The IsaMill™ - 25 Years of Stirred Milling

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ABSTRACT

Mount Isa Mines (MIM) had two significant liberation issues in the 1980's. The first being the inability to find a technical solution for the economic development of the massive McArthur River Mine (MRM) lead/zinc deposit. The second was the continuing deterioration in metallurgical performance at the Mount Isa lead/zinc concentrator due to increasing orebody complexity. In both cases, grinds as fine as P80 7 µm were required to address the liberation issues. Despite years of research and investigation, an adequate solution was not found using existing "off the shelf" technology or processes available within the mining industry. Conventional grinding technologies were inefficient and had high specific energy demands. Even when the target size was achieved, flotation response was inadequate - primarily due to the impact of steel grinding media on surface chemistry. Faced with this challenge, MIM was forced to look outside the mining industry for cross over technology from other industries that had to grind fine, eventually collaborating with world leader Netzsch-Feinmahltechnik to develop the IsaMill™ technology on-site at Mount Isa. The first commercial installation was at Mount Isa in 1994, and it then became the enabling technology for McArthur River in 1995. Based on the success of these installations, the IsaMill™ was commercialised in 1998 to make the benefits of large scale finer inert grinding available to the broader mining industry for the first time. The year 2019 marked 25 years since the first commercial installation of the IsaMill™, and today there are over 130 installations totalling 230MW of installed power, positioning the IsaMill™ as the industry-leading stirred milling technology. Future implementations of the IsaMill™ will be coupled with the Jameson Cell to revolutionise concentrator design at a reduced cost and lower footprint. This paper discusses the development history of the IsaMill™, subsequent commercialisation, scale-up, crossover to coarser grinding and the full circuit concentrator design.

1.0 INTRODUCTION

One of the keys to success in technology development in the mining industry is incremental scale-up, allowing potential problems to be identified and rectified iteratively. The IsaMill™ was developed to maturity using this method over a period of 8 years and then brought to market as a solution to complex deposits requiring fine grinding. This process follows G.T.'s unique technology transfer model, where we bring proven technologies to the market to solve an industry need. The need for this technology was born in the late 1980s due to the inability for Mount Isa Mines (MIM) to find a technical solution for the economic development of the massive McArthur River Mine (MRM) lead/zinc deposit. At the same time, addressing the continuing deterioration in metallurgical performance at the Mount Isa lead/zinc concentrator as a result of increasing orebody complexity. In both cases, grinds as fine as P80 7 µm had been identified to address the liberation issues. This paper outlines the steps and processes in the development in the IsaMill™ whilst demonstrating where we feel the future of the technology lies.

2.0 BACKGROUND

2.1 History of the Mount Isa and MRM Development

In the late 1980s, MIM embarked on a fine grinding project to address deteriorating ore conditions seen at the lead/zinc concentrator. It had been identified that there was a need to grind between 7-30 µms to liberate the locked sphalerite within the ore effectively. To achieve this grind size, MIM implemented a series of projects which included doubling the grinding and flotation capacity (Clark and Burford, 2004) and the implementation of a Tower Mill into the Low-Grade Middling (LGM) circuit, which dropped the target P_{80} to 12 µm (Clark and Burford, 2004).

The main issue identified from the tower mill installation was while sphalerite liberation improved by 20% (from 55% to 75%), recovery only improved by 5%. The lack of expected recovery was due to the surface chemistry issues, post grinding in ball, and Tower Mills, i.e. the influence of iron media reducing the slurry (Clark and Burford, 2004).

To address the iron concerns and to improve the recovery performance, Netzsch was contacted to trial their mill with an inert media, given their prior experience in ultrafine grinding. Netzsch, at the time, was an experienced fine grinding equipment supplier in the paint and food processing industry (Clark and Burford, 2004). The first mill that was used in the testwork was a ½ litre bench-scale mill which resembled a milkshake maker (Clark and Burford, 2004). Initial testing used fine copper smelter slag as the inert media to grind the ore and concentrate (Clark and Burford, 2004) due to its availability on the Mount Isa lease.

By January 1992, a small pilot-scale mill, LME100, had been designed and installed at the pilot plant at Mount Isa (Clark and Burford, 2004). A significant testwork program was conducted to take the pilot mill through to the first commercial mill, the M3000. This testwork looked at optimising various component trials for disc materials, spacing of components, separator, liners, chamber lengths, plant and lab testwork, mineralogical investigations and examinations, and most importantly, the development of the rotor (Clark and Burford, 2004).

In 1994 the first full-scale prototype IsaMill™ (later becoming the M3000), was installed in the lead circuit at Mount Isa. Not only did this improve lead performance, but zinc recovery in the zinc circuit also increased even though total sphalerite liberation had changed little (Clark and Burford, 2004). This was due to the improved flotation chemistry from the IsaMill™ allowed sphalerite to be redirected from the lead concentrate to the zinc circuit. The lead circuit was able to operate more efficiently and separate the lead from the zinc, leaving the zinc to report to the following zinc circuit (Clark and Burford, 2004).

In 1999 additional IsaMill™s' were installed in the lead/zinc concentrator to treat the George Fisher orebody at Mount Isa. These IsaMill™ installations increased sphalerite liberation by a further 5%, but zinc recovery increased by 10% and zinc concentrate grade by 2%. This equated to a 16%

recovery increase at the same concentrate grade (Clark and Burford, 2004). This demonstrated the fundamental changes to fines flotation made possible by ultrafine grinding in an IsaMill™ with inert media compared to conventional means (Clark and Burford, 2004).

2.2 Next Steps… Technology Enabler for the Albion Process

In the hydrometallurgical industry, the Albion Process is one of the straightforward processes. It is designed for the oxidative leaching of refractory base and precious metal-bearing sulphide ores (Harbort, Hourn and Murphy, 1998). The leaching occurs in conventional, non-pressurised reactors, which significantly reduces the capital cost compared to pressure and bacterial leaching processes (Clark and Burford, 2004).

What allows the leaching to be undertaken in atmospheric conditions is the addition of an IsaMill™ in the grinding circuit. The IsaMill™ produces mineral particles with a high degree of residual strain in the crystal lattice, and a very high surface area. This results in very high defect density within the individual mineral grains, resulting in the mineral being extremely active toward oxidation (Harbot, Hourn and Murphy, 1998). The conditions required to oxidise the mineral particle are less extreme than other leaching processes, with oxidation carried out at atmospheric pressure in agitated tank reactors. This is due to the mineral particle being highly fractured from the IsaMilling stage, enabling it to fall apart as it is leached (Clark and Burford, 2004). The leach residence time is typically 24 - 48 hours, and the leach does not use any reagents other than acid, limestone and oxygen (Clark and Burford, 2004).

The tight size distribution (p98:p80 ratio) is a crucial factor in leaching operations. Where a flotation process can have slightly oversized particles, which can either report to concentrate or regrinding stages without any significant effect on circuit recovery or grade, a leach circuit can be significantly impacted by the presence of large particles (Clark and Burford, 2004). Leaching processes need to have small enough particles to allow the leachant to fully leach the particle. Otherwise the oversize will represent a recovery loss as the mineral hasn't had the opportunity to be leached. That is why P_{98} is vital in leach circuits (Clark and Burford, 2004).

