

# Stirred Milling Design – Incorporating the IsaMill™ into the Jameson Concentrator

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## ABSTRACT

In 2021, Glencore Technology unveiled the Jameson Concentrator and announced the Ozernoye (due for commissioning in 2022) and New Britannia Projects (commissioned Q4 2021). As part of the Ozernoye project, a conventional circuit consisting of flotation tank cells coupled with a vertical regrind mill was compared to a Jameson Concentrator. The Jameson Concentrator replaced the entirety of the conventional flotation equipment with Jameson Cells, with the M20,000 IsaMill™ as the selected regrind mill. Selecting the Jameson Concentrator design for Ozernoye reduced the footprint to less than 50% of the conventional circuit, with a key saving to the project lowering the building height by 15 m. Reduced power demand and maintenance spares resulted in operating cost savings 50% lower than a conventional circuit. This Jameson Concentrator design has been implemented before and is deemed low risk in the industry. The success of this design has previously been seen at the Philex Concentrator in 1996 and most recently at Hudbay's New Britannia installation in 2021.

This paper addresses the strong influence of testwork in the design process of the IsaMill™. The IsaMill™ design in the Jameson Concentrator was based on testwork principles that allow for an accurate 1:1 scale up. This paper explores how the M20,000 in particular, and IsaMills™ in general, are designed and developed for commercial installation. Particular focus will be on testwork sample size, the accuracy of scale-up, the appropriateness of testwork, the impact on grinding media selection (on mill efficiency and OPEX), understanding the effect of viscosity, and the influence of particle size measurement techniques when analysing the results.

## **INTRODUCTION**

In 2021, Glencore Technology unveiled the Jameson Concentrator with the announcement of the Ozernoye Project, due for commissioning in late 2022. A conventional circuit consisting of flotation tank cells coupled with a vertical regrind mill was compared to a Jameson Concentrator during the feasibility study. This comparison led to selection of the Jameson Concentrator, which replaced the entirety of the conventional flotation equipment with Jameson Cells, with the M20,000 IsaMill™ as the selected regrind mill. Selecting the Jameson Concentrator design for Ozernoye reduced the footprint to less than 50% of the conventional circuit, lowered the building height by approximately 15 m, reduced the power demand (due to less equipment), and reduced maintenance spares. This results in an operating cost saving of roughly 50% of that of a conventional circuit.

This paper aims to highlight the benefits of the Jameson Concentrator and how the M20,000 IsaMill™ with its new reduced footprint design fits into this circuit, and aims to address some of the intricacies that are involved in setting up the regrind signature plots and the importance of various parameters (e.g. media size, same size, density, etc) on the mill sizing.

## **WHAT IS THE JAMESON CONCENTRATOR?**

The Jameson Concentrator is a product that was launched in 2021 that incorporates both the Jameson Cell and IsaMill™ (if regrind is required) into the full flotation/regrind circuit. This was developed to address performance inefficiencies, high costs and large carbon footprints seen within conventional circuit designs. Conventional circuits typically result in larger physical footprints and high circuit volumes, because conventional circuit sizing is based on the residence time to achieve the required recoveries. By design, the Jameson Cell does not incorporate residence time into the design process due to the intense mixing in the downcomer forcing collisions between bubble and particle and eliminating short-circuiting. By removing the residence time constraint, cell sizing becomes dependent only on carrying capacity and volumetric flow. The result is an overall smaller footprint and less equipment to achieve an equivalent duty.

With Jameson Cell designs having a 15-60% recycle for process stability, the circuit can absorb high variations in throughput rates and feed grades (assuming it's not carrying capacity-constrained). This, in turn, allows for the ability to absorb changes in feed mineralogy where other technologies struggle. The fast kinetics from the collisions within the downcomer enables the ability to target liberated minerals and scalp off a final concentrate, which significantly reduces the footprint of downstream equipment, increases process stability and reduces the circuit complexity.

Ultimately, selecting a circuit consisting only of Jameson Cells, with 35+ years of proven successes, has enabled a design with significantly reduced footprint and circuit inventory. By reducing the size of the circuit and having fewer moving parts (no compressors or agitators required), there are significant savings in both the CAPEX and OPEX while reducing the overall complexity of the circuit (fewer flotation units and stages which reduces recirculating loads). These benefits drove the decision to select the Jameson Concentrator for the Ozernoye Project. The Jameson Concentrator design was previously executed at the Philex Concentrator in 1996 (Harbot et al, 1997). The most recent success at Hudbay's New Britannia installation was commissioned in 2021, demonstrating and proving the concept that reduces any process risks.

To help demonstrate some of these benefits, Figure 1 below is an example showing the effective footprint reduction you would expect with a Jameson Concentrator for a ~1,400 tph Copper Nickel Concentrator. Seventy-six conventional cells have been replaced with eighteen Jameson Cells with two M3000 IsaMills. This equates to a footprint reduction of greater than 50% and a noticeable reduction in height due to no lifting constraints for agitators during maintenance.

