

Fine Grinding as Enabling Technology – The IsaMill

Pease, J.D.⁽¹⁾, Young, M.F.⁽²⁾, Curry, D.C.⁽¹⁾

⁽¹⁾ Xstrata Technology

⁽²⁾ Xstrata - Mount Isa Mines

Introduction

The new generation of stirred mills like the IsaMill has fundamentally changed the economics of fine grinding. This has made them enabling technology for several existing and planned operations, and has opened new fields of processing in hydrometallurgy. These opportunities are made possible by the unique combination of features of stirred mills :

- Very high intensity attrition grinding mechanism, suited to fines grinding
- Small media size, essential to increase grinding efficiency for fines
- The use of inert grinding media. This can deliver dramatic improvements to flotation kinetics and recovery, and improved leaching rates and chemistry.

Stirred milling was developed for fine grained ores that required an economic grind to sub 10 micron sizes. The first examples were lead zinc deposits – McArthur River, George Fisher and Mt Isa Blackstar orebodies enabled by the IsaMill, and Century which uses the stirred mill detritor (SMD).

The original application for ultra-fine grained orebodies is a relatively small niche, but it is now clear that there will also be applications in coarser grinding applications, particularly when power efficiency, space, and flotation surface chemistry are important. Two features specific to the IsaMill that make it attractive for coarser grinds are :

- the internal product classifier, which allows low cost open-circuit installations with a sharp product size
- the large unit size (currently up to 2.6 MW) suitable for large scale applications.

Installations at Lonmin Platinum and Anglo Platinum are examples where the IsaMill was chosen for coarser grind applications because of the flotation benefits of inert grinding. The case study of the Anglo Platinum tailings retreatment plant shows that the 2.6MW mill was the enabling technology for the operation.

It is expected that the lower cost of fine grinding will also enable the economics of many leaching technologies operations, eg Activox, Albion Process. For example, in the Albion process atmospheric leaching of otherwise refractory minerals is feasible at fine sizes.

Stirred Milling Technology

Three features of stirred mills that transform the economics of fine grinding are :

- the high intensity attrition grinding environment
- the ability to use fine grained media (eg 1 mm) to suit to the fine grained feed
- the ability to use cheap natural products (local sand, slag, ore) as grinding media

These features distinguish stirred mills as fundamentally different from both ball mills and Tower Mills, as demonstrated by Tables 1 and 2.

	Mill Diameter (m)	Mill Length (m)	Installed Power (kW)	Mill Volume m ³	Power Intensity (kW/m ³)
Autogenous Mill	10	4.5	6400	353	18
Ball Mill	5	6.4	2600	126	21
Regrind Ball Mill	3.2	4.8	740	39	19
Tower Mill	2.5	2.5	520	12	42
IsaMill	1.3	3	1120	3	280

Table 1: Power Intensity of Different Grinding Devices

	Power Intensity (kW/m)	Media Size (mm)	No. Balls / m ³	Surface Area (m)
Ball Mill	20	20	95,500	120
Tower Mill	40	12	440,000	200
IsaMill	280	1	1,150,000,000	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 2: Mill Comparison of Media Size, Power Intensity, number of grinding media

The ability to use smaller media is probably the dominant impact on grinding efficiency. It dramatically increases the grinding surface area and the number of grinding “events”, essential to efficiently grind fine particles. Figure 1 shows the grinding power required to grind a sample of KCGM pyrite concentrate to different target P80 grind sizes, using a ball mill (with 9mm steel media) or an IsaMill with sand media. There is little difference at coarser sizes, but below 30 microns the advantage of stirred milling becomes dramatic. Ball milling simply cannot produce a 10 micron product at any practical power consumption. In this case the IsaMill has extended the economic range of grinding from about 20-30 microns to 10 microns – enabling technology if a 10 micron grind is needed, as it was for the KCGM cyanide leach.

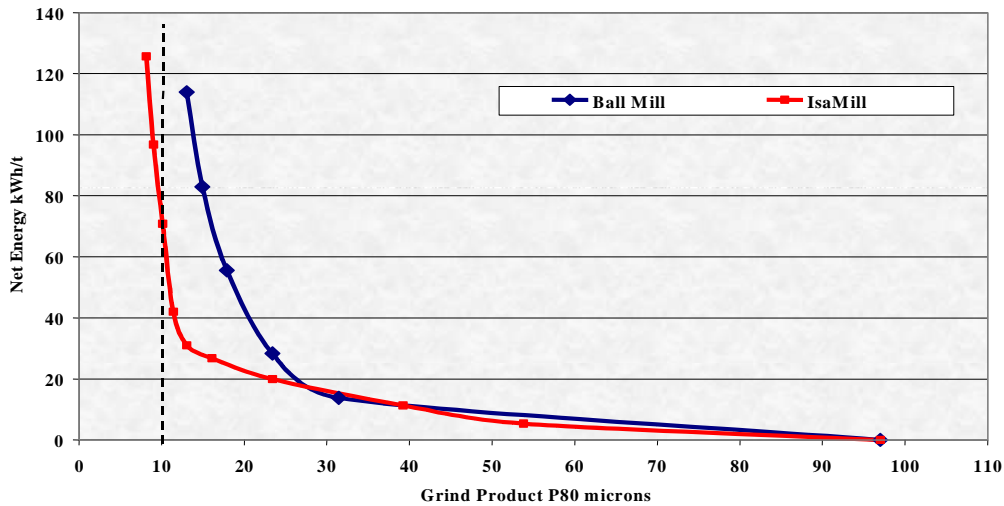


Figure 1 : Grinding Power to produce various product sizes in a Ball Mill (9mm balls) and an Isa Mill (2 mm sand) (for KCGM pyrite concentrate)

Chemistry Impacts

The use of inert grinding media gives a crucial advantage to stirred milling in fine flotation and leaching applications. Even if it were economic to grind to 10 microns in a steel mill with very small balls, the amount of iron in solution would almost certainly ruin downstream flotation or leaching processes. The chemical impacts of steel grinding have been well reported (Trahar, 1984; Frew et al 1994; Greet & Steinier 2004), and compete with the benefits obtained from better liberation. Many plant metallurgists still believe that “slimes don’t float”, in spite of the fact that between them, Mt Isa, McArthur River and Century produce over 1.5 Million tonnes a year of concentrate below 10 microns, at high recovery. At Mt Isa recovery in the zinc cleaners is above 95% in all size fractions from 1 micron to 38 micron. At McArthur River, 96% of individual particles recovered are under 2.5 microns (Pease et al 2004).

While high-Chrome media can reduce the chemistry impact, the cost is higher and the impact for fines is only marginal compared with inert media.

Fine Grinding Before Leaching

Unlike flotation, **leaching** applications do not suffer as much from the same surface chemistry impacts from steel media. The use of steel media, however, can still be detrimental to a leaching process. When fine grinding pyritic concentrates of precious metals, it is common to follow the fine grinding stage with a pre-aeration stage to remove active pyrite and pyrrhotite before cyanidation. Worn steel media in the ground pyrite can significantly increase the pre-aeration time needed. In a recent application of the Isamill, the existing regrind mill before gold leaching was consuming 10 t/day of steel balls. This reduced pulp Eh and extended residence time in subsequent pre-aeration and increased cyanide consumption in leaching.

