FINE GRINDING AND PROJECT ENHANCEMENT

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ABSTRACT

Fine grinding has the potential to revolutionise the mineral processing industry due to the benefits attained through being able to economically grind finer to enhance particle liberation for improved flotation and to introduce a high degree of strain into the mineral lattice to improve leaching rates in hydrometallurgical processes.

The development of fine grinding technology has enabled mining operations to be developed at a number of mine sites previously considered uneconomic. It has also enhanced the performance of existing mining operations at a number of mine sites and provided the key such that leaching can be carried out under relatively mild conditions in low cost open tanks. This paper is a review of a number of case studies that demonstrate the benefit that fine grinding has provided to a wide range of applications.

The use of inert media has provided further improvements in circuit performance and recovery.

The Mt Isa operation, MRM operations and the Albion Process are reviewed in this paper.

INTRODUCTION

Fine grinding technology has come a long way in the last decade. The ability to grind ore down to sizes below 10µm has lead to the establishment of new mines such as McArthur River, Century and George Fisher mines, as well as improving recoveries of lead and zinc at the established Mount Isa deposits.

Fine grinding has also opened up the door to new leaching processes. Leaching has always been regarded as a simple process, but as orebodies have become more complex, and oxide deposits giving way to more refractory ore, more advanced leaching is required. One of the technologies that fits this duty is the ALBION Process, however unlike competing technologies that incorporate complex processing steps, the development of fine grinding has made this process a very simple and effective process.

Both processing routes was made possible by the innovation of the IsaMill and other fine grinding processes, and this paper investigates the impact of this technology on the processing of complex ores through mineral processing and leaching.

BACKGROUND – MOUNT ISA

Mount Isa is a long established mining town situated in North West Queensland. Lead carbonate ore was first found by John Campbell Miles in 1923, which later revealed one of the biggest lead/zinc sulphide deposits of its time. Mount Isa Mines Limited was formed soon after the initial discovery, and lead mining, concentrating and smelting operations began.

Over time, the easy to treat orebodies gave way to harder to treat orebodies, which had lower grades and more complex mineralogy. The two main lead/zinc orebodies found at Mount Isa were named Racecourse and Black Star, described as: (Pease, Young et al, 1997):

- “Black Star” orebodies are massive and are mined by open stoping at lower mining cost, and therefore have a lower cut-off grade. Generally this ore is finer grained and has considerably more fine-grained carbonaceous pyrite, whilst core replacement of pyrite by galena (atolling) is more common and at a more advanced stage.

- “Racecourse” orebodies are narrow and mined by bench stoping with a higher cut-off grade. Generally these orebodies are higher in grade for lead and silver, coarser grained and lower in pyrite. The pyrite is more the euhedral type than the fine-grained carbonaceous type.

The other major lead/zinc orebodies in the region, also owned and mined by Mount Isa Mines Limited, was the Hilton and Hilton North orebodies, 20km north of Mt Isa. The mine was later renamed as the George Fisher mine. The orebodies were similar to the orebodies at Mount Isa, with the upper part of the orebodies having characteristics of the “Black Star” ore, and the lower orebodies similar to “Racecourse” ore (Pease, Young 1997).

The presence of pyrite was described as two types. The euhedral pyrite was described as course grained, while the fine grained carbonaceous pyrite is present in the 5 to 30µm range containing natural carbon and is naturally floating, (Munro 1993).

CONCENTRATOR PRACTICE AT MOUNT ISA

Ore at Mount Isa was mined and treated through the Lead/Zinc Concentrator. There have been various concentrators built on the site. The current lead/zinc concentrator, No. 2, operating today, was installed in 1966, and produces lead and zinc concentrates through sequential lead, then zinc flotation. It also had a LGM circuit which was a zinc rich bulk concentrate where “low grade middlings” were processed into a saleable product.

As the operations at Mt Isa progressed, the Racecourse orebodies provided the bulk of the ore during the early days of mine development, being higher grade. However over time more of the Black Star material was processed. The introduction to mining the Hilton orebodies began in 1987, and a lot of this material was trucked into Mt Isa to be treated through the Lead/Zinc Concentrator, (a lead/zinc concentrator was built at Hilton, and was commissioned in late 1989 for processing some of the ore).

Along with the changing orebodies, and the resultant mineralogical changes, the mining rate was also increased. This is highlighted in figure 1 (Pease, Young et al 1997), where head grades of the concentrator feed dropped while the throughput rate increased.

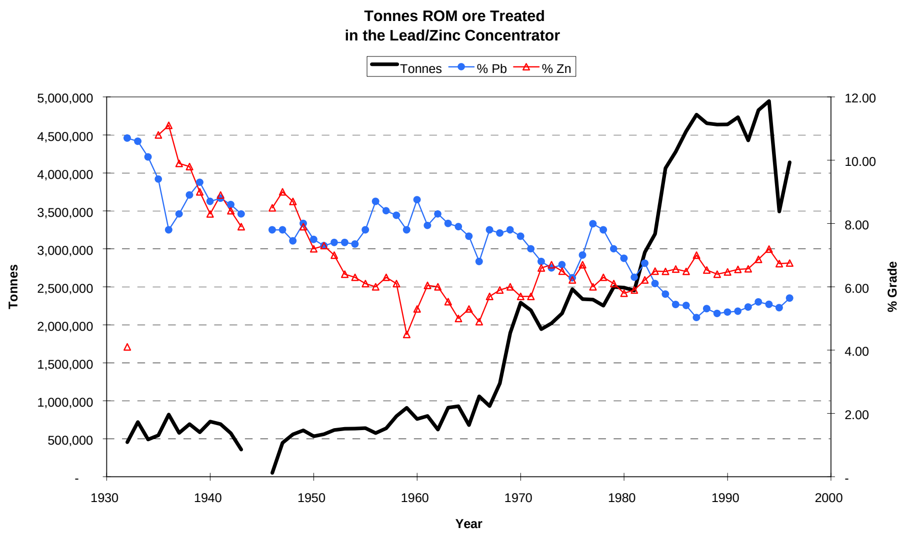


Figure 1 – Time vs Pb/Zn Head Grades

As more Black Star and eventually Hilton ore was being treated, the ore became finer grained and more complex. This was observed for all sizes of concentrator feed, having less liberated mineral species. Figure 2 shows the amount of sphalerite liberation per size class deteriorating over time, from 84/85 to 91/92.

