IMPROVING FINES RECOVERY BY GRINDING FINER

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ABSTRACT

"Conventional wisdom" has deemed that fine particles have low flotation recoveries. Plant size -recovery graphs often have the classic "hill" shape - high recovery in the mid sizes and low recovery at the fine and coarse ends. Yet if mineral liberation is poor, low fines recovery may be because you don't grind fine enough!

This apparent paradox is explained by the old concept of "sand/slimes" circuits, which recognises the different flotation needs of fine and coarse particles. This concept is overlooked in the push for simpler circuits and larger equipment. Most plants now treat all particles together in a wide size-distribution. Reagent conditions are set for the dominant coarser particles, so fines are starved of collector. Worse still if there are significant mid-sized composites - often these have to be rejected in cleaning to achieve target concentrate grade. But the conditions which reject mid-size composites - collector starvation and high depressants – also reject fine liberated particles. In fact, fines flotation can be excellent when flotation chemistry is tailored to fines.

After first recovering fast floating liberated particles, correct grinding to liberate remaining composites is essential to increase fines recovery. Firstly, liberating composites allows lower depressant and higher collector additions, since composites will not dilute the concentrate. Secondly, finer grinding narrows the size distribution to flotation, allowing reagent conditions to be set to suit all particles. Additionally, fine grinding in an inert attritioning environment like an IsaMill removes surface deposits that may have made some fines slow-floating.

An excellent case study is the installation of IsaMills in the Mount Isa lead zinc concentrator to grind lead and zinc rougher concentrate to 12 microns and zinc cleaner tailings to 7 microns. Most plant losses had previously been in the sub 10-micron fraction, yet ultra-fine grinding increased plant recovery by 5% lead and 10% zinc. Circulating loads dropped, reagent additions dropped in spite of the much higher particle surface area, and the plant became much more operable and responsive.

INTRODUCTION : THE CONVENTIONAL VIEW

The conventional view of the flotation size-recovery curve is shown in Figure 1. There is a good reason for this view – if you sample almost any flotation plant you will produce a similar curve. The numbers speak for themselves – fine particles float poorly in most plants. Operators carefully avoid "overgrinding" and "sliming" of feed.

Yet this obvious conclusion is challenged by practice in some other plants. For example, Xstrata's McArthur River Mine (MRM) produces 380,000 t/y of concentrate at a P80 size of 7 microns (μm), and a recovery of 82%. And Mount Isa Mines produces 260,000 t/y of lead concentrate and 350,000t/y zinc concentrates at P80 about 15 μm and over 80% recovery. The biggest problem for these plants is coarse particles – anything over 20 μm is considered as "gravel" which will reduce recovery.

Figure 1 : Typical Recovery vs Size Curve

RESOLVING THE PARADOX

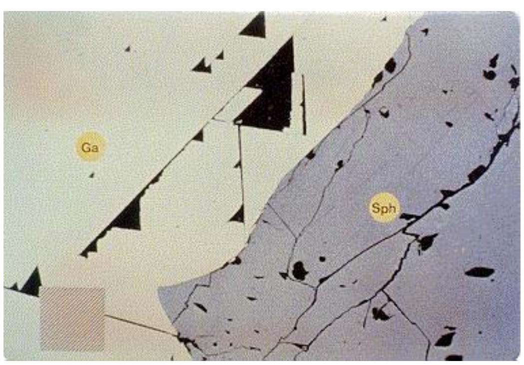
Why is it that most plants fear fines production, yet others rely on it? The answer lies in three areas:

- Mineralogy and liberation
- Operating constraints and strategy
- Flotation rates and surface area

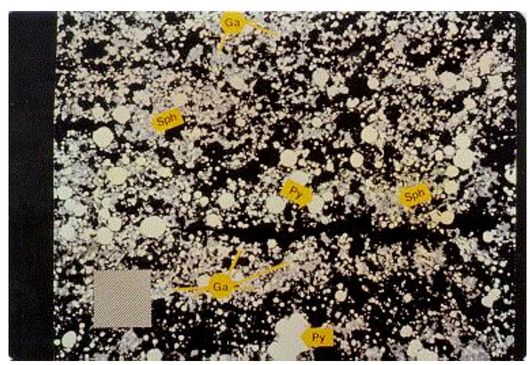
Mineralogy: make no mistake, you don't want to grind fine if you don't have to. It is power intensive and expensive. But if you have fine-grained mineralogy, you have no choice. Figures 2 shows photomicrographs of Broken Hill ore and McArthur River (MRM) ore at the same magnification. Broken Hill will never have a liberation problem – its metallurgists can focus on simple grinding and flotation circuits and avoiding "overgrinding". But for MRM and Mount Isa, no amount of fiddling with circuit design or reagent testing will help (trust us, we wasted years of our lives trying!). For these ores, there is one question that must be answered before anything else: "Will this circuit change/new reagent increase mineral liberation? " If not, do yourself a favour and keep your money in your pocket.

