

From base metals and back – IsaMills and their advantages in African base metal operations

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IsaMill™ technology was developed from Netzsch Feinmahltechnik GmbH stirred milling technology in the early 1990s to bring about a step change in grinding efficiency that was required to make Xstrata's fine-grained lead/zinc orebodies economic to process. From small-scale machines suited to ultrafine grinding, the IsaMill™ has developed into technology that is able to treat much larger tonnages, in coarser applications, while still achieving high energy efficiency, suited for coarser more standard regrind and mainstream grinding applications.

The unique design of the IsaMill™, combining high power intensity and effective internal classification, achieves high energy efficiency and tight product distribution which can be effectively scaled from laboratory scale to full-sized models. The use of fine ceramic media also leads to significant benefits in downstream flotation and leaching operations.

These benefits are key drivers for the adoption of the technology into processing a diverse range of minerals worldwide, and offer major opportunities for power reduction and improved metallurgy for the African base metal operations.

Keywords: IsaMill, regrind, energy efficiency, inert grinding.

Introduction

The development of the IsaMill™, by MIM (now GlencoreXstrata) and Netzsch Feinmahltechnik GmbH, was initiated to enable the development of the fine-grained ore deposits at Mt Isa and McArthur River in Northern Australia. To liberate the valuable minerals and so produce a saleable concentrate this ultrafine-grained ore needed to be ground to a P_{80} of 7 μm .

The conventional regrind technologies in the early 1990s, ball and tower mills, were unable to grind to these sizes economically. Additionally, the high steel media consumption and associated changes in pulp and surface chemistry were extremely detrimental to flotation metallurgy.

IsaMill™ technology was further transferred into mainstream inert grinding (MIG) and high throughput regrind applications with the development of the M10 000, 3 MW IsaMill™ in conjunction with Anglo Platinum at their Western Limb Tailings Retreatment facility near Rustenburg, South Africa. The successful commissioning of this mill in the Bushveld Complex resulted in rapid adoption of the technology by the platinum industry.

The development of the 3 MW IsaMill™, coupled with commercialization of the technology in the early 2000s, has accelerated the uptake of IsaMill™ technology. To date there are over 120 IsaMills™ installed around the world in a range of applications and industries, particularly in copper and lead zinc concentrate regrind duties.

IsaMill principles of operation

Grinding mechanism

The IsaMill™, as shown in Figure 1, is a horizontally stirred mill consisting of a series of 7-8 rotating grinding discs mounted on a cantilevered shaft THAT is driven through a motor and gearbox. The discs operate at tip speeds of 21-23 m/s, resulting in energy intensities of up to 300 kW/m³.