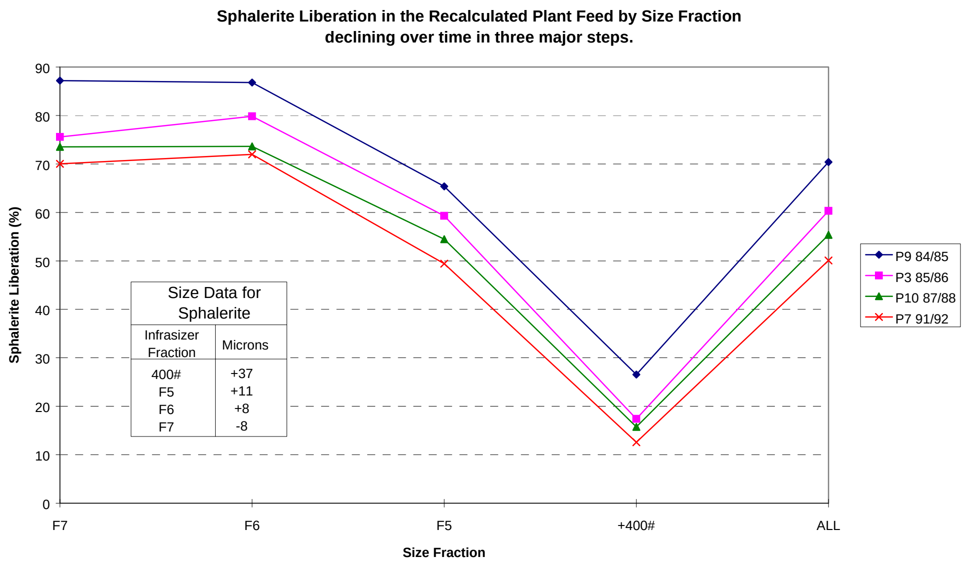


Figure 2 – Liberation Data

Also as more of the Black Star was mined, the proportion of carbonaceous pyrite compared to the euhedral pyrite increased. The carbonaceous pyrite is hydrophobic under most conditions and cannot be depressed easily, as well as consuming large amounts of reagents. The net effect of this change in terms of mineralogy is a greater concentration of iron sulphides in the concentrates (Pease, Young et al 1997). Any attempt made to depress the presence of iron sulphides in the concentrate such as the use of lime or dextrin, resulted in composites being depressed as well in the concentrate, which formed high recirculating loads in the circuit. This in turn limited cleaning and flotation capacity.

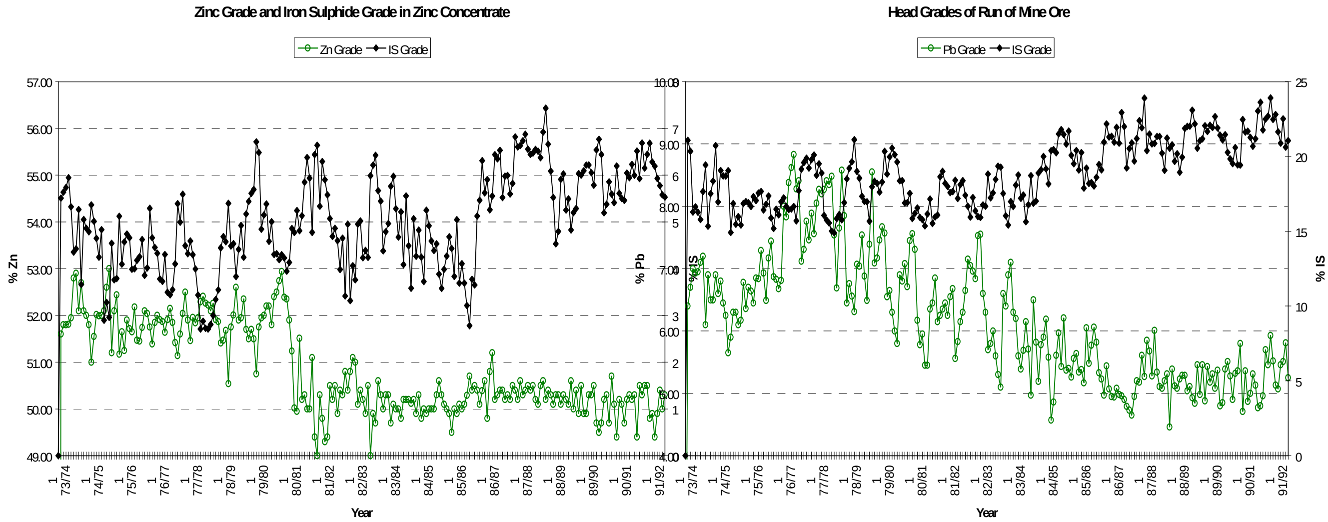


Figure 3 – Iron Sulphide Contamination of Final Concentrates

In summary the Lead/Zinc operation at Mount Isa was not recovering enough metal. The main concerns were:

- More fine grained ore
- Less liberation in the concentrator
- Greater presence of carbonaceous pyrite
- Increasing throughput

The net result was the detrimental impact of metal recovery. Figure 4 shows the gradual deterioration in zinc recovery following the decrease in zinc liberation.