Figure 2 : Different Grain Size of Broken Hill and McArthur River Ores

(both photos at the same magnification)



Broken Hill Ore



McArthur River Ore

SOME DEFINITIONS AND PERSPECTIVES

We often note that communication between different operating plants is confusing because we all use different definitions of "coarse", "intermediate" and "fine" particles. An operator of a "coarse" grained orebody may call minus 37 μm "slimes". To an operator at Mount Isa or McArthur River this is gravel. To them, anything above 20 μm is coarse, between 10 and 20 μm is intermediate, and less than 10 μm is fine or ultrafine.

We avoid using generic terms like "fines" in this paper. But if you hear someone saying that "fine" particles don't float well, ask them two questions:

- What do they mean by "fine"?
- Are they aware that in the last decade, Mount Isa Mines and MRM have produced over 10 million tonnes of concentrates at an average sizing less than 10μm, at over 80% recovery, in conventional flotation cells, with a simple xanthate reagent system?

Particle surface area per tonne increases rapidly as size gets finer. One tonne of 7 μm particles has 5 times the surface area of a tonne of 37 μm particles; for 2.5 μm particles the surface area triples again. This explains why grinding energy increases exponentially as grind size decreases (Figure 3), and why finer media with higher surface area is needed for grinding below about 30 μm. It also explains the higher collector need of fines.

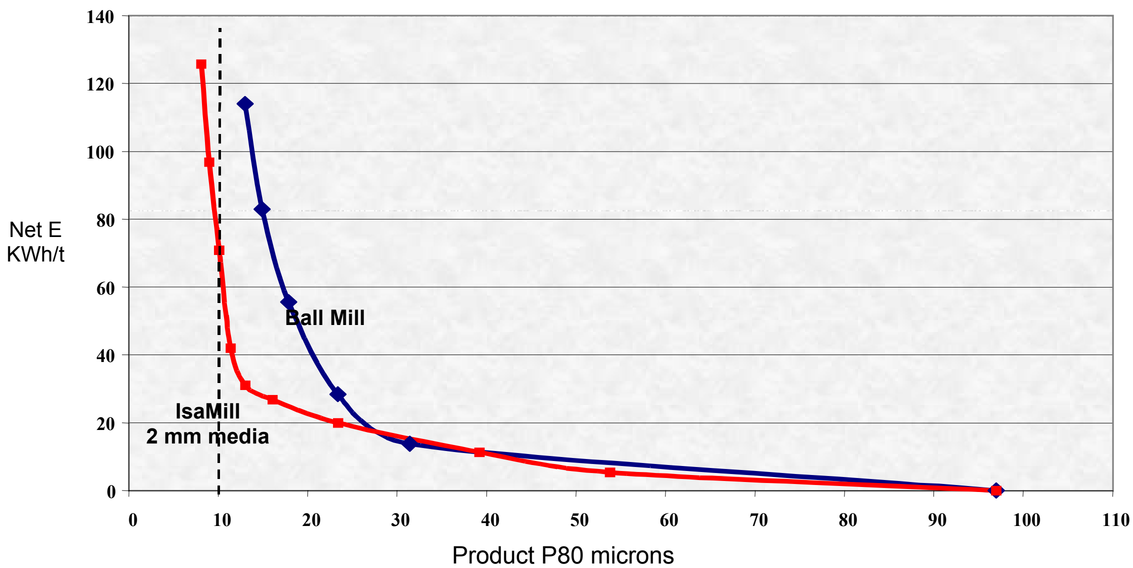
In this paper reference to a 7 μm particle means a single particle of that diameter. By convention a grind size of 7 μm refers to the 80% passing size (P80). For example, the regrind size at MRM is 7 μm, so only 20% of final product is 7 microns or coarser. Fifty percent weight of MRM concentrate is below 2.5 μm. Since flotation works on individual particles interacting with bubbles, consider this from a different perspective - 50% by weight less than 2.5 μm means that ***96 % of individual particles recovered at MRM are less than 2.5 μm !*** In spite of popular perception, fine particles float very well indeed.

ULTRAFINE GRINDING CIRCUIT DESIGN

If you have to grind below 25 µm, then you need to choose the right equipment. Three issues are particularly important:

- power efficiency
- classification within the grinding circuit
- the impact of grinding on flotation performance

Figure 3 : Grinding Energy versus Product Size for a Gold Ore



- **Power efficiency** is demonstrated by Figure 3, comparing 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 4, which shows the breakage rate in Tower Mills drops dramatically - the breakage rate for 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 4) can operate with much finer media and much higher intensity of power input (Table 1), meaning the peak breakage rate occurs at 20 µm, and doesn't drop as quickly below that.

