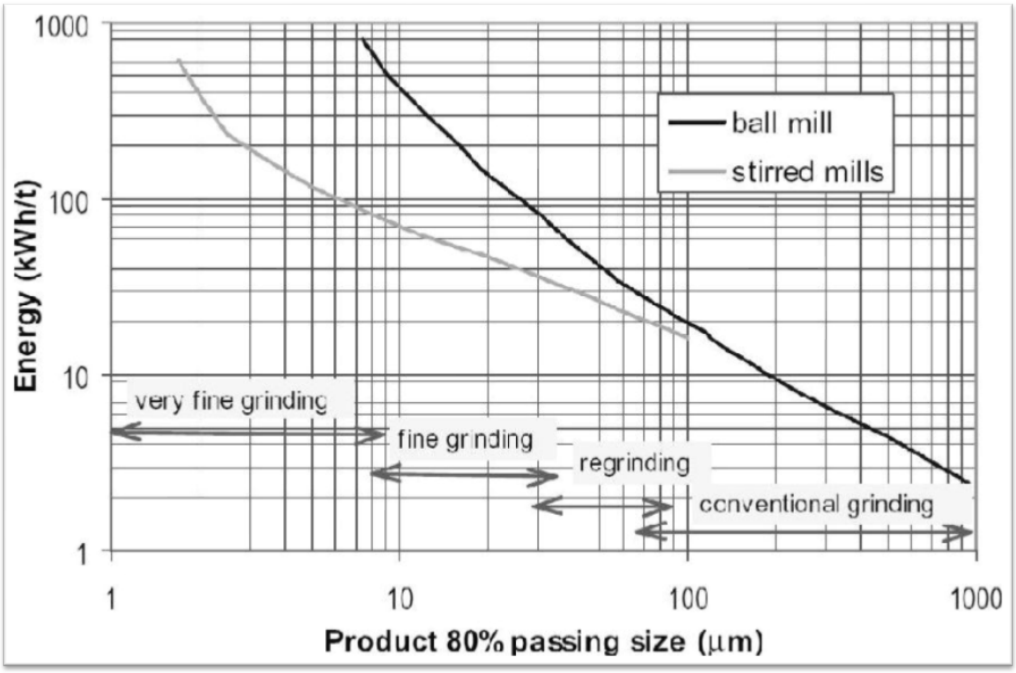

Figure 9-Energy consumption -vertical mill vs. conventional mill using a 5 mm ball charge

- *Grinding action and charge participation* – Stirred mills by design encourage a more direct and efficient mechanism of transferring the drive energy into particle breakage, unlike ball mills, which have large empty zones required for the tumbling action but which do not contribute to particle breakage. In other words, stirred mills have a much higher participation rate of the grinding media, thus a higher rate of breakage events
- *Charge surface area and mode of comminution* – The ability to use small-size media implies that the surface area available for grinding is that much greater. Again, by design stirred mills are dominated by attrition and abrasion breakage, both of which are more efficient breakage modes for producing fine and ultrafine progeny than impact breakage, which forms part of the grinding forces encountered in ball mills. This also contributes to the energy efficiency of stirred mills.

What needs to be in place beforehand

Energy efficiency is not a means to an end in itself, but a piece of a bigger picture that is increasingly becoming important to concentrator operators. So, before embarking on the journey of implementing stirred mills as part of optimizing energy usage, some key factors must be considered first. These are listed in the following sections.

Mineralogy

Deportment of valuables by size and mineral association is an important driver in unlocking not only the value in the ore being treated, but also in optimizsing energy usage. This is suitably illustrated by Rule[1], wherein a snapshot of the mineralogy of the UG2 reef is analysed to reveal the distribution of PGMs within the host rock and their association with gangue phases. This knowledge is essential in establishing the grind size for optimum liberation, thus curbing overgrinding. Overgrinding, particularly in the fine grinding range, is not a trivial matter since the relationship between grind size and specific energy is exponential in nature (refer to Figure 1).

Flotation

Although advances in the successful flotation of fine particles have been made, special attention must still be paid to floating the sub-10 µm particles, as indicated by Figure 10 after Gaudin[6]. This graph indicates a particular relationship between recovery efficiency and particle size, in that flotation kinetics of particles in the size range ≤ 10 µm and ≥ 106 µm is typically poor, thus resulting in inefficient recoveries. Although this work may be dated, it is still valid in that it demonstrates the fact that there is a distinct size range of particles in which flotation is not straightforward. Therefore, it is imperative that all the factors that may affect the flotation kinetics are reviewed before stirred milling is implemented. In fact, the regrind mill should be considered part of the overall flotation circuit, both in terms of liberation and process chemistry. Even when a ball mill is substituted with a stirred mill, it is important to conduct flotation tests as shown by Figure 9. Stirred mills are not only energy efficient; they also impact the resulting size distribution and chemistry. Davey[4] notes that the stirred mill product characteristics, and therefore the resulting grade and recovery curve, are closely related to the type of mill used.

Once all flotation tests are completed, the results, together with the mineralogy work referred to earlier, can then be used to inform the decision as to where the stirred milling technology can be used to return the most overall benefit.