Three mechanisms are important when fine grinding before leaching :

- **the liberation impact** – in simple cases the grinding is simply to expose fine grained minerals to leachant (eg exposing fine gold to cyanide). In this case dissolution of the host mineral is not needed.
- **the sizing impact** – “refractory” minerals often do react, but are passivated by reaction products forming a 2-3 micron “rim” on the particle. For a 30 micron particle this rim prevents the molecular transfer necessary to keep the reaction proceeding deeper into

the particle. But for a 9 micron particle this rim is sufficient for the mineral to disintegrate (Figure 2).

- **The mechanical activation impact** - the high energy intensity of fine creates a highly stressed surface, reducing the crystalline nature to amorphous phases (Figure 3). The surface defects act as electron transfer sites, accelerating the rate of surface oxidation reactions, and lowering the activation energy required to oxidise the mineral. This effect of mechanical (or mechanochemical) activation of minerals is well reported (Balaz, 2000; Juhasz and Opoczky, 1990; Grelach et al 1989). It means that subsequent leaching of the minerals can take place under much less aggressive conditions, with a reduction in the capital cost of the leach plant.

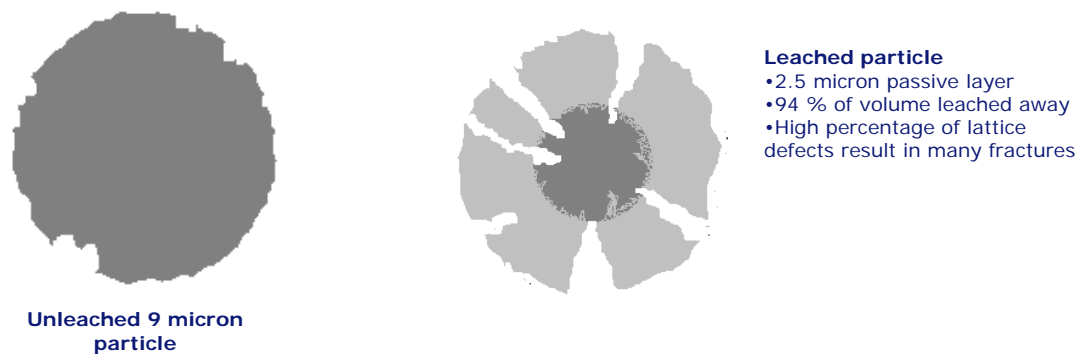
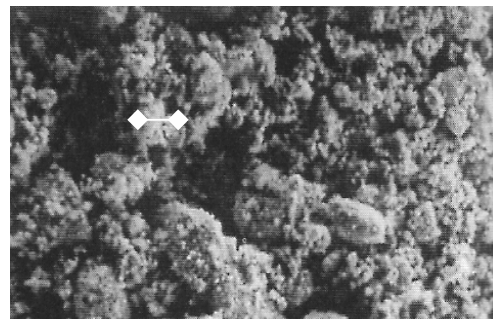
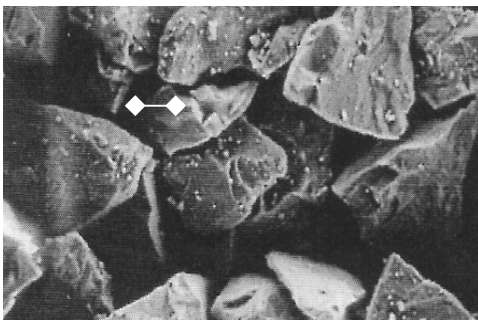


Figure 2: The sizing impact of fine grinding. For a bigger particle, a 2.5 micron passive layer will prevent further leaching, but for a 9 micron particle it is sufficient for the mineral to be consumed.



Chalcopyrite Concentrate prior to Grinding

Chalcopyrite Concentrate Following Ultrafine Grinding

Figure 3 : Impact of intense grinding on surface appearance of Chalcopyrite, the stressed and fractured surfaces on the right leach faster and with lower activation energy, even at the same size particles (from Balaz, 2000).

In practical situations all three effects of liberation, size reduction and surface activation occur together. Each increases leaching rate but it is difficult to distinguish the relative contributions. However the combined impact can be dramatic – eg in Xstrata’s Albion Process, the Isamill grinds and activates minerals to a point where bacteria or pressure are no longer required, and leaching can be carried out in simple open tanks. The extremely high power intensity in the IsaMill compared with other grinding methods suggest it would enhance mechanical activation.

Peculiarities of Fine Grinding – tips for new players

Some aspects of fine grinding are not immediately intuitive to operators of conventional grinding. While there is nothing fundamentally different about small particles, some effects that are minor at coarser sizes become dominant at fine sizes. Some important tips for those designing fines circuits are :

- ***beware the “knee” of the signature plot*** : Figure 1 shows that stirred milling extends the practical range of grinding, but at some point the signature plot still goes “vertical” (the “knee” can be pushed finer by using smaller media). Sometimes clients tell us their target grind size is “about 8 or 10 microns” – but the power to get to 8 microns may be double the power to get to 10 microns.
- ***The importance of consistent sizing technique*** : this follows from the first point. A one micron difference between two sizing machines can change an estimated power draw by 50% ! To compare different grinding devices or media near the “knee” of the signature plot, it is essential that you use the same sizing machine (ideally operated by the same person), otherwise noise in the sizings will overwhelm the results.
- ***The importance of classification*** : every grinding operator knows that sharp classification is important for grinding efficiency. But this is difficult to achieve for ultrafine grinding. A sharp cut at 10 microns needs 2 inch cyclones – but no-one who has ever operated a cluster of 2 inch cyclones in a concentrator will want to do it again. As a result, operators usually choose bigger cyclones, but the operability comes at the expense of grinding efficiency. The solution offered by the IsaMill is to classify within the mill by the centrifugal product separator, which produces a sharper cut than fine cyclones. It also eliminates the extra capital and operating cost of closed circuit cycloning.
- ***Density and Viscosity impacts*** : stirred mills operate at lower pulp densities than conventional mills. The efficiency of the IsaMill is much less affected by density than conventional mills. While efficiency does generally still increase with feed density, the maximum density will be limited by viscosity, and viscosity effects are much more apparent for fine products. Though it is ore dependant, as a general guide sub 10 micron applications will be limited to about 45-50% feed solids.

Power and Energy Efficiency

Grinding energy is one of the major costs of mineral processing. Choosing the right grinding machine and the best media are certainly important. Some other important factors that are sometimes overlooked :

- Energy efficiency should be defined in terms of ***power per unit product*** recovered, not per tonne of ore. Well targeted grinding will improve recovery.
- The ***energy usage of all production steps*** should be considered. This includes energy in the blasting, mining, milling and smelting. Eg, higher concentrate grade will reduce smelting fuel and fluxing needs. It also includes ***the energy content of grinding media*** (eg steel balls versus local slag or sand), and flotation reagents (typically lower consumption after inert grinding).

- The circuit design should aim to apply **the right grinding power in the right place**, on the smallest possible stream, and avoiding circulating loads (Pease et al 2004; Young et al 1997). The circuit needs to be designed to the size-by-size ore mineralogy.
- **Efficient classification.** Grinding before flotation or leaching should narrow the size distribution by reducing the top size particles; it should not waste energy grinding already fine particles. A sharp grinding curve, characterised by a low **ratio of P98 to P80** is vital. This is demonstrated by Figure 4.