Figure 4 : Breakage Rates in Different Grinding Devices

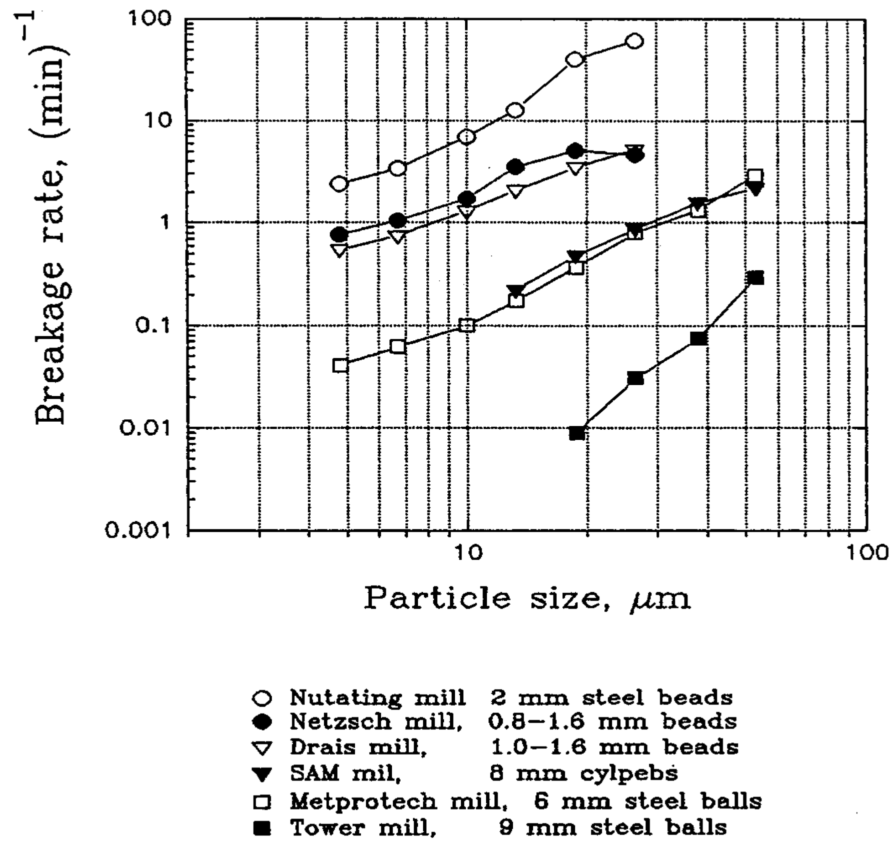


Table 1 : Comparison of Various Grinding Technologies Independent laboratory data

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

Figure 4 and Table 1: Extracts from AMIRA P336, Gao M and Weller K, Review of Alternative Technologies for Fine Grinding, November 1993.

- **Good classification** is vital for power efficiency in ultrafine grinding, just as it is in conventional grinding. However 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 achieves this by the internal classifier mechanism, using the high centripetal forces generated inside the mill to classify the discharge, ensuring a very sharp product size without external cyclones. The very short residence time in the IsaMill also minimises "overgrinding", further contributing to the sharp product size distribution. As an added advantage this mechanism also retains fine media very effectively, meaning that low cost media can be used, eg local sand, or granulated smelter slag.

  A cautionary word to those designing circuits – the benefits of good classification on power efficiency and media retention does not show up in laboratory tests. These tests are done in batch mills, and many technologies will show the same power efficiency in a closed device. The crucial questions are, what is the power efficiency, media retention, and product size distribution in a full-scale continuous installation.

- Managing the **impact of grinding on flotation performance** is the third crucial factor in plant design. Even if you can accept the low power efficiency of a mill with steel balls, you may not be able to deal with its impact of surface chemistry. Consuming so much power in a steel environment means high retention time and lots of steel contamination. The resultant low pulp potential changes flotation behaviour, requiring additional reagents and reducing selectivity. One early response to this problem was to use 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. Later we will show how IsaMills significantly improved the flotation behaviour of ultrafine particles at Mount Isa.

FLOTATION CIRCUIT DESIGN AND OPERATING STRATEGY

The view that "fine" particles don't float is caused by circuit design and the constraints of operating strategy. Simply, flotation works best when applied to narrow size distributions. A 5 μm particle has 10 times the surface area of a 50 μm particle, and fundamentally different hydrodynamics. Yet often our circuit designs assume they will behave the same, and treat them together in flotation. Texts as old as Taggart described the benefits of "sand/slimes" splits into separate circuits. This simple concept has been largely ignored in the push for circuit simplification and larger flotation cells.