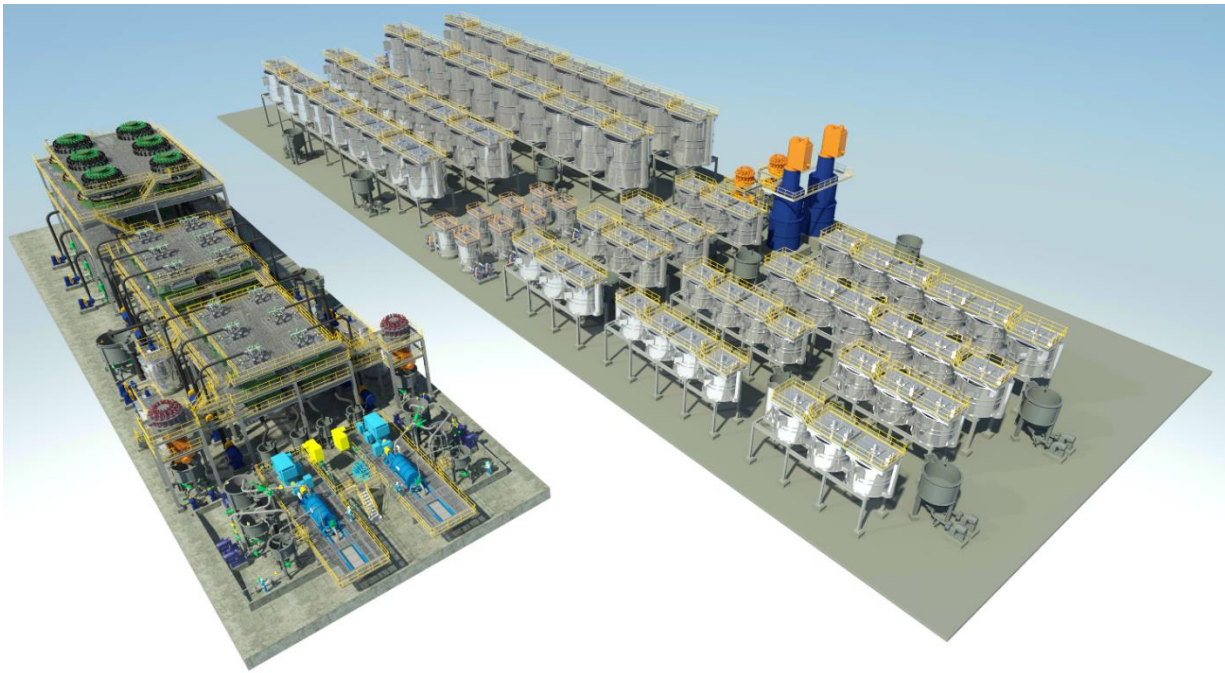


FIG 1 - Copper-Nickel concentrator comparison

### THE DEVELOPMENT OF THE REDUCED FOOTPRINT M20,000

In 2020 Glencore Technology recognised that an IsaMill™ needed to be developed that could treat higher volumetric throughput rates whilst remaining cost-effective in terms of OPEX (e.g. shipping of parts and maintenance spares). To satisfy this criterion, the M20,000 was developed with a 5 MW motor. Three of these IsaMill™ designs will be installed and commissioned as part of the Ozernoye project from late 2022 to early 2023.

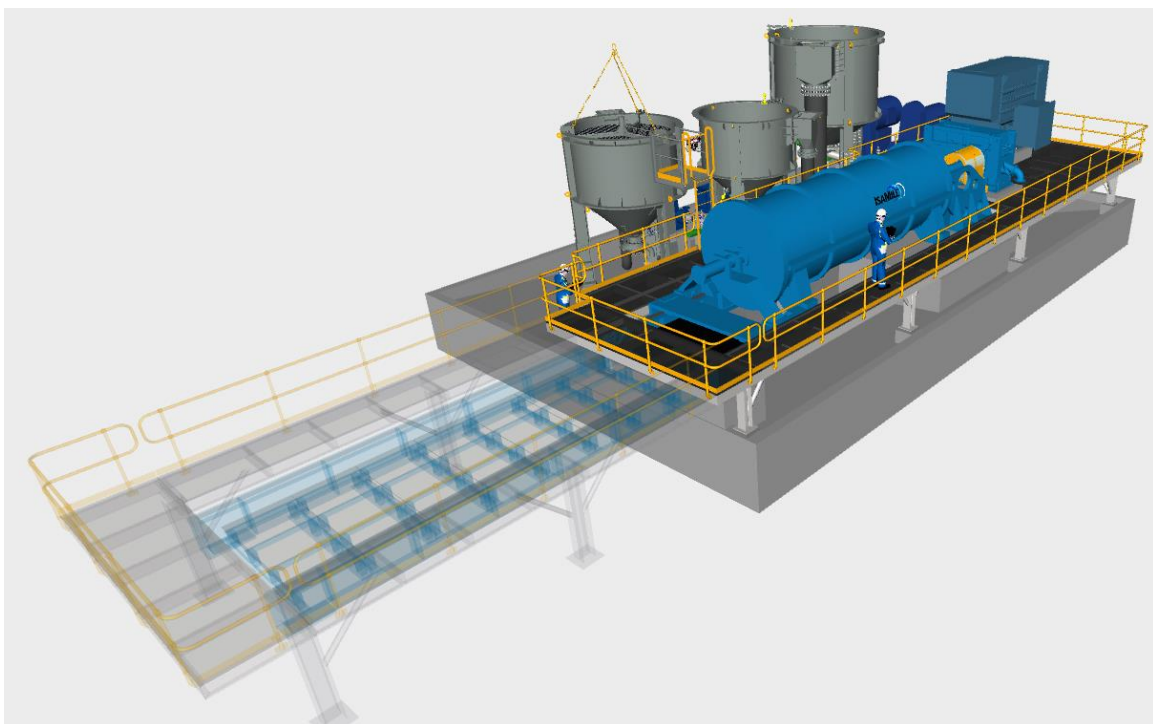


FIG 2 - 3D Model of the M20,000 IsaMill™

The new IsaMill™ design is a significant improvement over the taller, more capital-intensive designs of the pre-2020 period. It was recognised after engaging with industry; there was room to optimise and reduce the cost to the end client. Therefore, the IsaMill™ layout was re-designed to the "reduced footprint plant" version (Figure 2). The main changes to the design are as follows (Gurnett et al, 2021):

- The media hopper has been repositioned from under the IsaMill™ to the side. Due to the backpressure created from the rotor, it was possible to utilise this action to pump media out of the IsaMill™ to a media storage tank/hopper during its maintenance shutdown sequence rather than discharging to the hopper below the IsaMill™.
- The fixed rails are now optional (depending on layout and maintenance requirements), as now a removable rails structure allows for the option to reduce the footprint and allow for an additional maintenance service area when the mill is in operation.
- The IsaMill™ can utilise gland water injected directly into the plant's main supply, which eliminates the need for a gland water tank and corresponding pumps.
- The IsaCharger™ water can be directly supplied from the plant process water; this eliminates the need for an IsaCharger™ water tank and corresponding pumps.
- The overall costs have been reduced by changing several valves with alternative designs.
- Moving the Oil Lubrication Systems (OLS) to the side of the IsaMill™ and allowing for a gravity return (which dictates the height of the plant).

## TESTWORK

The IsaMill™ is fundamentally sized on two different factors; volumetric flow and specific energy. Both items are key to mass and heat balances. While volumetric flow is quite simple to derive, the specific energy is an intricate number from the IsaMill™ Signature Plot, which is conducted on an M4 IsaMill™ (Figure 3).

The IsaMill™ Signature Plot test is widely accepted as the industry standard for specific energy determination performed by accredited laboratories worldwide. It is known for the highly accurate 1:1 scale-up, with numerous previously published examples (e.g. Stirring the Pot: A New Direction for IsaMilling by Barns & Curry, 2006).