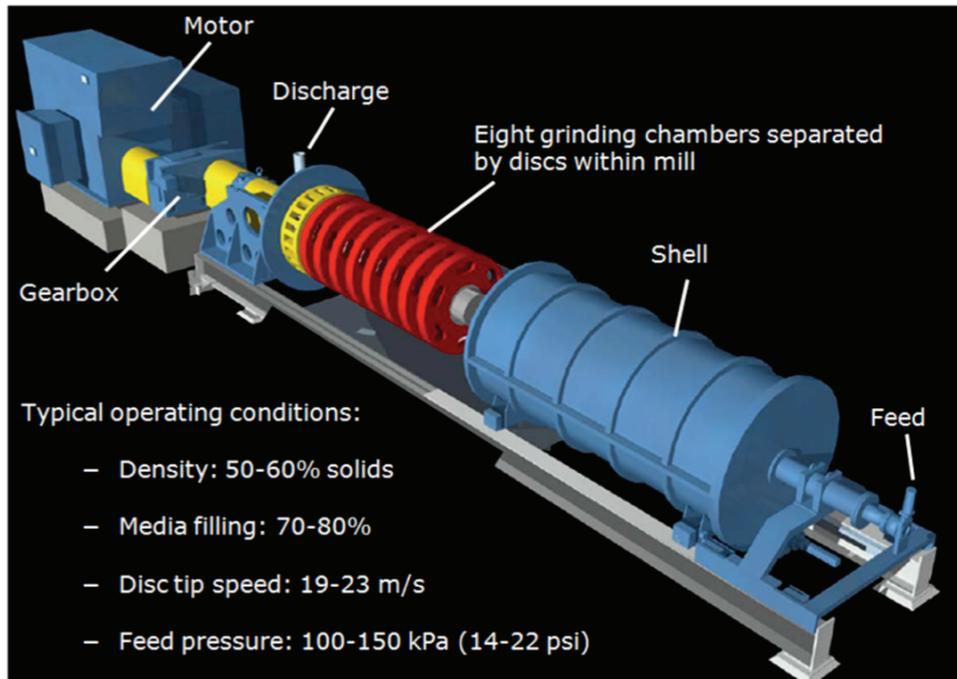


Figure 1. IsaMill™ layout

Figure 2 shows the principle of operation. The mill is filled with suitable grinding media, and the area between each disc is essentially an individual grinding chamber. As a result, the mill effectively comprises eight grinding chambers in series. The media is set in motion by the action of the grinding discs, which accelerate the media radially towards the shell. Between the discs, where the media is not as subject to the high outwards acceleration of the disc face, the media is forced back in towards the shaft – creating a circulation of media between each set of discs. Minerals are ground as a result of the agitated media, the predominant mechanism being attrition grinding.

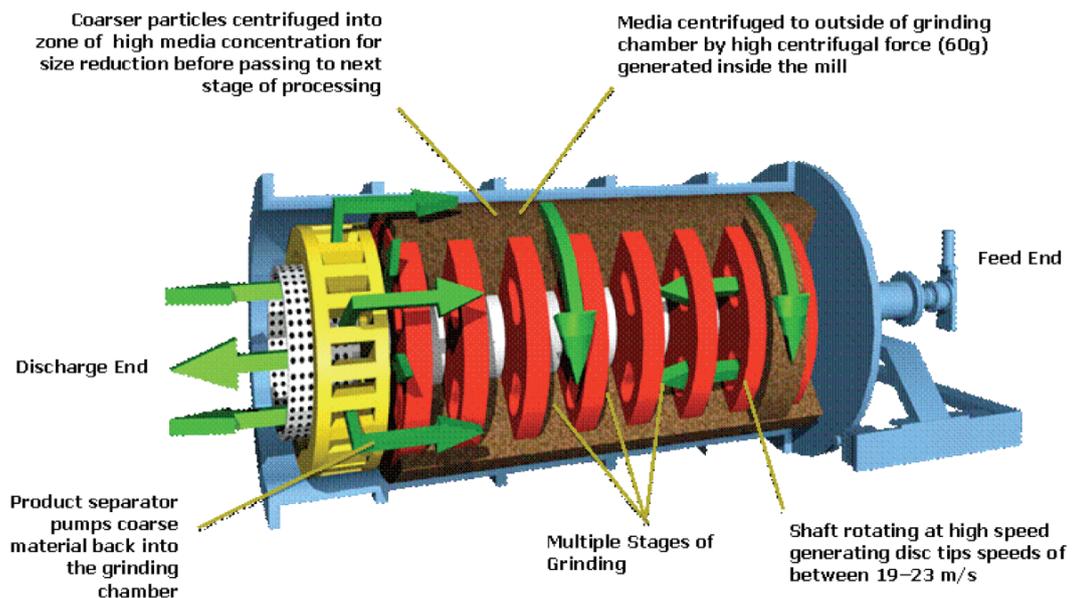


Figure 2. Operation of the IsaMill™

The eight chambers in series mean that short-circuiting of the mill feed to the discharge is virtually impossible. There is a very high probability of media-particle collision as a result of the high energy intensity and the eight chambers in series.

Energy efficiency

The energy efficiency advantages of IsaMill™ technology over ball mills and other stirred mills are shown in Figures 3 and 4 respectively. Figure 3 compares the energy required to grind a gold-pyrite ore in a ball mill with 9 mm steel balls with an IsaMill™ with 2 mm media. The IsaMill™ is much more efficient below about 30 μm – to grind this ore to 15 μm would take 28 kWh/t in the IsaMill™, but 90 kWh/t in a ball mill. Traditionally, this has been attributed to the difference between attrition grinding and impact grinding. However, by far the most important factor is media size, as shown by Figure 4. Figure 4 shows the breakage rate in tower mills dropping dramatically with decreasing particle size - the breakage rate for 20 μm particles is ten times lower than the rate for 40 μm particles. Even though the tower mill mechanism is full attrition grinding, in practice it is constrained to using relatively coarse media, 9 mm balls in this case. In contrast, the IsaMill™ (Netzsch mill in Figure 4) can operate with much finer media and a much higher intensity of power input, meaning the peak breakage rate occurs at 20 μm , and does not drop as quickly as the tower mill below that size.