As an example, in the George Fisher circuit 6 MW of additional grinding power was installed, but total energy efficiency was increased. This was because the inert milling increased flotation rates, increased recovery, dropped circulating loads (less pump and flotation energy and less spillage rehandling), and increased concentrate grade (less fuel in smelters). The circuit design of applying efficient regrinding to small streams meant that up-front grind size targets could be relaxed. The energy content of IsaMill media is free (granulated smelter slag). As a result, even with the extra grinding power total unit cost per tonne of ore did not increase, yet grades and recoveries increased significantly (Case Study 2).

Figures 4 and 5 demonstrate why the energy efficiency of the IsaMill is so high. Unlike conventional grinding, the size distribution of the IsaMill product **sharpens** with additional grinding. This unique behaviour is because :

- There is no short circuiting – particles have to pass through 8 consecutive grinding chambers, then pass the centripetal field of the product separator before leaving the mill.
- The low volume/high intensity means a short average residence time in the mill (typically 90 seconds). So a particle can travel through the 8 grinding chambers and “see” the product separator within 90 seconds. Fines will exit the mill, coarse particles will be retained.

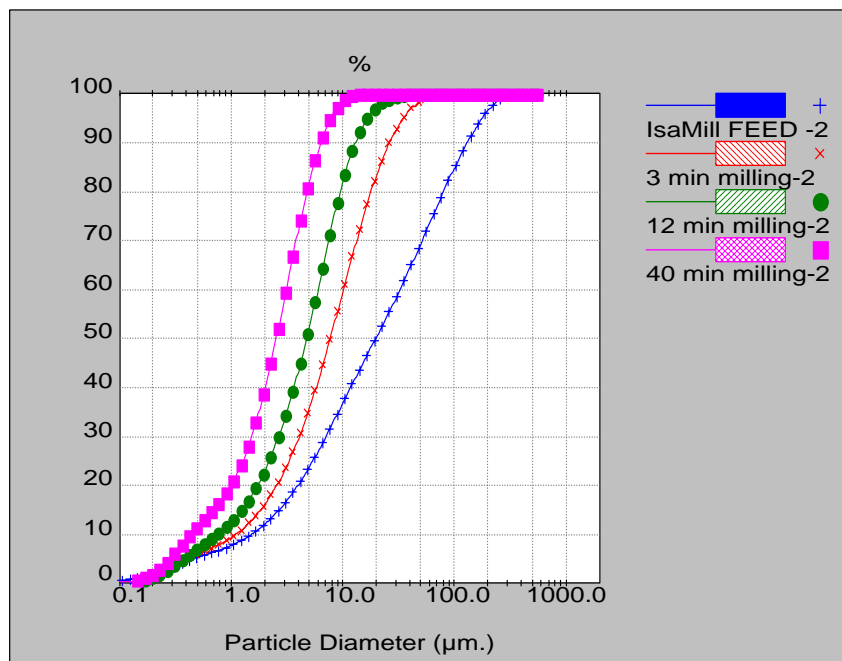


Figure 4: Increasing grinding in an open circuit IsaMill sharpens the product size

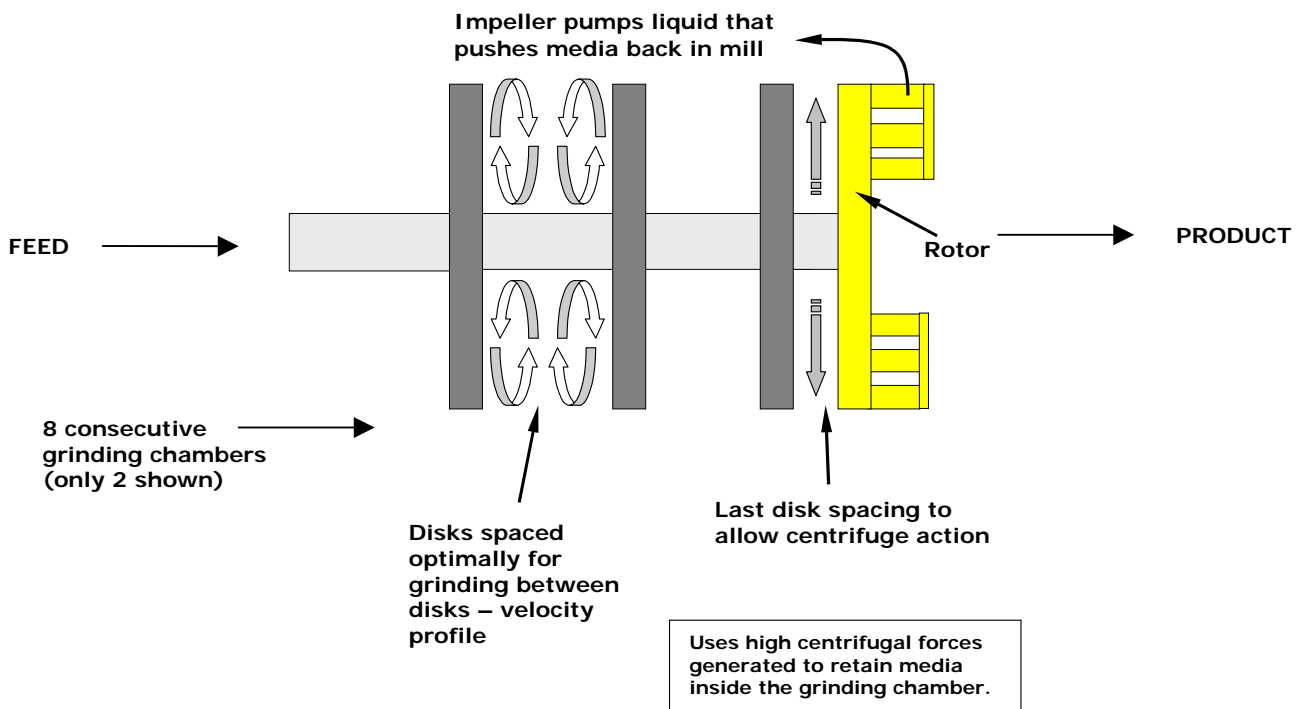


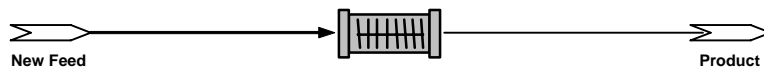
Figure 5: Grinding and Internal Classification Mechanisms in an IsaMill

Recent Developments in Stirred Milling

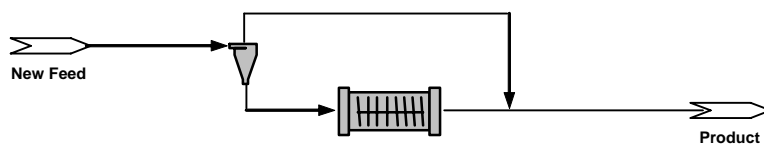
Stirred milling to enable fine grinding and flotation operations is well established - currently 21 MW of IsaMills are installed worldwide, and have produced over 10 Mt of concentrates at Mt Isa and McArthur River alone. Because these applications are in the “niche” of fine grained lead zinc ores, it is easy to overlook the potential for conventional grinding. Recent developments in IsaMills bring some crucial advantages to more conventional grind size:

- improvements in design and materials for **wear parts** – eg “slip-in” shell liners. IsaMills routinely achieve availabilities over 97% at McArthur River and Lonmin Platinum (lower at Mt Isa since mills are frequently taken off line to conserve ore).
- Taking advantage of the **internal classifier in the circuit design**. In early installations (eg MRM) we took a “belts and braces” approach to classification, backing up the product separator with cyclones. In fact, cyclones reduce circuit performance, resulting in a flatter size distribution than produced by an open circuit IsaMill. The ideal IsaMill installation is shown in Figure 6, precyclone mill feed if necessary, but run the mill in open circuit.
- Developments in **grinding media**. The product separator allows cheap local grinding media to be used (there is no screen to block if some media degrades). For example, Mt Isa operates on waste granulated smelter slag, MRM ran for 6 years on autogenous ore chips, and Lonmin and Anglo use local sand at \$US 0.08/tonne milled. Concurrently, there are new developments in manufactured media – higher cost, but low wear rates and much higher grinding efficiency in some applications. The availability of a standard product, with a choice of media size to suit the application, is important for the stirred mills to be accepted as a mainstream option.
- The successful scale up to the **2.6MW mill**.

In combination, these developments mean that IsaMills may be a low cost, high efficiency alternative in some mainstream grinding applications. The low cost comes from simple installation – low footprint, low crane heights and loads, no need for closed circuit cyclone installations – an IsaMill installation is fundamentally different from a conventional grinding mill installation.



Recommended Configuration : Open Circuit



If Densification Of Feed Required : Pre-Cyclone Circuit

Figure 6: Recommended circuit configurations for IsaMilling, taking advantage of sharp internal classification.

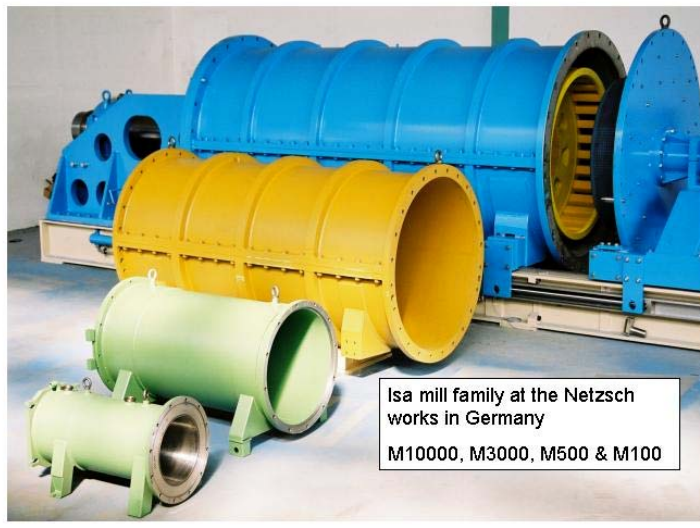


Figure 7: The IsaMill range (left); 'slip in' rubber shell liner

Case Study 1 : McArthur River Mining (MRM)

The McArthur River lead zinc deposit was the driving force behind the development of IsaMills. The orebody was discovered in 1955. It had a resource of 227 Mt at 9.2% Zn and 4.1% Pb, however no existing technology could economically treat the extremely fine grained minerals (Figure 8). The development of the IsaMill was truly enabling for this orebody. It allowed economic regrinding to 80% passing 7 microns, fine enough to reduce silica in bulk concentrate to marketable levels. Note that even at this size there is not adequate galena-sphalerite liberation to allow separate lead and zinc concentrates.

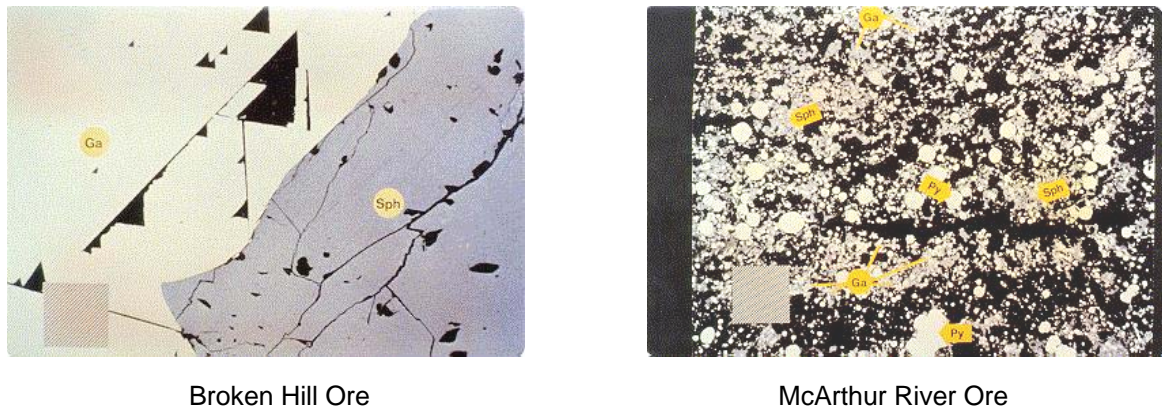


Figure 8: Different Grain Size of Broken Hill and McArthur River Ores (Grey Square is 40um)

The plant started mid 1995 with 4 IsaMills regrinding rougher concentrate. Media for the mills was provided by screening a fraction of ore gravel from the SAG mill discharge – a fully autogenous ultra-fine grind ! , Two more mills were installed to increase production and recovery (in 1998 and in 2001). In 2004 the media was changed from ore gravel to screened sand – the higher efficiency of the sand increased mill capacity, and reduced wear on mill components at the higher throughputs.

Table 3 shows production performance at MRM – very high concentrate grades and recoveries are achieved in spite of the ultrafine minerals. This disproves the view that “fines don’t float”. Consider the following perspective : a P80 of 7 micron means a P50 of 2.5 microns at MRM. While 50% of concentrate weight is finer than 2.5 microns, this means that 96% of individual particles recovered are less than 2.5 microns. Since flotation depends on individual particles attaching to bubbles, this means that 96% of the successful particle-bubble collisions at MRM happen for particles finer than 2.5 microns, into a high grade concentrate at high recovery. Fines float very well indeed after IsaMilling.

MINING			METALLURGY			
	Tonnes	Head Grade	Tonnes	Zn Recovery	Con Grade	
					%Zn	%Pb
1995/96	707,994	12.9%	759,519	66.4%	39.3%	11.2%
1996/97	1,035,222	14.4%	1,026,150	73.5%	43.5%	11.0%
1997/98	1,127,000	16.1%	1,139,000	74.3%	43.3%	11.9%
1998/99	1,222,238	16.4%	1,220,957	79.5%	45.0%	12.7%
1999/00	1,254,227	16.3%	1,262,639	80.9%	46.9%	12.0%
2000/01	1,226,499	15.4%	1,270,319	82.4%	46.8%	11.2%
2001/02	1,398,109	14.9%	1,404,539	82.7%	46.8%	11.1%
2002/03	1,505,306	12.7%	1,511,856	82.4%	46.6%	10.5%
2004	1,523,243	13.2%	1,579,762	80.1%	47.1%	10.4%

Table 3 : Performance of McArthur River since commissioning

Case Study 2 : George Fisher Oreboddy

The IsaMill technology for MRM was developed in the lead zinc concentrator at Mt Isa. It was clear that the technology would have benefits for the Mt Isa lead zinc orebodies, and it was to prove enabling for the George Fisher orebodies north of Mt Isa. While not as fine grained as MRM, components of George Fisher require a 7 micron grind to achieve acceptable concentrate grades and recoveries.