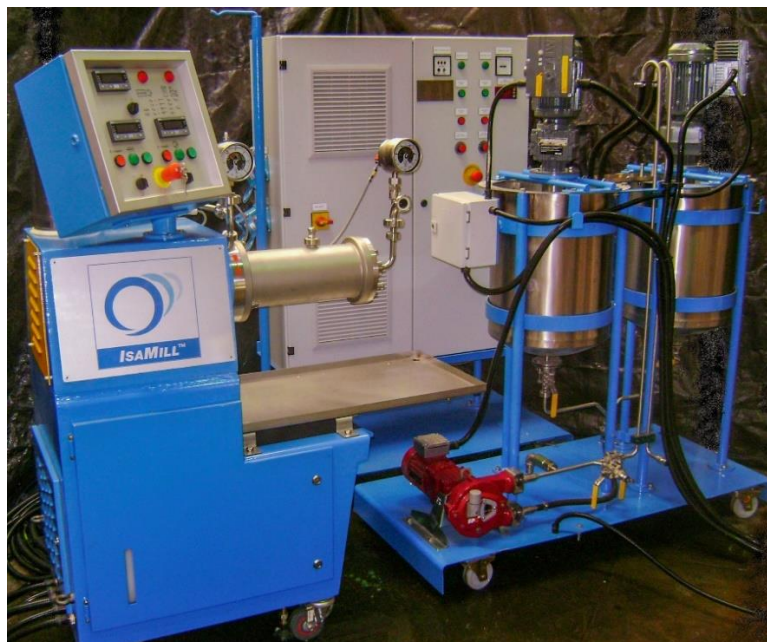


FIG 3 - M4 IsaMill in which Signature Plots are conducted in the laboratory (Gurnett et al, 2021)

While the test is an industry standard, there are many intricacies involved with setting up the test. This paper aims to help explain the conditions behind the test and why they are so important within the design process of the IsaMill™. Noticeable ramifications can affect the mill sizing if the Signature

Plot is done incorrectly. The following sections aim to provide an understanding of why the test is designed the way it is.

## **Sample size**

One of the biggest concerns raised by clients with the Signature Plot tests is that accumulating 15 kg of material for a greenfield site is an arduous and expensive exercise. The common question raised is 'why can't smaller masses be used'? This mass requirement is to ensure there is sufficient material to allow the test to achieve a steady state and produce accurate and repeatable results. Previous publications showed that for a stirred milling test to achieve steady state, there must be sufficient sample to replace the mill voidage volume at least 3-4 times (Larson et al, 2011). This stipulation avoids hold-up of coarse particles, which causes serious underestimation of energy in the range of 30-50%.

Figure 4 demonstrates this sample mass requirement quite clearly. A standard Signature Plot (dark blue) was conducted on an operating gold plant (3.5 SG feed). To validate the test conditions, the plant feed was surveyed (red dot). The graph shows that the plant feed falls on the Signature Plot line demonstrating the suitability of the Signature Plot relationship for predicting operating plant data – enabling direct scale-up from the Signature Plot test to full plant conditions.

To demonstrate the impact of insufficient sample material and how this results in reporting undersized specific energy, a 5 kg sample was run through the Signature Plot procedure. The results of this are shown in Figure 4 (light blue line). This reduced sample mass produced a Signature Plot relationship for the tested material below the initial test. By aligning the plant sampled feed point with the revised energy plot, the outcome is an estimation of grinding energy approximately 30-40% lower. This underestimation of the energy requirement is simply from not having sufficient mass in the sample and not allowing the test process to come to a steady state within the mill.

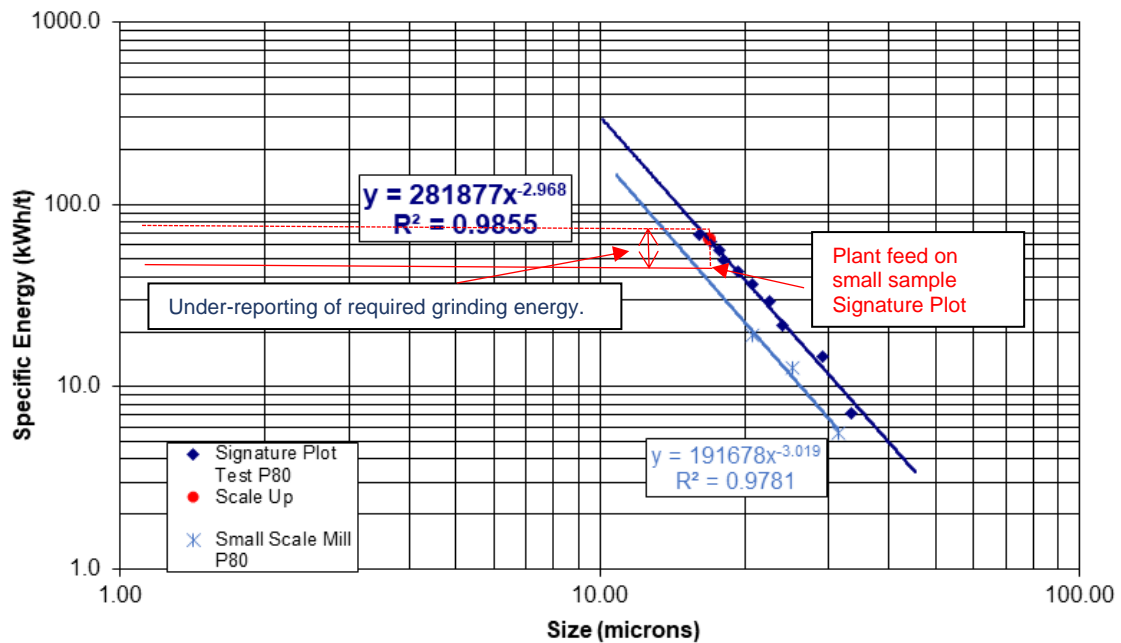
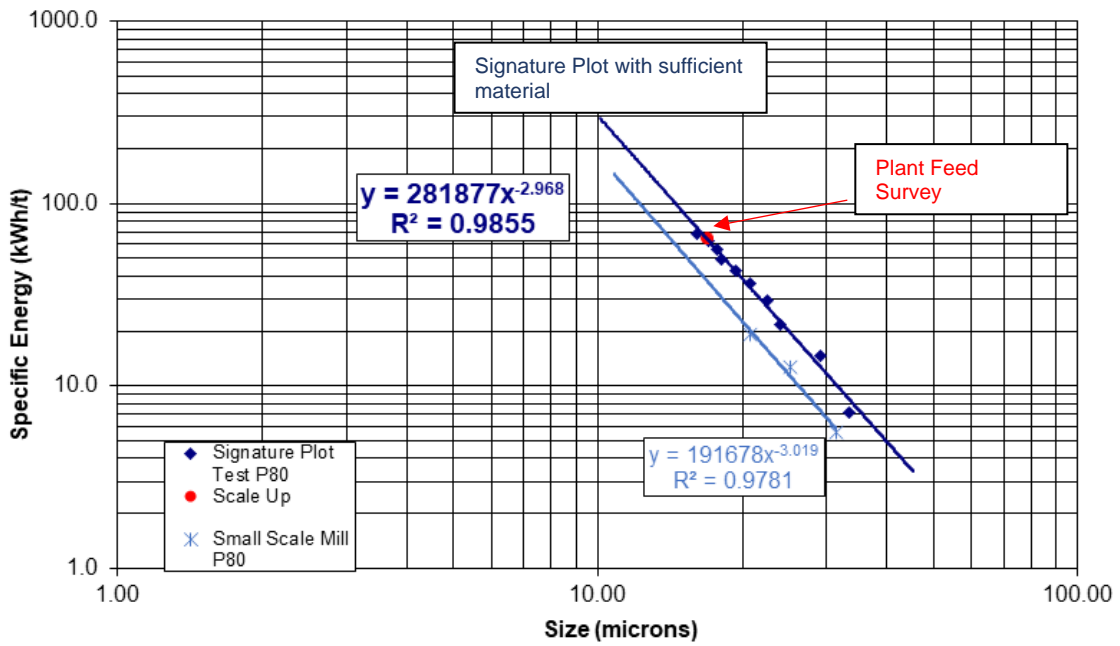


FIG 4 - Comparative scale-up Signature Plot with a small mass sample (Gurnett et al, 2021)

This underestimation in specific energy from the 5 kg test is expected when comparing the ratio of sample mass (undergoing the test) to the void volume of the mill.