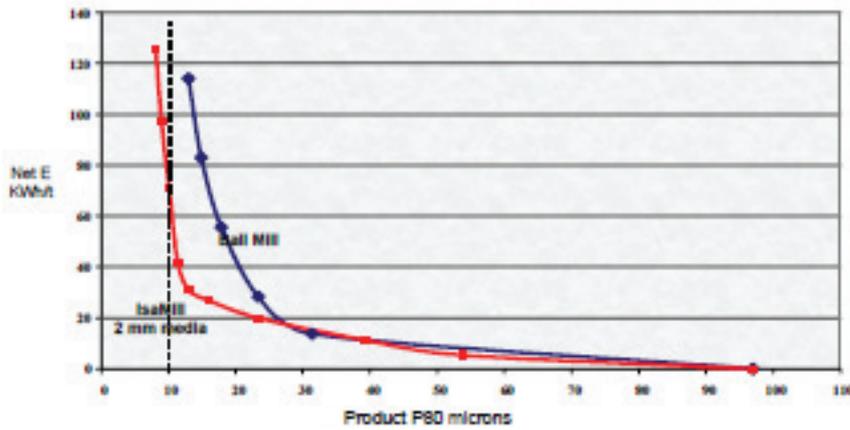


Figure 3. Grinding energy vs product size for gold-pyrite ore (Pease et al., 2004)

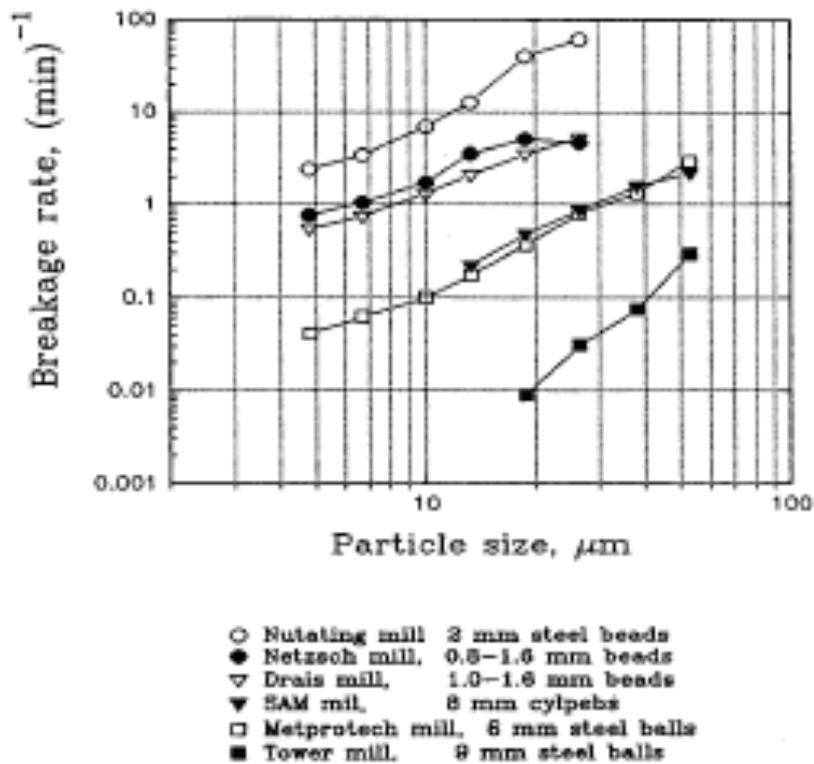


Figure 4. Breakage rates of different grinding machines (Gao and Weller, 1993)

Particle size distribution

Due to the horizontal layout of the IsaMill™ and the multiple effective grinding chambers, the IsaMill™ is capable of producing a very steep product size distribution when compared to alternative technology such as ball and tower mills. As shown in Figure 5 the preferential size reduction of the coarser sized material over the finer material results in progressively steeper product size distributions at increasing specific energies.