A circuit was designed to treat the mix of ores from George Fisher, Hilton, and Mt Isa lead zinc orebodies (Young et al, 2000). The circuit included eight 1 MW IsaMills, grinding lead rougher concentrate and intermediate zinc streams as shown in Figure 9. The principles of the circuit design were :

- **Only grind the minerals you have to** – this needs a thorough understanding of size by size mineralogical performance throughout the circuit. Recover what minerals you can at coarser sizes, then apply successively finer grinding and flotation stages to recover the finer grained minerals.
- **Float in narrow size distributions and tailor the flotation conditions to suit** – this is achieved in the staged grind and float circuit in Figure 9, with separate zinc recovery stages for 37 micron, 15 micron and 7 micron particles. A vital principle is to avoid circulating loads – if particles don't float in the 37 micron circuit, **don't** send them back to roughing, send them to regrinding and a custom designed circuit. The circuit may look more complex on paper, but in reality is much simpler to operate.

In fact the benefits of the inert grinding and the staged flotation design were so profound that it took us 6 months to appreciate them. Figure 10 shows the immediate 5% zinc recovery gain after installing. This was the gain due to extra liberation of sphalerite, and was all we expected. The “second wave” of even higher benefits happened when we realised that the clean surfaces from inert milling, and the staged flotation circuit, fundamentally changed mineral behaviour. In spite of the finer grind we didn't need more reagent, we needed less. We didn't need more flotation capacity, we needed less – fine minerals floated quite fast in conventional cells when they had clean surfaces and the right reagent conditions. The net impact of the circuit changes was :

- Lead recovery increased by 5% and lead concentrate grade increased by 5%
- Zinc recovery increased by 10% and zinc concentrate grade increased by 2% (in economic terms equivalent to 18% recovery increase at the same grade).
- Unit cost per tonne of ore was unchanged in spite of 6MW of extra grinding power.

Figure 11 demonstrates the combined effect of the staged grinding and cleaning approach – high zinc recovery (+95%) in all size fractions from 1 micron to 38 micron.

