Stirred Mill Optimisation – Am I Getting the Most Out of My Mill?

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Over time, fundamentals, and institutional knowledge on how to operate critical equipment tend to be lost due to turnover in staff and attention being placed on the next “bottleneck”. Ultimately, developing plant conditions (mineralogy, throughput, particle size distribution, etc.) change the operating philosophy of any concentrator, and poorer or unoptimized operation of key equipment can become the standard operating practice. Using the IsaMill™ as a case study to aim to prevent this all too familiar scenario, the authors have prepared a blueprint on how to audit your existing stirred mill to ensure that you can get the most out of it.

Key areas the authors will explore are: how to survey the IsaMill™ correctly; optimise your media selection; optimise your operating density; how to benchmark your mill to design; and typical strategies to minimise wear within the IsaMill™. By following these steps, operating sites should be able to ensure their stirred mill is fully optimised.

Keywords: IsaMill™, Stirred Mill Optimisation, Process Audit

1.0 INTRODUCTION

Significant testwork undertaken by Mount Isa Mines (MIM) in the late 1980s attempted to apply the Netzsch small horizontal bead mill operating in paint products, to the mining industry to address complex liberation problems. MIM did significant work modifying the mill's mechanism to operate it in large-scale continuous mining environments with low operating costs. The result was the first internal IsaMill™ being installed in Mount Isa in 1994. External commercialisation of the IsaMill™ occurred in the early 2000s and has led to more than 145 installations worldwide and acceptance as the world's leading stirred mill in the mining sector.

The paper aims to highlight the fundamentals of the mill's operation and provide guidance for understanding your IsaMills™ and how to evaluate operating conditions to achieve the best performance. The aim is to allow users across any operating plants that utilise an IsaMill™ to audit, troubleshoot and optimise their mill using best practices.

2.0 WHAT'S HAPPENING INSIDE THE ISAMILL

The IsaMill™ is a horizontal, high-intensity stirred grinding mill containing rotating rubber-lined grinding discs mounted on a cantilevered shaft. Ceramic grinding beads are used within the mill and will recirculate between the rotating discs. Grinding of the feed slurry occurs through attrition and abrasion mechanisms. A simplified configuration of the internals of the mill is shown in Figure 1 and Figure 2.

Feed is pumped into the mill chamber, which contains the horizontal shaft with the discs mounted on it, rotating at approximately 15-20m/s tip speeds. The discs provide the high-intensity mixing environment of the ceramic grinding media and the slurry. Coarser particles and the grinding media tend to centrifuge to the circumference of the mill, with finer particles being displaced towards the shaft and moving down the shaft towards the discharge end of the mill. At the discharge end, the product separator classifies the fine and coarse particles and is unique to the IsaMill™ and key to the very sharp product size distribution.

Various internal configurations, including the number of discs and disc diameter, can be adjusted to account for specific operating conditions.

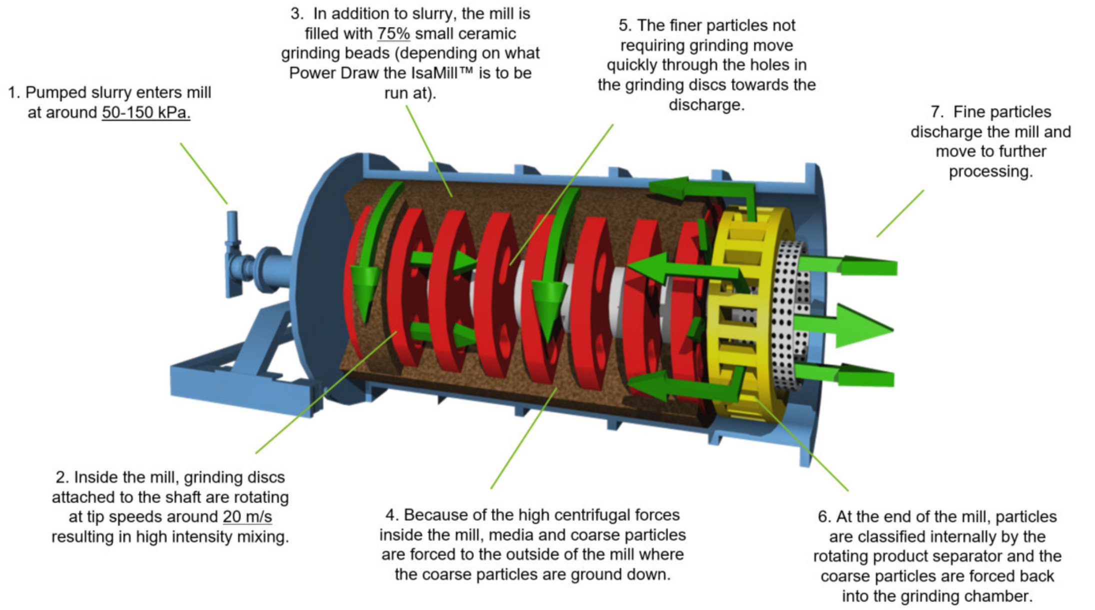

Figure 1 – Internal mechanism of an IsaMill™ (Gurnett et al., 2021)

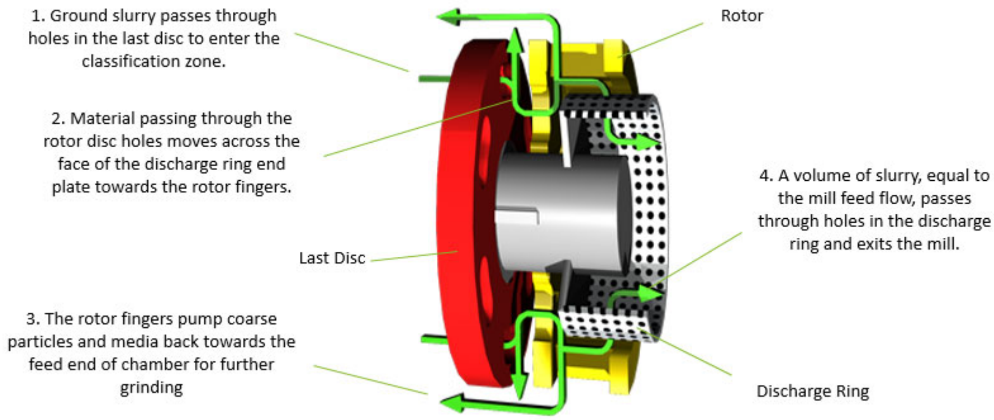

Figure 2 - IsaMill™ Internal Classification (Gurnett et al, 2021)

3.0 SPECIFIC ENERGY

3.1 ROLE OF ENERGY

The purpose of the IsaMill™ is to achieve size reduction and improve mineral liberation. Power in any grinding application is one of the most important parameters to understand and quantify correctly based on a defined throughput.

Power is the rate at which the IsaMill™ motor applies energy to the charge (slurry and media), measured in kW.