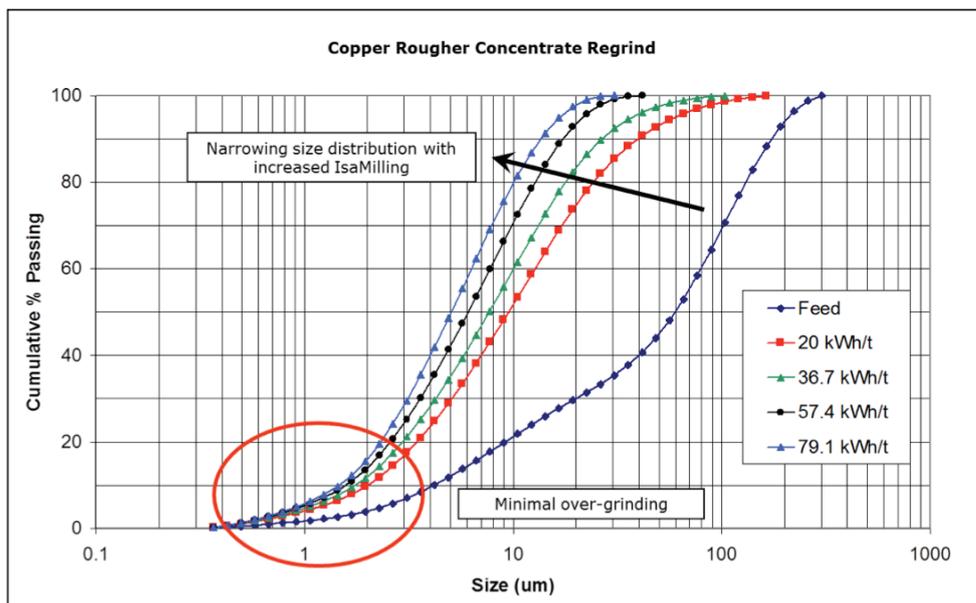


Figure 5. Preferential reduction of coarser size fractions

The IsaMill™ preferentially targets the coarser size fractions in the slurry stream, producing a sharper particle size distribution curve. This is often a deciding factor in designing grinding and flotation circuits, as gangue entrainment in the flotation concentrate and the ultra-fine size fractions can influence final concentrate grades.

Benefits of inert grinding

After the initial comminution stages of crushing and/or SAG/AG milling, historical practice employed steel-charged ball or tower mills for the subsequent grinding stages. The impact of grinding using steel media often offset any benefits gained by improved liberation, particularly as the target size decreases below 25 µm. Grinding in a steel environment results in the precipitation of metal and iron hydroxides on the surface of ground particles. These conditions affect floatability and flotation selectivity, and lead to higher reagent consumptions to overcome the surface coatings and regain recovery (Trahar, 1984; Pease *et al.*, 2006).

The benefits of inert grinding at several locations have been comprehensively reported (Pease *et al.*, 2006, 2005, 2004; Young *et al.*, 1997; Grano *et al.*, 1994). While the negative impacts of steel grinding will be greatest at fine sizings due to the large surface areas and high media consumptions involved, inert grinding has also been shown to produce benefits at coarser sizings (Grano *et al.*, 1994; Greet *et al.*, 2004; Pease *et al.*, 2006). For a long time, chrome media has been offered to, and investigated by, ball and tower mill operators as a means of improving pulp flotation chemistry by reducing the amount of iron released into the grinding pulp and contaminating freshly ground surfaces. Greet and Steiner (2004), analysed the surface of galena ground in three different environments for the presence of iron. It is clear from Table I that although grinding in a high-chrome environment reduced the surface iron contamination from 16.6% to 10.2%, grinding in a ceramic environment reduced the detectable surface iron to less than 0.1% - a significant improvement over both media types.