Mt Isa Pb / Zn Concentrator Flow Sheet

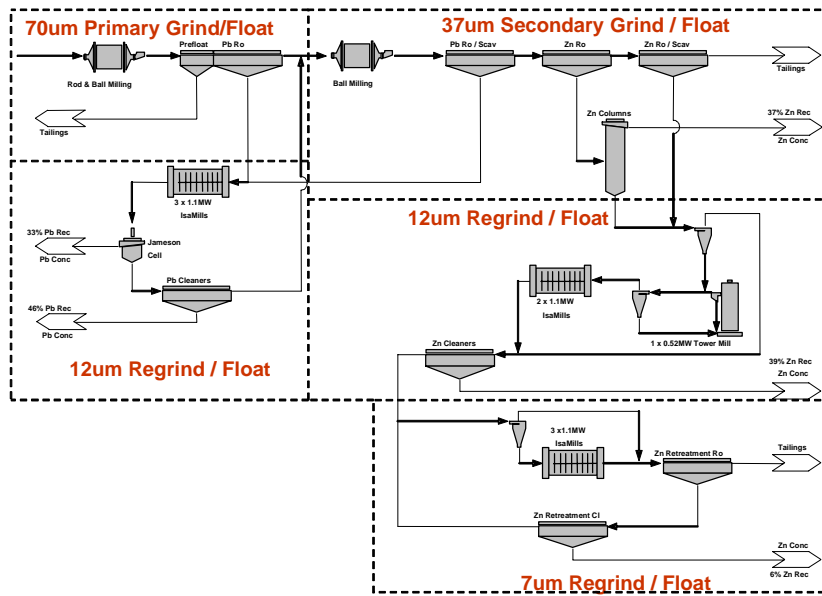


Figure 9: Mt Isa Pb/Zn Concentrator Flow Sheet

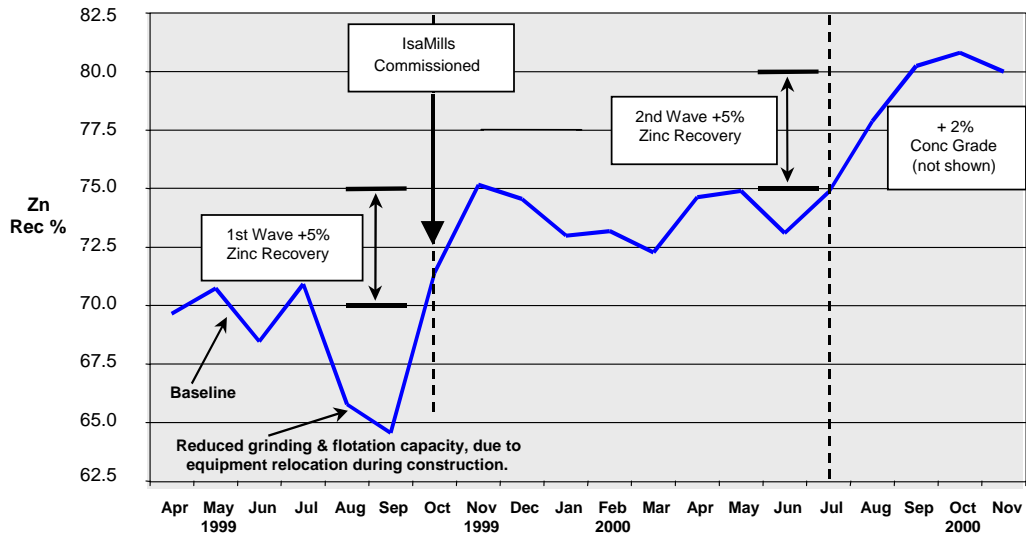


Figure 10: Zinc Recovery Increase from IsaMilling

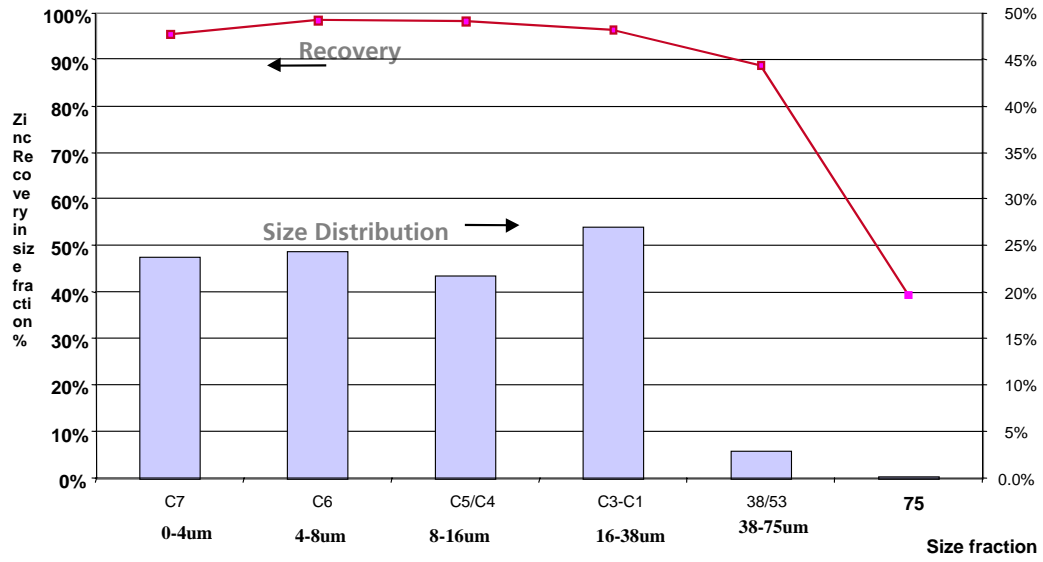


Figure 11: Mt Isa Zinc Recovery from Rougher Concentrate by Size

Case Study 3 : Mt Isa Black Star Open Cut

Surface resources at Mt Isa had long been a target for open cut mining. However the poor metallurgical response was always a barrier to production. Much of the ore is “transitional” between surface oxides and deeper primary sulphides. The transition ore is lower grade than primary ore, has fine grained mineralogy, and leaching has activated pyrite and sphalerite, leading to non-selective flotation. Constant attempts over the last 80 years failed to make the ore economic, with flotation unable to make smelter quality concentrates at any recovery.

The development of the IsaMills and the flowsheet to treat George Fisher ore changed this. The fine grinding achieves mineral liberation and cleans the mineral surfaces by attrition, and the combination of high intensity inert grinding and the correct water chemistry in flotation stops re-activation of unwanted minerals. The impact is shown by the grade recovery curve in Figure 12 - target concentrate grades can now be made at acceptable recoveries.

As a result, the IsaMills were the enabling technology that led to the approval of the Black Star Open Cut project at Mt Isa. Stripping commenced in 2004 and ore mining will commence in the first half of 2005, targetting 1.5M t/y to supplement underground production, produced from a mineral resource of 25Mt at 5.1%Zn and 2.7%Pb. This project represents only a small portion of the potential open cut resources at Mt Isa, the economics of which will also be reassessed once this project has been successful.

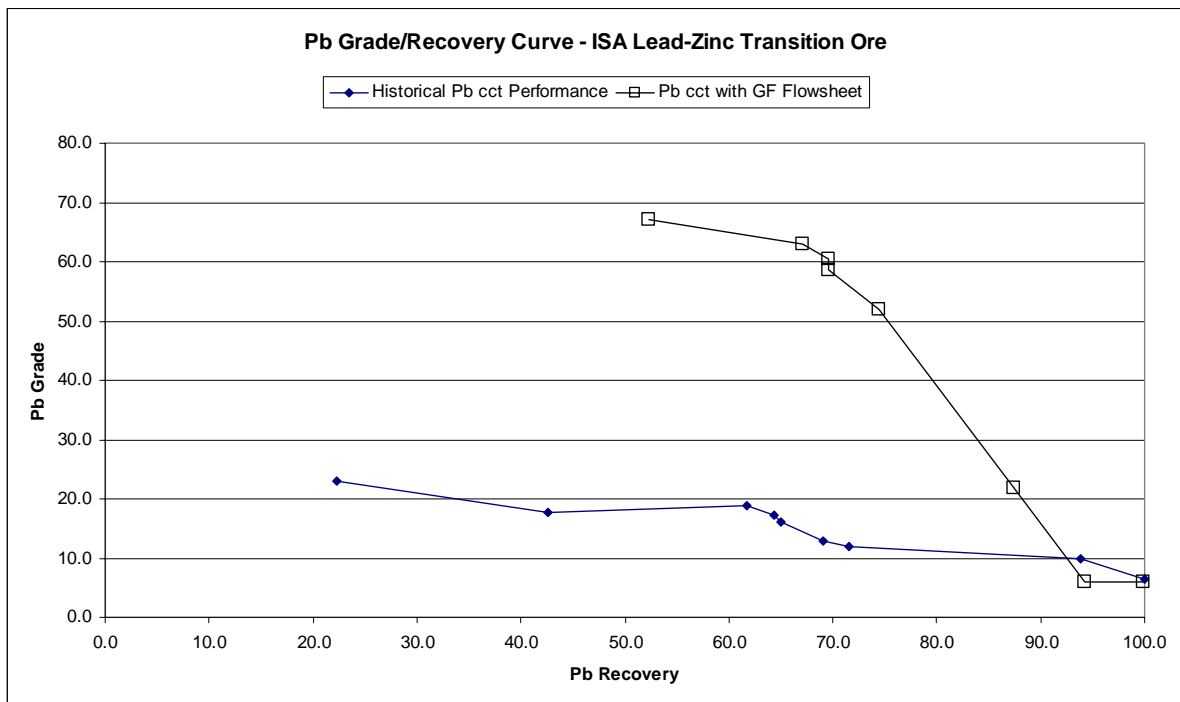


Figure 12: Pb Grade/Recovery Curve – ISA Lead-Zinc Transition Ore

Case Study 4 : Merensky Platinum Tailings Retreatment Plant

During 2001 and 2002, Anglo Platinum assessed the retreatment of dormant tailings dams in the Rustenberg area in South Africa. These tailings represented a possible economic resource with the new grinding technology. Two processing issues were:

- The fine grained mineralisation of platinum (why it wasn't recovered first time)
- Surface oxidation and oxidation products which harmed flotation – some of the tailings were placed over 100 years ago.

A collaborative project was undertaken by Anglo Platinum and Xstrata Technology to find an economic treatment. To achieve economies of scale for the project the IsaMill had to be scaled up from 1,000 kW to 2,600kW.

The program was successful, and the large IsaMill proved to be the enabling technology for this project due to :

- The ability to grind fine at low cost – the mill operates in open circuit, and uses cheap local sand as the grinding media.
- The clean mineral surfaces resulting from the inert grinding environment. This was crucial to achieve target grades and recoveries after regrinding.

Figure 13 shows the improvement that IsaMill regrinding makes on cleaning rougher concentrate (Buys et al, 2004). The mill grinds rougher concentrate, thereby reducing power input compared with targeting a fine primary grind. It was found that this also improved cleaner flotation compared with fine primary grinding before roughing. It is likely that the clean surfaces produced in the IsaMill would re-oxidise during the 45 minute roughing period. In contrast, fine grinding immediately before cleaning **increased** flotation kinetics in cleaning (in contrast to the common observation that regrinding in a steel mill slows kinetics of all minerals).

Anglo Platinum commissioned the Western Limb Tailings Retreatment Plant in 2004. At the end of 2004 they concluded that (Buys et al, 2004) :

- IsaMill technology was enabling for the WLTR project since it allowed acceptable concentrate grades to be made from oxidised slow floating tailings.
- Flotation kinetics improved after fine grinding due to both extra liberation and the removal of iron oxide surface coatings. Inert fine grinding of rougher concentrate was necessary.
- The scale up to the M10,000 IsaMill (from 1 MW to 2.6 MW) was successful.

