

Increasing the Energy Efficiency of Processing

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Can we double the energy efficiency of grinding ?

- *Diminishing returns on research ?*
- *Radical new technologies?*
- *10 years or longer ?*

Mineral comminution consumes about 3% of the world's energy.

So improving the efficiency of grinding has long been an important objective for operators and researchers. Much progress has been made. Entire research institutions like the JKMRRC have dedicated decades of study with almost the sole objective of improving comminution efficiency.

Does all this work mean that the big gains have been made, and that we are on diminishing returns from our research ?

Has conventional technology reached its limit ? Is equipment just getting bigger, but not more efficient ?

Do we need radical new technologies like microwave grinding to make a step change in grinding efficiency ?

A new collaborative research program, AMSRI has a \$20 M budget and the ambitious target to double grinding efficiency in 10 years. Is this a realistic target, given the enormous amount of work already done?

No, we don't think 10 years is a reasonable target. We think it can be done today !

The tools are already available



- *Laboratory grinding and flotation characterisation*
- *Quantitative mineralogy*
- *Basic thermodynamics*

In fact, processing efficiency can be significantly increased by using tools already developed by our previous research.

We don't need radical new technologies, we need to combine the tools we already have in the right way.

These tools are :

- Laboratory grinding and laboratory flotation tests
- Quantitative mineralogy
- basic thermodynamics of smelting and refining

To grind the right mineral in the right place to the right size.

In many cases this approach can double the energy efficiency of ***processing***.

Note that I refer to processing efficiency, not grinding efficiency. Grinding is not an end in itself. It is just one step in the processing chain. It cannot be considered in isolation of the downstream process. This is why I have included smelting thermodynamics in the list of tools. It is no point reducing grinding energy if this increases smelting energy.

We already have the tools to double the efficiency of *processing* :



- *grind the right streams,*
- *in the right place,*
- *to the right size*

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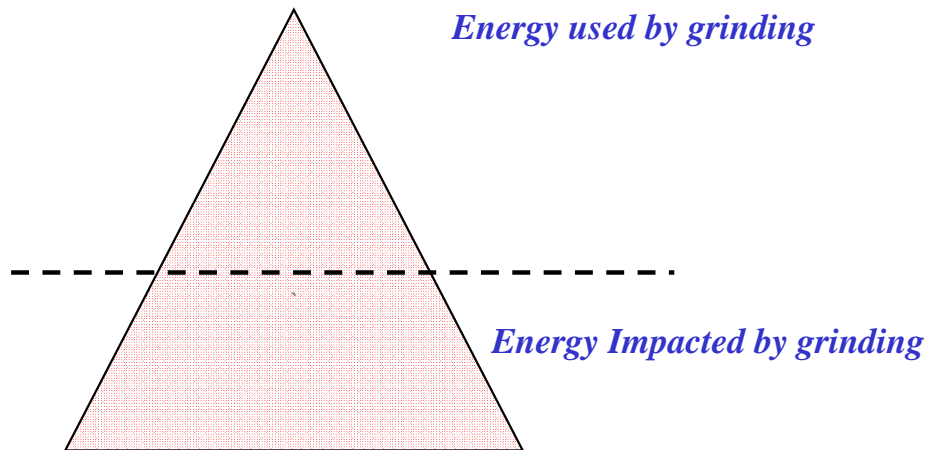
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Processing Efficiency ...