A mathematical demonstration of this is provided in Table 1 below. The data shows the effect of SG and required sample sizes within a standard M4 (4L) IsaMill™. As shown, with the range of nominated SG of the material, between 13.4 to 22.4 kg is required to achieve sufficient material turnover in the mill to meet steady-state conditions. As the mill's volume increases, the underestimation effect will be further exaggerated unless more feed sample mass is available.

TABLE 1 - Explanation of sample requirements for the IsaMill™ to achieve steady state

Media volume @100%, L	3.4		
Media volume @74%, L	2.5		
Void space between packed beads, %	24%		
Total available void space inside mill, L	1.5		
Volume of void space in between beads, L	0.6		
Void space in mill not occupied by media, L	0.9		
SG of solids in the sample	3.0	4.0	5.0
Volume of solids to reach steady state (3x), L	4.5	4.5	4.5
Minimum mass of sample required, kg	13.5	18.0	22.5

Based on the example above, a 5 kg sample (at a SG of 3.0) will provide sufficient material only for a single full pass, not reaching steady-state conditions. The inability to reach steady-state conditions will result in the coarse material inherently retained within the stirred mill, incorrectly influencing the specific energy plot. Without reaching steady-state conditions, this will always result in underreporting of the energy required.

Glencore Technology has investigated small sample test trials for the last 25 years using its M4 IsaMill, unfortunately without much success in this field. While it is a challenge, Glencore Technology has not given up on this quest and continues to seek solutions with smaller sample mass. However, it is worth highlighting the recent development of the Ellison Test (Johnston, 2014).

The authors note that the results of the Ellison tests are becoming commonplace in initial concept studies and their inclusion in NI 43-101 disclosure reports (Standards of Disclosure for Minerals Projects – Canadian Securities Administrators). At a high level, the Ellison test can utilise an 800 g sample to provide results accurate at +/- 35% (Johnston, 2014) and can be used as an indicator of the magnitude of power you will need, e.g. 10 v 20 kWh/t. However, to guarantee the 1:1 scale up, the Signature Plot is still required to be conducted in the design process as the project proceeds.

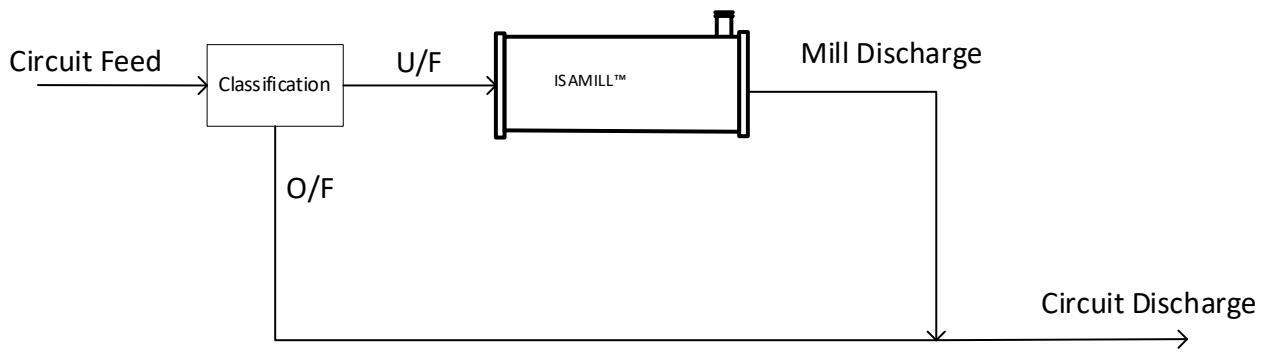
## Importance of sample selection

Glencore Technology has a Signature Plot database that can be used in the absence of any sample/site-specific test work. The database contains hundreds of tests conducted on various ore types and minerals. When Signature Plot test work is conducted on a sample, the full sample is treated through an M4 IsaMill™ to produce a Signature Plot representative of that material type.

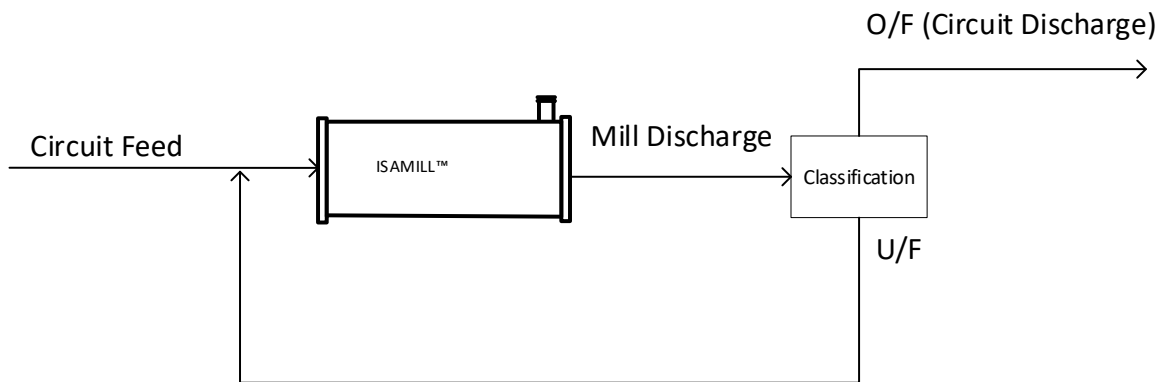
Generally, Signature Plots are undertaken on a sample of material generated from an upstream separation process, commonly froth flotation at a laboratory or pilot scale. It is challenging to duplicate the cyclone separation with such material quantities to prepare a feed to the IsaMill™ similar to an open-loop circuit (feed from a cyclone underflow). Attempting this would result in a test that may not be reliably scalable to full plant conditions.

In some brownfield applications, it is possible to conduct a Signature Plot on the “direct feed” from a classification stage, assuming it can be sampled correctly. There are numerous applications in pre-leach grind duties where this has been conducted.

A common misunderstanding within the industry is the scale-up of the Signature Plot to full plant sizes where the mill may be installed in either a closed or open-loop circuit. A simplified example of these is shown in FIG 5.