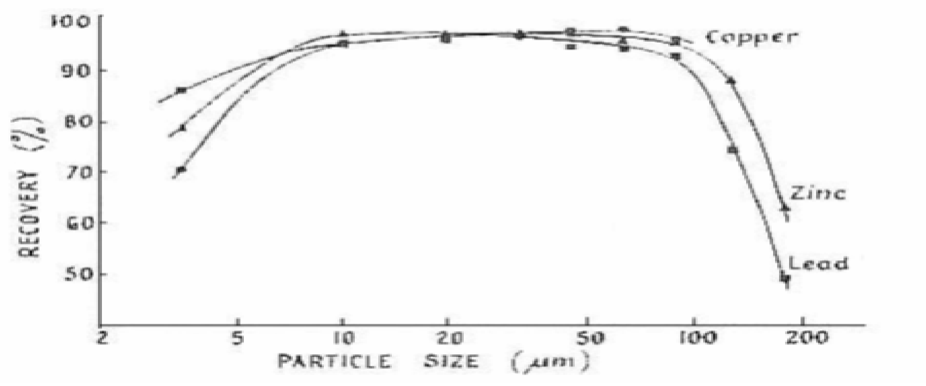

Figure 10-Flotation response to particle size (after Gaudin[6])

Process design

The technology selection criterion, together with process design, should be carefully considered before implementing stirred milling technologies. The overarching objective should be to end up with the lowest total cost of ownership solution after all factors have been accounted for. Some of the factors are listed below:

- *Surface activation* – Does the downstream flotation process benefit from the attrition action of the stirred mill through improved flotation kinetics? If yes, then perhaps using scalping cyclones ahead of the mill is not a good idea. If, no, then there is the added benefit of taking out the material that is already at the required product size, thus preventing overgrinding and reducing the power requirement for the subsequent grinding stage
- *Mill feed density* – In the case of the flotation concentrate regrind, the feed to the mill is typically outside the range preferred by stirred mills. Consideration must therefore be given to how this material will be thickened. Questions to be asked are; does the project capital allow for the procurement of a thickener if the case of scalping cyclones is negated by the surface activation benefit? Alternatively can dewatering cyclones be as effective?
- *Cyclones* – If it turns out that cyclones have to be used, then at very fine sizes, for instance, sub-10 µm, small diameter cyclones must be used. This, by necessity results in dilution of the percentage solids in both the cyclone feed and product. This eventuality might just be prohibitive for downstream processes to handle. This, together with the operability and the availability of the small diameter cyclones, must be adequately addressed beforehand
- *Number of mills* – Will the fine grinding circuit experience excessive swings in feed rate? If so, because fluidized media mills have a poor turndown capability, the option of using multiple smaller mills as opposed to one big mill may be beneficial. In the case of the gravity-induced mills, these have a limited turndown ability, which will mitigate against fluctuations in feed rate to up 10 per cent below nameplate power. This is another decision point that must be considered prior to implementation

- *Product specification* – The correct specification of the target grind cannot be overstated. Defining the product requirement by the customary P_{80} or other alternatives such as the P_{98} (product top size) or P_{10} (amount of fines generated) will have material impact on power consumption and the grade-recovery curve. If not specified correctly during test work, the much-promised benefits of stirred milling may not materialize.

The above are but a few key items that, if not properly addressed prior to the implementation of the stirred milling solution, may just weaken the value proposition of stirred milling technologies.

The opportunity matrix for stirred mills

Figure 11 presents a succinct illustration of the typical operating ranges of ball and stirred mills, together with their point of efficiency with respect to product size.

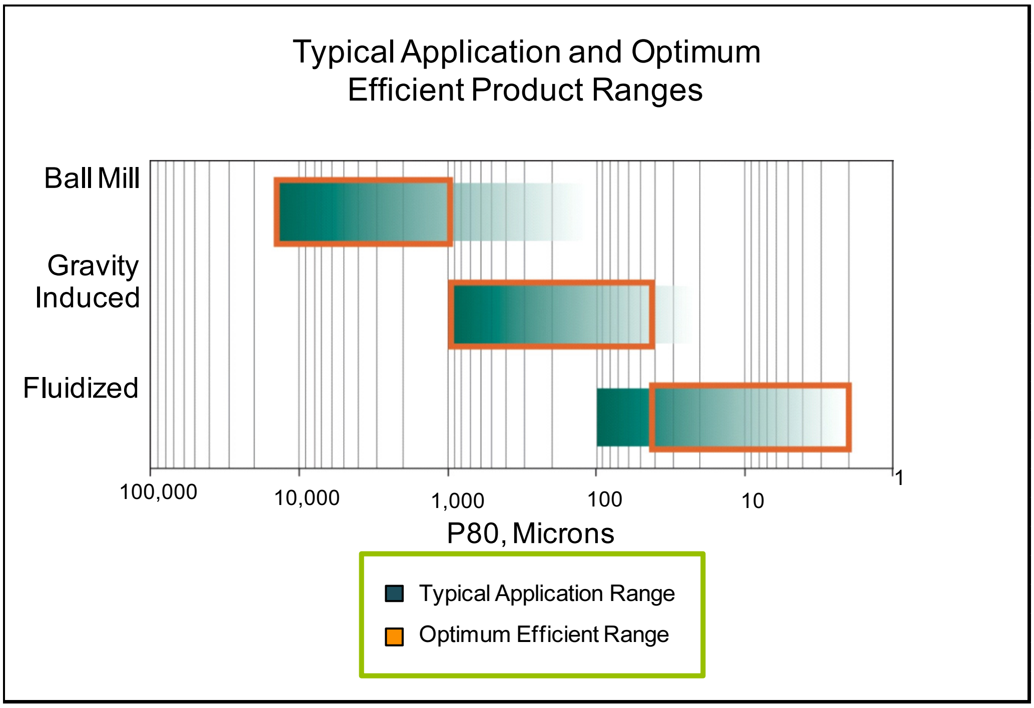

Figure 11-Typical operating ranges for conventional ball and stirred mills

As can be seen from Figure 11, the typical 80 per cent passing value in the feed to stirred mills can be as coarse as 1000µm. For ball mills, this figure can be as high as 10 mm. Of more interest, though, is how fine the various mills can grind before efficiency is compromised.