We are not advocating complicated flotation circuits. However if you have fine-grained minerals then you must design your circuit to suit the needs of fine particles, not coarse particles. The Mount Isa circuit developed into an excellent balance of the needs of different minerals, relying on several stages of grinding and flotation. The design principals are:

- **Don't grind anything more than you need to**. Fine grinding is expensive – technically the best solution for Mount Isa would be to grind everything to 12 μm, but this would not be economic. Therefore stage grind and float to suit the mineral behaviour – at Mount Isa this means a 37 μm grind before roughing. Some mineral is liberated at this size and can go to concentrate. Other minerals in rougher concentrate need to be ground to 12 μm. Some of these are rejected in cleaning and need to be reground to 7 μm.

- **Float minerals in narrow size distributions** – this happens automatically with the staged grinding approach described above, and is assisted by the inherent sharp size distribution produced by the IsaMills.

- **Minimise circulating loads, and open-circuit as much as possible** – this is another automatic outcome of staged grinding. It is pointless to recirculate a composite particle unless you are going to grind it to liberation. If you do regrind it, you should now float it separately with similar sized particles.

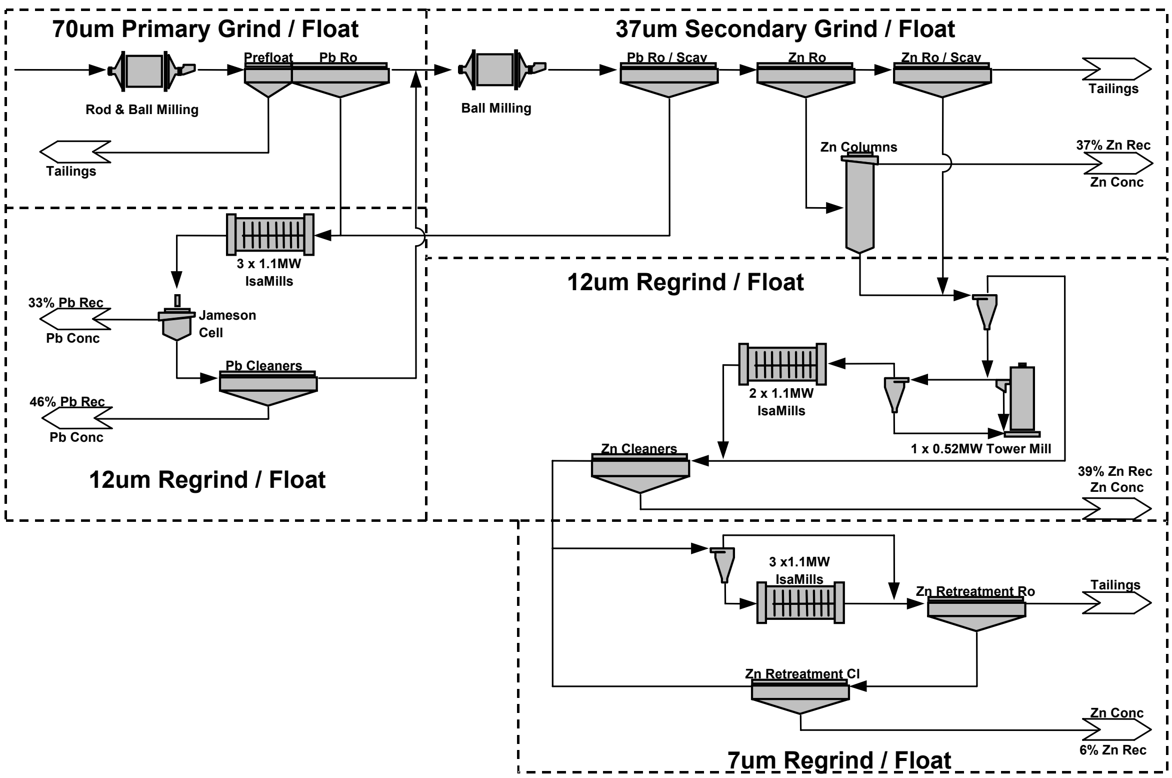
These principles can be seen in the simplified Mount Isa flotation circuit in Figure 5. Though the circuit may appear complicated, it is better than the alternatives of either:

- Grinding everything to 12 μm and floating together (too expensive)

- Recirculating regrind products and trying to float them with coarser minerals (causing poor performance of the reground minerals, high circulating loads and low recoveries).

Contrary to appearance, these developments at Mount Isa greatly simplified circuit operations. Lead recovery increased by 5% and lead concentrate grade by 5%, zinc recovery by 10% and concentrate grade by 2%. More surprisingly, reagent needs dropped, circulating loads dropped, and the circuit became far more stable. Flotation suddenly became as easy and predictable as the textbooks say it is!

Figure 5 : Mt Isa Pb / Zn Concentrator Flow Sheet



Overall Recovery: Pb = 79 %
Zn = 82 %

COMPETING FLOTATION RATES OF DIFFERENT PARTICLE SIZES

The profound impact of a narrow size distribution to flotation feed is explained by mineralogy and operating constraints. In a system with just pure liberated sphalerite and quartz, flotation could achieve good recovery in all size ranges, even though the "fines" have slower flotation rates. But in real circuits there are two crucial constraints:

- Other contaminant minerals such as pyrite and pyrrhotite also exhibit some floatability. If so, a "coarse" pyrite particle may have the same flotation rate as a "fine" sphalerite particle.