Throughput, a function of circuit fresh feed flow rate (m^3/h) and density (kg/m^3), is the rate at which the feed material is supplied to the IsaMill™ circuit, generally measured in tonnes per hour (t/h). Size reduction is a function of the energy input to each tonne processed, defined as the IsaMill™ specific energy[1].

$$Specific\ Energy = \frac{Power}{Throughput} = kWh/t$$

Feed distribution (particle size), throughput and density are often constrained to fairly tight operating limits and commonly set by upstream unit operations. Therefore, the primary control of the IsaMill™ product size is the IsaMill™ power draw, controlled through the intermittent addition of media to achieve a target operating power set point.

3.2 MEASURING SPECIFIC ENERGY

Specific energy is calculated using the following formula:

$$Specific\ Energy\ (\frac{kWh}{t}) = \frac{IsaMill\ Net\ Power\ Draw\ (kW)}{Circuit\ Fresh\ Feed\ (\frac{t}{h})}$$

$$IsaMill\ Net\ Power\ Draw = IsaMill\ Gross\ Power\ Draw - No\ Load\ Power$$

Specific Energy is independent of the IsaMill™ Feed Flowrate (the direct flow to the mill); it depends only on the IsaMill™ (net) power draw and circuit fresh feed rate. Increasing or decreasing the direct IsaMill™ feed flow rate will only vary the amount of discharge recycled.

Specific Energy is also independent of the arrangement of the classification circuit. A common misconception within the industry is the scale-up of the Signature Plot (the characterisation of the specific energy to grind size) to full plant sizes where the mill may be installed in either a closed or open-loop circuit. A simplified example of

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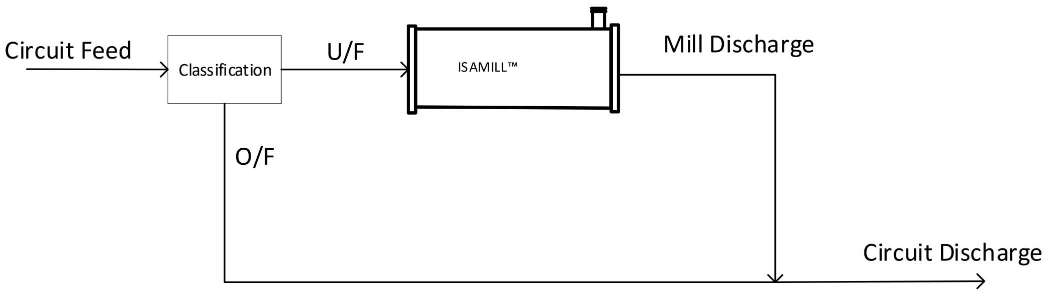
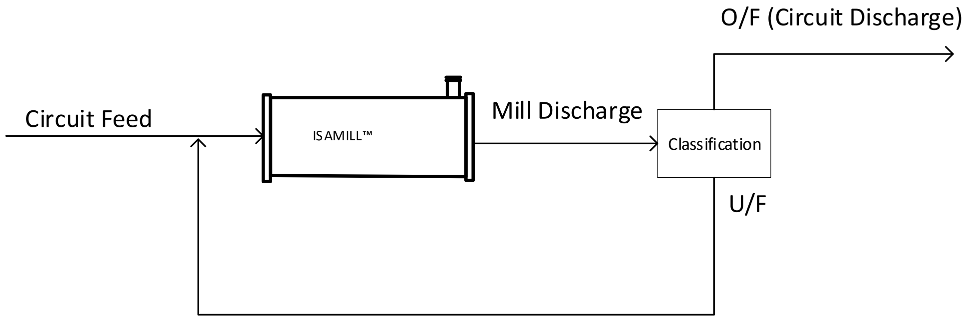
[1] Grinding efficiency will increase as operating density increases until an upper limit is reached.

these is shown in Figure 3.

The scale-up from ‘circuit feed’ samples in the Signature Plot database has reliably been used to verify that specific energy requirements for a given set of target grinding conditions are independent of the open or closed classification configuration.



Simplified Open Loop Circuit



Simplified Closed Loop Circuit

Figure 3 - Simplified IsaMill™ operating circuits (Gurnett et al., 2022)

In open-loop circuits with cyclone classification of the feed, coarser material reports to the IsaMill™ at a reduced tonnage rate (compared to the circuit feed). Cyclone underflow will require more energy input (per unit mass), due to the coarser feed, with the trade-off at lower mass rates. This is more simply demonstrated for an open-loop circuit in the example Figure 4 below.

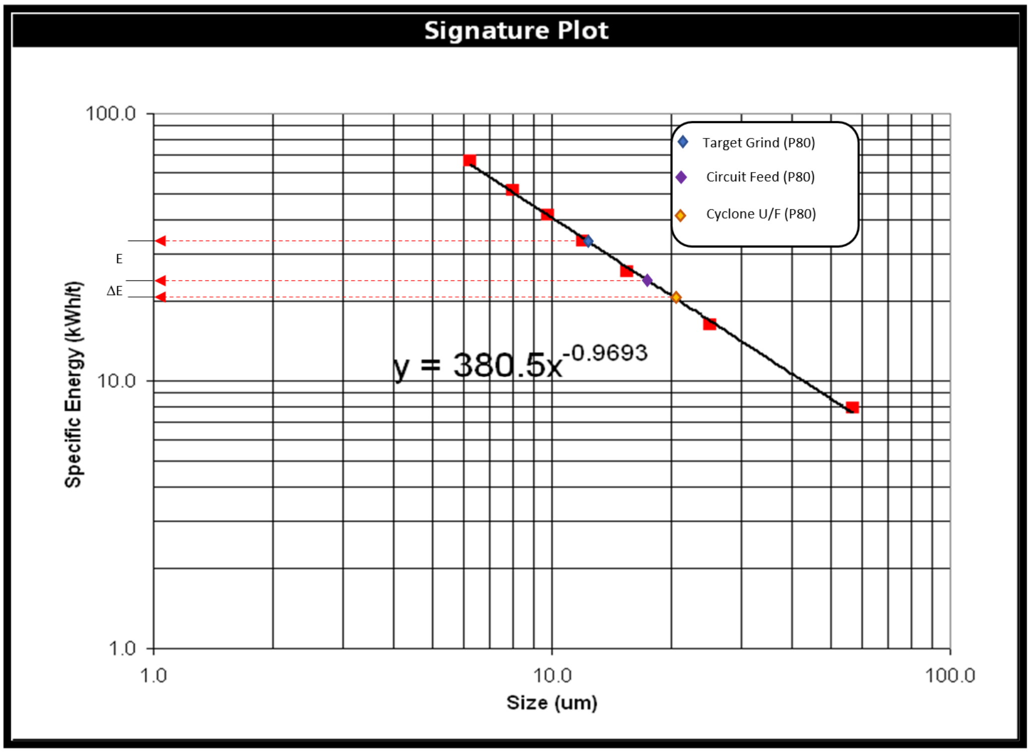


Figure 4 - Signature Plot application to cyclone classification of the feed (Gurnett et al., 2022)

Based on a history of successful scale-up from testwork to full-scale installations, the following relationship holds:

$$E \times T_{circuit} \approx (E + \Delta E) \times T_{CycloneUF}$$

where,

E = circuit specific energy, duty based on circuit feed to target grind size [kWh/t]

ΔE = specific energy, additional duty based on reducing the coarser cyclone underflow to the circuit feed size [kWh/t]

$T_{circuit}$ = circuit solids throughput [dry t/h]

$T_{cycloneUF}$ = classification underflow solids throughput [dry t/h]

When considering a closed-loop circuit, the specific feed rate to the mill will increase with the higher circulating load from classification. The key to note is that the fresh feed is the same between the arrangements. Any fine (below grind target size) material recirculating does not impact the overall energy requirements. Due to the internal classification within the IsaMill™, the coarse fraction will preferentially undergo grinding, with the fines preferentially bypassing the grinding zones within the mill.