In Metso's experience, gravity-induced stirred mills will maintain their grinding efficiency up to grinds of 45 to 40 µm, while fluidized mills will optimally use energy down to a grind of 2 µm. It must be pointed out, though, that there will be areas of overlap, driven largely by project conditions and sometimes client preferences. Also, in reality and for several reasons, mills are typically used to grind past their efficiency point.

Now, the fact that stirred mills can be applied to coarse feeds opens up the opportunity to employ them as secondary mills in addition to the other established duties. Also, in instances where tailings are the primary source of the feed stock, such as in the case of tailing retreatment projects, gravity-induced mills can be used as primary mills. Finally, grinding energy efficiency can be further enhanced by employing two stages of grinding by arranging stirred mills in series; this is particularly beneficial in instances where high reduction ratios are sought.

Case studies

In this section a mixture of industrial- and laboratory-scale case studies will be used to demonstrate the efficacy of stirred mills as used in the various grinding duties. The performance of these mills is always compared to that of the conventional ball mill.

Case tudy 1: Regrind application

In work reported by Brissete[5], an industrial-scale comparative study was conducted at a lead-zinc concentrator located in Canada. This study involved a head-to-head performance evaluation of a ball mill *versus* the VTM™ in a regrind duty. Refer to Figure 12 for the circuit details.

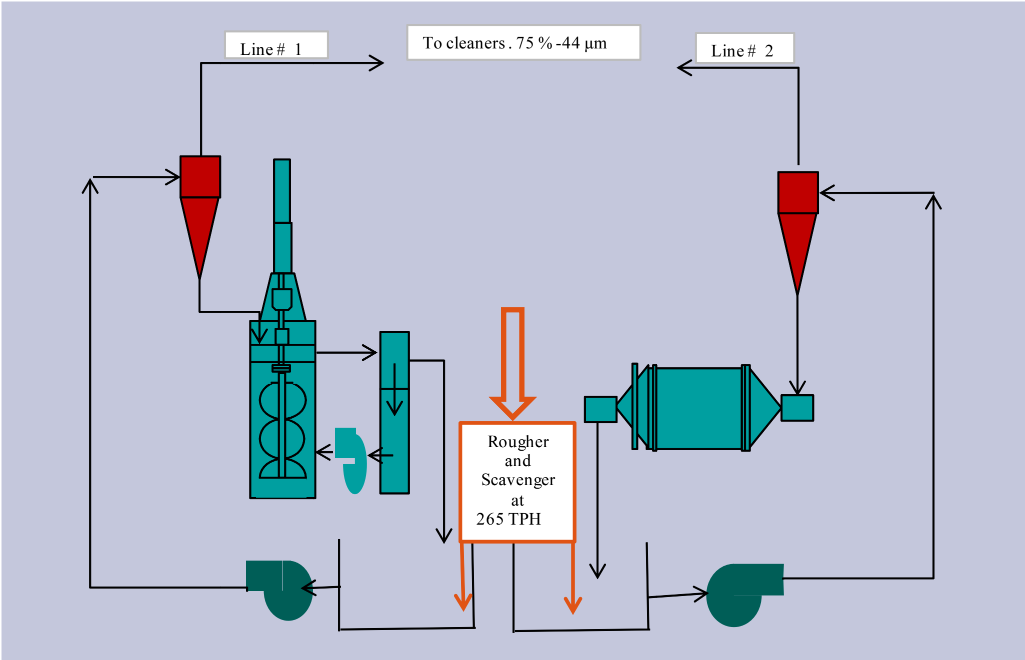

Figure 12-Conventional ball mill circuit *vs*. a VTM™ circuit in a regrind duty

This concentrator initially operated two identical primary mill and floatation circuits in parallel. The regrind stage comprised a single 4.27 m diameter by 6.86 m long overflow discharge ball mill, fitted with an 1864 kW drive system.

Instead of duplicating the ball mill for the expansion of the regrind circuit, the mine opted to test the VTM™-800-WB (597 kW installed). This size Vertimill™ was deemed to sufficient to perform the same duty as the ball mill. Table I summarises the outcome of this work.

Table I-Comparative industrial results – ball mill *vs*. VTM™

Mill Type	Test Period	Power Draw	Circuit Product
[-]	[days]	[kW]	[% - 44 µm]
Ball Mill	28	1044	73.5
VTM™	29	587	75.2

The two grinding circuits were operated independent of each other and were configured to perform the same grinding duty, namely, to grind 265 t/h to a target grind of 75 per cent passing 44 µm. Both mills were charged with 25 mm steel balls.

As shown by the results in Table I, the Vertmill™ circuit consumed 44per cent less energy than the conventional ball mill. Also, note the marginal increase in the quantity of the -44 µm product created by the VTM™.