**Simplified Open Loop Circuit**



**Simplified Closed Loop Circuit**

FIG 5 - Simplified IsaMill™ operating circuits

In open-loop circuits with cyclone classification of the feed, the coarser material will report to the IsaMill™ at a reduced tonnage rate (compared to the circuit feed). The trade-off is that the cyclone underflow will require more energy input (per unit mass) as the material is coarser, albeit at lower mass rates. This is more simply explained in FIG 6 below (selected data points have been exaggerated for clarity of explanation) for an open-loop circuit.

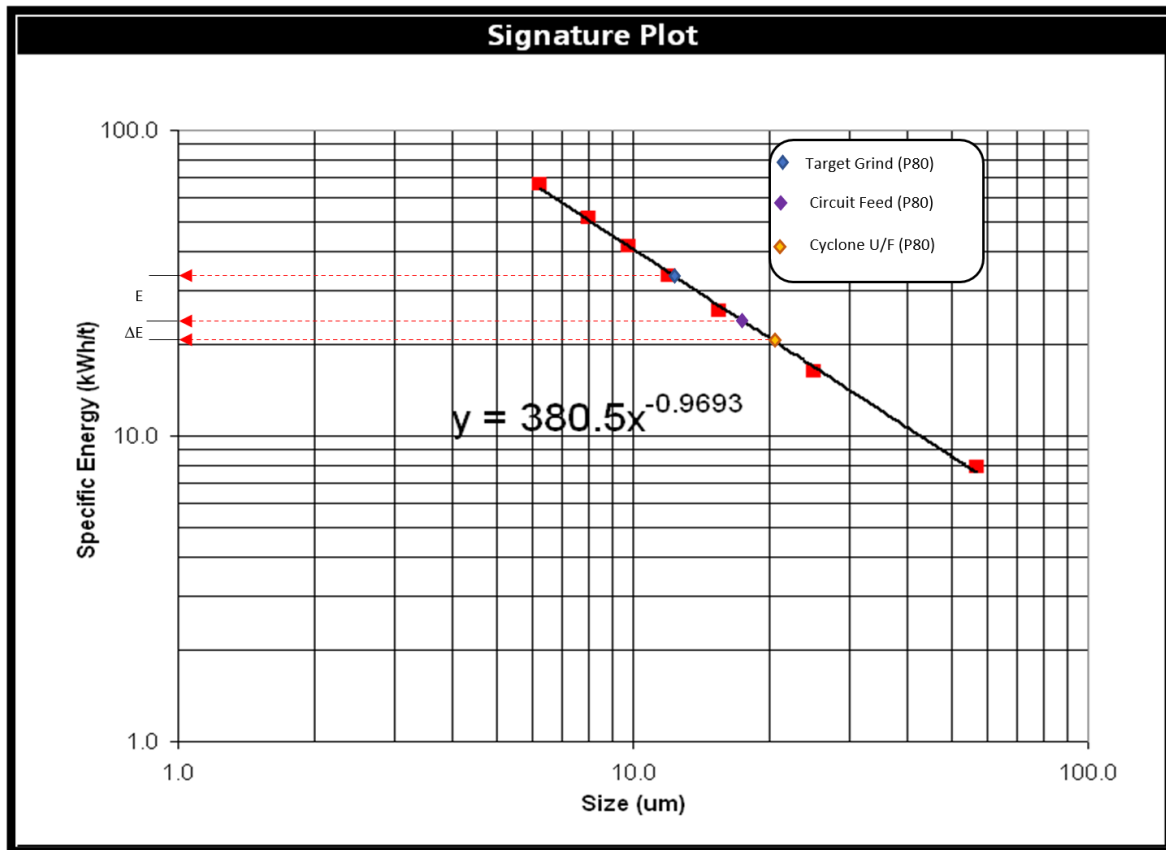


FIG 6 - Signature Plot application to cyclone classification of the feed

Based on the successful scale-up of many applications in open loop circuits, the following relationship holds:

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

where,

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

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

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

$T_{\text{cyclone UF}}$  = classification underflow solids throughput [dry t/h]

In a closed-loop circuit, the 'fresh feed' will be consistent with the open-loop (same circuit fresh feed); however, the specific feed rate to the mill will increase with the circulating load from the cyclone stage. Fine material circulating back from the cyclones does not impact the overall energy requirements as this material will preferentially bypass the grinding zones within the mill. However, the IsaMill™ will preferentially treat the coarse fraction within the feed due to the internal classification within the mill.

The scale-up from 'circuit feed' samples in the Signature Plot database has reliably been used to demonstrate that the specific energy requirements for the target grinding conditions are independent of the open or closed configuration. Sizing of the IsaMill™ is therefore done based on appropriate sample selection applied to the circuit 'fresh feed'.

In practice, it is helpful to consider the Signature Plot profile as a 'circuit' specific energy that will be valid for either open or closed-loop applications.

This relationship was beneficial during the design development of the Ozernoye Project, as the mill was then fixed in size based on the Signature Plot and fine grinding plant capacity. Plant design progression that required both open and closed loops evaluation did not impact the final mill sizing. This allowed certainty of mill size to progress through the unit's fabrication, plant footprint, and mill grind performance early in the project.

## Bond Work v IsaMill™ Signature Plot

Often Glencore Technology is requested to use Bond work indices for IsaMill™ sizings, mainly when expensive testwork campaigns have already been completed without considering appropriate fine grinding testwork. There are several issues with applying the Bond work test results to fine grinding. Glencore Technology has recognised several fatal flaws when applying these results under 100 microns to the IsaMill™.

$$W = WI \times \left( \frac{10}{\sqrt{P_{80}}} - \frac{10}{\sqrt{F_{80}}} \right)$$

The diagram shows the equation  $W = WI \times \left( \frac{10}{\sqrt{P_{80}}} - \frac{10}{\sqrt{F_{80}}} \right)$  with four orange callout bubbles pointing to its components:
 

- A bubble pointing to  $W$  contains the text "Grinding Energy Requirement".
- A bubble pointing to  $WI$  contains the text "Work Index (from test)".
- A bubble pointing to  $P_{80}$  contains the text "80% passing size (product)".
- A bubble pointing to  $F_{80}$  contains the text "80% passing size (feed)".

FIG 7 - Bond Work Index equation

Bond's theory (Figure 7) proposes an exponential energy curve with a constant power of -0.5. While this is a good approximation down to 100 µm, below this the exponent varies significantly among particularly different ores. The Bond Work Index relationship will then underestimate energy requirements at fine sizes.

When comparing both testwork and full-scale operational differences between a stirred grinding mill and a ball mill, this logically makes sense, as the Bond test has different media sizes, ball and ore trajectories, and ball-particle/ball-shell interactions. Additionally, the Bond test uses plant feed, not regrind circuit feed, with the material characteristics between a concentrate and a circuit feed being significantly different.

## Impact of ceramic media selection

Grinding media has a significant effect on IsaMill™ efficiency and OPEX. Selecting correct media will result in substantial improvements in specific energy; conversely, choosing incorrect media has a detrimental impact on mill performance. Multiple variables impact grinding efficiency, critically media size, media SG and condition of the media itself. To demonstrate the effect of these criteria, the Signature Plots in Figure 8 and Figure 9 illustrate the impact of media size and SG selection.