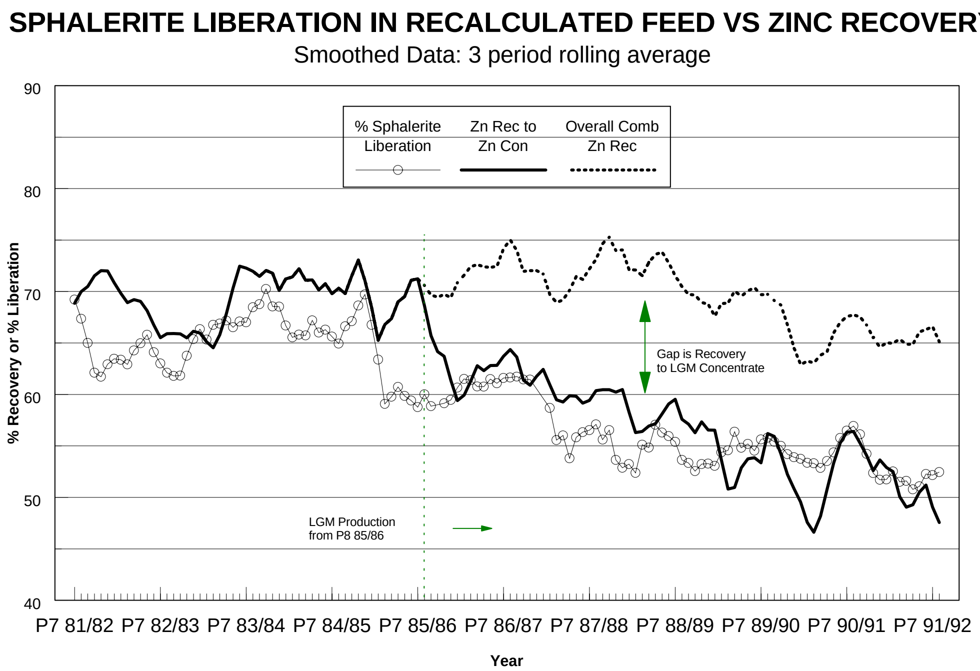


Figure 4: Zinc Liberation and Recovery

At the same time as this trend was occurring, MIM Holdings, the parent of Mount Isa Mines Limited, was embarking on processing the ore from the McArthur River deposit in the Northern Territory. This material was extremely fine grained and required grind sizes down to 7µm to liberate the particles. Obviously, new processing techniques were required to turn around the trend.

ADDRESSING THE LIBERATION AND SEPARATION PROBLEMS PRE 1994

At the start of the nineties there was very little equipment available for fine grinding in mineral processing, (fine being defined as below 25um at least). There was conventional ball milling, and tower milling, and the emergence of metprotech mills, but these were inefficient, as well as impacting on downstream flotation.

Never the less, Mount Isa Mines tried to address the impacts of deteriorating ore by implementing the following as described Pease, Young et al 1997:

- Tower mill regrinding installed in the LGM circuit (1991), dropping the p80 to 12um
- The “Fine Grinding Project,” which doubled grinding and flotation capacity and instituted a “cold” lead reverse cleaning circuit (1992). This project addressed both key issues, ie liberation in the zinc circuit and separation (of carbonaceous pyrite) in the lead circuit. The flotation feed dropped from a P80 of 80µm to a p80 of 37µm due to an increase in secondary grinding from 6.3 MW to 11.5 MW
- Improvement in liberation allowed circuit simplification, the increased use of conventional tools (eg high pH zinc circuit cleaning) and relocation of regrinding duties from the LGM circuit to the zinc retreat circuit.
- Generally, the application of process control became more effective with the improvements because of more achievable targets.

Details of these circuit changes were described in detail by Pease,Young et al 1997. A brief summary of the observations at this stage was that by grinding finer up front in the LGM circuit some of the liberation problems were being addressed. The liberated carbonaceous pyrite contamination of the concentrates were being improved by the reverse flotation in the lead circuit, the use of traditional depressants to knock out the pyrite, as well as the increased capacity to allow for the adequate separation separation.

Of the changes in the circuit it was reported that major gains had been achieved by the extra regrinding with some of the composite zinc that had reported to the LGM having been liberated enough to report to the zinc concentrate. This achieved an extra 5% of zinc recovery to the zinc concentrate. However, zinc liberation, had been increased to 20%, and higher recoveries were expected at this level of liberation than what had actually been achieved.

THE IsaMill DEVELOPMENT

In 1984 to 1986, fine grinding work had been conducted in the pilot plant at Mt Isa to investigate fine grinding circuits. Tower mill test work had also been investigated in 1991, with poor results due to the inability of the equipment to grind fine enough. The other drawbacks of these circuits was the high iron content in the mill charges and the resulting impact on the surface chemistry due its effect on the redox potential.

The introduction of a small stirred mill to the Mt Isa site could only be described as a major turning point in fine and ultrafine grinding in mineral processing. The mill, a ½ litre bench scale mill, resembled a milk shake maker, and initially used fine copper smelter slag to grind the ore and concentrate. It was provided by Netzsch, an experienced fine grinding equipment supplier, in the paint and food processing industry! Testwork on McArthur River Ore started in 1991, and by January 1992, a small pilot scale mill, LME100, had been designed and installed at the pilot plant at Mt Isa.

In a relatively short time, the influence of the bench scale testwork lead to the development of the first pilot scale mill. Mill development is shown in the following table.

Time	Installed Mill
Jan 1992	LME100 model, powered by a 55KW motor used in pilot plant at Mt Isa
Nov 1992	LME500 model powered by a 205KW, then 250KW motor at the Hilton Concentrator, Mt Isa
Nov 1993	ISA1500 model powered by a 900KW motor installed in the Lead/Zinc Concentrator
Dec 1994	IsaMill M3000 (earlier known as 280/7)powered by 1.1MW motor installed in the Lead/Zinc concentrator
Dec 2003	IsaMill M10000 powered by a 2.6MW motor installed at Anglo Platinum Western Limb Tailings Retreatment Project

Table 1: IsaMill Development Timeline

The table highlights the major mill models that evolved, but does not attempt to show the detail of testwork that was involved with both the mill and flotation circuit downstream of the mill. To go into the development is a case study within itself. Needless to say there were hundreds of trials involved to develop the commercial mill, the M3000, including 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 screenless discharge – ie. product separator.

It is important to note that in just 11 years since the first unit was installed in an operating plant at Hilton Concentrator, the units have increased their capacity 13 fold from 205KW to 2.6MW. Mill volume has increased 20 times in this time frame. This is a very rapid increase in capacity. In comparison, autogenous milling technology took 19 years to increase power draw just 6 times from 1940 to 1959, and this was for a technology that had been around since 1907 in the goldfields of South Africa, (Weiss 1985), (Metso 2004).