Case study 2A: Applying stirred milling to secondary grinding – silver/lead concentrator

Typically, secondary grinding is the most power-intensive processing step in a concentrator. This is due in part to the fact that more often than not the duty is such that both the feed size and target product size are typically in the fine end of the spectrum. As indicated earlier, the relationship between energy consumption and fineness of grind is exponential (Figure 1). This, coupled with the usually high throughput rates treated, makes secondary grinding a prime area for energy optimization, as illustrated by the following case studies.

In this case study, a silver, lead, and zinc concentrator located in Australia embarked on an expansion programme to increase plant throughput. Initially the concentrator operated only a single-stage autogenous (AG) mill to produce a floatation feed of below 95 µm. While changes could be made to the AG mill discharge arrangement and circuit configuration to increase throughput, this came with the unintended consequence of an unacceptably coarse product, resulting in recovery losses. It became obvious that to maintain the product quality below 95 µm while increasing plant capacity, additional grinding power was required. The concentrator conducted various desk-top studies evaluating the most energy-efficient solution, and finally settled on the VTM™ as the best alternative to a conventional ball mill to undertake the secondary grinding duty. Figure 13 depicts the flow sheet adopted for the expansion.

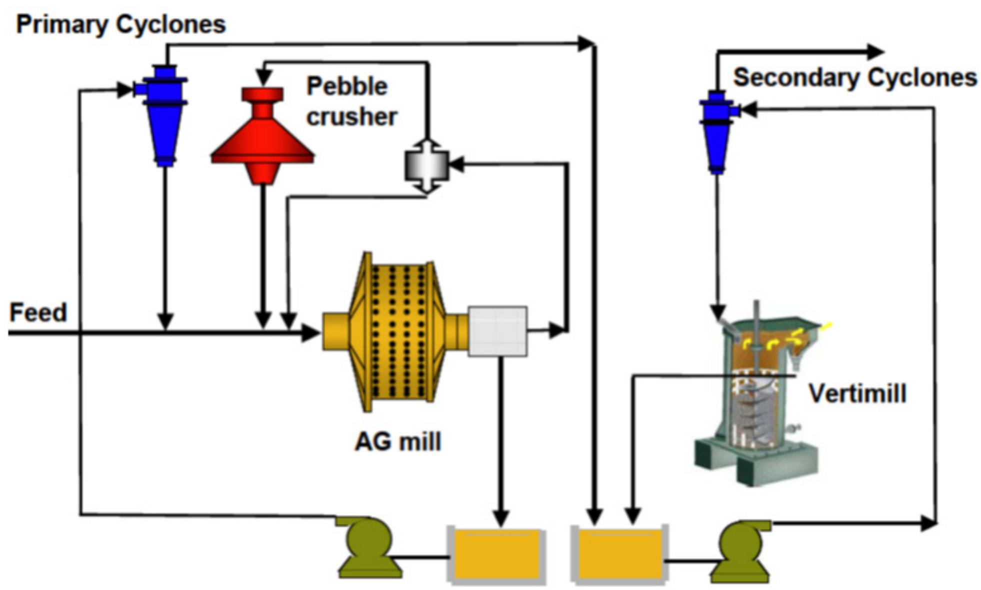

Figure 13-An AG circuit incorporating the VTM™ for the secondary stage of grinding

Table II-provides a summary of the circuit performance after commissioning in 2003.

Table II- Summary of circuit performance

Survey number		1	2	**3**	**4**	5	6
Fresh feed	[tph]	319.9	320.5	**329.8**	**319.2**	335.2	337
AG mill power	[kW]	4569	4561	**4527**	**4544**	4921	4849
VTM™ power	[kW]	640	631	**614**	**619**	685	754
Primary cyclone overflow	[µm]	100	146	**150**	**150**	133	131
Secondary cyclone overflow	[µm]	76	106	**94**	**109**	100	93
Operating Work Index	[kWh/t]	14.6	17.3	**15.6**	**17.6**	17.4	16.7

Surveys 3 and 4 were conducted on the entire circuit and similarly, Bond Ball Mill Work Index (BBWI) tests were conducted on corresponding ore samples. This enabled the comparison of the VTM™ performance to that of an equivalent ball mill. The BBWI for ore samples for survey 3 and 4 were reported as 17.2 and 18.7 kWh/t respectively, while the corresponding operating work index was reported as 15.6 and 17.6 kWh/t respectively. The fact that in each case the operating work index is lower than the BBWI indicates a very energy-efficient circuit performance. An equivalent ball mill for this duty would require 1800 kW of installed motor power. The VTM-1500-WB that was selected for this application has only 1119 kW of installed motor.

Case study 2B: Applying stirred milling to secondary grinding – gold concentrator

This case study is based on work conducted at a gold mine in Chile. The VTM™ was implemented in a secondary grinding role where it processed feed from a semi-autogenous (SAG) mill down to a P_{80} of 300 µm. The existing ball mill from the previously used three-stage crushing and ball milling circuit was run in parallel to the VTM™ to evaluate performance. Refer to Figure 14 for the circuit arrangement.