- Composite particles. To explain the problem with composites, imagine a simple 37 μm sphalerite-quartz binary. This particle has to be rejected since typically zinc concentrates must be less than 3% silica. The low collector and high depressant needed to reject the 37 μm composite will also depress the slower floating 10 μm liberated sphalerite particle.

Some further problems arise when floating coarse and fine particles together:

- It is no point depressing the 37 μm composite particle unless you can liberate it. While plants often "send it to regrind", this is often a conventional ball mill or Tower Mill that has very low breakage rates on sub 30 μm particles. This causes high circulating loads of composite particles.

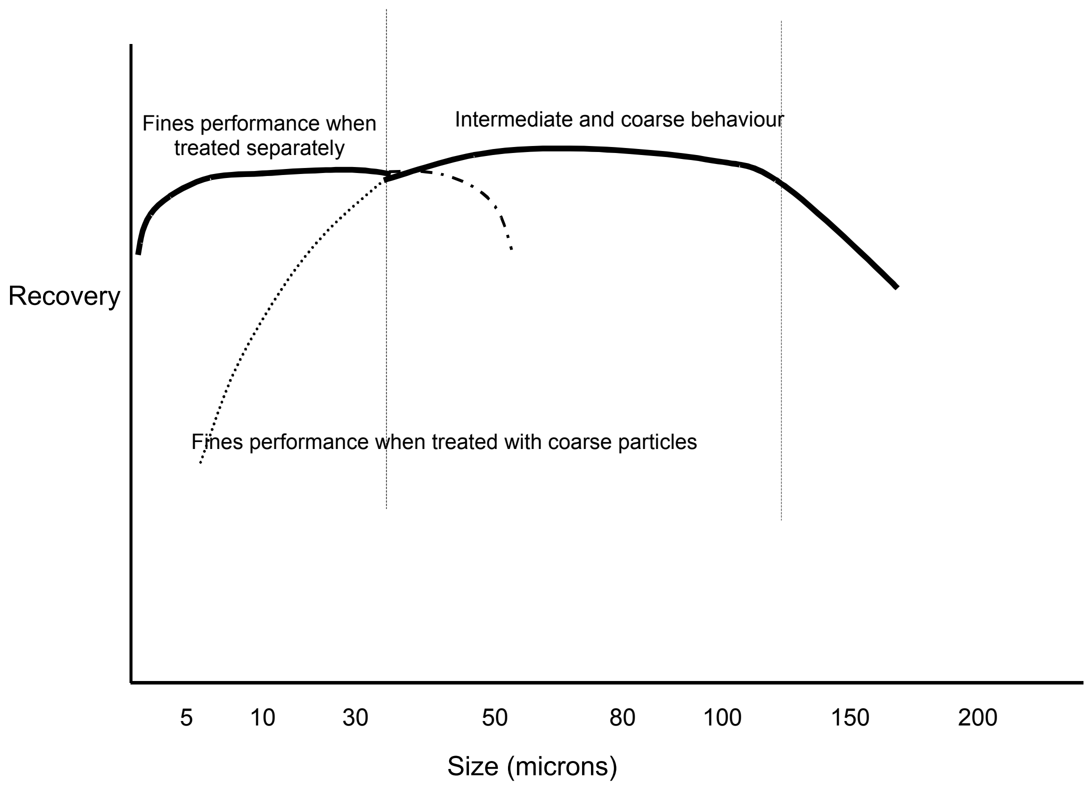
- The high circulating loads then take up volume and reduce residence time in roughing and cleaning. Since fine particles are slower floating, this drop in residence time further hurts their recovery.

- If high pH is used for depression, and lime is used to get high pH, then a surface chemistry problem is introduced. Circuit water can become super-saturated in Calcium ions. This leads to reaction with sulphate ions, which causes gypsum to precipitate on the nearest surface – usually a mineral particle. SEM work at Mount Isa before IsaMills showed that up to 80% of sphalerite surface was masked by gypsum. This has a more serious effect on sub 20 μm particles.

RECONCILING THE REALITY WITH THE PERCEPTION

The common perception is that “fines” don’t float, the reality is that they will in the right conditions. Figure 6 explains this conceptually – in most plants, sub 20 μm particles do perform poorly because they are mixed with coarser particles with much different needs. If these particles were floated in a narrow size distribution, flotation conditions can be tailored to them and they perform well. This explains the performance of the Mount Isa staged grind and float circuit.