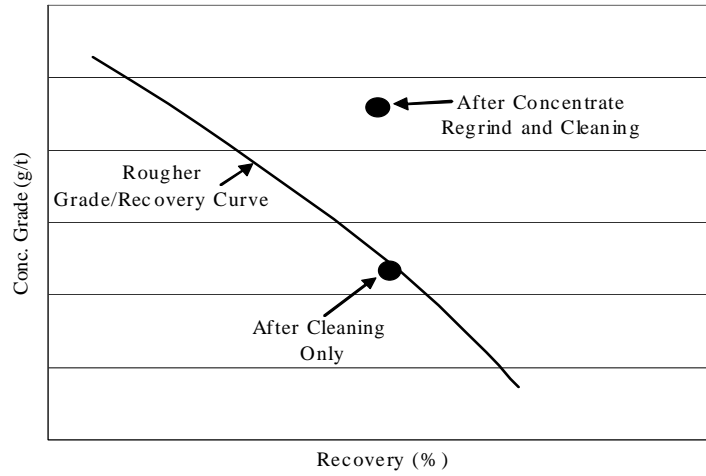


Figure 13: Improvement in Platinum Grade/Recovery After IsaMilling for Western Limb Tailings Retreatment

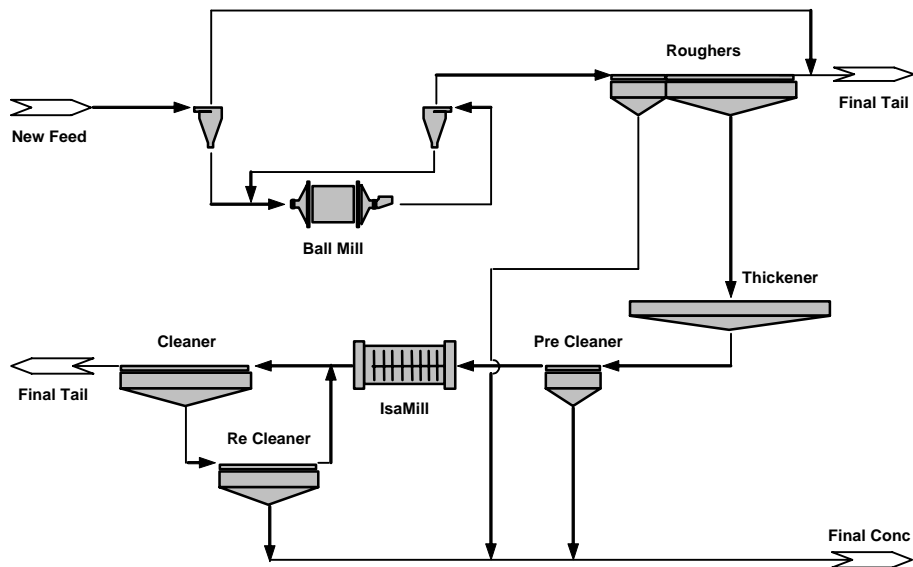


Figure 14: Western Limb Tailings Retreatment Flowsheet

Case Study 5 : Hydrometallurgical Processes and The Albion Process

The ability to efficiently grind minerals to 10 microns is an enabling step for several hydrometallurgical technologies. Fine grinding improves both kinetics and thermodynamics of leaching. The high surface area of fine particles gives high leaching rates at relatively low temperature and pressure, reducing capital and operating costs. Fine grinding also reduces the activation energy required to leach minerals. Several patented processes rely on fine leach feeds, eg the Activox process, the UBC/Anglo process (Driesinger and Marsh, 2002; Hourn and Halbe, 1999), the Phelps Dodge Process (Marsden and Brewer, 2003), and Xstrata's Albion Process (Hourn and Halbe, 1999).

In these processes, metals are leached from a sulphide concentrate by oxidation. Oxidation is typically achieved using ferric iron or oxygen. Fine grinding facilitates the action of both ferric iron and oxygen, making the mineral easier to leach. Fine grinding also ensures that the mineral disintegrates before the leaching surface is passivated by the deposition of leach products.

Fine grinding can also help leach precious metal from sulphide concentrates where oxidation is not required. Preferential breakage of minerals along grain boundary fractures, where occluded gold and silver often accumulate, can significantly improve precious metals recovery.

The Albion Process is a graphic example of the powerful combination of fine grinding plus leaching. Minerals traditionally regarded as "refractory" leach easily at atmospheric pressure and temperatures below 100 degrees when ground finely. Xstrata has demonstrated this process for leaching of sphalerite, chalcopyrite, pyrite, arsenopyrite, stibnite, pentlandite, cobaltite and enargite

Xstrata Technology's 1 t/d Albion Process pilot plant recently operated for 20 months treating McArthur River zinc concentrate, achieving 98% Zn recovery in leaching at 18 - 24 hrs residence time. Leaching was carried out at atmospheric pressure and 80 - 90 degrees. The pilot produced over 30 tonnes of full scale SHG zinc cathodes. Xstrata Zinc is currently undertaking a feasibility study for a full scale plant using this technology.

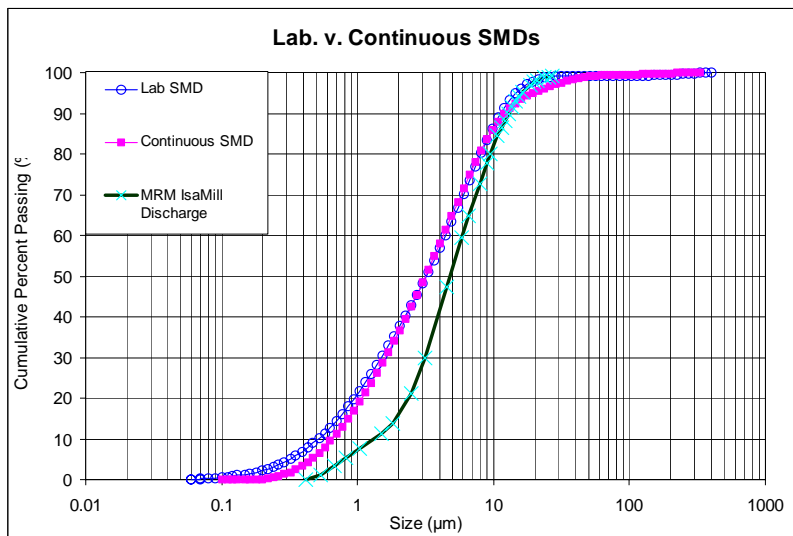
Advantages of the Albion Process are :

- The ability to treat a lower grade copper or zinc concentrate than conventional roasting or smelting. This may allow a lower ore cut-off grade. For MRM, the ability to leach a low-grade concentrate would increase economically recoverable zinc from 3.6 million tonnes of recoverable zinc to 11.5 million tonnes.
- Compared with conventional zinc refining, the Albion Process avoids either the high pressure autoclave leach, or the roasting step before leaching. The capital cost savings are estimated at \$ 1000 per annual tonne of recovered zinc, with the roaster, acid plant, acid storage facilities and concentrate filtration and storage sheds eliminated.
- Either a Goethite or Jarosite stage can be used for iron control. Goethite is favoured since it precipitates as coarse particles, which are easy to filter and environmentally stable. Any arsenic present in concentrate is fixed in residue as ferric arsenate, a stable phase for tailings impoundment. This could prove enabling for high Arsenic copper ores that cannot be treating by primary smelting methods.
- The simplicity of operating a grinding mill and rubber lined atmospheric tanks means that the Albion process can suit small operations, eg refractory gold operations in remote sites. Such operations would be unlikely to bear the cost and complexity of high pressure or bacterial leaching processes. The rapid leach kinetics typical of Albion Process

residues in cyanide leaching can mean that the Albion leach circuit can be retrofit using existing tanks. In such cases, the only substantial new equipment may be the Isamills.