Table I. Composition, determined by X-ray photoelectron spectroscopy (XPS), of the un-etched surfaces of Rapid Bay galena ground with different media (Greet, 2004)

Media type	Surface atomic adsorption (%)			
	O	Pb	Fe	S
Forged steel	53.1	15.6	16.6	14.7
High chrome	50.0	20.6	10.2	19.2
Ceramic	33.6	32.0	<0.1	34.4

Applications in industry

Early IsaMill™ adoption in zinc – lead processing. – Mt Isa Mines

The changes to the Mount Isa circuit as part of the ‘George Fisher Project’ re detailed by Young and Gao (2000) and Young, Pease, and Fisher (2000). In summary, the George Fisher project involved adding 6 x 1.12 MW M3000 IsaMills™ to the existing Mt Isa Pb-Zn concentrator to regrind lead rougher concentrate to a P_{80} of 12 µm, zinc rougher concentrate to 12 µm, and a zinc regrind to P_{80} of 7 µm as shown in Figure 6. As a result of the circuit changes, lead concentrate grade increased by 5%, and lead recovery 5% (equivalent to 10% increase in lead recovery at the same grade). Zinc recovery increased by 10%, in two steps, and zinc concentrate grade by 2% (equivalent to 16% increase in zinc recovery at the same grade).

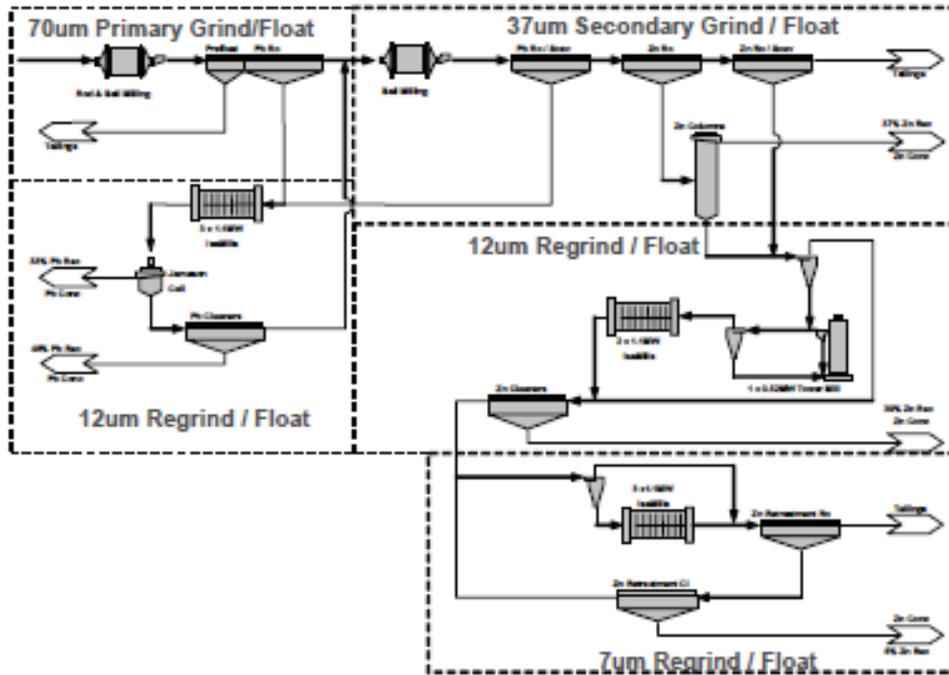


Figure 6. Mt Isa Pb/Zn concentrator flow sheet (Pease et al., 2006)

Due entirely to extra liberation, the project predicted 5% higher zinc recovery and no increase in concentrate grade. This was achieved instantly, as shown in Figure 7. The surprise was the ‘second wave’ increase in recovery – a further 5% zinc recovery increase and 2% increase in zinc concentrate grade. This second wave occurred because although fines flotation improved after grinding finer, it took 6 months to understand how to optimize fines flotation and customize the circuit to suit. The biggest challenges to understanding the flotation of fines were:

- False expectations that a lot more reagents would be required after IsaMilling due to the significant fresh surface area created. Some reagent additions were expected to triple
- Not taking the depressant (lime to pH 11) off the zinc cleaners
- ‘Pulling’ flotation harder because of the misconception that flotation of fines would be slower.