Figure 6 : Conceptual description of staged grind and float circuit



CASE STUDY – MOUNT ISA LEAD ZINC CONCENTRATOR

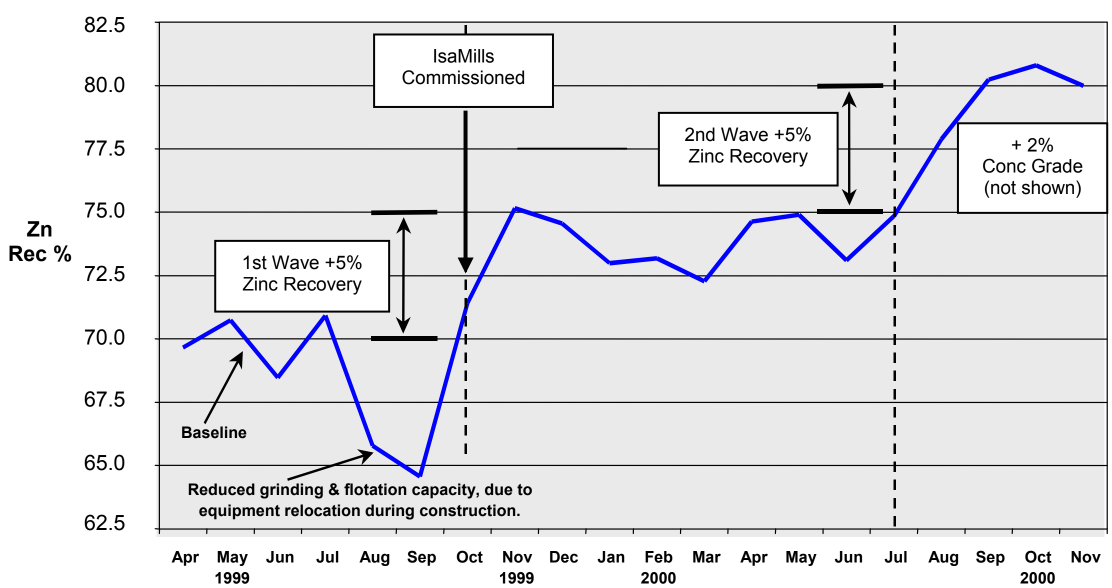
The changes to the Mount Isa circuit as part of the "George Fisher Project" are detailed elsewhere (Young & Gao, 2000, Young, Pease & Fisher, 2000). In summary, the project involved adding a further 6 IsaMills, to regrind lead rougher concentrate to P80 of 12 μm, most zinc rougher concentrate to 12 μm, and a zinc regrind to P80 of 7 μm (see Figure 5). Lead performance also increased by 5% concentrate grade and 5% recovery (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). The story of zinc metallurgy can be told in Figures 7, 8 and 9.

The project predicted 5% higher zinc recovery (and no extra concentrate grade) due to extra liberation. Figure 7 shows this was achieved instantly. What surprised us was the "second wave" of a further 5% zinc recovery increase and the 2% increase in zinc concentrate grade. This was because fines performance improved after we ground finer.

It took us about 6 months to discover how much better the fines could perform because we were so used to flotation performance after conventional grinding rather than after IsaMilling. The three biggest mistakes we made were:

- We thought we would need a lot more reagents after IsaMilling. Since we we created a huge amount of new surface area we expected some reagent additions to triple.
- We didn't take the depressant (lime to pH 11) off the zinc cleaners.
- We thought flotation rates would be slower, so we "pulled" flotation banks harder to compensate.

Figure 7 : Zinc Recovery Increase from IsaMilling



This resulted in four fundamental changes:

- Circulating loads had dropped dramatically, because we had finally addressed the liberation problem. This created significantly more flotation capacity than we had expected, and reduced reagent need.

- We no longer needed depressant on the cleaners since there weren't many composites left. The liberated minerals "behaved" properly. This was a crucial step, since removing the lime dropped the calcium in circuit water, dropping gypsum formation and further increasing flotation rate of sub 15 μm particles.

- The narrow size distribution in each stage of flotation made flotation easy. Together with the low circulating loads and open-circuit design, the flotation circuit became steadier and simple to control.

- The inert grinding environment and attritioning in the IsaMill improved mineral behaviour and changed reagent needs. Our initial expectations were way off – we added far too much reagent, and in the wrong places.

Over the next 3 months we learnt to challenge every known "truth" about the behaviour of our circuit, and accept that grinding could improve mineral flotation behaviour rather than reduce it. Once we understood that we had to approach the circuit as a "clean sheet", we rapidly improved recovery by the 5% shown in the "second wave". In spite of adding 6 MW of grinding power to the circuit, we were amazed that unit costs ultimately did not increase:

- Overall reagent consumption remained the same in spite of the extra surface area – since we no longer had competing depressants and collectors battling with composites.

- Total power consumption did not increase as much as we thought, since circulating loads of over 100% simply disappeared. As a result we were able to shut down some flotation capacity.

- With lower reagents and no circulating loads, spillage was almost eliminated.