Work conducted in 1994 by Hydrometallurgy Research Laboratory (now Core Resources) tested several fine grinding bench scale mills, leaching copper sulphide concentrate using the Albion process (Clark and Burford, 2004). While all fine grinding methods produced a similar P_{80}, the IsaMill™ produced the finest P_{98}. This P_{98}/P_{80} ratio is an excellent indication of how sharp the feed sizing is, i.e. the closer to 1, the sharper the cut, and its amenability to leaching duties (Clark and Burford, 2004). This is why the IsaMill™ was selected for the Albion Process™.

2.3 Scale-Up to the M10,000

When the M3000 had been developed, Xstrata Technology (now Glencore Technology) had considered expanding the size of available IsaMills™ as a natural expansion of the marketed product range. There were also several internal projects that were under consideration at the time, which envisaged the use of larger-scale IsaMills™ (Curry, Clark, Rule, 2005). For large concentrators with high tonnage regrind applications, having a significant number of smaller M3000 machines was not considered desirable from a capital, operating and maintenance perspective. Therefore, an investigation was undertaken to try and scale the IsaMill™ with Anglo Platinum in South Africa.

Anglo Platinum investigated the retreatment of dormant tailings dams in the Rustenburg area in 2000. Given the market value of platinum and palladium and U.S. dollar exchange rates at the time, the concentration of Platinum Group Metal (PGM) minerals in the dams represented a significant economic resource. Metallurgical test work identified that a considerable proportion of these minerals could be recovered via fine grinding and flotation (Curry, Clark and Rule, 2005).

The pilot-scale program was developed to confirm concepts previously identified during laboratory-scale testing. The laboratory tests suggested that the recovery of PGM's from the tailings dams was sensitive to the grind size presented to flotation. Significantly, flotation kinetics increased with the finer grind and the additional liberation of PGM's and associated base metal sulphides. Effectively, the IsaMill™ technology enabled this tailings retreatment project as smeltable concentrate grades could be produced from the oxidised, slow floating tailings. This economic resource allowed for the IsaMill™ to undertake a development to scale up to the M10,000. However, to mitigate any potential risks to this design, several initiatives needed to be resolved before the first installation.

- To reduce process risk with the first installation, a variable frequency drive was installed (Curry, Clark and Rule, 2005). The previous method of scale-up (to the 1.1 MW M3,000 size) was based on the conservation of power intensity. With the larger M10,000, the media agitator (grinding disc) tip velocity would be excessive using this method (Curry, Clark and Rule, 2005). A 'constant tip velocity' method had to be developed, which proved more complex than power intensity models, as power does not scale up linearly with volume (Curry, Clark and Rule, 2005).

- The next stage was to investigate the rotor (classifies the mill product and retains grinding media). As centripetal acceleration decreases with increasing diameter (at constant tip speed) and pumping efficiency decreases with lower radial velocity, both the centrifuging and pumping actions of the rotor had to be re-designed. The new design focused on improving efficiency of the rotor suction region, rotor pump finger shape and product classification efficiency (Curry, Clark and Rule, 2005).

- Component and materials selection was vital to the operating cost competitiveness of the new mill. A key design aspect was to control disc wear, and the design proposed that the disc surface abrasion rate was within 3 % of the M3,000 mill's rate. As the M10,000 disc design was larger in diameter and thickness, the increased volume of rubber would mean a longer disc life than in the M3,000, as abrasion rates are a function of area and the power density per unit area would be lower (Curry, Clark and Rule, 2005).

Once these areas were addressed and the IsaMill™ commissioned, the M10,000 scaled up accurately both in power and product Particle Size Distribution (PSD). Power efficiency appeared equal to the laboratory mill, with control of the product PSD marginally better. This process was repeated in 2015 with the initial scale-up for the M15,000 IsaMill™ at Red Dog Mine and in 2021 for the M20,000 IsaMill™ at Ozernoye.

2.5 *The Timeline of Developments*

The following table is a summary of the timeline developments for the IsaMill. It shows applications into new commodities as well as developments that have been undertaken.

Table 1: Timeline of IsaMill™ Developments

1992	January – The LME100 model, powered by a 55KW motor, was used in pilot plant at Mount Isa (Clark and Burford, 2004). November - LME500 model powered by a 205KW, then 250KW motor was trialled at the Hilton Concentrator at Mount Isa (Clark and Burford, 2004).
1993	November – The ISA1500 model IsaMill™ powered by a 900KW motor was installed in the Lead/Zinc Concentrator (Clark and Burford, 2004).
1994	December - The IsaMill™ M3000 (earlier known as 280/7) powered by a 1.1MW motor installed in the Lead/Zinc concentrator (Clark and Burford, 2004).
1994	First M3000 IsaMill™ Installed in MIM (Clark and Burford, 2004). The Albion Process was patented (Hourn and Turner, 2012). The first lead/zinc application for the IsaMill™ was now officially in place at Mount Isa Mines (Clark and Burford, 2004).
1995	Enabled the McArthur River Mine project to go ahead via IsaMill™ Ultrafine grinding technology (Clark and Burford, 2004).
1996	
1997	
1998	The IsaMill™ technology was commercialised and now available to the wider market (Harbort, Hourn and Murphy, 1998)
1999	
2000	The first gold application was installed at KCGM's Gidji Roaster (IsaMill™ n.d.).
2001	The first PGM application was installed at Lonim's EPC Concentrator (IsaMill™ n.d.).
2002	
2003	The scale-up from the M3000 to M10,000 was completed (Curry, Clark and Rule 2005). The first M10,000 commissioned in South Africa MIG at Sibanye (2.6MW) – (Rule and De Waal, 2011).
2004	
2005	Ceramic Media becomes available for onsite use. Ceramic media (MT1) is first trialled at Centerra Gold's Kumtor operation in the Kyrgyz Republic (Curry and Clermont, 2005) The first copper application was installed at Phelp Dodge's Morenci Concentrator (IsaMill™ n.d.).
2006	MRM - IsaMill™ being used in a primary grind capacity (Anderson, Smith and Srohmayr, 2011)
2007	
2008	
2009	The first nickel application was installed at Glencore's Cosmos Operation (IsaMill™ n.d.).
2010	The first molybdenum application was installed at TCM's Endako Concentrator (IsaMill™ n.d.). Small Diameter Discs (SDDs) trialled in South Africa to improve media compaction issues (Rule and De Waal, 2011). The hydraulic IsaCharger was developed and trialled in South Africa (Rule and De Waal, 2011). The first commissioned Albion Application was installed in Spain (Hourn and Turner, 2012)
2011	The first M5000 was retrofit at McArthur River Mines (Anderson, Smith and Strohmayr, 2011)
2012	

2013	Conical Spacers are trialled at Oceana Gold, New Zealand to improve IsaMill™ energy efficiency (Anderson and Bandarian, 2018). The first magnetite application was installed at Arium, Australia (IsaMill™ n.d.).
2014	
2015	Acoustic analysis had been trialled for internal shell wear. This testwork was the foundations of the Acoustic Emissions Analyser. The first M50,000 is designed for large scale duties.
2016	
2017	The M10,000 IsaMill™ was scaled up to an M15,000- 3.8 MW IsaMill™
2018	The first tin application was installed at Minsur B2, Peru (IsaMill n.d.). The first M15,000 was installed at Red Dog Mine, USA (IsaMill n.d.).
2019	The first commercialised Acoustic Emissions Analyser was installed at Woodlawn Mine, Australia The first coal application was installed at Corbin Mine, USA (Glencore Technology, 2018)
2020	The IsaMill plant package is re-designed into the new reduced footprint design. The M7500, M20,000 & M30,000 designs are developed for the market.
2021	The first M20,000 is purchased for the Ozernoye Lead Zinc Concentrator Project.