The specific energy is therefore always calculated based on the appropriate power applied to the circuit 'fresh feed'.

4.0 CERAMIC MEDIA

4.1 MEDIA SELECTION AND CONSUMPTION

Unlike most alternative grinding mills, which use steel balls, the IsaMill™ typically uses high quality ceramic beads, with the selection of correct media having the ability to significantly improve grinding efficiency and hence operating costs. Grinding efficiency is impacted by several variables related to media selection, the most significant being media diameter and media density.

When selecting the correct media, it must provide sufficient breakage energy to reduce the coarsest particle in the feed at the rate they enter the mill. Glencore Technology (GT), who owns the rights to the IsaMill™, typically recommends a reduction ratio (F80 ÷ P80) of less than 8 per media type (diameter range, i.e., 1.5 mm, 2.0 mm, 2.5 mm etc.) for an IsaMill™. For benchmarking purposes, GT also recommends the following media for selecting the media top size as a starting point for optimisation.

	Feed Size, F80 (µm)											
Product Size P80 (µm)	<20	20-30	30-40	40-50	50-60	60-70	70-100	100-130	130-160	160-200	200-250	>250
<7	1.5	1.5	1.5-2	1.5-2	2	2						
7-11	2	2	2	2	2	2	2.5					
11-15	2.5	2.5	2.5	2.5	2.5	2.5	2.8	3				
15-20	2.5	3	3	3	3	3	3	3-3.5	4			
20-25	x	3	3	3.5	3.5	3.5	3.5	3.5-4	4.5	4.5	4	
25-30	x	x	3.5	3.5	3.5	4	4	4	4.5	4.5	4.5	5.5
30-35	x	x	x	4	4	4.5	4.5	4.5	5	5	5	6
35-40	x	x	x	4.5	4.5	5	5	5	5	5.5	5	6
>40	x	x	x	5	5	5	5	5.5	5.5	5.5	5.5	6

Figure 5- Media Selection Matrix Media Selection Matrix (Gurnett et al., 2021)

Recently, as more ceramic media suppliers are entering the market, the introduction of higher density (SG) media is more readily available, particularly focusing on the vertical stirred grinding mill market. In horizontal milling configurations, such as with the IsaMill™, the higher SG media was found to have reduced grinding efficiencies while wear of the internal components increased. The improvements in media life are understood to only be statistically noticeable once the SG increases above 5.

GT was provided ceramic media costs for different densities from a well-known grinding industry media supplier to investigate SG impacts on operating costs. An operating cost model was developed for an IsaMill™ operating at 2,500 kW, with media consumed at an average of 12 g/kWh. Selecting the preferential 3.7 SG for the IsaMill™ above a high SG media of 4.5, showed that over two years of operation, the cost savings in media ($0.7M compared to $2.1M) was equivalent to the value of a second M10,000 IsaMill™.

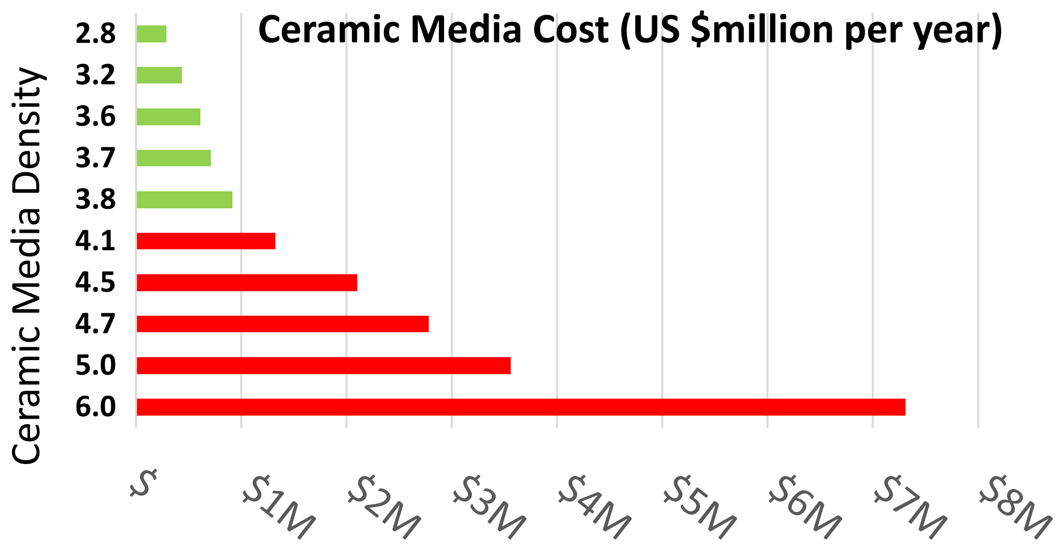


Figure 6 - Comparative Costs for Different Media SG (Gurnett et al., 2021)

4.2 MEDIA CONSUMPTION

Media addition to the IsaMill™ occurs automatically through programmed logic to target a specific power draw. It is critical for operations teams to not only understand their media consumption rates, but to actively monitor the media itself. The most reliable metric for grinding media consumption is grams of media/IsaMill™ kWh. Good quality grinding media should wear at a rate close to 12 g/kWh or less.

There are a few critical checks that can be undertaken regularly to identify if media wear/consumption is negatively impacting the mill performance and operating costs:

- *Is your media a mix of two suppliers/different products?*
  It is essential that mixing of media types is avoided. Mixed (difference hardness) media types will have different grinding properties, with softer media essentially being ground by the harder media, leading to higher consumption rates and unnecessary higher associated operating costs.

  Even different formulations from the same supplier will have a risk of doing this.

- *Does my media supplier provide good quality material?*
  Good quality beads will wear evenly, as shown in Figure 7, maintaining their sphericity and grinding efficiency. Poorer quality beads may wear into different "shapes", as in Figure 8, and have a detrimental effect on the overall media wear rate, but may also impact the wear rate of the IsaMill™ internal components. Poorer quality beads may also break, leaving fine shards of ceramic which can cause significant wear to the mill's internal components.

  Checking reclaimed media shape on shutdown should be undertaken at each opportunity.

- *Am I seeing media losses to my discharge product stream?*
  This will most commonly be caused by a combination of high flow, high power draw (media load) and mill configuration.

  Incorrect start-up sequences may also cause inadvertent media losses to the product. Media may exit through the discharge line as the IsaMill™ shaft ramps up to full speed on start-up. Therefore, the IsaMill™ start-up sequence must be programmed to be in full recycle mode (recycle valve 100% open) during the motor start.