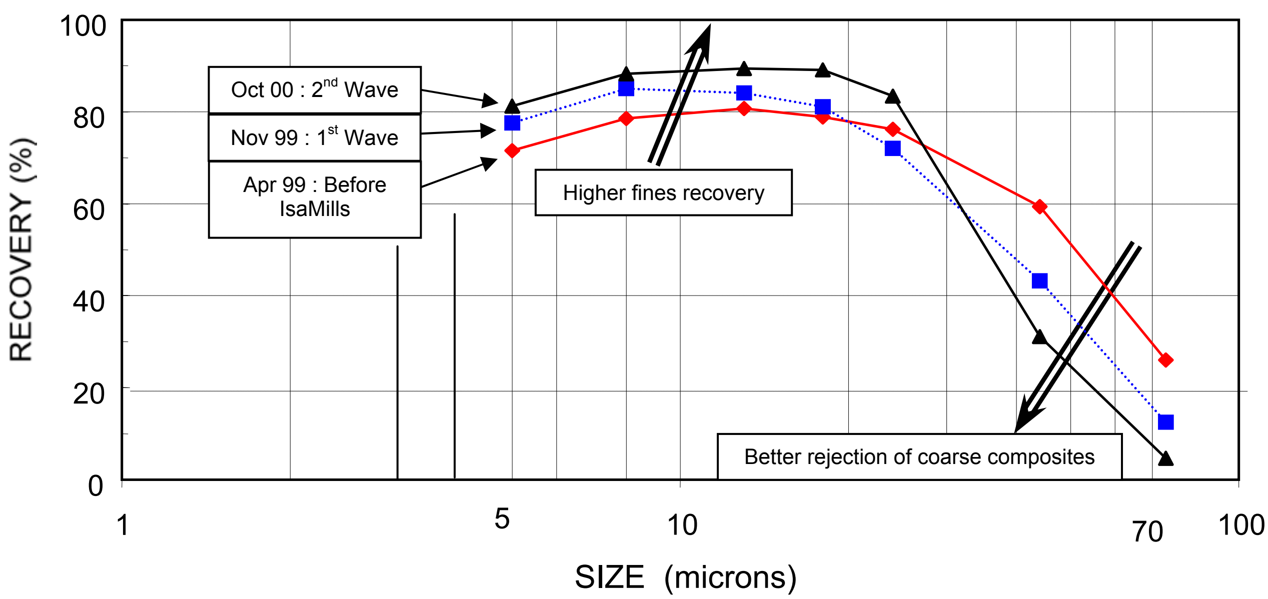
- The very steady nature of the circuit meant that simple stabilising control worked, keeping equipment at high efficiency.

- The IsaMill grinding media is free, granulated lead smelter slag that would otherwise be discarded.

The improvements in flotation are further described by Figure 8, which records size-by-size performance for sphalerite. Not only did the IsaMills put more material in the liberated sub 15 μm size range, they also improved recovery of all sub 25 μm particles. For example, recovery of 8 μm liberated particles increased from about 78% to about 88% after Isa Milling. Though recovery in the coarser fractions has dropped, this was what was needed to improve total recovery since:

- The coarser fractions had contained the composites, previously rejecting these composites also rejected fines.
- After IsaMilling, very fast floating coarser particles (ie liberated ones) were still accepted, but the slower floating ones were sent for regrinding and liberation.
- There was much less material in these coarse size ranges after IsaMilling – coarse composites were reground into finer size ranges with higher recovery (and higher grade since they were more liberated).