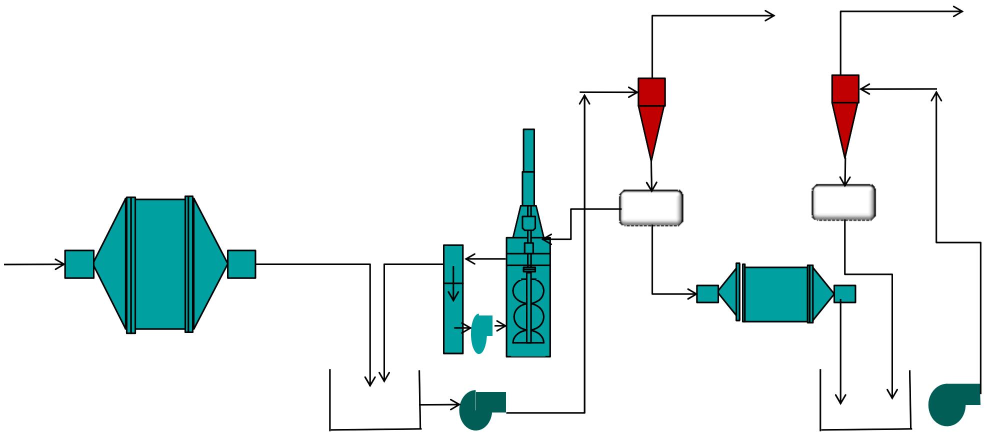

Figure 14-A gold plant trial flow sheet – ball mill and VTM™ in secondary grinding duty

Table III-Summary of mill performance – tumbling ball mill *vs*. VTM™

	Units	Ball Mill	VTM™
Mill input power	[kW]	76	54
Feed tonnage	[tph]	25	25
Specific energy	[kWh/t]	3	2.1
80 % passing - mill feed	[µm]	840	840
80 % passing - mill product	[µm]	307	303

As evidenced by Table III, when the operating work index is calculated for both mills, the VTM™ is 30 per cent more energy efficient than the tumbling ball mill.

Table IV, on the other hand, shows the product size distribution resulting from the two mill types and the energy advantage that the VTM™ has over the ball mill per size class produced. Put differently, the VTM will on average consume between 22 and 37 per cent less energy to produce the same particle size than a ball mill. Also, note the marginal change in the product size distributions from the two mills. Since the next process step is sulphide floatation, this may affect the performance of the floatation circuit.

Table IV-Size analysis and efficiency improvement by size

Screen Size [microns]	Feed [% passing]	Ball Mill Product [% passing]	VTM™ Product [% passing]	% Efficiency Advantage
2360	93.4	100	99.7	n/a
1180	86.8	99.2	98.0	22.0
425	68.2	91.7	89.9	23.4
212	44.7	68.5	70.7	35.4
150	31.2	52.2	54.7	36.6
106	11.7	20.9	21.7	35.1
P_{80}	**840**	**307**	**303**	

Case study 2C: Pilot-scale study comparing energy efficiency between stirred mills and ball mils in coarse grinding applications

In work conducted by Shi[7] *et al*., laboratory tests using the Bond Ball mill and a laboratory-scale vertically-stirred pin mill akin to the VTM™ were conducted on three different ore types. The ball top size that was used for the ball mill was between 31.5 and 37.5 mm, while for the stirred mill 11 mm steel shots were selected. Every precaution was taken to ensure that the feed samples to the two mills were as close to each other as possible for each test. The standard Bond tests were conducted at 250 per cent circulating load and screen closing sizes of 125 µm, 106 µm, and 75 µm. The similar locked-cycle tests were adopted for the stirred milling tests. Please refer to the cited paper for further details. A summary of the outcome of this work is presented in Table V.

Table V-Summary of test results – ball mill *vs*. stirred mill in coarse grinding application

Ore	CG 2		GHB		SMT	
Mill type	**Ball mill**	**Stirred mill**	**Ball mill**	**Stirred mill**	**Ball mill**	**Stirred mill**
F_{80} [µm]	1968	2287	2000	1999	2017	2065
P_{80} [µm]	84	73	83	78	49	52
Closing screen [µm]	125	125	106	106	75	75
Specific energy [kWh/t]	11.6	8.7	16.9	10.6	23.8	17.4
Energy savings [%]	**-**	**25**	**-**	**37**	**-**	**27**

A statistical analysis indicated that the differences in the specific energies between the two mills are real.

The work concludes that on average an energy saving of 30 per cent is achieved by using a stirred mill instead of a ball mill, further confirming the advantage that stirred mills have over ball mills. The fact that this work was conducted on coarse samples indicates the fact that the right type of stirred mill can be applied to coarse feeds and the mill will maintain its energy-efficiency advantage.

Cases 2A, B, and C collectively show that the right type of stirred mill such as the Metso VTM™ can be successfully applied to secondary grinding duties and that the attendant energy saving benefits will still be available.

With the above in mind, and to illustrate the potential in using the right type of stirred mill in the right place in concentrator circuits, Table 6 from Rule[3] has been extended to include the VTM™ (Table VII). The original data (Table VI) shows the energy savings due to implementing a high-pressure grinding roll (HPGR) in a conventional Platreef comminution circuit. Due to this change, an average energy savings of 19 per cent was reported for grinds ranging between 300 µm and 45. Now, if the entire ball milling duty in the HPGR circuit is replaced by a VTM™, thus introducing an average of 30 per cent reduction in energy consumption, then the energy consumption of such a circuit is further reduced by an average of 27 per cent. If such a circuit was to be adopted, then there is potential to reduce the overall comminution energy by up 46 per cent compared to the conventional circuit.