3.0 CURRENT OVERVIEW OF ISAMILLS

3.1 How they work?

Figure 1 illustrates the grinding mechanism within the IsaMill™. The IsaMill™ typically operates around 70% media filling volume. As the shaft rotates, the grinding discs agitate the media such that it is centrifuged out along the face of the discs towards the shell liner. As it reaches the shell liner, the media is redirected back towards the mill shaft area. This happens on the face of each disc, where there is sufficient media present, and sets up a chamber of agitated grinding media between each of the grinding discs. Slurry to be ground enters opposite the shaft end cap at one end of the IsaMill™. It must pass through each of the agitated grinding chambers in series before it can exit, making it virtually impossible for any material to short circuit the IsaMill™ (Anderson and Bandarian 2018).

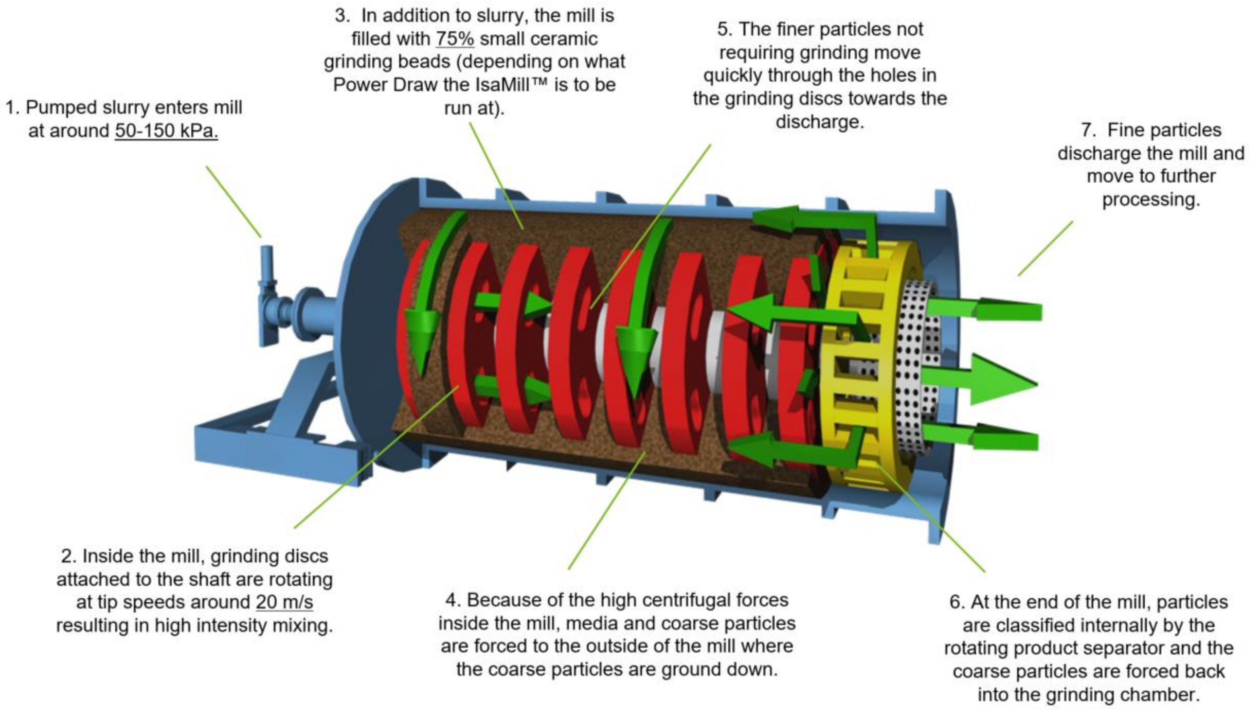

Figure 1: Internal mechanism of an IsaMill™ (Anderson and Bandarian, 2018)

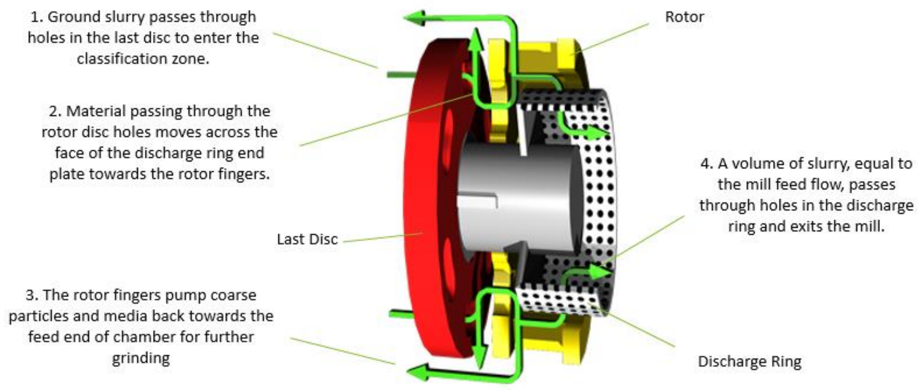

Figure 2: IsaMill™ internal classification (Rule and De Waal, 2011)

At the discharge end of the IsaMill™ is the patented (Anderson et al., 2005) product separator (Figure 2), which makes use of a closer spacing between the final disc and the rotor disc to centrifuge any coarse particles and media towards the shell. The rotor, which acts like a pump, then returns this material to the grinding zones. This mechanism allows ground product to flow through and exit the IsaMill™ whilst retaining the grinding media inside, all without the use of fine screens. (Anderson and Bandarian, 2018)

3.2 Market Share

Since commercialisation in 1998, interest in the IsaMill™ has expanded significantly. There are now over 130 installations, undertaking various duties in a total installed power base of 230 MW across nine commodities. The IsaMill™ now has applications in Lead/Zinc, Gold, Copper, Moly, Nickel, Platinum Group Metals (PGMs), Magnetite, Tin and Coal (reflected in Figure 3).

The most popular installation is the M10,000 with 56 installed IsaMills™. The countries with the highest number of IsaMills™ is Australia (predominately lead/zinc) followed by South Africa (predominately PGMs). These IsaMills™ have a feed (F_{80}) of up to 400 µm and produce a P_{80} as fine as 5 µm (although some testwork has shown P_{50}'s of 1 µm). This size range has allowed IsaMills™ to be used in multiple applications, such as:

- Tertiary/Quaternary Grinding
- Flotation concentrate/scavenger regrind
- Pre-leach regrind
- Magnetic separation regrind
- Tailings regrind