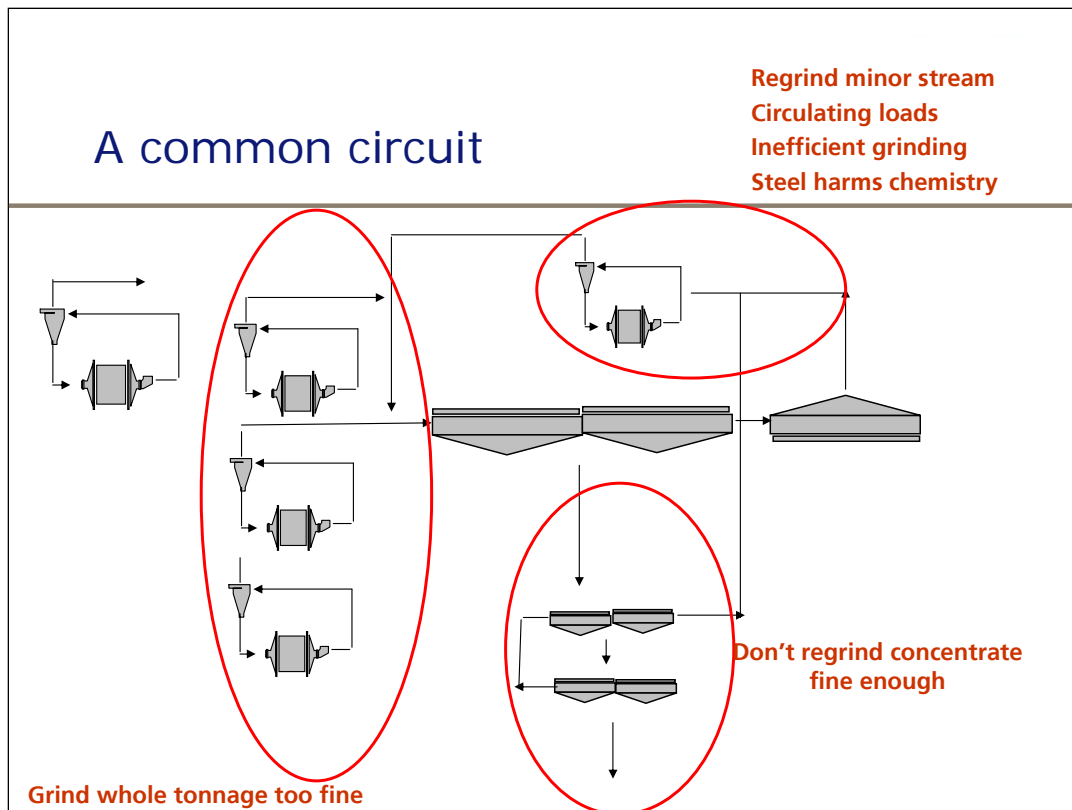
So of course, the real question is about the energy efficiency of the whole process, not just the grinding step.

It is no point reducing grinding energy if it increases downstream energy by more.

This is the same logic we all understand about mine-to-mill. One of the advances in the last decade has been to recognise the importance of the mine-to-mill interaction. Most of us will be familiar with the classic example of the mining engineer who reduced his blasting cost by 20 c/tonne, only to reduce SAG mill throughput by 10% and increase milling cost by \$1/tonne. Sometimes the right answer is to spend a bit more and blast finer in the mine, and save much more in the mill.

Well of course, the same applies between the mill and the smelter. Yet how many of us check the thermodynamics of smelting, and see what we can do in the mill to reduce smelting energy? Maybe that's not a fair question, because we don't have simple tools to help us do it. Have you ever seen a grinding model that includes some simple smelting thermodynamics to help you minimise processing energy? Which research group is working on it? We have research proposals to develop more and more sophisticated grinding simulations, to seek the last little bit of grinding efficiency. But where do they consider smelting energy?

I think this is a huge oversight, and a huge opportunity – we are just like the mining engineer who tried to reduce his blasting cost with no consideration of what it would do to grinding efficiency.



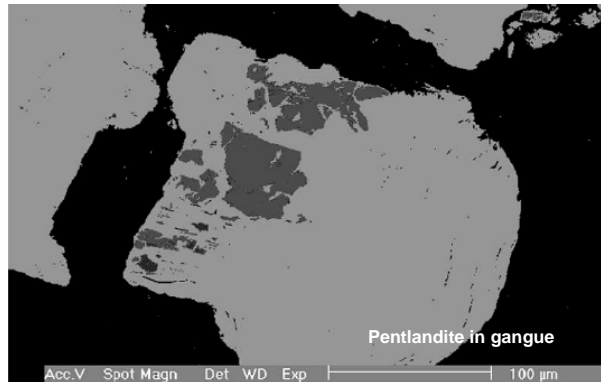
This is a flowsheet of a common circuit. How can we use existing tools to reduce the energy need.