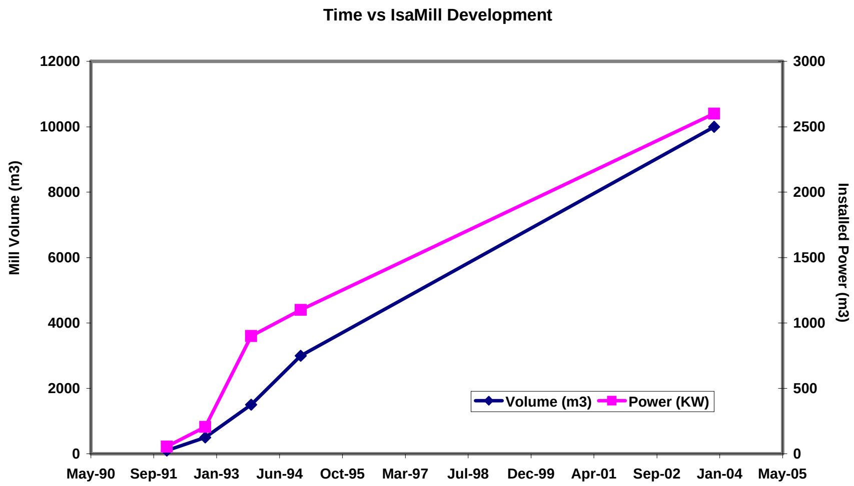


Figure 5: IsaMill Power and Volume Increase

The current model IsaMill, M10000, is powered by a 2.6MW motor, and has enabled large scale mineral processing applications to consider fine grinding as an economic option.

Once installed at Mt Isa and McArthur River, and the resultant success at the operations (as described later), MIM Holdings, allowed the IsaMill to be sold on a commercial basis. This still continues under Xstrata Technology, who actively promote the mill in mineral processing and leaching operations.

Today there are 27 IsaMills installed throughout the world. 14 are installed in Xstrata mines, McArthur River and Mt Isa, the rest are at non Xstrata mines. The mills have been installed by Xstrata Technology and Netzsch.

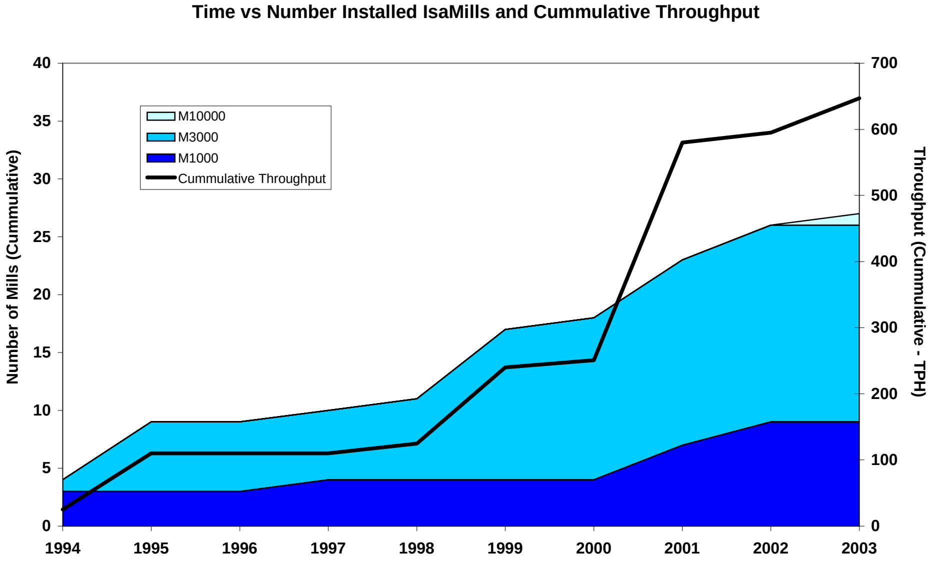


Figure 6: Number of Installed IsaMills (Not counting pilot and lab scale mills)

The technology, while developed to overcome serious liberation problems at the McArthur River and Mt Isa deposits, has become an industry standard in large scale fine grinding applications. It was probably due to its conception at a mine site, and the need to be reliable and robust at these operations that have made it accepted technology in fine grinding.

Of the 27 mills operating at mine sites, approximately 650T/Hr of material is now ground with the IsaMill, or **5.2M tonnes per annum**. The product sizes ranges from a P80 of 7µm to 25µm, for materials ranging from lead and zinc sulphides, platinum concentrates, industrial minerals, iron oxide and refractory gold concentrate. Such a new technology has been embraced by those operations that rely on the finer grinding to achieve metal recovery.

A summary of the Australian lead/zinc operations using IsaMills are as follows:

Operation	Material	Annual Treatment (T/Yr)	P80 (µm)	Recovery (% Metal)	Total Treatment Since IsaMill Installation (MT)
Mt Isa	Zn Cons	350,000	15	>80%	1.7 MT [A]
Mt Isa	Pb Cons	260,000	15	>80%	3.0 MT [B]
McArthur River	Zn/Pb Cons	380,000	7	82%	2.9 MT [C]

[A]: 1994 to June 04
[B]: 1999 to June 04
[C]: 1995 to June 04 – this figure equates to 4.9MT of feed to IsaMills

Table 2: IsaMill Pb/Zn Operations in Australia

In short almost **1MT of lead/zinc concentrate is produced by IsaMills every year in Australia alone**! The average of this material is well under 15µm, which before the development of the IsaMill would never have been economical to treat!