Figure 7 – Uniform Grinding Media Wear (Glencore Technology, 2018a)

Figure 8 – Non-Uniform Grinding Media Wear: Angular (left), Flat (Right) (Glencore Technology, 2018a)

5.0 PROCESS RELATIONSHIPS

5.1 WHAT DO I CONTROL?

Understanding how all the interconnected process relationships interact will provide the best chance to run your IsaMill™ at its optimal conditions. Many process variables interact, and changing one can significantly impact several others. Upstream plant variables will also affect the operation of the IsaMill™. A useful rule-of-thumb relationship check for mill health is shown in Figure 9.

- *What variables can I control within the IsaMill™ circuit:*

	Finer Grind	Coarser Grind
Rarely control	↓ Ore Hardness	↑ Ore Hardness
Sometimes control	↓ Feed Size	↑ Feed Size
	↓ Throughput	↑ Throughput
	↑ % Solids	↓ % Solids*
Usually control	↑ Power Draw	↓ Power Draw

Figure 9 - Factors affecting IsaMill™ performance (Glencore Technology, 2018b)

**Grinding efficiency increases as the operating density increases until an upper limit is reached. This has to do with viscosity and will be discussed later.*

Reviewing process data trends on a shift and weekly basis will identify a site's specific process responses to variation. Sudden changes can indicate instrument or electrical problems, while slower changes over time are often process-related. Many short-term process disturbances will resolve on their own with the help of automatic control systems, but it is recommended to do regular reviews of the process data over longer-term trends e.g. 6 months.

5.2 DENSITY

The design of the IsaMill™ is typically to operate under feed conditions of 18 to 20 % solids (v/v) for regrind applications. As solids density rises, the further production of finer material from the grinding action subsequently increases the overall particle surface area. Viscosity impacts within the mill have an increased likelihood of occurring with the higher exposed surface areas. These operating conditions can cause the mill behaviour to no longer act as a highly turbulent agitated grinding environment, but as a rotating viscous plug of mixed media and material. This 'lock-up' of the charge can cause the power draw to drop significantly. The relationship between density/viscosity and efficiency has been outlined in Figure 10.

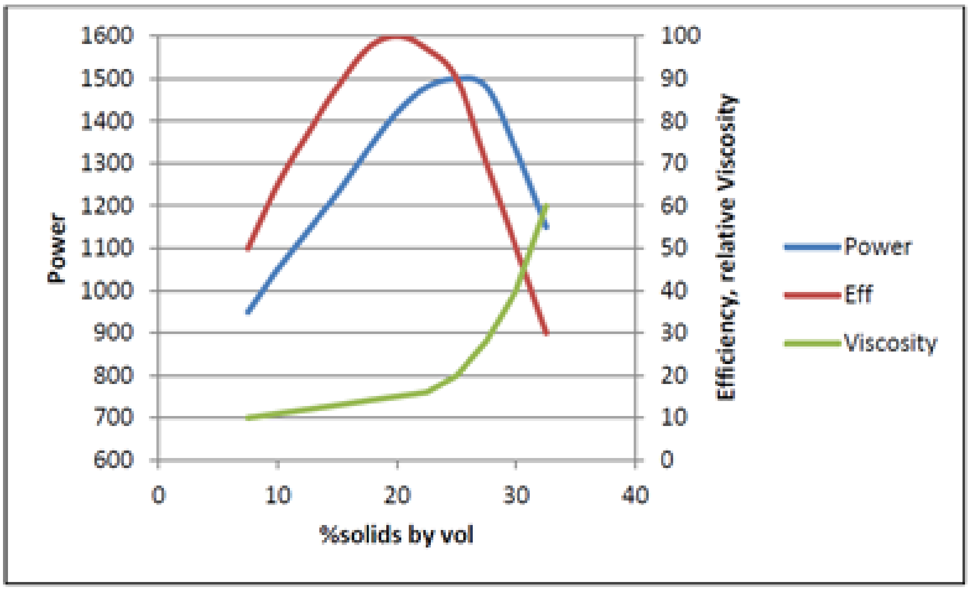


Figure 10 - Effect of density on the grinding efficiency within the IsaMill™ (Gurnett et al., 2021)

Therefore, to assist with diagnosing density issues, the following flowchart shown in Figure 11 was developed to check on the process conditions that may diagnose a density issue. If there is a density issue, diluting the feed with process water is recommended if there is sufficient capability onsite.

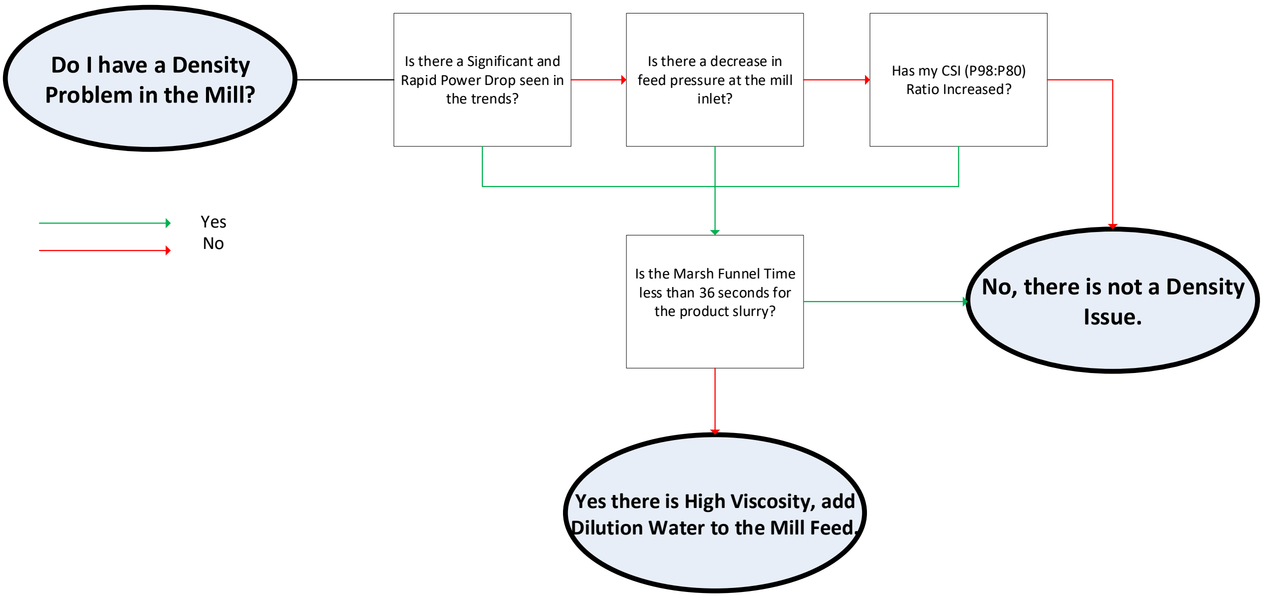


Figure 11 - Diagnosing Density Issues

Therefore, to mitigate this issue in the design process, it is recommended to operate the IsaMills™ at 20% solids (v/v). The purpose of this is to limit the viscosity impacts on grinding efficiency. Table 1 and Table 2, reference various SG and density conditions.