When media is normally selected, it must provide sufficient energy to break the coarsest particles in the feed at the same rate as they enter the IsaMill™, utilising a reduction ratio ( $F_{80} \div P_{80}$ ) of less than 8 per media type (diameter range i.e. 1.5 mm, 2.0 mm, 2.5 mm etc.). This is the minimum requirement with room for efficiency improvements when the media is optimised correctly. As demonstrated in Figure 8, in a trial undertaken at a gold mining operation, an energy variation of 23 kWh/t was observed when increasing media size (diameter) from 1.5 mm to 3.5 mm.

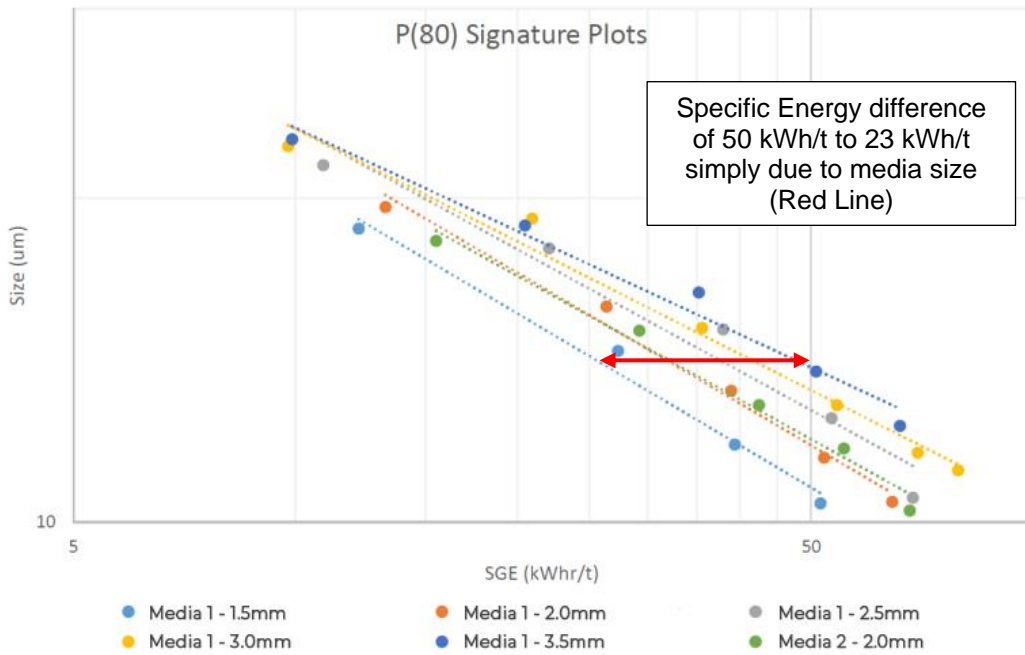


FIG 8 - Effect of media size on milling efficiency (Gurnett et al, 2021)

With more ceramic media suppliers supplying into the market, there has been a notable uptake in available types of media. One of the most apparent trends of late has been the introduction of higher SG media, particularly in the vertical mill market. In horizontal milling configurations, such as the IsaMill™, the higher SG media was found to be inefficient whilst causing accelerated wear of the internal components.

In Figure 9 below, this relationship is demonstrated with 4.5 SG media (High SG). This media was run multiple times for repeatability against the normal (3.7 to 3.8 SG) media typically used in an IsaMill™. Each trial of the High SG (4.5) media showed an average increase in specific energy of 20%. The authors believe that the higher energy demand is attributed to the increased energy to move media. This additional energy only offsets a smaller portion of the extra energy imparted in the breakage mechanisms, resulting in an overall decrease in grinding efficiency.

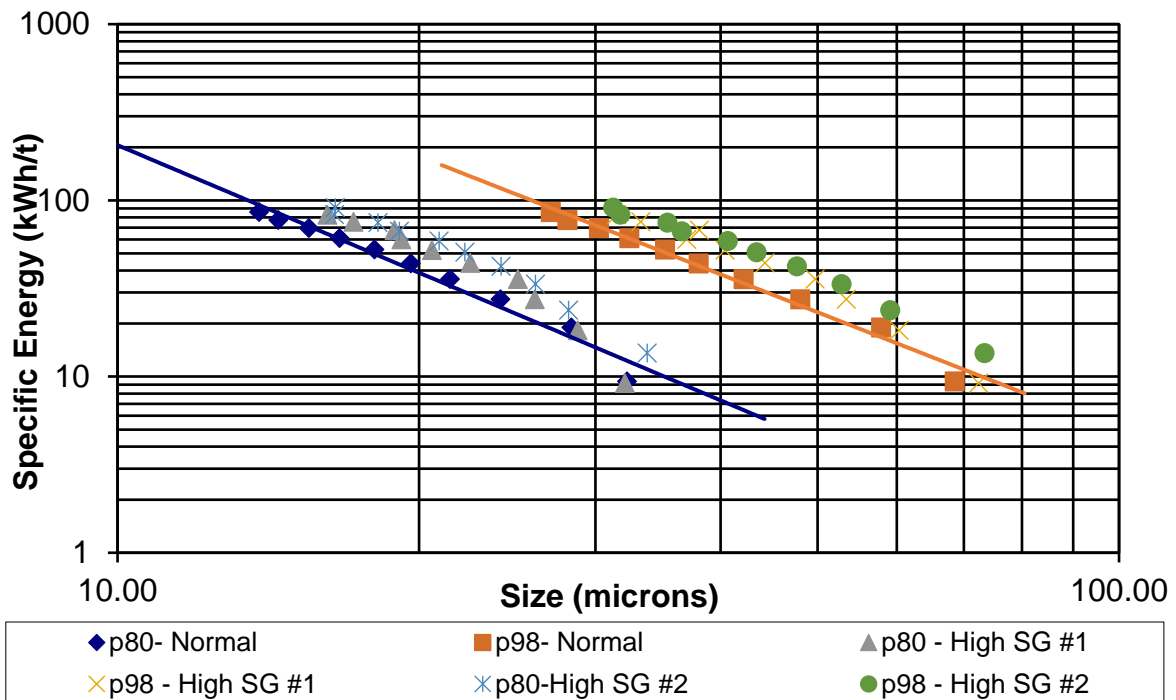


FIG 9 - Normalised Signature Plot – 3.7 SG media v 4.5 SG media - (Gurnett et al, 2021)

In Figure 10 below, Glencore Technology obtained the 2020 cost of ceramic media for different densities from a well-known media supplier. To model the impact of SG selection on operating expenditure, the yearly cost for ceramic media was estimated for a mill operating at 2.5 MW and a typical media consumption rate of 12 g/kWh. The difference between selecting 3.7 SG media over 4.5 SG media could theoretically result in OPEX savings every two years, roughly equivalent to the cost of a single M10,000 IsaMill™.