Table VI-Energy savings attributable to the HPGR circuit compared to the conventional circuit (after Rule[3])

Target grind size [µm]	300	150	106	75	45
Stage 1 - HPGR energy [kWh/t]	3.3	3.3	3.3	3.3	3.3
Ball milling of HPGR product [kWh/t]	16.2	25.6	32.8	57.7	53.7
Total HPGR route energy [kWh/t]	19.5	28.9	36.1	61.0	56.9
Stage 1 - Jaw crshing energy [kWh/t]	2.4	2.4	2.4	2.4	2.4
Stage 2 - Rolls crushing energy[kWh/t]	0.9	0.9	0.9	0.9	0.9
Jaw + rolls crushing energy [kWh/t]	3.3	3.3	3.3	3.3	3.3
Ball milling for conventional products [kWh/t]	23.6	33.7	40.0	63.0	70.0
Total conventional route energy [kWh/t]	26.9	37.0	43.3	66.3	73.3
Net energy savings HPGR route [kWh/t]	7.4	8.1	7.2	5.3	16.4
Energy savings [%]	27.6	22.0	16.7	8.0	22.3
Average energy savings [%]	19				

Table VII-Extension of table 6 showing the potential impact of the VTM™ on overall energy reduction

Target grind size [µm]	300.0	150.0	106.0	75.0	45.0
Stage 1 - HPGR energy [kWh/t]	3.3	3.3	3.3	3.3	3.3
Ball milling of HPGR product [kWh/t]	16.2	25.6	32.8	57.7	53.7
Total Ball - HPGR route energy [kWh/t]	19.5	28.9	36.1	61.0	57.0
Vertimilling of HPGR product [kWh/t]	11.3	17.9	23.0	40.4	37.6
Total VTM - HPGR route [kWh/t]	14.6	21.2	26.3	43.7	40.9
Stage 1 - Jaw crshing energy [kWh/t]	2.4	2.4	2.4	2.4	2.4
Stage 2 - Rolls crushing energy[kWh/t]	0.9	0.9	0.9	0.9	0.9
Jaw + rolls crushing energy [kWh/t]	3.3	3.3	3.3	3.3	3.3
Ball milling for conventional products [kWh/t]	23.6	33.7	40.0	63.0	70.0
Vertimilling of conventional products [kWh/t]	16.5	23.6	28.0	44.1	49.0
Total conventional route energy [kWh/t]	26.9	37.0	43.3	66.3	73.3
Total Vertimilling of convetional product [kWh/t]	19.8	26.9	31.3	47.4	52.3
Net energy savings HPGR route [kWh/t]	7.4	8.1	7.2	5.3	16.3
Net energy saving HPGR - Vertimill route [kWh/t]	4.9	7.7	9.8	17.3	16.1
Energy savings HPGR - Ball mill route compared to conventional route [%]	27.5	21.9	16.6	8.0	22.2
Energy savings HPGR - Vertmill route comparred to HPGR - Ball mill route [%]	24.9	26.6	27.3	28.4	28.3
Average energy savings HPGR route compared to conventional route [%]	19				
Average energy savings HPGR - VTM route comapred to HPGR - Ball mill route [%]	27				
Grand Total [%]	46				

Finally, the capability of the VTM™ in coarse / secondary grinding together with the associated energy savings has been demonstrated. However, what about its applicability in the typical high-tonnage secondary grinding environment? To answer this question, assumptions on the efficiencies of the drives of the two mill types are made as follows:

- VTM™ typical drive efficiency of 98 per cent
- Ball mill typical drive efficiency of 95 per cent.

The current biggest VTM™ that Metso can manufacture is the VTM-4500-WB; this mill has 3356 kW of power installed. If an average savings of 30 per cent in energy usage is applied and allowance is made for drive losses as assumed above, then an indicative comparable ball mill will have an installed power of 4500 kW.

So in very simple terms, a secondary grinding duty requiring a ball mill with approximately 4500 kW installed can be replaced by a single VTM-4500-WB.

Case study 3A – Selecting a stirred mill that is fit for purpose – single-stage milling* vs. *two stages

As previously described, Metso can provide two types of stirred mill designs, and this provides the opportunity to offer the optimum solution for a particular duty. This flexibility ensures that a solution that is fit for purpose is always on offer.

Among the various requirements that must be considered when selecting stirred mills, one key requirement is optimizing the energy consumption to the reduction ratio required. An example based on laboratory work is used to demonstrate how test data can be effectively used to guide the selection of an appropriate stirred milling circuit.

Figure 15 shows the results of tests that were undertaken on a copper sulphide concentrate using both the VTM™ and SMD. The VTM™ was charged with 19 mm steel balls, while 3 mm ceramic balls were used for the SMD. The objective of the tests was to understand the relative energy efficiency of the two mills when applied to fine and ultrafine grinding.