Solid particle surface area is also an important aspect of viscosity. As solid particles undergo size reduction (small particle diameters), the total solid particle surface area within the grinding chamber of the same volume increases, and hence apparent viscosity increases. Generally, for the majority of ore types tested within the IsaMill™, the volumetric solids concentration (a good representation of total surface area) of approximately 20 solids (v/v) is a good starting point for operating the mill. Factors such as particle surface roughness and particle shape can also contribute towards viscosity effects in the mill and may need optimisation of the target feed % solids for a specific ore type.

Table 1 – Solids density conversion table

Solids SG	% Solids (v/v)	% Solids (w/w)
2.6	20%	39.4%
2.8	20%	41.2%
3.0	20%	42.9%
3.2	20%	44.4%
3.4	20%	45.9%
3.6	20%	47.4%
3.8	20%	48.7%
4.0	20%	50.0%
4.2	20%	51.2%

Table 2 – Solids density look-up reference

	Solids SG								
	2.6	**2.8**	**3**	**3.2**	**3.4**	**3.6**	**3.8**	**4**	**4.2**
% Solids (w/w)	**% Solids (v/v)**								
30.0%	14.2%	13.3%	12.5%	11.8%	11.2%	10.6%	10.1%	9.7%	9.3%
32.5%	15.6%	14.7%	13.8%	13.1%	12.4%	11.8%	11.2%	10.7%	10.3%
35.0%	17.2%	16.1%	15.2%	14.4%	13.7%	13.0%	12.4%	11.9%	11.4%
37.5%	18.8%	17.6%	16.7%	15.8%	15.0%	14.3%	13.6%	13.0%	12.5%
40.0%	20.4%	19.2%	18.2%	17.2%	16.4%	15.6%	14.9%	14.3%	13.7%
42.5%	22.1%	20.9%	19.8%	18.8%	17.9%	17.0%	16.3%	15.6%	15.0%
45.0%	23.9%	22.6%	21.4%	20.4%	19.4%	18.5%	17.7%	17.0%	16.3%
47.5%	25.8%	24.4%	23.2%	22.0%	21.0%	20.1%	19.2%	18.4%	17.7%
50.0%	27.8%	26.3%	25.0%	23.8%	22.7%	21.7%	20.8%	20.0%	19.2%
52.5%	29.8%	28.3%	26.9%	25.7%	24.5%	23.5%	22.5%	21.6%	20.8%
55.0%	32.0%	30.4%	28.9%	27.6%	26.4%	25.3%	24.3%	23.4%	22.5%

To convert % Solids (w/w) by mass to % Solids (v/v) by volume. The following formula can also be used:

$$\%\,Solids\ (vol) = \frac{\%\,Solids\ (mass)\ \times\ Slurry\ SG}{Solids\ SG}$$

If deviations are seen in feed density, the operations team should check the following:

<u>Upstream processes</u>
- *Has the tonnage/flow rate changed significantly?*
- *Have the flotation conditions changed?*

<u>Cyclone performance</u>
- *What is the cyclone pressure?*
- *Are any cyclones roping or have blockages?*
- *Has there been a change to cyclone feed density or flow rate?*

<u>Circuit Water Addition</u>
- *Has the water addition to the circuit changed?*
- *Are we adding makeup water started for some reason?*
- *Is dilution water control not working?*
- *Has a spillage sump pump started?*

<u>Manual Reading</u>
- *Is there some discrepancy between a manual reading and the density gauge?*

5.3 POWER AND TEMPERATURE

Increased specific energy results in a finer product but also higher discharge temperatures. At higher temperatures, the properties of rubber begin to degrade, and the rubber internals of the IsaMill™ are much more susceptible to accelerated wear. GT has conducted decades of rubber testing to improve wear characteristics at high temperatures, but even so, the IsaMill™ has a discharge temperature interlock that will shut it down (70°C) to prevent rubber damage. The operator should monitor discharge temperature and investigate anything that causes it to rise significantly.

As fresh feed to the IsaMill™ circuit decreases (specific energy increases), the recycle will increase and the discharge temperature will rise. A reduction in fresh feed rate is often the cause of increased discharge temperatures. Figure 12 shows the relationship between feed density, power draw and discharge temperature.

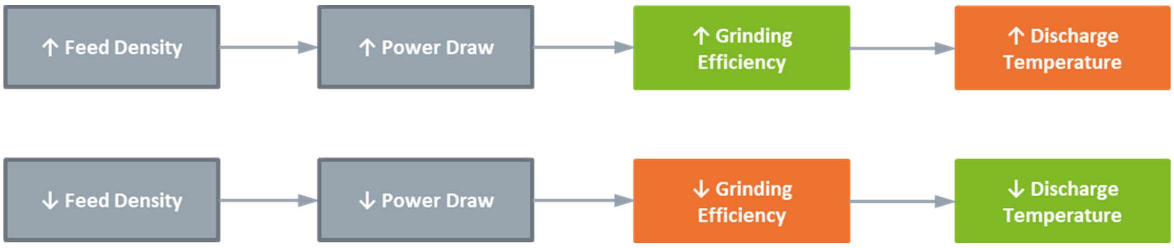


Figure 12 – Energy and Temperature (Glencore Technology, 2018b)

If the power draw reading behaves unexpectedly, check the following:

- **Feed Density** – Generally power draw increases with slurry density. Is the density within normal operating ranges?
- **IsaMill™ Feed Flowrate** – If the mill feed flow rate is too high, there is potential for media loss to the mill discharge stream. Media in the rotor area will cause an increase in power draw until media begins to pass into the discharge stream. Is the flow rate within normal operating ranges?
- **Media Charge** – If the media hopper is empty, then the IsaCharger™ system will continue to operate, but no media will be sent to the mill.
- **Viscosity** – If the IsaMill™ internal viscosity has become too high, the power draw may drop dramatically due to a “free-wheeling” effect. When was the last time a Marsh Funnel check was done?
- **Media Distribution** – Media in the rotor area may cause the IsaMill™ Main Motor to draw more power. Has the mill's thermal profile (thermal camera image) been completed recently?
- **Coarse Particle Build-Up** – Has the IsaMill circuit feed coarsened significantly? How are the cyclones performing?
- **Sump-Pump Operation** – If the IsaMill™ area spillage sump pump is started, any media in the bund will be pumped into the feed pump box and subsequently to the mill, resulting in increased media load and power draw.

5.4 MEASURING PRODUCT SIZE

Correct reporting of product size is critical to determining if the mill is performing its intended duty. Standard particle sizing tools include sieves or screening, image analysis and laser particle-size-analysis units (e.g., Malvern Mastersizer). It is important to note that when using a laser sizer, the “equivalent sphere” method is utilized, which generally reports coarser results when compared directly with a screen sizing method, as the volume of the particle is assumed to be a sphere. Particle shape can significantly influence the results of the measurement tool used and then impact how operating plant data is interpreted.