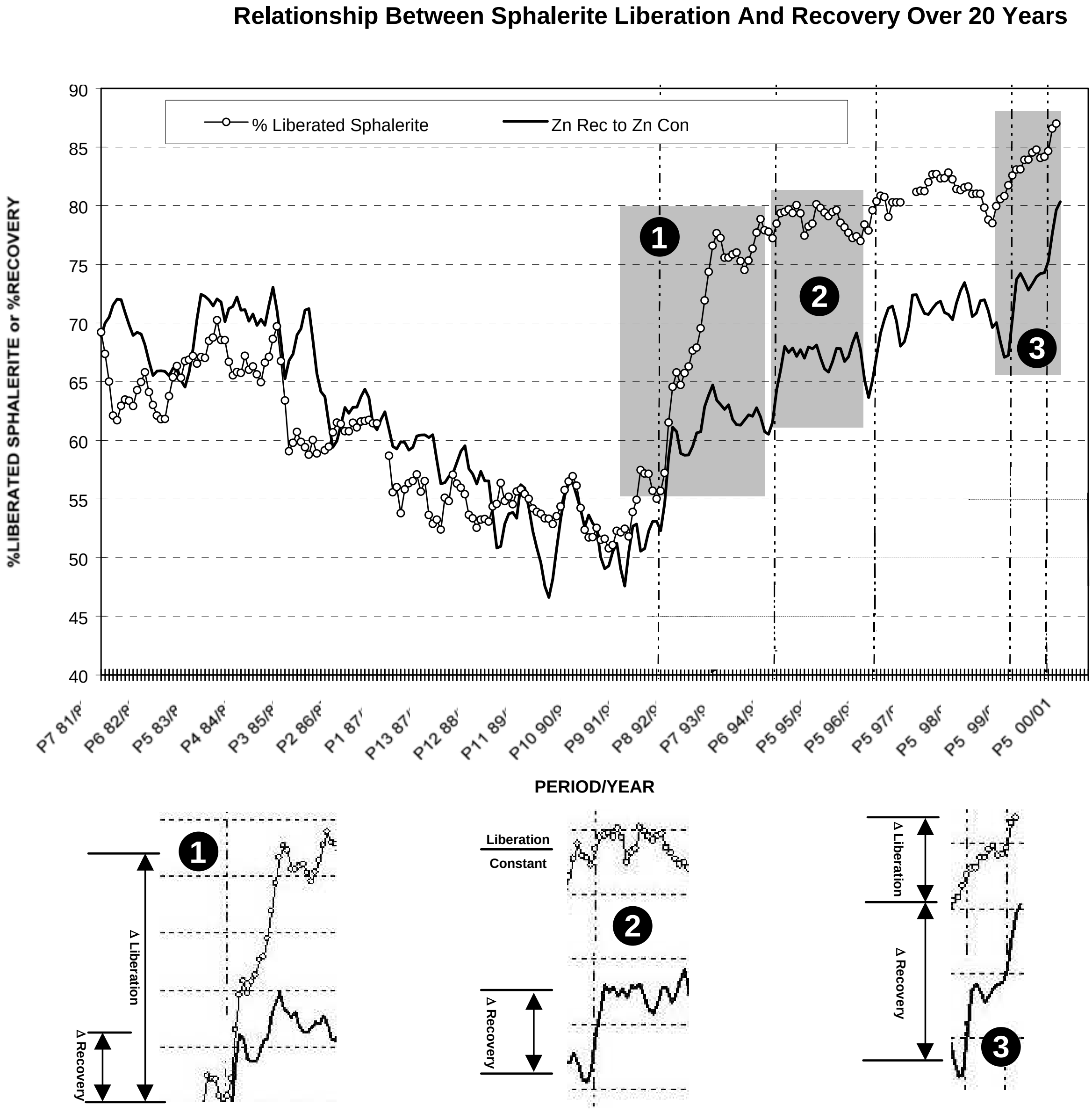
IMPACT OF IsaMills AT MOUNT ISA

As discussed earlier, the addition of more conventional secondary grinding and Tower Mill regrinding resulted in sphalerite liberation improving by 20% (from 55% to 75%), but recovery only improved by 5%. The lack of expected recovery was due to the extra difficulty of floating after grinding in ball and Tower Mills, ie the influence of iron media reducing the slurry.

In 1995 the first full scale prototype IsaMill (to become the M3000) was installed in the lead circuit. Not only did this improve lead performance, but zinc recovery in the zinc circuit also increased even though total sphalerite liberation had changed little. This was because the improvements due to grinding by iron free media from IsaMilling 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.

In 1999 the installation of additional IsaMills for the treatment of the George Fisher orebody, 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. This demonstrates the fundamental changes to fines flotation made possible by ultrafine grinding in IsaMills with inert media compared to conventional means

This is well described in the following graph, figure 7, showing the dramatic turnaround in liberated sphalerite that was recovered to zinc concentrate. During this period ore quality still deteriorated, as more Black Star and George Fisher was being mined, containing the fine grained ore, as well as increasing levels of carbonaceous pyrite.



Ball & Tower Milling Added

Liberation increased by 20 %

Recovery increased by 5 %

Recovery increased less than liberation due to negative impact of steel media on flotation of fines

First IsaMills Added in Lead Circuit

Sphalerite liberation constant

Zn recovery increased by 4 % due to better rejection from Pb conc after IsaMilling

IsaMills Installed In Zinc Circuit

Liberation increased by 7 %

Recovery increased by 10 %

Conc grade increased by 2 %

Recovery benefit higher than liberation increase because of improved flotation after IsaMilling

Figure 7: Zinc Liberation and Recovery

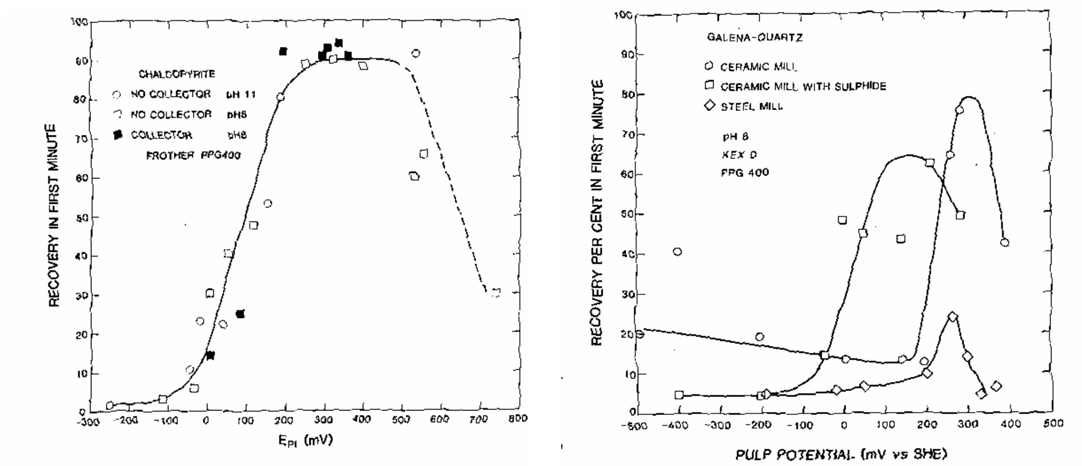
BENEFITS OF IsaMills

From the Mt Isa experience, size is important. It was important to get to 10µm to liberate the complex ore in the zinc circuit. The lead circuit was courser at 25µm. However even with the use of conventional mills and Tower Mills that could get to 25µm, the expected recovery was not achieved. It was only with IsaMills that the size and flotation performance improved. Why?