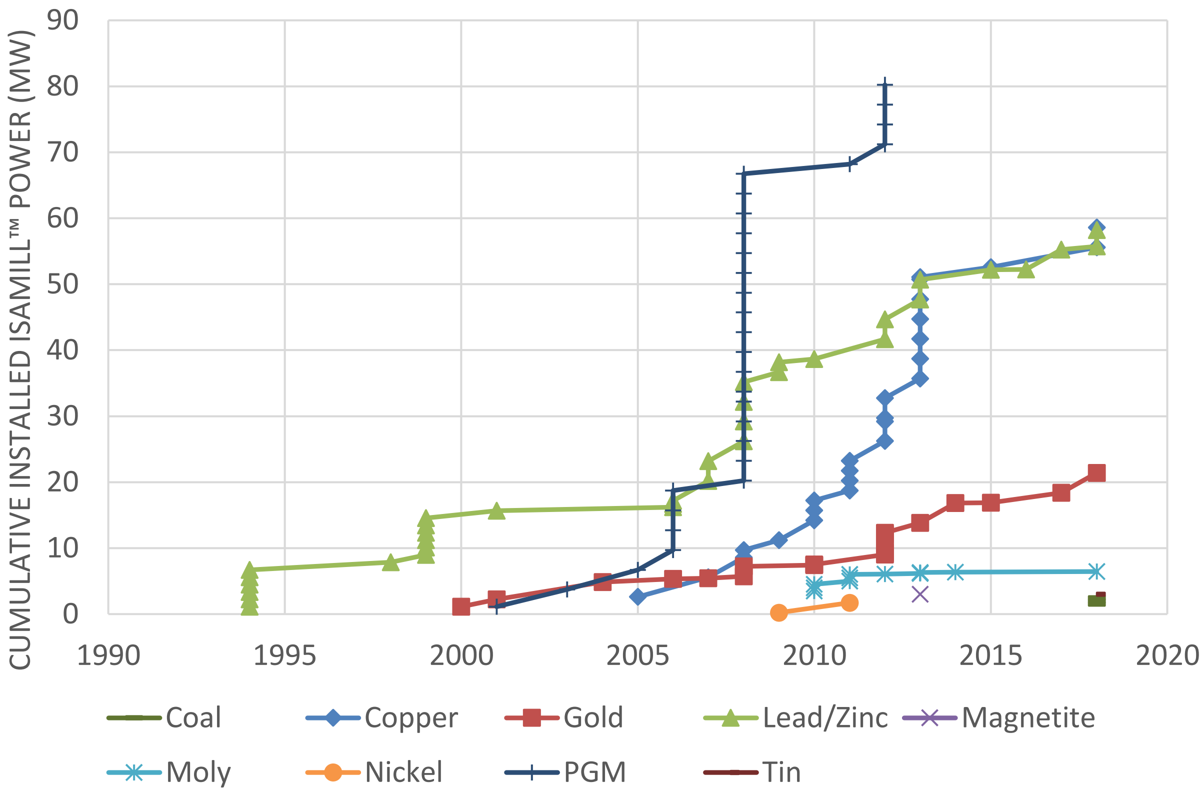

Figure 3: IsaMill™ Installed Power by Commodity (Glencore Technology, 2018)

3.3 Laboratory testing and Scale-Up

The laboratory-scale unit (M4) and pilot-scale unit (M20) are widely used in grinding tests for IsaMill™ selection, which are usually performed in a continuous mode to mimic the performance of full-scale units. For laboratory-scale unit M4, a sample amount of approximately 15 kg, depending on the solid specific gravity, is required to provide three times the mill voidage volume through the mill to ensure steady-state discharge (Larson et al.,2011). If there isn't enough sample to achieve this steady-state condition in any stirred mill specific energy test (Jar, Signature Plot, HIG5), then there is the potential to underestimate power by up to 50%.

Due to the similarity of the operating conditions, feed size distribution and uniform, homogeneous grinding mechanisms between the laboratory scale and full-scale IsaMill™, a 1:1 direct scale-up is usually achieved with many validation studies published in the past two decades (Larson et al., 2011). An example of this scale-up can be seen in the MRM example in Figure 4.

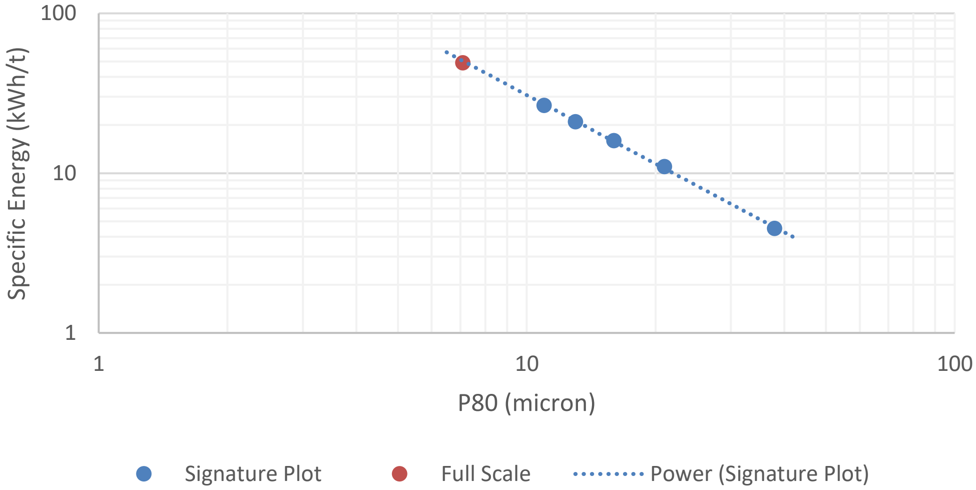

Figure 4: McArthur River Scale Up (Barns, K et al., 2006)

Typically, the "go-to" when conducting mill sizing's has been the bond work index (BWI). However, for a regrind application, the bond work index test itself is open to several flaws, as under 100 microns, it assumes an exponential energy curve to a constant power of 0.5. This does not reflect actual ore mineralogy and can give you vastly different answers. When making IsaMill™ comparisons, we find inefficiencies in the test due to the test using a standard ball charge (highly inefficient at finer sizes) which have sensitive variations to mill charge and liner wear. This is why the BWI varies significantly between laboratories (Larson et al., 2012).

To show the variations in these tests and the importance of 1:1 scale up from vendor recommendations. Surveys were taken on several sites to benchmark actual performance versus original design from vendor scale-up data. As can be seen in Table 2, most of these tests have underestimated power requirements, which is why it is important to understand the scale-up in the regrind test that you select when doing mill sizings. Otherwise, if you underestimate power on a finely demesinated deposit like MRM, there is the potential that the project could be uneconomical. This is why we push the importance of the 1:1 scale-up that is seen in the IsaMill™ signature plot test.