An example of how shape influences the reported value, as shown in Figure 13, is seen when a 100 µm long, 20 µm wide particle could potentially pass through a 21 µm aperture screen but would measure as a 39 µm particle in the Malvern laser sizer.

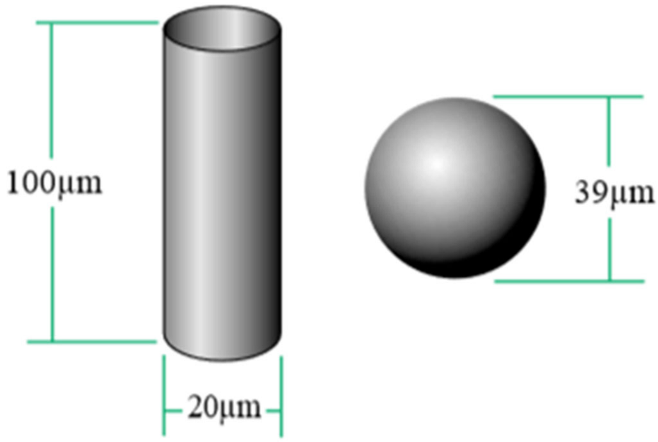


Figure 13 - Effect of particle shape on sizing (Malvern, 2014)

Since shape is a significant factor in the analysis method, when samples are measured and it is understood to contain a larger degree of non-spherical particles, e.g., micaceous silicates, the "coarseness" of the Malvern compared to screen sizing results will be exaggerated. This can create a misleading environment where a higher specific energy may be required depending on the particle analysis method. Therefore, if this is known, it is recommended to do laser sizing and screening and allow the testwork manager to determine which method will be used for all particle analysis. When surveys are conducted on IsaMill™ feed and discharge streams, a standard measurement tool must be used compared to the original testwork.

6.0 CYCLONES

6.1 CYCLONE PERFORMANCE

Cyclones in regrind applications are commonly operated to achieve a feed pressure set point as measured in the cyclone feed header, either by the number of operating cyclones or by adjusting pump speed based on site-specific preferences. A high-level rule of thumb for operating cyclones and their relationships to the process is given in Table 3.

Table 3 – Cyclone Operation Rules-of-Thumb (Magee, 2004)

	Cut Size	Recirculating Load	Cyclone Efficiency
▲ Pressure	▼	▲	▲
▲ Feed Density	▲	▼	▼
▲ Spigot Size	▼	▲	▲
▲ Vortex Finder Size	▲	▼	▼

Regular visual inspections of the cyclones can improve grinding performance by identifying upset conditions. A simplified schematic of cyclone underflow discharge is shown in Figure 14.

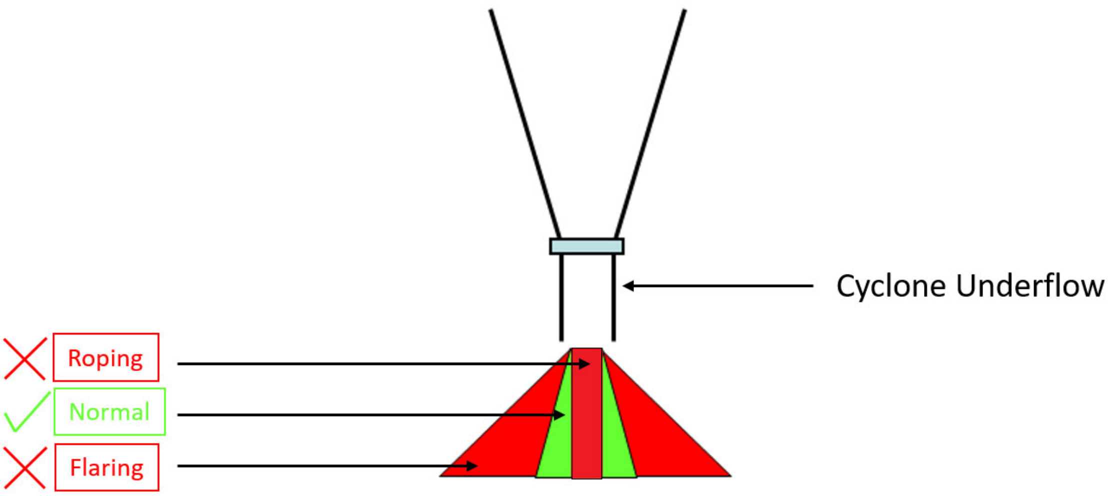


Figure 14 – Cyclone Underflow Flow Behaviour (Magee, 2004)

Operations personnel should look for the following:

- Flaring, leading to fine material in underflow and lower underflow density.
    - Spigot opening is too great for volume of solids reporting to underflow.
    - Check that operating parameters are within range (feed rate, density, pressure).
    - Close a cyclone in cluster to increase feed pressure.
- Roping, leading to coarse material in overflow and higher underflow density.
    - Spigot opening too narrow for volume of solids reporting to underflow.
    - Check that operating parameters are within range (feed rate, density, pressure).
    - Open a cyclone in cluster to decrease feed pressure.
    - Check other cyclone spigots for blockage.
- No Flow, all material exiting in overflow.
    - Foreign objects may be blocking the spigot or roping has sanded cyclone.
    - Isolate the cyclone immediately by closing the feed valve and opening another.
    - Clear blockage from the spigot.

Cyclones should be inspected regularly, and conditions recorded as part of standard operator checks. The operator should be asking:

- *Are the spigots roping or flaring?*
- *Do we have leaks on any part of the cyclone body?*
- *Is the cyclone feed pressure abnormally low or high?*
- *Can I detect abnormal cyclone vibration?*

During routine maintenance, vortex finders and spigots should be measured and recorded as part of standard maintenance practices (inspections per number of operating hours e.g., 500 hours). Worn components should be replaced to ensure best operation and routine cyclone surveys should be performed to evaluate process performance.

6.2 CYCLONE OVERFLOW VERSUS ISAMILL™ DISCHARGE

With the case of open-circuit IsaMill™ configurations, circuit surveys should include a comparison between the classification cyclone overflow and the IsaMill™ product discharge. Anecdotal evidence has shown that where a difference of greater than 20 µm exists between the IsaMill™ discharge and cyclone overflow streams, downstream processes may be subject to a bi-model feed impacting either cleaning flotation or leaching processes.

- *Is the mill discharge stream and cyclone overflow P_{80} difference less than 20* µm*?*
  Consider if the cyclones' operating conditions result in a coarser than desired overflow.

7.0 WEAR MONITORING AND OPTIMISATION

7.1 TEMPERATURE PROFILES AND WEAR MONITORING

As with all stirred grinding mills, wear components are a considerable part of operating cost expenditure. Ensuring that the mill is set up to minimise wear is beneficial to minimising the cost of replacement parts and limiting unnecessary maintenance downtime and production losses. Thermal imaging, similar to the example in Figure 15, of the external surface of the IsaMill™ can help to monitor the wear state (or potential wear events) of the shell liner and/or media distribution along the length of the mill.