Often the primary grind can be coarsened. We don't need complete liberation for roughing, we just need to liberate enough gangue away from the valuable mineral to get high rougher recovery. We can then achieve the liberation we want for cleaning by regrinding a smaller tonnage of rougher concentrate (or a part of it).

This is the biggest single impact on grinding energy – why grind big tonnages of silica finer than you need to? Grinding too fine up front also causes us to put in more roughing flotation capacity than we really need. Coarsening primary grind also has other advantages for tailings storage and reactivity.

Where is the lowest energy place to remove this impurity ?

- *Mine*
- *Preconcentration*
- *Roughing*
- *Cleaning*
- *Smelting/refining*



Grind it out.

Or add Silica and limestone, and melt it out at 1350°C

Improving energy efficiency means asking a simple question : where is the cheapest, lowest energy place to remove this impurity ?

- in the mine (by dilution control) – requiring no energy
- in a preconcentration stage (removing some gangue while it is still coarse)
- in roughing – ie by grinding the whole mill feed
- in cleaning – ie by grinding a much smaller tonnage of rougher concentrate
- in the smelter – by melting it out ?

Of course, cleaner feed tonnage is much lower than rougher feed tonnage. So ideally, so it is obviously better to grind the lower tonnage of rougher concentrate rather than rougher feed. So long as you grind rougher feed just enough to get recovery into the rougher concentrate.

The photo of the composite shown is taken from a paper on Nickel metallurgy. The gray is pentlandite, the white is MgO. Excellent work was done in the flotation circuit to allow recovery of this low grade composite. Even so, this particle causes a problem for the smelter – MgO causes highly viscous slag. The smelter has to add Silica and lime fluxes, then heat the whole lot up to 1350°C to remove the MgO. This consumes a lot of energy – over 10 times the energy it would take to grind the MgO out. The high temperatures also make smelting difficult and reduce refractory campaign life. So to improve energy efficiency, the concentrator should regrind this particle – so long as the mill can still recover the pentlandite.

How can we use existing tools better ?



- **Simplify use of quantitative mineralogy**
- **Make better use of regrinding**
- **Look at the mill-smelter interface**

I think there three areas where we can improve our use of the existing tools to improve energy efficiency, which I will discuss in the next few slides.

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What do we want to achieve in each part of the circuit, eg

- Primary grind and rough for recovery
 - Look for gangue liberation, not mineral liberation
- Regrind and clean for grade
 - Look for mineral liberation and entrainment

Distinguish symptoms from causes

- Eg fines in tails may mean ...
 - ... you are grinding too fine
 - OR you are grinding too coarse !

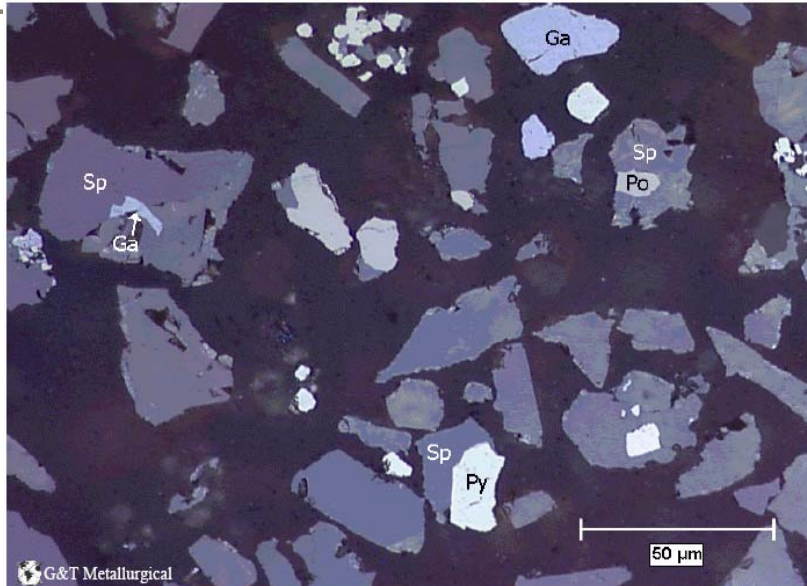
Because quantitative mineralogy is so powerful, sometimes we overcomplicate it. It can generate so much data that we get lost in detail, and can't see the forest for the trees. We need to keep it simple, and apply the 80/20 rule. Avoid the temptation to find out everything about every mineral in every liberation class in every stream. Ask a few simple questions about what you are trying to achieve in each stage of the process. And look for root causes rather than symptoms. The mineralogy can only be interpreted with a good understanding of how the circuit is operated.