Table 2: Jar test Comparisons to Existing Operations (Larson et al., 2011)

Site	Duty	Design		Actual Plant Performance		Requirement to Design P80		Under Design (%)
		Energy	P80	Energy	P80	Energy	P80	
Mount Keith	Nickel Regrind	11.7	60	12.6	64	13.5	60	15%
Cannington	Zinc Regrind	19.4	20	52	11	25.5	20	31%
Confidential (North America)	Iron Ore Regrind	9.4	30	7.5	43	13.8	30	47%
Teck Red Dog	Zinc Regrind	5.7	30	3.3	85	9.4	30	65%
Teck Red Dog	Tertiary Grind	7.1	45	3.3	85	12	45	69%
Cannington	Secondary Grind	4.4	63	2	100	7.9	63	80%
Cannington	Prefloat Regrind	16.7	20	87	17	31	20	86%
Ernest Henry	Copper Regrind	6	45	8	60	13	45	117%

4.0 ONGOING TECHNICAL DEVELOPMENTS

4.1 Reduced Footprint Layout

As part of a cost reduction strategy to the client, the IsaMill™ layout was re-designed to the "reduced footprint plant" design (Figure 6). This was done to reduce civil infrastructure costs and reduce the overall footprint. An example of how the designs have changed can be seen in Figure 5 and Figure 6. In Figure 6, this new design has been modelled against a competitor to demonstrate that it sits in the footprint of an equivalent powered stirred mill on the market. The following changes to achieve this new "reduced footprint plant" layout are as follows:

- Moving the media hopper away from under the IsaMill™ to the side. Due to the backpressure created from the rotor, it was possible to utilise this to pump media out of the IsaMill™ and into a media storage tank/hopper during its maintenance shutdown sequence rather than discharge it to the hopper below the IsaMill™.
- Replacing the rails with a removable rails structure, this allows for a significant reduction in footprint and an additional maintenance service area when the mill is in operation.
- Tying the gland water directly into the plant main freshwater, this eliminates the need for a gland water tank and corresponding pumps.
- Tying the IsaCharger water directly into the plant process water, this eliminates the need for an IsaCharger water tank and corresponding pumps.
- Reducing the overall costs by changing several valves with alternative designs.
- Moving the Oil Lubrication Systems (OLS) 's to the side of the IsaMill™.

Dropping the height of the mill has significantly reduced installation costs whilst producing a mill that's safer and easier to operate and maintain.

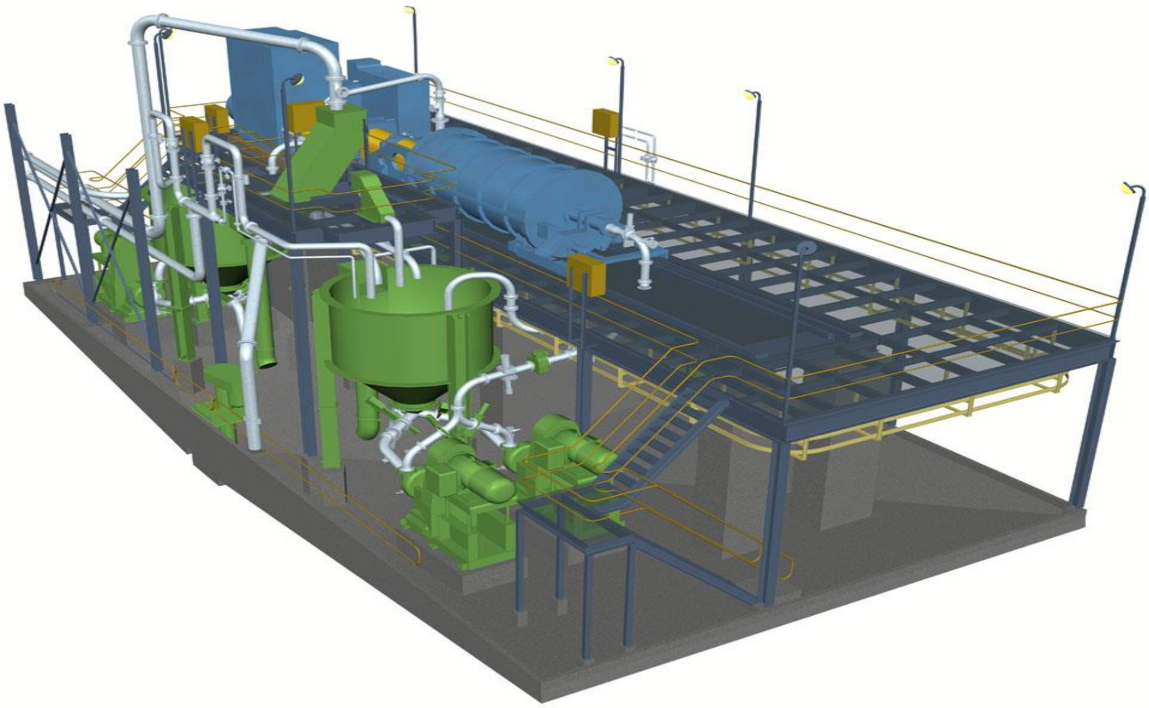

Figure 5: Before: Original IsaMill™ Plant Design

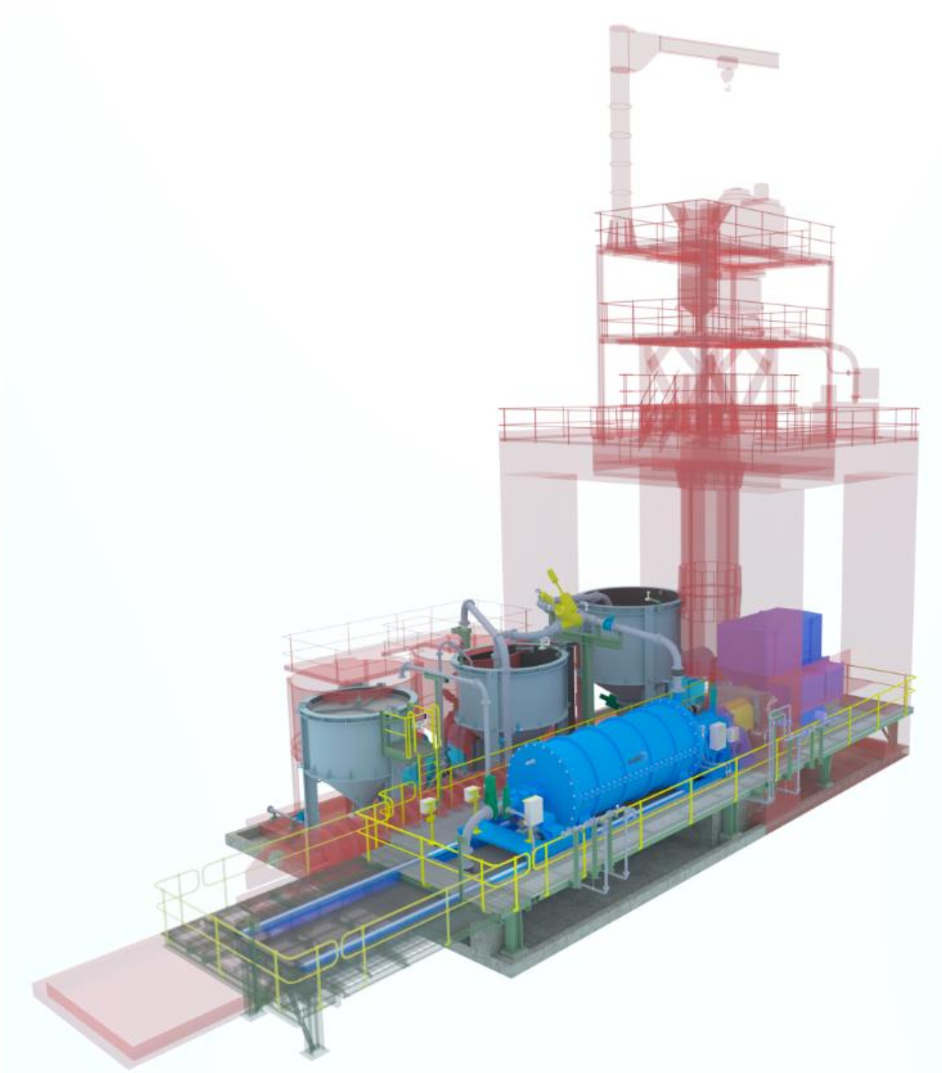

Figure 6: Reduced Footprint Plant Layout for an M10,000 against a competitor's model.