The mechanisms of leaching fine particles (particle size and surface stress) highlight the importance of the grinding and classification circuit. A high intensity environment like the IsaMill would be expected to create highest surface activation. It is hard to quantify this effect separately, because the IsaMill also produces a much sharper size distribution than other mills, also contributing to higher leaching rate. This impact has not been quantified, because it is hard to distinguish it from the sizing effect. Figure *** above demonstrates the crucial importance of P98 in leaching. A 30 micron particle simply may not leach after the 3 micron passive layer has formed – so a P98 of 30 microns may give 2% lower recovery than a P98 of 19 microns, even for the same P80. Similarly, if the objective of grinding is simply to expose finely disseminated gold to a cyanide leach, then gold disseminated in 30 micron particles will be lost.

Figure 15 illustrates the different size distributions of two large scale industrial applications – IsaMills at McArthur River, and detritors at Century (Reemeyer, 2004). Both operations produce a similar P80, but the IsaMill produce a much finer P98. In flotation this difference is not dramatic, but it is for leaching. There is a vital conclusion for project economics – achieving a sharper size distribution (lower P98/P80 ratio) may mean that the same recovery can be achieved at a coarser grind size (measured by P80). In ultrafine grinding, this may mean a 30% lower power requirement (see Figure 1), or alternatively higher recovery at the same power consumption. This highlights the crucial importance of sharp classification in circuits before leaching. The sharp size distribution from open-circuit IsaMills is because each particle has to first pass through 8 consecutive grinding segments, then has to escape the centrifugal forces of the product separator before leaving the mill.



MRM plant IsaMills:

P80 9.5

P98 19.5

Century plant

P80 8

P98 38

Century Lab scale

P80 8

P98 19.5

Figure 15: Comparison of Sizings from MRM (IsaMill) and Century (SMD)

This effect has been demonstrated frequently in laboratory scale leaching. Table 4 and Figures 16 and 17 show the effect of different grinding technologies on sizing and copper recovery for chalcopyrite leached in the Albion Process. For the same P80, copper recovery varied by 3 % for different grinding machines, due to a combination of different P98 and different surface condition. A measure of the sharpness of the sizing curve is the ratio P98/P80. A value closer to unity means a sharper size distribution, and a higher leach recovery.

% 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

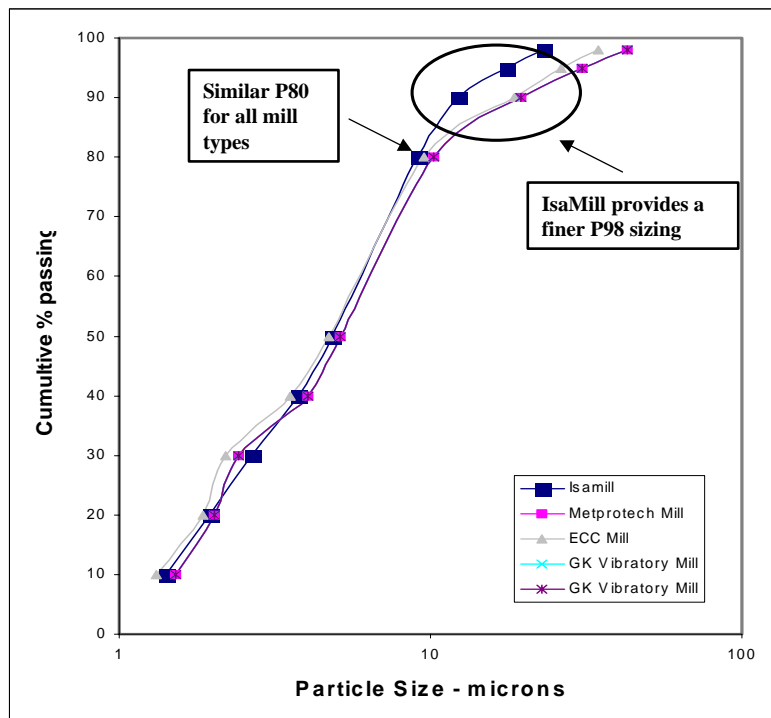


Table 4 and Figure 16:
Particle Size Distributions for Chalcopyrite Concentrate with Varying Grinding Mills
 laboratory grinding with different mills, with the same feed and same sizing device)

Grinding Sharpness vs Leach Extraction

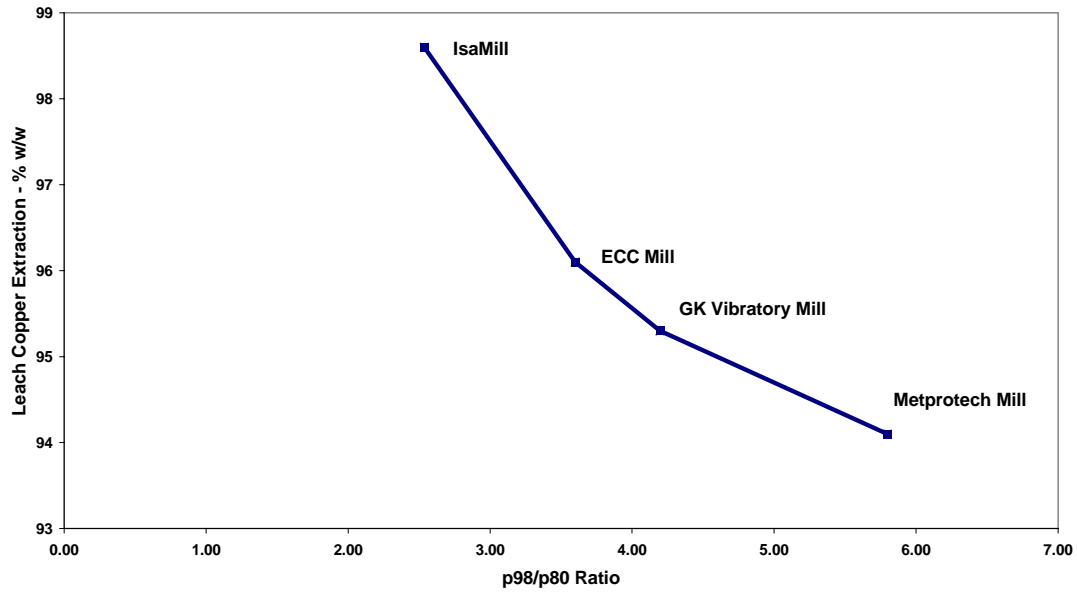


Figure 17: P98/80 Ratio vs Leached Copper Extraction (Copper Bulk Concentrate)

Of course, other grinding mechanisms can also produce a sharper cut by placing mills in series to minimise short circuiting, and/or by closed circuit cycloning of the mill discharge. But closed circuit cycloning is expensive and difficult, requiring a cluster of small cyclones to cut sharply at fine sizes. Further, a sharp cut in closed-circuit cyclones usually requires water dilution of cyclone feed – which may then necessitate a cost intensive dewatering stage before leaching. In this case the IsaMill can produce a sharp size distribution with two less unit processes, at lower capital cost, lower operating cost, and better energy efficiency.

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