Two simple questions are :

1. in roughing, how coarse can I grind and still be able to get good recovery to rougher concentrate. You don't need to worry about grade yet, that is, you don't need to worry about the mineral liberation, but rather the gangue liberation – is enough gangue liberated from the mineral to allow it to float into rougher concentrate.
2. In cleaning, the question changes to how fine you need to grind to make a high grade concentrate. Now mineral liberation is important. So is entrainment of liberated gangue. If there are coarse composites in concentrate that could be easily liberated, these are “low hanging fruit”. Even if you are already at concentrate grade, by removing the easy impurities you make room to “pull” the rest of the circuit harder.

This point is an example of distinguishing root causes from symptoms. You will always find fine liberated values in cleaner tailings and rougher tailings. Perhaps this means you are grinding too fine – “overgrinding” your valuable minerals. But, paradoxically, more often it means you aren't grinding fine enough ! The next slide shows why.

Problem or Symptom ?



G&T Metallurgical

*Sp-Sphalerite, Ga-Galena, Py-Pyrite, Po-Pyrhotite

This is a photomicrograph of zinc concentrate. Look at the composite particle of sphalerite and pyrite at the bottom. It has a fair amount of exposed sphalerite surface, so it floats well, and is too valuable to throw out. Yet it is also too low grade to accept into concentrate - it probably assays about 20% Zn, it needs to be about 50% to be payable.

Because it floats relatively easily, the operator only has two choices :

- If he accepts it in concentrate, it lowers con grade. He has strict limits on the concentrate grade and Fe content, so he now has to pull the roughers and cleaners more gently to keep the concentrate grade. He can't chase coarse composites, or slow floating fines in tailings, because he doesn't have the processing power to recover them at a high grade.
- Alternatively, he tries to reject this composite, in this case by starving collector and running high pH. But these are the very conditions that will cause low recovery of the fines. Look at the fine liberated sphalerite particles near the composite – they have less sphalerite surface than the composite, so depressing the composite will probably depress them as well.

So no matter what the operator does, if he has to make a concentrate grade, then dealing with this composite will cause him to lose fines (and coarse composites). Instead, regrinds the composite removes the pyrite which increases concentrate grade without depressant. The higher concentrate grade leaves him room to pull his roughers and cleaners harder. Regrinding will improve his fines recovery.

This shows the importance of using quantitative mineralogy like forensics, not like a computer sledgehammer. Don't get hung up on there being fines in tails. Look at the composites in concentrates, if you fix this root cause many of the symptoms disappear.

Before you can ask the right questions of your mineralogy, you **have** to understand how the circuit is operated.