4.2 The Mill Size Range

The first commercial, IsaMill™, which was installed, was an M3000. Since then, there have been several iterations with the design of the IsaMill™ as it has scaled up into more and more applications. Since 1993 there have been ten new IsaMill™ sizes been released to the market. With the M20,000 and M30,000 being the latest additions in 2021. The largest mill, the M50,000, was designed in 2015 under the old-style design (Figure 5). In 2021 G.T. has applied the reduced footprint model to the M50,000. However, there are no current M50,000s installed yet. A breakdown of volume, motor size and flowrate for the IsaMills™ that G.T. produces can be seen in Table 3.

Table 3: All IsaMill™ Models available on the Market

Model	Volume (L)	Motor Size (kW)	Max Flowrate (m^3/h)
M100	100	75	12
M500	500	200	30
M1,000	1000	500	90
M3,000	3000	800	150
M5,000	5000	1120 or 1500	200
M7,500	7500	2200	275
M10,000	10000	3000	350
M15,000	15000	3800	600
M20,000	20,000	5000	800
M30,000	30,000	6000	1000
M50,000	50,000	8000	>1000

4.3 Coarse Grinding Applications

When the M10,000 was developed, the IsaMill™ was no longer limited to fine-grinding applications (sub 100 µm). There are over 50 IsaMill™ installations that are currently in operation with an F_{80} >100 µm, at a total installed power base of 63.5MW. These applications exist in Copper, Lead Zinc, Molybdenum, Tin, Platinum Group Metals (PGM's) and Gold. With the highest F_{80} being at the Ernest Henry site in Australia, which has an F_{80} of 300-350 µms (Larson *et al.,* 2012). The theoretical max using 6 mm media is 400 microns.

Although the IsaMill™ was initially developed for ultra-fine grinding, the particle size range which it is able to efficiently treat has grown with each subsequent step up in available mill size. Originally, when the IsaMill™ was developed, the optimum media selection was around 2mm due to the low P_{80}'s that were required (7 µm) for MIM and MRM deposits. Through testwork, and a better understanding of the physical mechanisms involved in stirred milling, combined with new ceramic grinding media suppliers entering the market, has allowed the IsaMill™ to operate at a greater range of media sizes. As a result of this work, the following media selection matrix was generated, which allows for G.T. to accurately size the IsaMill™s via the correct media selection.

Table 4: Media Selection Matrix

		Feed Size, F80 (µm)											
		<20	20-30	30-40	40-50	50-60	60-70	70-100	100-130	130-160	160-200	200-250	>250
Product Size P80 (µm)	<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

Testwork has proven that if there is a significant size reduction required (reduction ratio >8), the energy requirements can be minimised by using two stages of size reduction by designing the IsaMills™ in series (Anderson and McDonald, 2016), each with a different grinding media size. The energy efficiency of the size reduction and sharpness of the product particle size distribution is maximised by using the optimal media size for each stage in the grinding process.

4.4 Conical Spacers

Throughout 2010 to 2013, several test work programs were carried out using conical spacers to improve the overall efficiency of the IsaMill™ (Anderson and Bandarian, 2018). On an M20 scale, the resulting drop in IsaMill™ power consumption with the spacers installed was approximately 15% for the same media load and operating parameters. When slurry was processed through the mill, an efficiency improvement of 15% was realised at a target final grind size of 15 µm; i.e. a product grind size P_{80} of 15µm was achieved for 15% less power when conical spacers were installed compared to the standard spacer design (Anderson and Bandarian, 2018). This power reduction also replicates internal testwork conducted with the Knob tetranex designs (Netzsch castellated disc design) of approximately 15%, without the increased wear you would expect with castellations on the discs.

Following the successful trials on the M20, Glencore Technology developed a set of spacers for an M1000 IsaMill™; these were installed at a gold operation in pre-leach grinding duty to conduct full-scale plant trials (Figure 7). In this case, the conical spacers presented a decrease in power of 20% under the same media load and operating conditions. This resulted in an overall efficiency improvement of ~15% over a range of target product sizes of 20 - 21 µm. The results obtained from this test campaign resulted in the continued use of conical spacers (Anderson and Bandarian, 2018).

The most significant efficiency gains was observed at finer product size fractions, and the test work indicated that efficiency gains might be less pronounced for coarser duties. The spacers were shown to have no adverse impact on the shape of the product particle size distribution.

Figure 7: Installed Conical Spacers (Anderson and Bandarian, 2018)

4.5 Acoustic Emissions Analyser

Glencore Technology has commercialised a process to quantify acoustic measurements and charge position, by the installation of an Acoustic Emissions Analyser. The analyser is a series of accelerometers (circled red in Figure 8) located on the IsaMill™ shell that interprets a range of acoustic frequencies to determine what is occurring within the IsaMill™ (Anderson and McDonald, 2016).

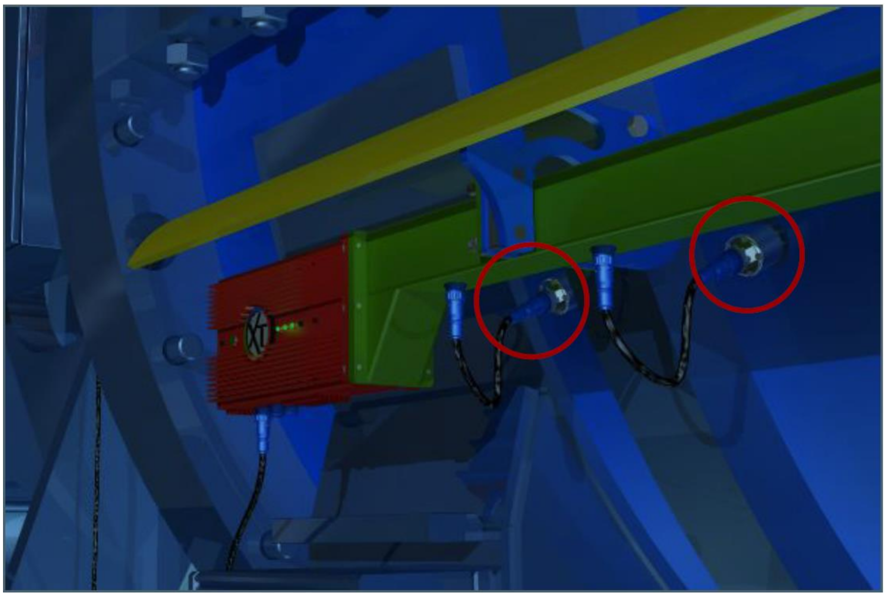

Figure 8: Drawing of the Acoustic Emissions Analyser Mounting and Accelerometers

The analyser interprets stress waves that are generated by the impact of grinding media with the internal shell liner. An acoustic emission mean signal is then collected from various points along the length of the mill shell, including the rotor, for analysis (Anderson and McDonald, 2016). Generally, a step-change in the acoustic signal will correspond with increased wear of a part within the IsaMill™. Anderson and McDonald (2016) published uses of acoustic interpretation where it identified that the Acoustic Emissions Analyser detected that a shell liner was likely to fail 24 hours (Figure 9) in advance due to a change in acoustic signal (Anderson and McDonald, 2016).