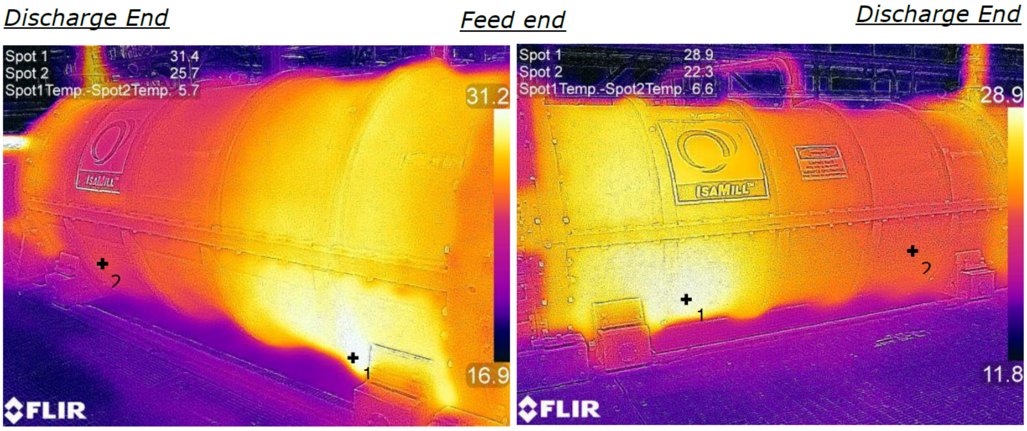


Figure 15 – Thermal Surveys of an IsaMill™ (Glencore Technology, 2018c)

Regions of higher temperatures indicate media compaction (non-fluidized behaviour) and/or increased shell liner wear. Thermal profiles of the mill shell are an excellent indicator of the wear profiles observed when the mill is opened for maintenance inspections. Identifying the likely wear regions will allow maintenance and production teams to adjust their planning to address the wear concerns. If gouging is seen on the shell liner, it is recommended to perform routine temperature profiles while the mill is operational.

Comparison of thermal profiles between maintenance windows will allow operations teams to identify the impact of process changes on the wear performance of the mill. Profiles will be affected by the sun's position on the shell, so measurements should be taken at the same time each day. As a rule:

- ΔT > 5°C between adjacent points OR
- ΔT > 10°C over the whole mill,

shows that temperature differentials are beginning to increase too high, suggesting that media compaction zones are forming.

Figure 16 shows several temperature profiles of an M10,000 IsaMill™ operating under different conditions and internal configurations. External shell temperatures were measured at 14 equidistant points along the axial direction of the mill and then plotted. The impact of internal configuration on the media distribution and subsequent internal component wear profile is evident.

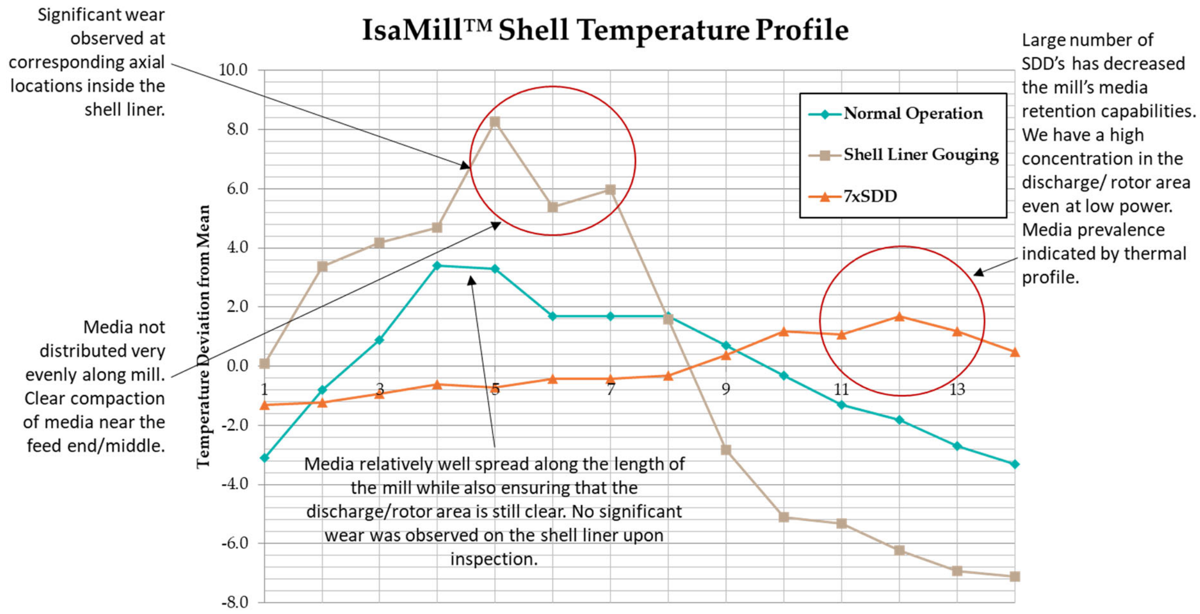


Figure 16 – M10,000 IsaMill™ Thermal Survey (Glencore Technology, 2018c)

Strategies exist to manipulate process operating conditions and modifications to IsaMill™ internals to shift the media charge within the mill. Figure 17 shows the factors affecting media distribution (along the length of the shell.