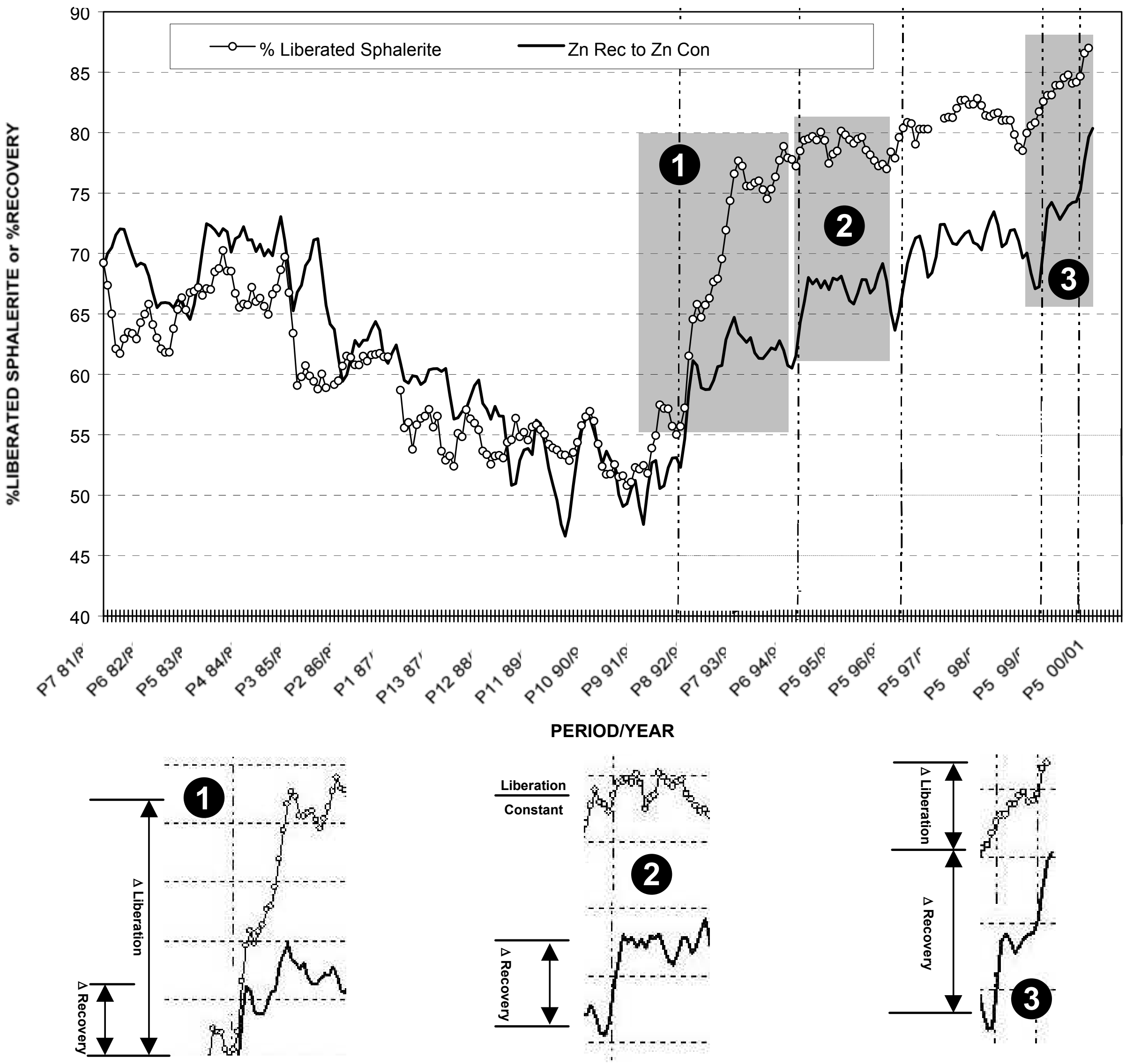
Figure 8 : Increased Fines Recovery After Fine Grinding in the IsaMills



THE BIG PICTURE

The history of changes at Mount Isa is described by Figure 9, which considers sphalerite liberation and zinc recovery. As ore became finer grained in the 1980's, liberation dropped and recovery dropped accordingly. In 1992 we installed conventional ball and Tower Milling to improve liberation. Sphalerite liberation improved by 25% (from 55% to 80%), but recovery only improved by 10%, due to the extra difficulty of floating after grinding in ball and Tower Mills. In 1995 we installed the prototype IsaMills in the lead circuit. Not only did this improve lead performance, but zinc recovery also increased even though total sphalerite liberation was little changed. This was because the improvements from IsaMilling allowed sphalerite to be redirected from the lead concentrate to the zinc circuit. In 1999 the installation of additional IsaMills increased sphalerite liberation by a further 5%, but zinc recovery increased by 10% and zinc concentrate grade by 2% (net impact equivalent to 16% recovery increase at the same concentrate grade). This demonstrates the fundamental changes to fines flotation made possible by ultrafine grinding in IsaMills.

Figure 9 : Relationship Between Sphalerite Liberation And Recovery Over 20 Years



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

REFERENCES

Gao, M and Weller, K R, 1993.
Review of Alternative Technologies For Fine Grinding. *AMIRA Project P336, Report P336/20, November.*

Holder, R.K, 1994
Improvements in copper and silver flotation at Hellyer using high energy conditioning. *AusIMM Fifth Mill Operators' Conference, Roxby Downs, Australia, 16 – 20 October.*

Young, M F, and Gao, M, 2000.
Performance of the IsaMills in the George Fisher Flowsheet. *AusIMM Seventh Mill Operators Conference, Kalgoorlie, Australia, 12-14 October..*

Young, M F, Pease J D, and Fisher K S, 2000.
The installation of the George Fisher flowsheet in the Mount Isa Lead/Zinc Concentrator. *AusIMM Seventh Mill Operators Conference, Kalgoorlie, Australia, 12-14 October.*

Harbort, G., Murphy, A., Vargus, A., Young, M F, 1999.
The introduction of the IsaMill for ultrafine grinding in the Mount Isa Lead/Zinc Concentrator. *Extemin99, Arequipa, Peru, September.*