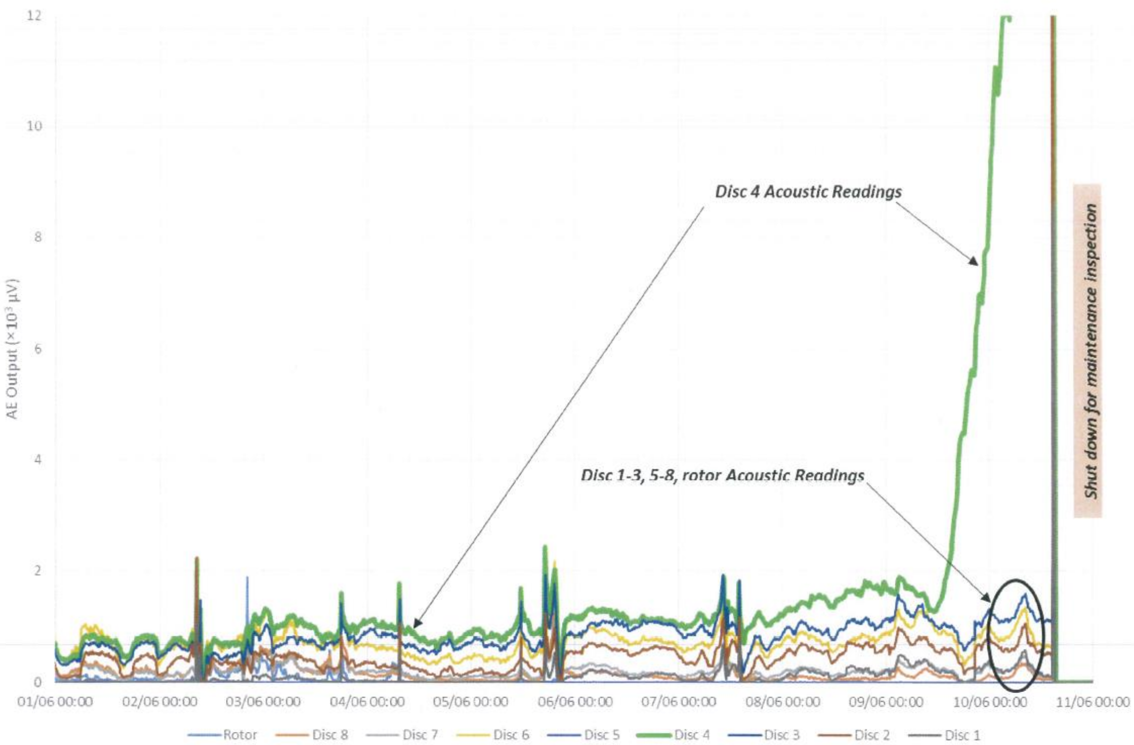

Figure 9: IsaMill™ Acoustic Emissions Reading prior to a Shell Liner Holing (Anderson, 2016)

This technology is commercialised and is continually being improved/developed at the operating sites with active installations. Ongoing plant trials are in the process of being conducted using this technology to provide particle size distributions on the discharge of the IsaMill™.

4.6 IsaCharger Development

The IsaMill™ requires that the complete grinding media charge be removed from the mill prior to a scheduled inspection, with the media hopper being situated next to the mill. This mechanism has been designed to utilise the back pressure of the rotor design to push media out of the mill and back into the media hopper.

The media hopper is also used to store new media that is required to replenish the mill charge as the media is consumed as part of the grinding process (approximately 8 g/kWh). In the past, a screw feeder was originally used to transfer ceramic media from the media hopper into the IsaMill™ feed tank, from where it is pumped into the IsaMill™ as a slurry/media mixture. To improve upon this design, the IsaCharger™ utilises a custom-built high-pressure venturi type device to transfer media utilising a high powered jet of water from underneath the media hopper into the mill feed tank (Rule and De Waal, 2011). This system is demonstrated in Figure 10. This new design has resulted in improvements in equipment availability (with no moving parts) with similar media recharge and unloading times as achieved by the original screw feeders (Rule and De Waal, 2011) whilst providing the ability to drop the height of the IsaMill™.

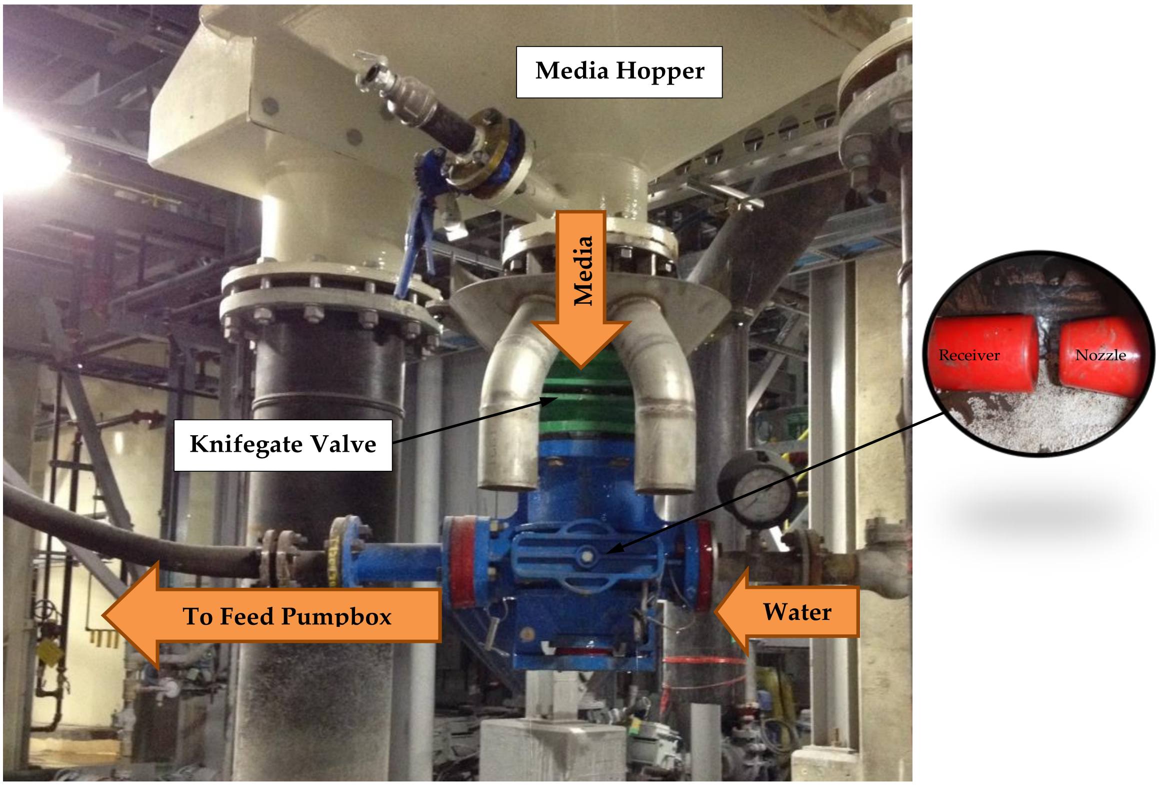

Figure 10: Isacharger System (Glencore Technology,2018)

By combining this Isacharger™ system with the recycle system used by the IsaMill™. There is no other stirred mill in the industry that has the ability to be able to maintain process stability, rapidly charge and discharge media (via the scuttle) and be able to respond to process disruptions in the plant.