Three major benefits are gained from IsaMills over competing technologies reported by Pease et al 2004. They were:

- **Impact of grinding on flotation performance.**

  Milling using steel balls as media will effect the Eh as the balls reduce the pulp, creating negative redox potential. This reduces metal recovery, and will only improve as the flotation is oxidised. This is well documented as shown by work in figure 8 (Trahar 1984). The graph showing the impact of ceramic media is especially relevant to IsaMills as the sand media, like ceramics, are inert and has negligible effect on the pulp chemistry. Also conventional and Tower Mills generally have much higher residence times than IsaMills, resulting in lots of steel contamination. In these circuits additional reagents will be required, reducing selectivity or use innovative processes such as High Intensity Conditioning (HIC), eg at Hellyer, to reverse the negative impact of Tower Milling on surface chemistry. Processes like IsaMilling are far more efficient by providing this high intensity as part of the grinding action, and grinding in an inert environment.



Floatability-potential curve for chalcopyrite in presence and absence of collector.

Floatability-potential curves for galena at pH 8 after grinding in different environments.

Figure 8: Redox Potential vs Recovery

- **Power efficiency**

Even if size reduction could have been achieved by conventional milling, tower mills, or other stirred mill technology, only IsaMills provide efficient use of energy. Figure 9 compares the power required to grind a gold ore in a ball mill with 9 mm 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 10, is the breakage rate. In Tower Mills this drops dramatically; the breakage rate for a 20 μm particles is ten times lower than the rate for 40 μm particles. Even though the Tower Mill is full attrition grinding, practically it is constrained to using relatively coarse media, 9mm balls in this case. In contrast, the IsaMill (Netzsch mill in Figure 11) can operate with much finer media and much higher intensity of power input (Table 3), meaning the peak breakage rate occurs at 20 μm, and doesn't drop as quickly below that.

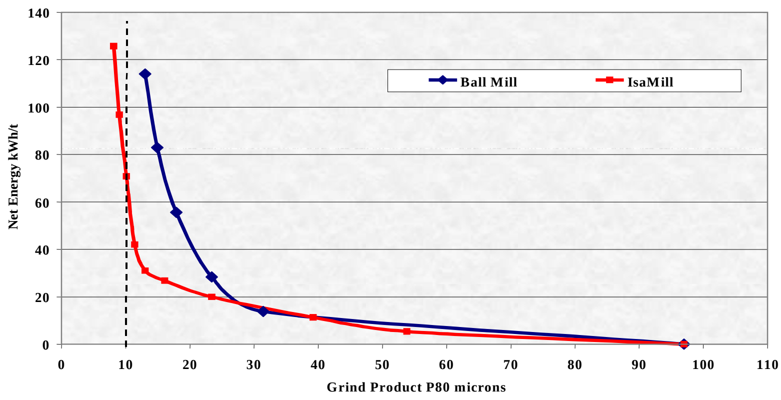


Figure 9: Efficiency of IsaMills Compared to Ball Mills

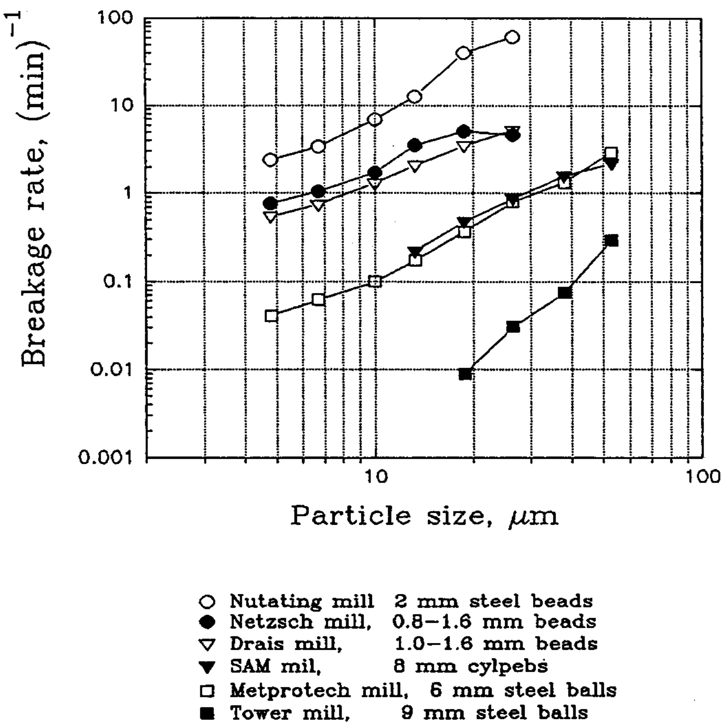


Figure 10: Particle Size vs Breakage Rate for Fine Grinding Mills

(Extracts from AMIRA P336, Gao M and Weller K, Review of Alternative Technologies for Fine Grinding, November 1993)

Comparison of Various Grinding Technologies Independent laboratory data			
FEATURE	**ISAMILL**	**TOWER MILLS**	**VERTICAL PIN MILLS**
Grinding Intensity (kW/L)	**0.54**	**0.005**	**0.15 - 0.18**
Residence Time to 15 µm (min)	**0.6**	**154**	**7 - 9**
Power Usage to 15 µm (kWh/t)	**17.4**	**59.6**	**37.5 - 39.0**
Media Material	**Various**	**Steel**	**Steel**
Media Size (mm)	**0.8 - 1.6**	**9 -12**	**6 - 8**

Table 3: IsaMill, Tower Mill and Vertical Pin Mill Comparison
(Extracts from AMIRA P336, Gao M and Weller K, Review of Alternative Technologies for Fine Grinding, November 1993)

The influence of the sand media greatly improves the chances of contact of the grinding medium and particle. It comes down to simple geometry; the smaller the size the bigger the surface area, and the more particles per volume. This creates a greater chance of contact, as highlighted in Table 4.

	Power Intensity (kW/m^3)	Media Size (m)	No. Balls / m^3	Surface Area (m^2/m^3)
Ball Mill	20	0.02	95541	120
Tower Mill	40	0.012	442321	200
IsaMill	280	0.001	1146496815	3600

Ball Mill is a 5.6m D x 6.4m L @ 2.6MW
Tower Mill is a 2.5m D x 2.5m L @ 520KW

Table 4: Mill Comparison of Media Size, Power Intensity

- **Good classification**

Like all grinding operations, good classification is vital for power efficiency in ultrafine grinding. But the problem posed by particles less that 15 µm is how is it possible to classify this low using conventional technology? In short it is difficult. It is not generally practical to use cyclones to close-circuit a grinding mill with a target below about 15 µm. To get good cyclone efficiency at these sizes requires small cyclones, eg two inch (50 mm) diameter or smaller. This is virtually inoperable on a large scale, so the circuit is either compromised (and less power efficient) by using bigger cyclones, or an alternative solution is needed. The IsaMill at the Mt Isa operations achieved the cut size of 10µm in the zinc circuit by using an internal classifier mechanism, figure 11. This device uses the high centripetal forces generated inside the mill to classify the discharge, ensuring a very sharp product size without external cyclones. At the same time it prevents the fine media from passing out of the mill meaning that low cost media can be used, eg local sand, or granulated smelter slag. Also the very short residence time in the IsaMill also minimises “overgrinding”, further contributing to the sharp product size distribution. This novel classification device replaced the conventional screen that was on the prototype mills in the early 90’s, as it was found impractical to screen out fine particles.