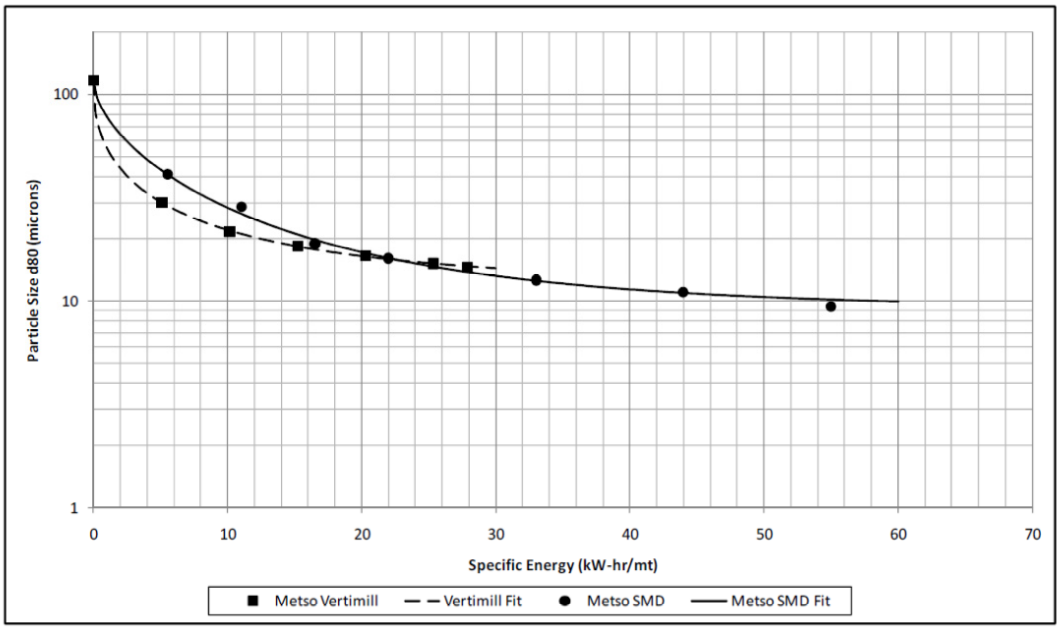

Figure 15-Copper concentrate 1- relative performance of VTM™ *vs*. SMD

The results of this work indicates that the VTM™ is more energy-efficient than the SMD up to a grind size of 80 per cent passing 16 µm, after which the SMD becomes the more energy-efficient alternative.

Similarly, tests conducted by Metso on other ore types confirm this trend. In fact, depending on feed top size, there is typically a point of intersection whereby to achieve a certain product size specification the relative energy efficiency of the two mills either deteriorates or is maintained. This point of intersection is driven largely by the top size in the feed stream to the mill and explained by the size of balls that can be used in the respective mills and the inherent grinding mechanism, as explained previously.

So, in this particular example the VTM™ should be recommended if the milling duty requires a target grind of up to 16 µm, anything finer will be best suited to the SMD. However, the accompanying rider to this recommendation is that a view must be taken on the appropriateness of the top size in the mill feed stream for each of the mills.

The next case study shows an approach that was taken by Metso when recommending mills for the Barrick Cowal concentrator. The Metso approach considers the effect that both the feed top size and grind size will have on energy consumption for each mill size. Once a total energy picture is established, the optimum circuit configuration is recommended.

Case study 3B: Selecting stirred mills for Barrick Cowal

As with any stage of grinding, it is always prudent to precede the mill selection and sizing step with test work. This is especially important when the ultrafine grinding application requires high reduction ratios, as was the case for Barrick Cowal.

The benefit of this important step is illustrated by the work that was done for the Barrick Cowal mine located in Australia. The Barrick Cowal concentrator treats a primary sulphide gold ore and uses different types of concentration methods; namely, gravity, and flash and conventional floatation to recover the gold. The cumulative effect of the various concentration methods, each with a different P_{80}, meant that aggregating them would result in a stream with a coarse D_{80} (150 – 200 µm). On the other hand, mineralogy work had indicated that to further enhance gold recovery, the flash and conventional floatation concentrate streams would have to be re-ground to a size of 80 per cent passing 15 µm. So, this work sought to find the most energy-efficient grinding route for this application.

To this end, Metso conduct a suite of laboratory tests that involved a single stage and two stages of grinding for both the VTM™ and SMD technologies. Table VIII presents a summary of the comparative results obtained.

Table VIII-Barrick Cowal test results – single-stage milling *vs*. two-stage milling

Parameter	Unit	Single Stage Milling	Two Stage Grinding
F_{80}	[µm]	150	150
T_{80}	[µm]	-	40
P_{80}	[µm]	15	15
Intermidiate reduction ratio	[-]	-	3.75
Overall reduction ratio	[-]	10	10
Specific energy	**[kWh/t]**	**39**	**14**

The test results indicate the two-stage grinding circuit to be vastly superior in terms of energy efficiency than the single-stage circuit. In fact, the two-stage option reduces energy consumption by 25 kWh/t. Based on these results, Metso recommended a two-stage circuit, in which the first stage of milling is carried out by the VTM™ followed by two SMDs in series. This energy saving benefit and subsequent recommendation by Metso is based on understanding the intersection point as referenced in case study 3A and the ability to then select the optimum size media for each stage of grinding.

Figure 16 presents the circuit that was recommended to and adopted by the Barrick Cowal mine.