4.7 Materials Testing Trials

As part of the commitment to continuously improve the IsaMill™, several initiatives have been undertaken to extend the life of the IsaMill™ components. These activities have included the addition of instrumentation on discs and the shell (Figure 11), material trials as well as investigations into fabrication techniques.

Figure 11: Instrumented Discs

In several trials, wireless instrumentation has been included in each of the discs. This has allowed Glencore Technology to determine the torque on the discs and temperatures via Resistance Temperature Detectors (RTDs). Torque and temperature tend to be closely correlated to failure rates, and a further understanding of different process conditions impact on this; will assist in optimising the internal components of the IsaMill™.

Figure 12: Pizza Flange Trials (Material Testing)

As the IsaMill™ has been scaled up and used in different mineral applications. Several types of rubber linings have been developed, e.g. Duro60 & Duro70. However, to get to this point, multiple types of materials have been tested during this process over 25 years, making G.T. the market leader in these applications. These have materials we have tested have included ceramics, rubbers, polyurethane etc.

When these trials are conducted, they are done on a "pizza flange" where multiple materials are put on the Non-Drive End Flange in the style of a pizza (demonstrated in Figure 12). These materials are then tested within a working on-site IsaMill™ over a timeframe of two months to a year.

4.0 THE FUTURE

There have been recent developments in Jameson Cell design, with the new Z8500/12 and B8500/12 cell now available in the marketplace. This high volumetric flow design (~1500 tph) allows the Jameson Cells to comfortably move into roughing and scavenger duties and has further enabled the full Jameson Cell/IsaMill™ concentrator concept. The full Jameson Cell circuit is not a new concept as demonstrated with the Philex concentrator in 1996 (Harbort et al., 1997). At Philex, there was a noticeable improvement in metallurgical performance, where a 3.3% increase in copper recovery, 2.6% increase in copper grade and 4.5% increase in gold recovery was seen from implementing the all Jameson Cell circuit design while reducing the footprint by 67%.

A prime example of this optimised design is the 875 tph lead/zinc concentrator project in Russia, called Ozernoye, which is due to be commissioned in late 2022. As part of this project, a comparison between a conventional circuit (tank cells/vertical regrind mills) was compared to a Jameson Cell circuit with M20,000s as the choice of regrind IsaMill™s (Figure 13). In the Jameson Cell/IsaMill™ design, the footprint was <50% of the conventional design, with a building height reduction of 15m. The OPEX for the Jameson Cell design was ~50% lower in comparison due to power savings and reductions in spares.

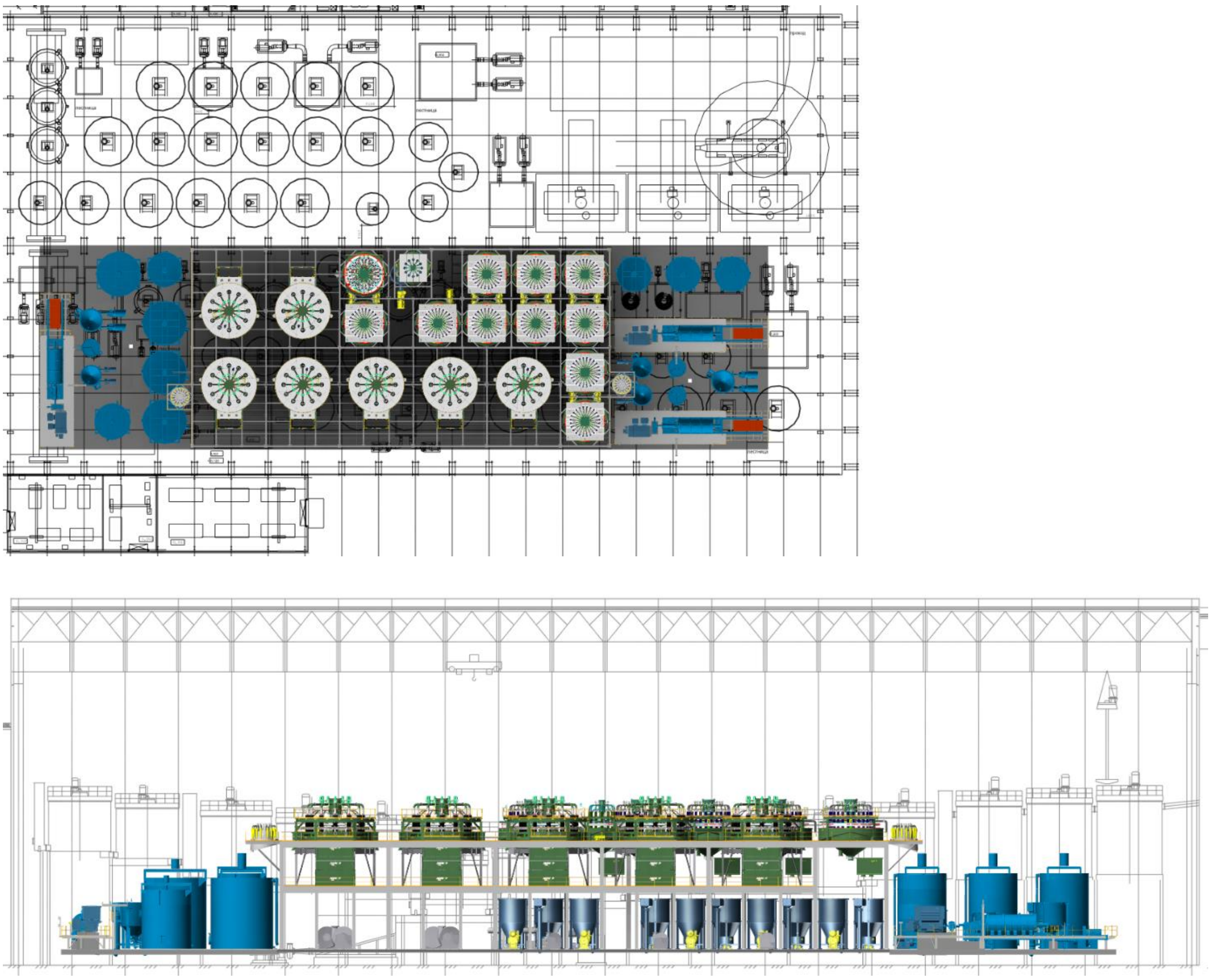

Figure 13: Ozernoye Footprint Comparisons

Glencore Technology believes that the IsaMill™ coupled with the Jameson Cell can revolutionise concentrator design and at a reduced overall cost and with a more environmentally responsible small footprint. It is this circuit design where we can see the benefits of the horizontal IsaMill ™.

CONCLUSION

The IsaMill™ has been the pioneering technology in stirred milling. As the IsaMill™ has scaled up in size it has expanded into coarser grinding applications (P_{80}'s of up to 400 µms) and continues to remain the technology to achieve the ultrafine grinding fractions (sub 10 µms) with the sharpest particle size distributions. It has expanded into several commodities and continues to evolve through product development; this is why it remains the most energy-efficient, safest stirred mill in today's competitive environment.

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