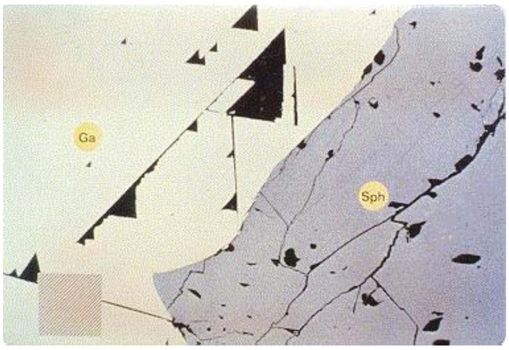
Figure 11 – Patented IsaMill Product Separator

IMPACT OF IsaMills at McARTHUR RIVER

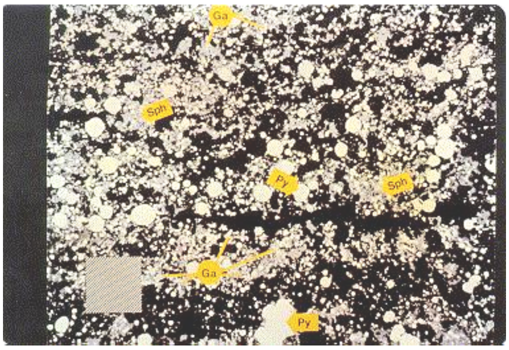
As discussed earlier, the trialing of IsaMills at Mt Isa was to evaluate the use of this new technology for McArthur River. It was well documented the orebody was terribly fine, and was one of the reasons why the orebody had not been developed. It had been discovered in an exploration campaign in 1955 (Legge 1990), but the fine grain structure meant that conventional grinding couldn't liberate the grains fine enough. Figure 12 below, shows a sample of the ore compared to the courser grain structure of a Broken Hill sample (Pease, 2004)

Figure 12 : Different Grain Size of Broken Hill and McArthur River Ores

(Grey Square is 40um)



Broken Hill Ore



McArthur River Ore

However, the success of the IsaMill at the Mt Isa Lead/Zinc concentrator, meant that this deposit could be processed. The IsaMills were described as "enabling technology", and had the ability to grind down to 7µm to produce concentrate economically.

The plant started mid 1995 with 4 IsaMills, followed by another mill in 1998, and another in 2001. Circuit changes over the years have now resulted in a bulk concentrate being produced, where all rougher concentrate is presented to the IsaMills. A cycloning stage separates approximately $^{2}/_{3}$ of the rougher concentrate for regrinding by the IsaMills. It is interesting to note that while the P80 target is 7µm, approximately 50% of the final concentrate is less than 2.5µm. If this was viewed from a number of particles basis, it would mean **96% of the particles are less than 2.5µm report to the final concentrate**, (Pease 2004). This shows it is possible to grind fine and float fine particles.

INFLUENCE OF IsaMilling ON HYDRMETALLURGICAL APPLICATIONS

IsaMills are finding a potential use in fine grind leaching applications. It is currently a very important part in the Albion flowsheet, and has been looked at for other hydrometallurgical leaching processes for nickel and copper sulphides.

In the hydrometallurgical industry the Albion Process is one of the simpler processes. It is a process designed for the oxidative leaching of refractory base and precious metal bearing sulphide ores. The leaching occurs in conventional, non-pressurised reactors, which significantly reduces the capital cost compared to pressure and bacterial leaching processes.

What allows the leaching to be undertaken in relatively mild 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, (Hourn 1999). 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, which enables it to fall apart as it is leached. When the mineral is copper sulphide, the disintegration of the particles prevents the formation of the passive layer that prevents further leaching of the particles. The leach residence time is typically less than 24 hours, and the leach does not use any reagents other than acid, limestone and oxygen.

While other fine grinding technologies can be applied to the ALBION flowsheet, the IsaMill has the advantage of producing a very tight particle size distribution, as displayed in figure 13. The IsaMills are constructed with 8 grinding disc in a small chamber. Every disc acts as a separate grinding operation, therefore 8 disc implies 8 grinding operations. When this is coupled with the product separator, all chances of short circuiting are eliminated. However, other fine grinding practices have a tendency to produce a broad particle distribution as they short circuit some of the feed material.

The tight size distribution is an important factor in leaching operations. Where a flotation process can have slightly oversized particles, which can either report to concentrate or regrinding stages without any major effect on circuit recovery or grade, a leach circuit can be greatly impacted by the presence of large particles. Leaching processes need to have particles that are small enough 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 P98 is important in leach circuits.

Work conducted by Hydrometallurgy Research Laboratory (now a part of Xstrata Technology) conducted several test using different fine grinding bench scale mills, leaching copper sulphide concentrate using the ALBION process. While all fine grinding methods produced a similar P80, the IsaMill produced the finest P98. When the products were then leached, the IsaMill produced an extra 3% of leachable copper compared to other processes. This is displayed in figures 14, where the ratio of P98/P80 is plotted for each grinding process. The ratio of P98/P80 is an indication of how tight the feed sizing is, ie the closer to 1 the sharper the cut.