Grind the right minerals in the right place



- *Primary grind as coarse as you can*
- *Regrind as fine as you need*
- *Regrind cleaner feed, not cleaner tail*
 - *No step change from grinding a minor stream*

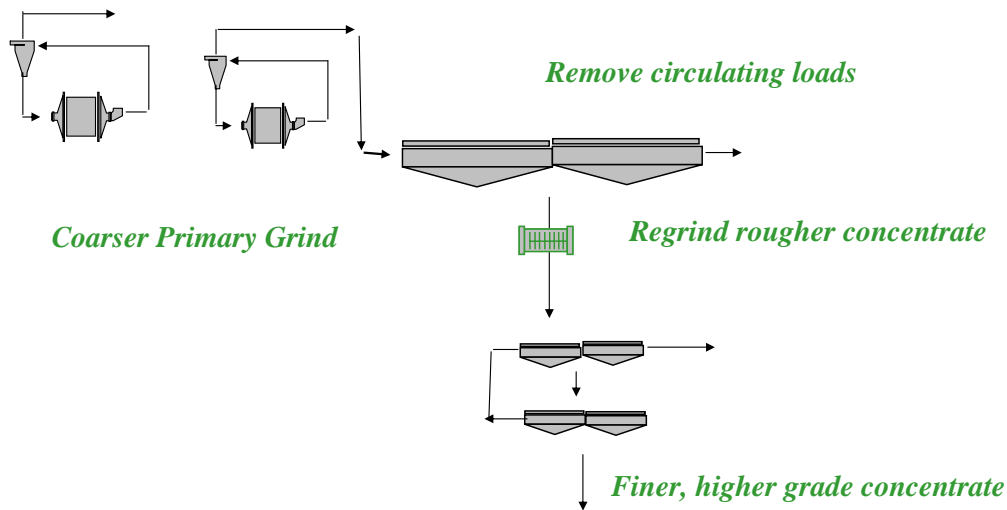
In summary, use quantitative mineralogy to ask these simple questions. In roughing, how coarse can I grind and still get recovery to rougher concentrate.

In cleaning, how many composites can I remove from the concentrate by regrinding finer.

We think the result is that many circuits could grind the main stream coarser, but need to regrind the cleaner feed finer than they do. They can make a higher grade at the same recovery, with less energy.

So many of our circuits regrind cleaner tailings, not cleaner feed. But if regrinding is a powerful tool, why save it until after you have made most of your concentrate? If composites like the one in the previous photo go straight to concentrate, the damage is already done. Cleaner tailing has a small portion of the metal, so you can't get a step change by regrinding it.

Energy Efficient circuit



Compare this flowsheet to the one on page 6. Often the primary grind can be coarsened. We don't need complete liberation for roughing, we just need enough liberation of valuable from gangue to allow high recovery in roughing. We can then achieve the liberation we want for cleaning by regrinding a smaller tonnage of rougher concentrate (or a part of it).

This is the biggest single impact on grinding energy – why grind big tonnages of silica fine when you don't need to. Grinding too fine up front also causes us to put in more roughing flotation capacity than we really need.

The regrind mill shown here is an IsaMill. These mills grind in open circuit, producing a sharp size distribution than conventional grinding and hydrocyclones.

Coarsening primary grind also has other advantages for tailings storage and reactivity.

Do we do enough Regrinding ?



- **Fines are hard to float ?**
 - Not with clean surfaces and good size distributions
- **Regrinding hurts chemistry ?**
 - Not with inert grinding
- **Regrinding is inefficient ?**
 - Not any more

We think many concentrators don't regrind fine enough. When they do regrind, they regrind small difficult streams like cleaner tails or scavenger concentrate, not the main cleaner feed.

This probably reflects some perceptions about regrinding and subsequent flotation. Indeed, these concerns are valid, and most plant operators have experienced them. Conventional regrinding to fine sizes is inefficient, it uses lots of media, and the steel media hurts flotation. Therefore we avoid regrinding cleaner feed so we don't risk harming our main stream; we save regrinding to cleaner tailing, a relatively small and difficult stream.

But this has all changed with the advent of high intensity inert grinding. The IsaMill is much more efficient than ball or Tower Mills for fine grinding, it uses inert media that produces clean surfaces for flotation, and produces sharp size distributions.

Regrinding used to be one step forward for liberation, one step back from chemistry. Not any more.

Fines float very well when :



They have clean surfaces

- Inert regrinding

You add reagents to suit

- Don't try to depress composites at the same time
- Avoid circulating loads

96% of recovered particles at MRM are less than 2.5 microns

Traditionally we thought that fines don't float well, that we need special reagents and flotation cells, and still get poor performance.