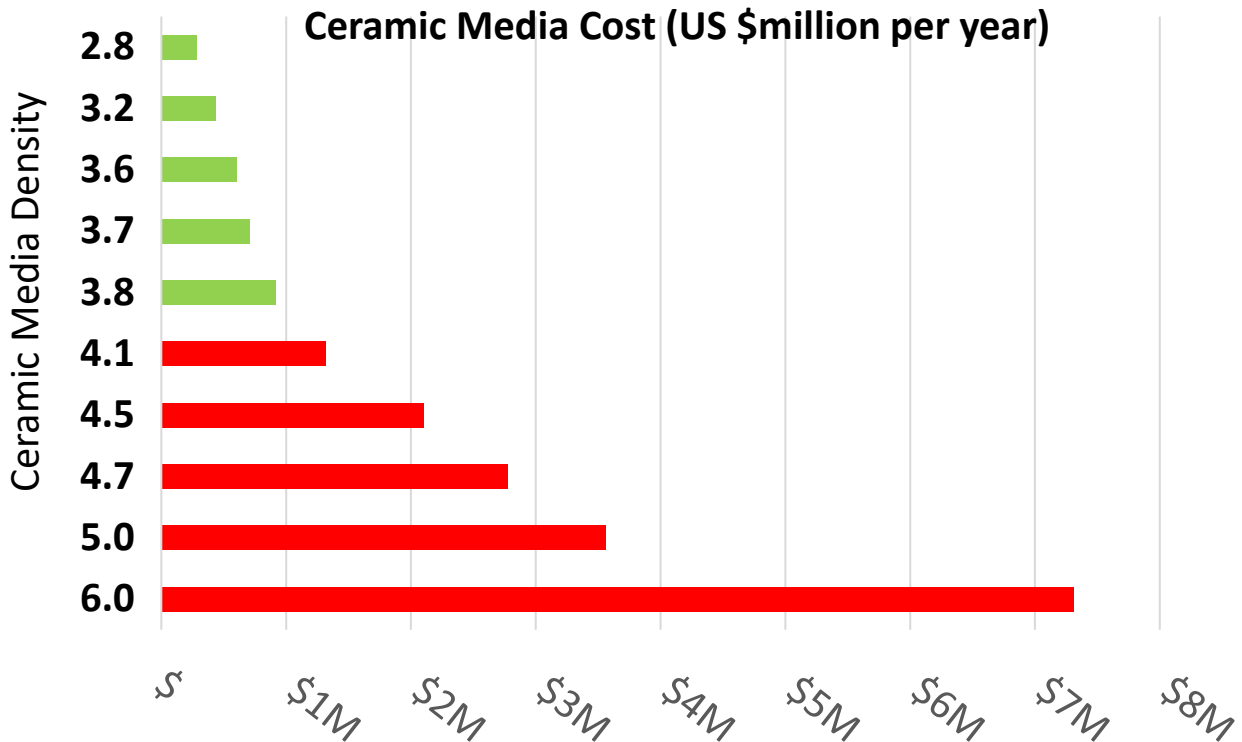


FIG 10 - Comparative costs for different media SGs (Gurnett et al, 2021)

While it is known stirred vertical mills have been utilising higher SG media to address the challenge of media retention within the mills, the benefits to the horizontal IsaMill™, through its ability to use low SG media, are not adequately appreciated. The use of 3.7-3.8 SG media substantially reduces the operating cost for the IsaMill™ and makes it the ideal selection for Jameson Concentrator designs.

### Understanding the effect of viscosity

When the IsaMill™ Signature Plot test is undertaken, it is conducted with a feed condition of 18 to 20 % solids (v/v). The purpose of this is to limit the viscosity impacts on grinding efficiency. As the density (%v/v solids) increases and the material progressively grinds finer, it increases the likelihood of viscosity impacts arising from the increased exposed surface area. This can cause the charge to "lock-up" and turn into a viscous mass exhibiting as a rotating plug of material and media rather than the desired highly agitated, turbulent grinding environment. This is evidenced by a significant and rapid drop in the IsaMill™ power draw, a decrease in feed pressure and an increase in the Coarse Size Index (CSI) ratio (P98:P90 ratio).

The high viscosity can push the IsaMill™ into a situation where it will start to be overcharged as a result (the media top-up system responds to the drop in power draw by adding grinding media) and can potentially lead to heavily accelerated internal component wear rates. Therefore, to mitigate this issue, Glencore Technology designs the IsaMills™ to operate at 20% solids (v/v). As the Signature Plot is designed to replicate the full-scale mill performance, density has to be controlled in the

testwork phase. The relationship between density/viscosity and efficiency has been outlined in the M4 testwork in Figure 11.

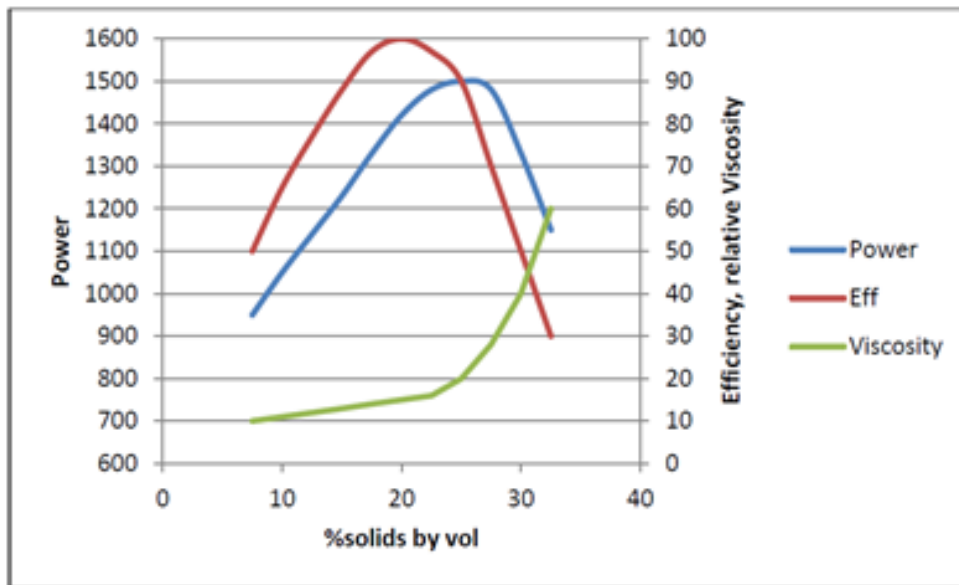


FIG 11 - Effect of density on the grinding efficiency within the IsaMill™ (Gurnett et al, 2021)

### Influence of particle size measurement techniques

Due to the fundamental principles on which laser particle-size-analysis units (e.g. Malvern Mastersizers) work, they generally report a coarser result compared with a screen sizing method. This is because laser sizers utilise an “equivalent sphere” method. They measure the volume of non-spherical particles, calculate the diameter of an equivalent sphere, and use this as the particle diameter for the Particle Size Distribution (PSD) calculations (Malvern 2014). In Figure 12 below, an example of how shape influences the design 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.