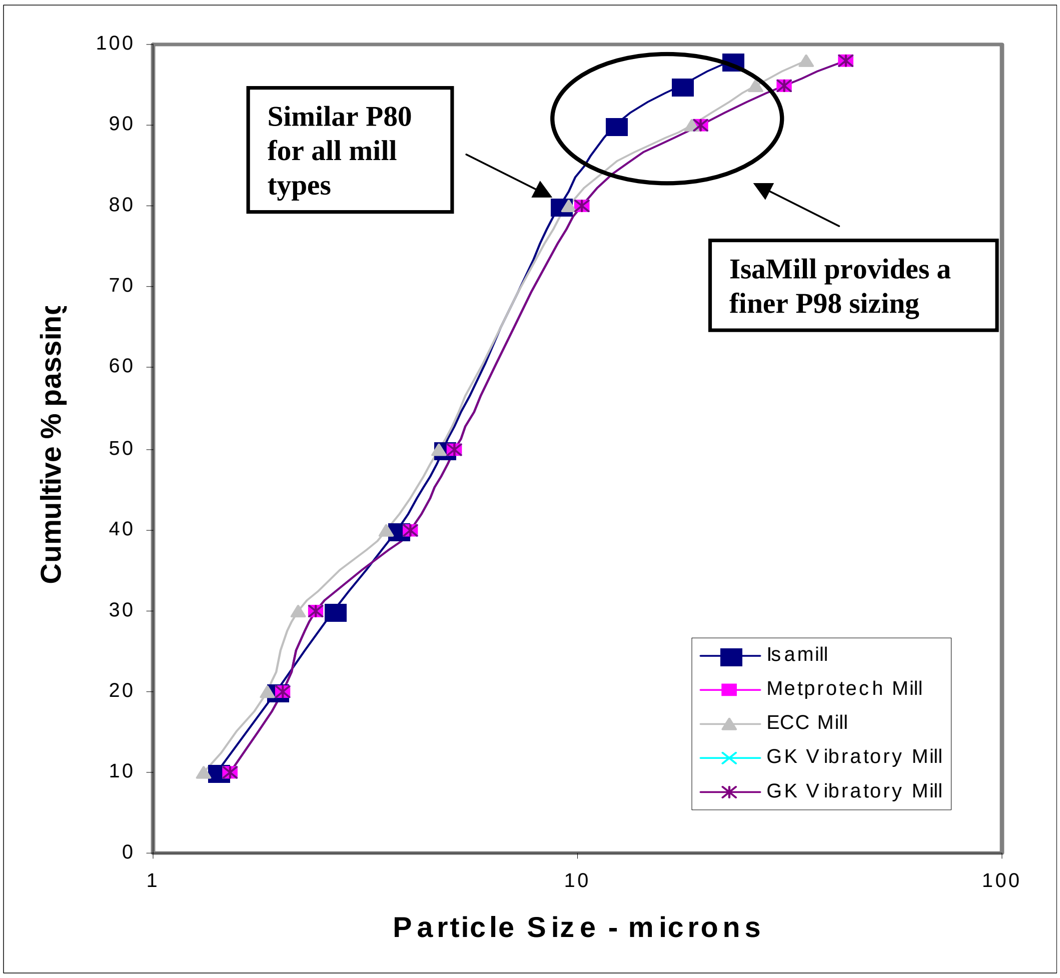


Figure 13 – Particle Size vs % Passing per Fine Grinding Method (Copper Bulk Concentrate)

% Passing - microns	IsaMill	ECC Mill	GK Vibratory Mill	Metprotech Mill
98	23.1	34.4	42.8	51.90
95	17.44	26.33	30.61	33.40
90	12.31	18.6	19.44	23.41
80	9.11	9.56	10.2	8.95
50	4.85	4.71	5.12	4.10
40	3.76	3.55	4.03	3.31
30	2.66	2.21	2.41	2.31
20	1.94	1.86	2.02	1.96
10	1.42	1.32	1.51	1.61

Table 5 – Fine Grinding Method vs Product Sizing (Copper Bulk Concentrate)

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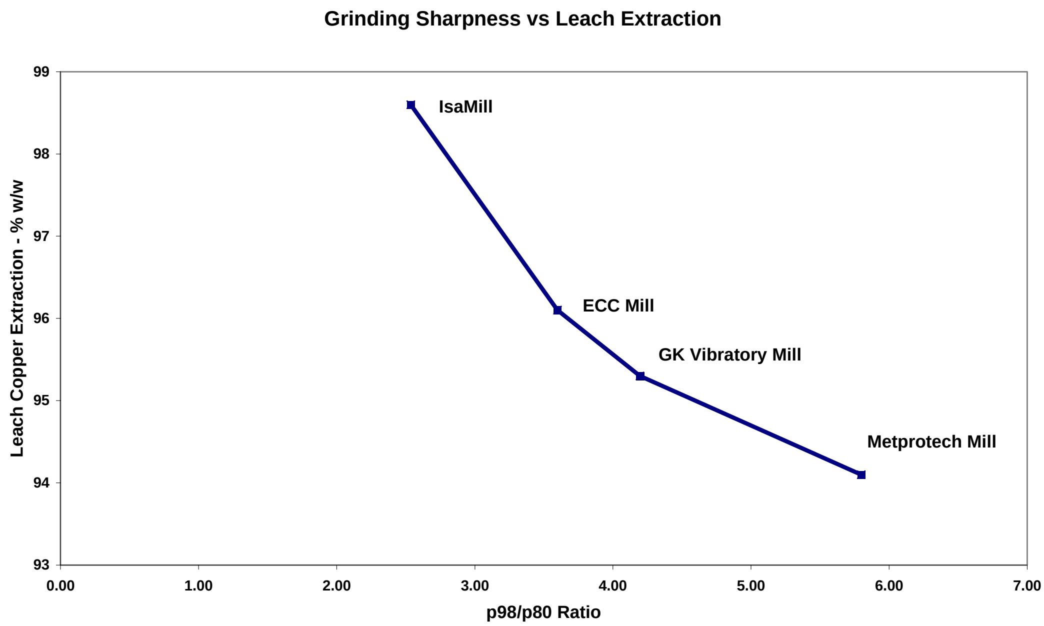

Figure 14: P98/80 Ratio vs Leached Copper Extraction (Copper Bulk Concentrate)

Finally, after the oxidative leach stage of the ALBION Process, the iron is precipitated out as goethite. This stage precipitates the iron and acid liberated during the oxidative leach, as well as neutralising any acid remaining in the slurry ahead of thickening and filtration. Goethite precipitates grow as coarse particles, considerably improving the settling properties of the finely ground leach residue.

The particle size distribution of the goethite residue is significantly coarser than the leach feed. A goethite precipitation stage also has the added benefit of precipitating any arsenic in the feed concentrate as a ferric arsenate, improving the stability of the arsenic phase in a tailings impoundment.

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