We now know this isn't true. Numerous operations get excellent fines flotation, with conventional flotation cells and standard reagents. We just have to give them clean surfaces, and make sure they aren't competing with composites – that is, we need to be able to add enough collector to float the fines, without having to worry about floating unwanted composites at the same time (as we discussed before).

When we do this, we find that fines down to 1 micron float just as well as intermediate size particles, and almost as quickly. In the Mt Isa lead and zinc circuit, cleaning recovery after IsaMilling of cleaner feed is above 95% for all size fractions above 1 micron, until dropping above 37 microns due to composites.

For another example, consider Macarthur River, an operation whose entire concentrate is finer than 7 microns, floated in conventional cells. Lets look at what this means in terms of individual particles. I know we only get paid for weight, not number of particles. But flotation is about individual particles connecting with bubbles.

So 96 percent of the successful particle-bubble interactions at McArthur River occur for particles less than 2.5 microns.

So fines do float,, and very well indeed.

High Power Efficiency High Power Intensity
- media size



- stir small media at high speed.

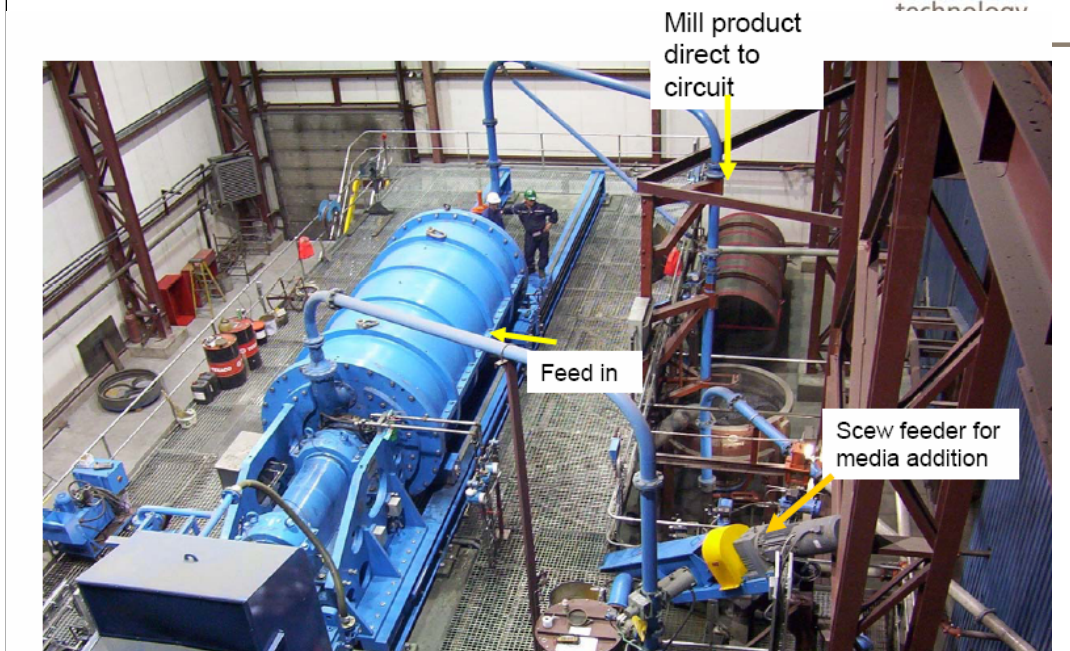
	Power Intensity (kW/m³)	Media Size (mm)	No. Balls / m³	Surface Area (m²/m³)
Ball Mill	20	20	177,000	222
Tower Mill	40	12	818,000	370
IsaMill	300	2	176,500,000	2,220

A lot has been written about grinding efficiency, and the relative efficiencies of ball mills and Tower Mills and high speed stirred mills. In fact, it is fairly simply. Overwhelmingly the biggest effect is media size. If you run a ball mill slowly with 12 mm media, it will be as efficient as a Tower Mill. Its just that we don't normally run ball mills with 12 mm media. Similarly, a Tower Mill with 5 mm or smaller media will be more efficient again. But practically, no one ever runs a Tower Mill with 5 mm media – the media cost and wear would be prohibitive. As an aside, if you get testwork done, make sure it is done with the same media size you will use in the plant. We have heard of occasions when a Tower Mill energy need has been predicted from a test with 6 mm media, whereas the plant will use 12 mm or coarser, which will require significantly more energy.