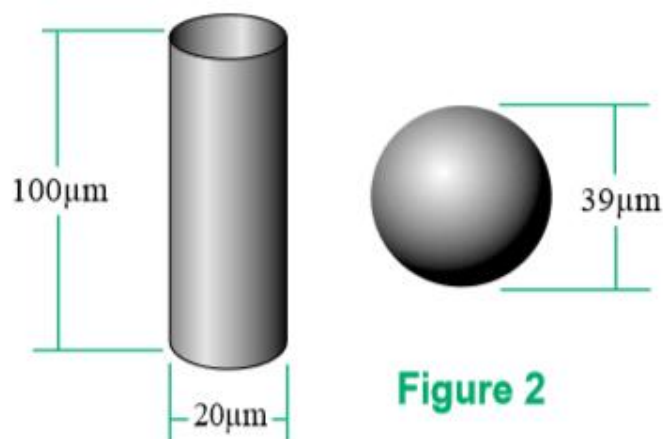


FIG 12 - Effect of particle shape on sizing (Malvern, 2014)

Therefore, if a sample has lots of non-spherical particles, e.g. micaceous silicates, the “coarseness” of the Malvern compared to screen sizing results will be exaggerated. The effect should theoretically be reduced as the particles are ground through more IsaMill™ passes and increasingly become

spherical. This feeds the design process when scale-up of the regrind mills is undertaken; the same method of sizing analysis needs to be used as in the testwork. It is up to the testwork coordinator to decide which particle sizing method the laboratory should use.

## THE FUTURE

While the Jameson Concentrator is a step forward in concentrator design, there are still design improvements being undertaken. It has been recognised (particularly in colder climates) that the size of the structure for the concentrator (roof and height of the building) could be optimised.

Glencore Technology is currently developing an ERM-Less design, which is removal of the External Recycle Mechanism (ERM) that sits below the Jameson Cell. This new design will allow the installation height of the Jameson Cell B series to be significantly reduced. This reduced height Jameson Cell complements the horizontal milling capabilities of the IsaMill™ and should dramatically reduce capital costs through reduced building height/volumes, structural supports and crane requirements. Figure 13 demonstrates the achievable height saving for the B8500/12 Jameson Cell.

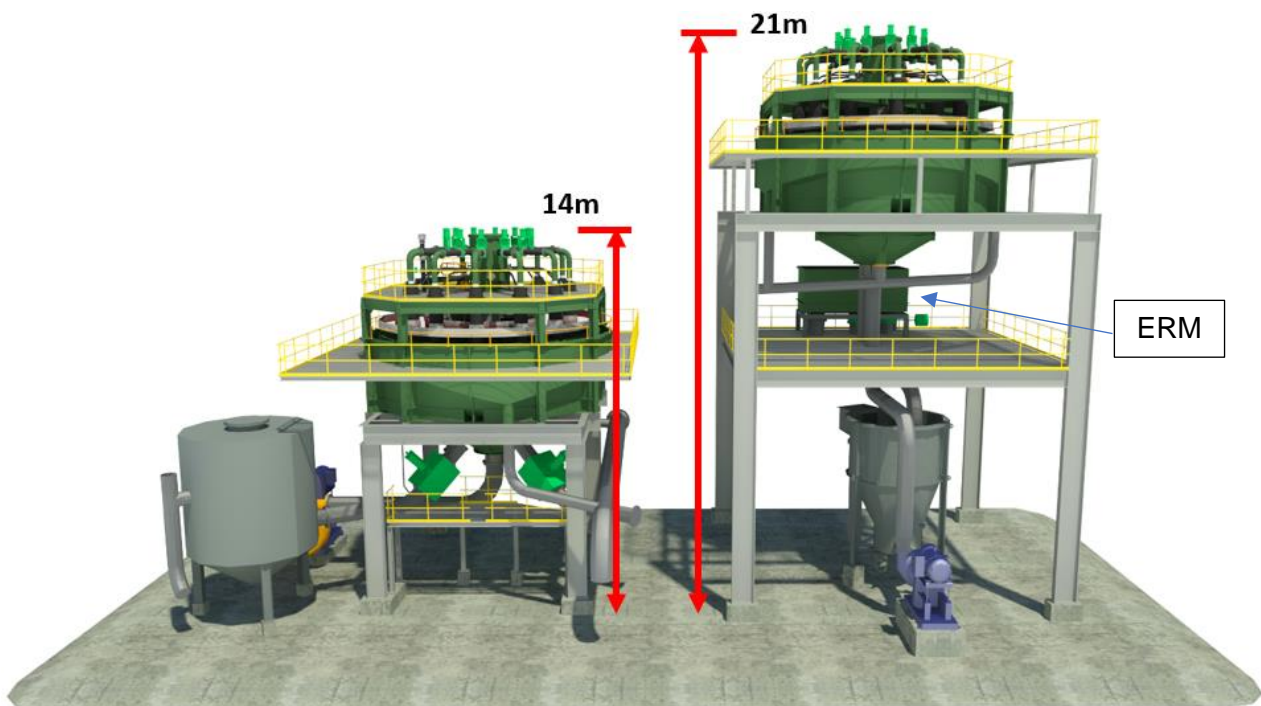


FIG 13 - New B8500/12 ERM-Less design

While there are opportunities for further layout optimisation, there is also scope to increase the processing applications of the IsaMill™. When the IsaMill™ was first introduced to the market in the late 1990s, the target grind size was in the sub -10-micron range, as this was the specific need of Mount Isa Mines and McArthur River Mining at the time. The IsaMill™ quickly became a market leader in ultra-fine grinding. When ceramic media were introduced, improved efficiencies were achieved in the IsaMill™ (Curry & Clermont, 2005). As more ceramic media suppliers have entered the market, this has driven costs down and allowed larger media to be developed.

Current testwork conducted on the IsaMill™ has demonstrated that the mill can operate with a feed of 400 microns ( $P_{80}$ ) and top size of 1 mm using 6 mm media. Ceramic media in the range up to 14 mm is now commercially available, effectively meaning that the IsaMill™ theoretically can operate in the secondary/tertiary milling space.

This further enhances the scope of the Jameson Concentrator to offer greater value through improved capital and operating cost savings. Research and Development programs in this field are currently underway.

## CONCLUSION

The author intends that this paper provide some guidance on the Signature Plot conditions and the importance of test variables' influence on obtaining a 1:1 scale up on specific energy. Underestimating energy requirements can lead to bottlenecks in new designs. As grades decline and liberation becomes more complex and critical, understanding your stirred mill and its ability to achieve a desired grind size is fundamental for project success. The IsaMill™ is the preferred stirred mill choice in the Jameson Concentrator, as it is a mature low risk technology that repeatedly achieves the desired performance from reliable testwork.

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