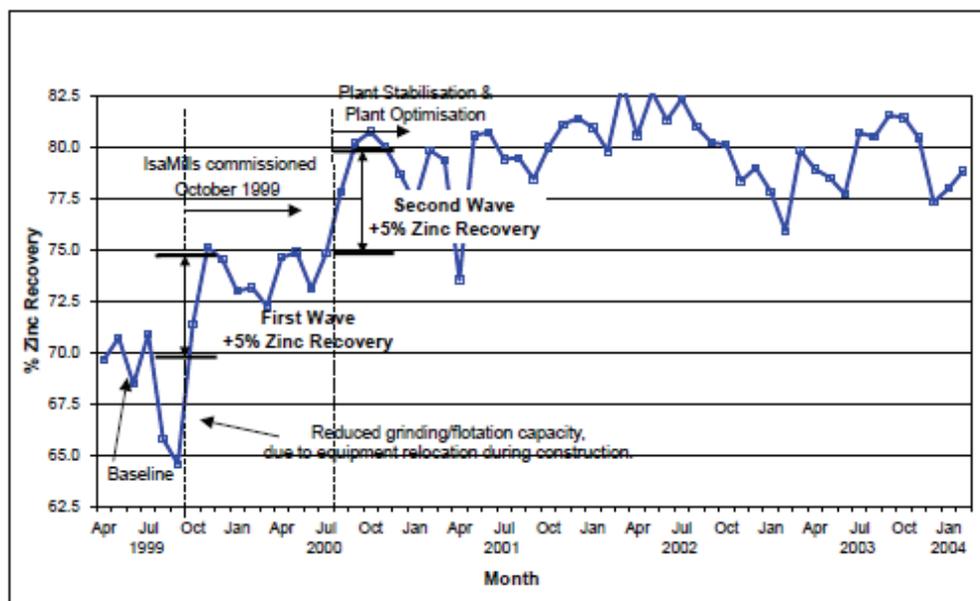


Figure 7. Zn recovery increase from IsaMill™ technology (Pease et al., 2006)

In reality, even with the introduction of over 6 MW of extra grinding power, the operating cost per ton of feed did not increase. This was because of the following factors :

- Lower reagent additions – this was unexpected but logical. The inert grinding environment meant that even though there was significantly more mineral surface area (the surface area had been increased threefold), the cleaner surfaces achieved with inert grinding meant that less collector was required in solution to drive the diffusion of collector through any surface coatings to the surface of the mineral. The truly clean surfaces that were achieved by grinding in an inert environment meant that lower solution concentrations can achieve high surface coverage. Flotation after inert grinding is profoundly different
- Elimination of circulation loads between roughing and cleaning by recovering minerals and removing them to final concentrate as soon as recoverable. A lot of power (and flotation capacity) was wasted in the conventional circuit pumping circulating loads of 100%–300%
- New designs in pump boxes and pumps, reduction in circulating loads, and lower reagents eliminated spillage. When mineral surfaces are clean due to the inert grinding environment, bubble contact angles are predictable compared to those on the highly altered surfaces found in other systems. MIM was able to drop circulating loads from 200–300% to less than 50%. Liberated minerals with clean surfaces in narrow size distributions respond quickly and do not form large circulating loads. The low circulating loads mean lower density, which gives better dilution cleaning. Low circulation loads also mean fewer flotation cells are needed – eliminating a 100% circulating load doubles the residence time
- The reduction in reagents and circulating loads reduces or eliminates spillage. The elimination of spillage stops the cycle where returning spillage disrupts a circuit, creating new circulating loads and even more spillage.

Figure 8 shows the recovery by size in the zinc cleaning circuit at Mt Isa after the adoption of IsaMill technology (with respect to rougher concentrate or IsaMill™ feed). Recovery is above 95% for all size fractions from 1 μm to 37 μm. Although recovery drops above 37 μm there are very few particles in this size range, and these are composites that the circuit directs to further regrinding. Interestingly, the highest recovery, over 98%, is in the 4–16 μm range. This size range is sometimes called 'slimes', and it is often said that 'slimes don't float'. Indeed, after steel grinding they often don't.