The other important parameter in this slide is power ***intensity*** – it is no point being power efficient (like a Tower Mill with 5 mm media) if the power intensity is so low that you need a huge installation to get the necessary installed power.

So let me summarise – a Tower Mill with small media will be just as efficient as a high speed stirred mill with small media (the optimum media size for each device will be different). But the low power intensity of Tower Mills means you need a much bigger installation. These points are made by Nasset et al in their paper “*Assessing the Performance and Efficiency of Fine Grinding Technology*”, CIM 38th Annual Canadian Mineral Processing Operators Conference, Ottawa 2006.

3 MW IsaMill Installation



This is a picture of a 3 MW IsaMill installation, showing the features that make it such a different technology.

Firstly, note the scale from the people at the discharge – this is a 3 MW grinding mill. Consider the size of a 3 MW ball mill or three, 1 MW Tower Mills.

Note the simple installation. The mill is pressured, with feed in, outlet pipe straight to process (no closed circuit cyclones) and simple media system under the floor. Media is added to the mill feed pump by the screw feeder. Note the low footprint, low head height, and simple crane needs.

A Step Change in Technology



1.1 MW Tower Mill

- plus media handling
- plus close circuit cyclones

3 MW Isa Mill



Media system under floor

Open circuit operation

To give an idea of difference in scale – the IsaMill is not an incremental change, it is a step change – an order of magnitude smaller than conventional technology. Until now, the Tower Mill was considered the most efficient, modern technology for regrinding. After 55 years, the biggest model is still only 1.1 MW (shown).

The IsaMill next to it has been scaled to keep the people about the same size. This is a 3 MW IsaMill – three times the power of the much bigger Tower Mill. This is what we mean by power intensity. Think of the difference in installation cost if you need 3 MW of Tower Mills (with associated media handling, cranes, and closed circuit cyclones).

This is why we say that the IsaMill changes the way we can think about circuit design. It is much easier to imagine putting 3 MW of open circuit IsaMill in the middle of a flotation circuit.

A new tool for plant design



Regrinding that

- **is energy efficient**
- **improves mineral surfaces and chemistry**
- **has a small footprint and head height**
- **doesn't need cyclones**
- **can be installed throughout the circuit**

The tools to grind the right minerals in the right place

The IsaMill is a step change in regrinding technology. It was developed to change the economics and efficiency of ultrafine grinding. But it has now brought the same advantages to conventional grinding and regrinding, where it will have its biggest effect on the industry.

This fundamentally changes the way we can think about the design of circuits. A lot of regrinding power can be installed in a small space and in a simple installation that can be located where it is needed throughout the plant.

Using existing tools better ...



- Simplify use of quantitative mineralogy
- Make better use of regrinding
- **Look at the mill-smelter interface**
 - A bigger problem than Mine-to-Mill ?

The third reason we don't take achieve the energy efficiency we could is because of the mill to smelter interface.

Some time ago we recognised the mine to mill interface as a problem. We knew it was a problem because we could hear the miners and metallurgists squabbling on sites. Since then a lot of work has been done to better co-ordinate mining and milling to improve overall efficiency – eg is it better to spend a bit more on mine blasting (drilling and chemical energy) to save more energy in the SAG mill.

But how often do we hear the same questions being asked about concentrating and smelting ? Or do we just accept that the target grade is 25% Cu because that suits the smelter contract. I think the mill-to-smelter interface is a more serious problem than mine to mill, because there is virtually no dialogue between us. You can't even hear us fighting, because we don't talk. The smelter may be owned by another company, and based overseas. My commercial people talk to your commercial people, and they argue about supply/demand balance. Can anyone imagine that they are negotiating about the most energy efficient way to remove impurities.