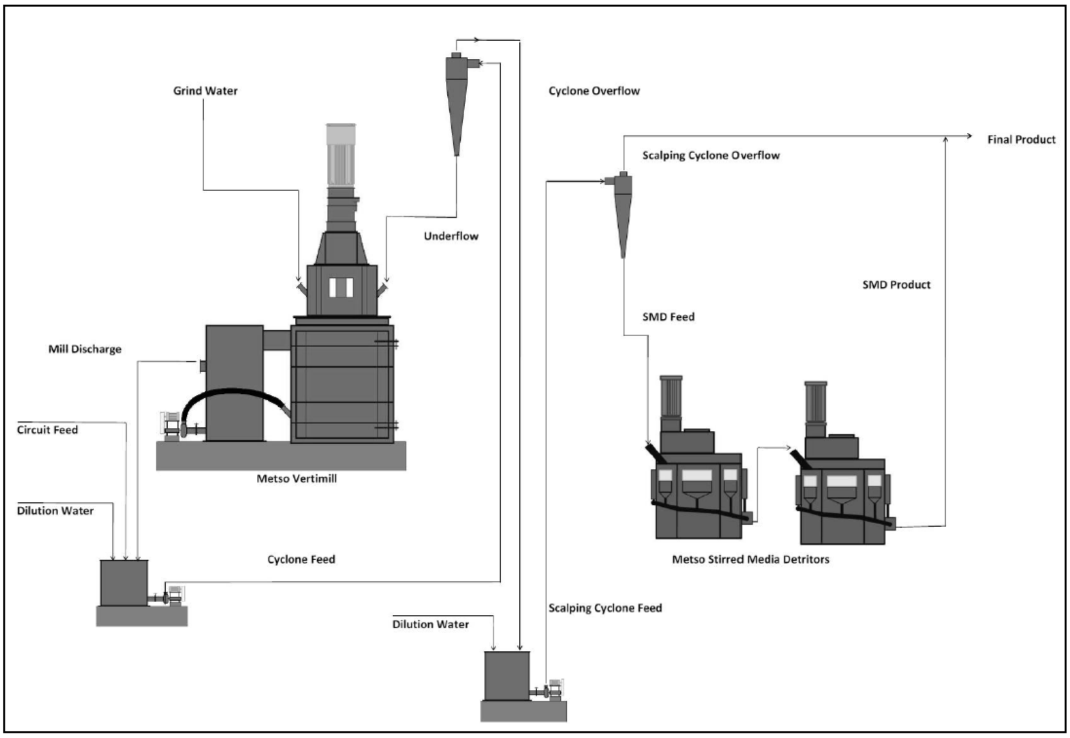

Figure 16-Barrick Cowal ultrafine grinding flow sheet

Of course, part of the decisionmaking in adopting or rejecting a two-stage grinding option must take into cognisance the capital costs for the additional mills and associated ancillary equipment. Most importantly though, is the total cost of ownership over the life of the mine that the concentrator will incur by either adopting or rejecting the two-stage circuit. Such evaluations can be easily computed based on certain known facts and assumptions and can be used to guide the final decision. In the case of the Cowal project, the value proposed by the savings in energy consumption in itself was persuasive enough to justify the adoption of the two-stage circuit. In instances where the savings in energy is marginal, then the full financial implication should be evaluated and ranked before a decision is made.

The energy savings demonstrated through all of the case studies discussed can also be represented in terms of GHG emission reductions, particularly carbon dioxide (CO_2). As stated earlier, South Africa's reliance on fossil fuel to generate electricity implies that the GHGs are by-products of its generation. Since mining is a significant user of electricity, this means that it is also a significant contributor of the anthropogenic GHGs. The negative impact of GHGs on the environment is well documented. So, for mining to reduce energy consumption and thus emissions of GHGs makes good business sense.

Carbon dioxide (CO_2), being one of the major GHGs, is typically used to measure emissions by relating a unit of CO_2 produced to a unit of electricity generated. In South Africa, this relationship is estimated to be 0.978 kg CO_2 per kilowatt-hour (0.978 kg/kWh) of electricity generated by means of a coal-fired power station. Therefore, every kilowatt-hour saved will reduce an operator's carbon footprint by 0.978 kg of CO_2.

Conclusions

- An overview of energy challenges facing the platinum mining industry has been discussed
- An average saving of 30 per cent in energy consumption is achievable by substituting ball mills with stirred mills
- Stirred milling technology, particularly the VTM™, can be applied to secondary grinding
- With this extension of the VTM™ into secondary grinding duty, if complemented with an HPGR, energy consumption can be significantly impacted. A saving of 46 per cent has been estimated
- A two-stage stirred milling circuit can result in optimum energy usage in some ultrafine applications
- The implications of energy savings achieved through implementing stirred milling in concentrators impact not only the profitability of operation but also translate into the reduction of GHGs. In the medium term this will result in either further financial gains or at the very least in good corporate citizenry, which will bolster the goodwill item on the balance sheet.

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Charles Ntsele Obtained his NHD Extraction Metallurgy from the University Of Johannesburg in 1994.

He began his career as a trainee at one of the De Beers Diamond Mines.

He then moved on to the Anglo Research Laboratories, where he was responsible for the comminution pilot plant. It is at this stage where he developed his grounding and passion for comminution, particularly grinding. His work experience includes the following areas:

- Trouble shooting
- Equipment commissioning and process optimisation
- Techno-Economic evaluation of new equipment/process
- Ore characterisation, data interpretation and developing conceptual comminution flowsheets
- Test formulation and supervision
- Plant surveys, modelling and simulation
- Sales and marketing

One of his most note-worthy achievements to date is the work he conducted to prove the case for Autogenous milling for kimberlitic ores, which culminated in the installation of an industrial scale test mill at Jwaneng mine.

He is currently the sales manager for grinding equipment at Metso Minerals