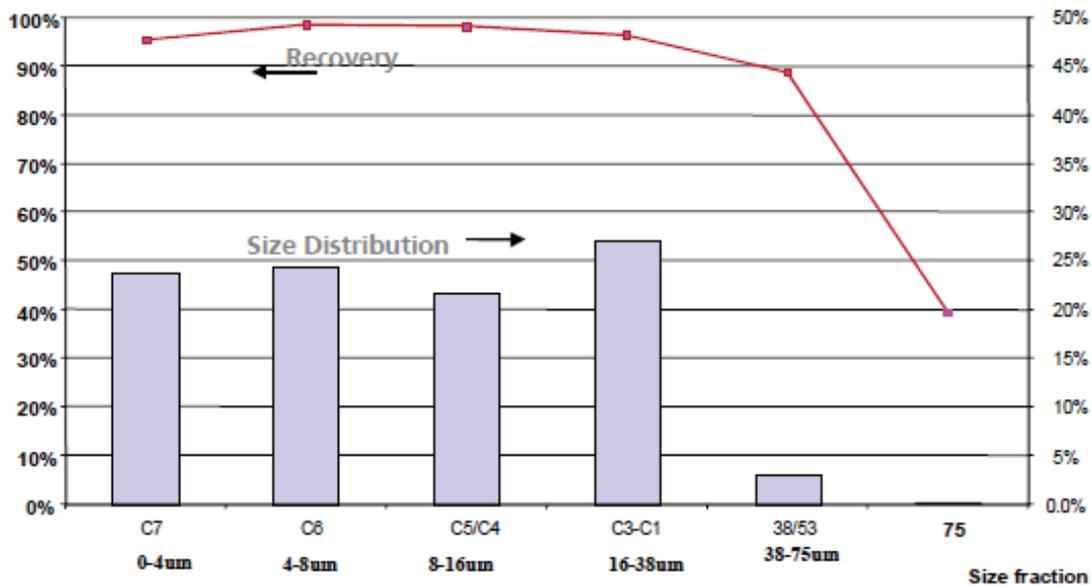


Figure 8. Zn recovery increase from IsaMill™ technology (Pease et al., 2006)

IsaMill transforming copper flow sheets – Phu Kham

The Phu Kham copper-gold operation is located approximately 100 km north of the Laos capital Vientiane. It is owned by PanAust, an Australian-listed mining company.

The Phu Kham deposit hosts two distinct styles of mineralization: an oxide gold cap and beneath this transitional/primary copper-gold. The oxide gold cap is the principal deposit for the Phu Bia heap leach gold mine, the first phase of the development of the Phu Kham deposit, which entered into production in 2005. As discussed by

Bennett *et al.*, (2012) the second phase of development, the 12 Mt/a concentrator designed to treat the high-pyrite copper-gold skarn ore, was commissioned in 2008.

The Phu Kham concentrator design was driven by the complex and variable mineralogy, where, due to the geological nature of the orebody the concentrator treats varying native, oxide, secondary, and primary copper species over a short time periods, and to the high pyrite content of the ore, with over 90% pyrite rejection required to achieve a 23% copper grade.

Expansions since the 2008 start-up have been driven by the relatively poor recovery when compared to other low-grade copper-gold deposits and have included an increase in rougher and cleaner capacity and the installation of a Jameson cleaner. Figure 9 shows the Phu Kham flow sheet following installation of the Jameson Cell cleaner in 2011. Of note is the original 3 MW M10,000 IsaMill™ installed to produce a cleaner feed size P_{80} of 35 μm and the 24 downcomer Jameson Cell installed in 2011 to improve flotation recovery.