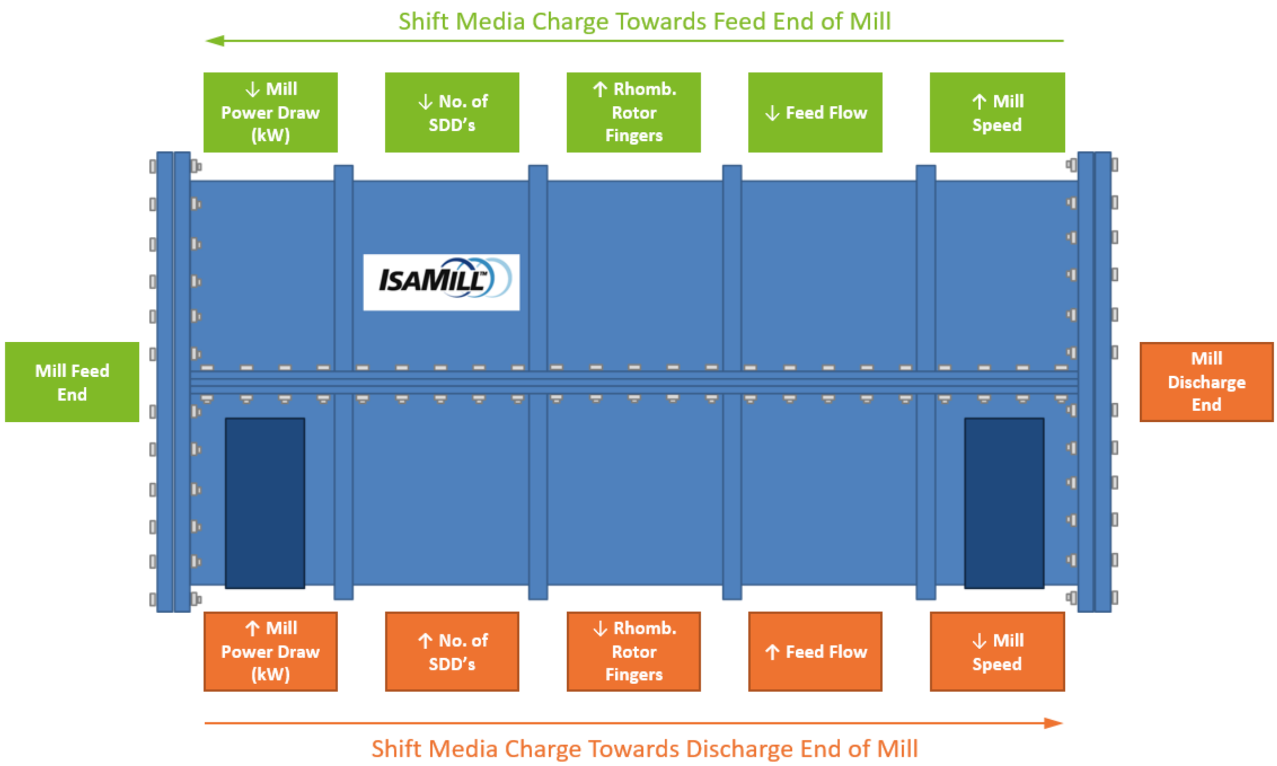


Figure 17 - Factors affecting media distribution in the IsaMill™ (Glencore Technology, 2018c)

These factors affect performance by:

- IsaMill™ internal component configuration:
    - Number of Small Diameter Discs (SDDs) – smaller diameter discs leave a larger gap between the disc and shell, allowing more room for the media to retain its fluidised behaviour.

Introducing a small diameter disc (SDD) at the point of identified media compression provides more space, removing heat from that zone of compression. Demonstrated in Figure 18.

  - Rotor Finger Types (Square vs. Rhomboidal vs. De-rated) on the product separator – changing the efficiency of the pumping action of the rotor. By replacing a fraction, or all, of the standard square fingers with alternate rotor finger shapes, the rotor's 'back- pumping' effect is alternate to allow for greater or reduced media retention capability depending on the mill flow/power draw requirements.

- IsaMill™ Feed Flow: The higher the volumetric flow into the mill, the greater the force pushing media towards the mill discharge end.
- Internal Viscosity – whether the media retains its fluidised behaviour and does not move as a single plug unit.
- Feed Particle Size Distribution: Very coarse particles in the feed can act as pseudo-media, displacing the grinding media towards the mill discharge end.
- Mill Speed (VSD Mills only): As the mill speed drops, the rotor is de-rated (as observed during start-up) and media shifts towards the mill discharge end.
- Power Draw: The greater the volume of media in the mill to achieve higher power draws, the further the media charge will extend down the mill.

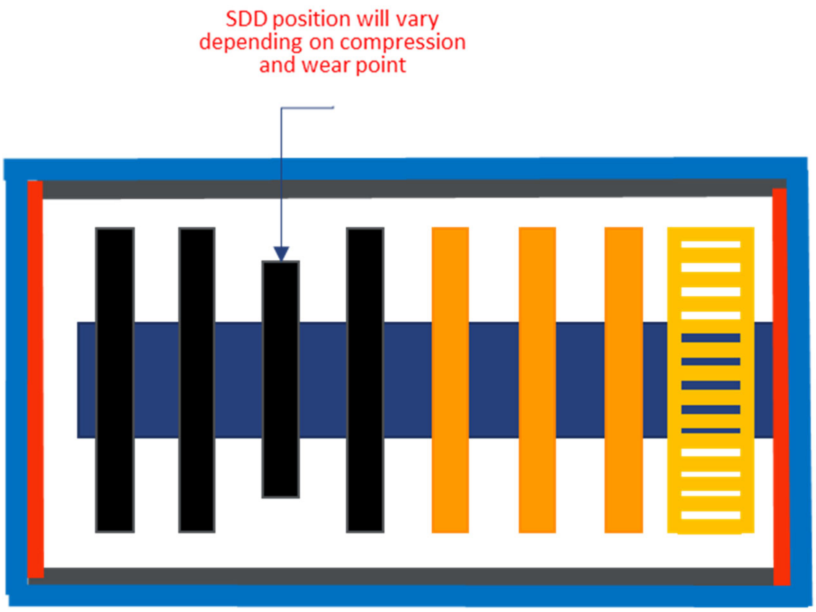


Figure 18 - SDD installed at Zone of Compression (Gurnett et al., 2023)

Localised occurrences of heat build-up along the mill may also be addressed by utilising alternative rubber selections such as HD60 and GD70 rubbers formulated with compounds to dissipate heat. Additionally, by removing a disc and installing larger spacers, a seven-disc IsaMill™ configuration, as shown in Figure 18, can still draw close to 100% of the available motor power by optimising the components and process variables. GT has worked with many installations for decades to optimise the internal component configurations of IsaMills™ across the globe.

7.2 TOOLS TO OPTIMIZE

The simplest and most fundamental measure of the condition of a regrind plant is the performance of unit operations downstream, such as flotation or leaching. If the regrinding process is achieving target outcomes, there should be tangible benefits to the overall plant operation, (e.g., recovery, grade, reagent consumption). Small step changes made gradually may be overlooked when observing short-term data. Considering longer-term trends ensures that you compare conditions before and after observed wear rate increases. Process stability – not just long-term averages – is also important to observe. An unsteady process is much more likely to lead to increased wear rates.

By regularly reviewing the following areas, troubleshooting within the IsaMill™ circuit can become a straightforward and reliable routine to maintain overall plant performance:

- Has there been no change in IsaMill™ process conditions? Review them, with the following parameters a good starting point for investigation:
    a. IsaMill™ Power Draw
    b. IsaMill™ Feed Density
    c. IsaMill™ Feed Pressure
    d. Upstream performance (flotation recovery, changes in the primary grind/cyclone performance)
- Has the quality of media deteriorated? Is the media angular and not wearing evenly?
- Are there foreign objects getting into the IsaMill? Larger objects like nuts and bolts are not designed to be ground in the IsaMill™ and can rapidly damage the internal components.
- What does the temperature profile of the IsaMill™ look like? Does it suggest that there may be media compaction (large, localized concentrations of media, creating "hot spots")?
- Conducting regular regrind circuit surveys, which should include samples of the following streams:
    e. IsaMill™ circuit fresh feed
    f. IsaMill™ feed
    g. IsaMill™ discharge
    h. (Optional) IsaMill™ Circuit Discharge – Combined cyclone overflow and IsaMill™ discharge (installed in open loop configuration).

  Because of the recycle around the IsaMill™, mill fresh feed (not mill feed) needs to be used when calculating specific energy (compared to the power in the mill per tonne of fresh feed treated).

8.0 CONCLUSION

By regularly reviewing the operating conditions of the IsaMill™ as outlined in this paper, operating sites should have the tools to optimise and maintain their stirred mills at the highest-levels. By optimising media selection, understanding how density and viscosity impact the mill's efficiency, and simple troubleshooting guidance outlined in this paper, the blueprint for auditing existing IsaMills™ can be applied to any commodity.

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