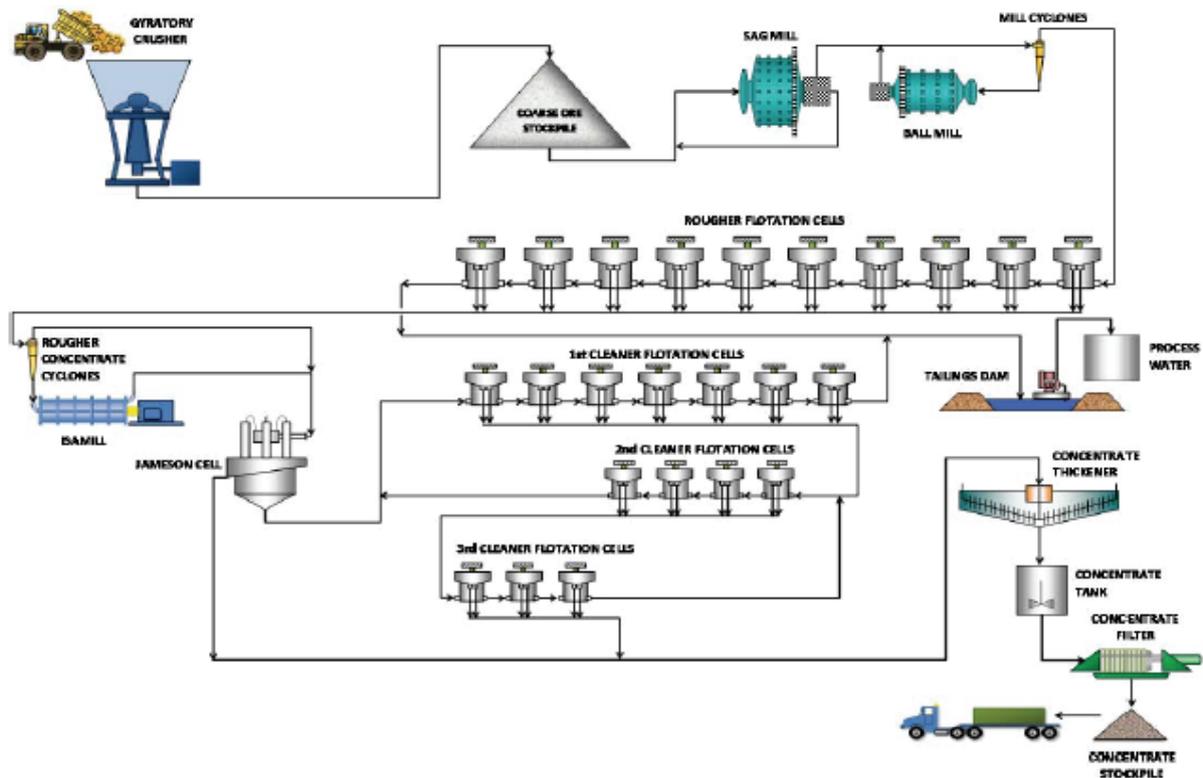


Figure 9. Phu Kham flow sheet in 2011 (Bennett, 2012)

Since installation of the Jameson Cell, the Phu Kham processing plant has undergone two further major upgrade projects. The Phu Kham Upgrade Project commenced in early 2010 and, as discussed by Bennett (2012), the focus of the project was to ensure the concentrator could maintain concentrate production at over 60 kt/a after 2013 as the copper grade starts to decrease. To maintain concentrate production, overall plant throughput had to be increased from 12 Mt/a to 16 Mt/a in the limited real-estate environment at site.

The Increased Recovery Project (IRP), for which initial studies started in 2009, was focused on increasing copper and gold recoveries to overcome the ‘flat line’ in recoveries (shown in Figure 10) that resulted from poor liberation coupled with increasing pyrite content. As part of the IRP project, two mineral processing options for increasing recovery of the low-quality copper sulphide – non-sulphide gangue binary particles were tested: mainstream inert grinding of the rougher tails and bulk sulphide flotation in the rougher circuit. The selected bulk sulphide flotation processing route targeted rougher mass recovery to maximize copper recovery across all ore types, rougher concentrate regrind product size, and cleaner capacity.

Monthly composite mineralogy data and laboratory test work determined that a regrind size of P_{80} 20 μm was required to achieve 80% copper sulphide liberation and so maximize copper sulphide liberation in the cleaner feed. To achieve this regrind target at increased rougher concentrate production, a second 3 MW M10,000 IsaMill™ was

Conclusion

Necessity was the mother of invention for ultra-fine-grained orebodies, which were uneconomical to process with conventional ball and tower milling. High-intensity stirred milling was the breakthrough that transformed the economics of these deposits. It is the advantages of IsaMill™ technology – high power efficiency, simple installations, large single unit size, sharp size distributions in open circuit, and inert attrition of mineral surfaces that have resulted in the rapid transfer and uptake of the technology in base metal applications around the world.

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