How do we choose concentrate grade ?



By considering the optimum energy/cost trade off between grinding and smelting ?

- Mineralogy plus smelting thermodynamics to minimise energy ?

OR :

By getting maximum recovery at “target” grade ?

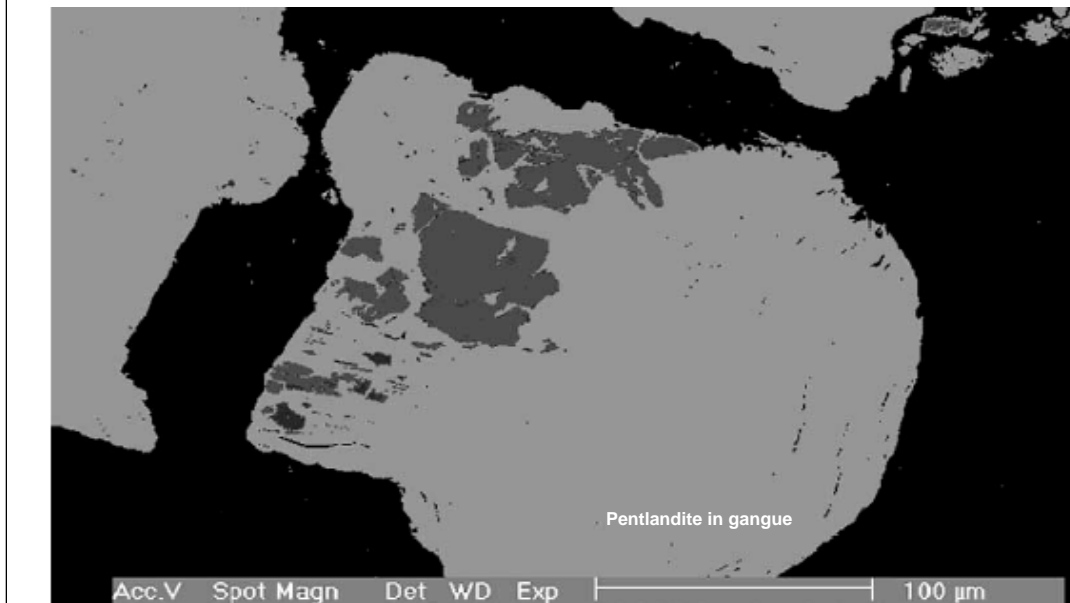
- With target grade set by commercial negotiation ?

It is logical for the concentrator to maximise return based on the smelter contract. They will work out what grade concentrate gives them the best return given contract terms and transport costs. Then they will maximise recovery and minimise costs at this grade. They will set KPI's, and be rewarded to minimise cost and maximise recovery – which will “lock in” that target grade. What incentive do they have to question the grade ? Why would they volunteer to increase costs, maybe even drop some recovery, in order to make a higher concentrate grade, if this just helps another company's smelter. Of course, they won't.

The concentrator can only respond to the contract. And can we expect the contract negotiators to be optimising the trade off between mineralogy, smelting thermodynamics and energy efficiency ? Of course we can't.

This is why I think mill to smelter is a bigger problem than mine to mill. There is simply no dialogue. The metallurgy and calculations are fairly easy, but we don't do it. We don't even recognise it as a problem. Of all the research projects you have heard of to improve grinding efficiency, how many include the smelter ?

Case Study – Nickel



Let me give an example. I return to the Nickel composite we looked at earlier. This photo was taken from a paper by G. Senior and S.Thomas, “*Development of a New Flowsheet for the Flotation of Low Grade Nickel Ore*”, *International Journal of Mineral Processing* 78(2005), Elsevier.

It is a photo of a low grade composite floated into scavenger concentrate at Mt Keith circuit. Excellent work was done in the concentrator to be able to recover this low grade composite, without requiring a finer primary grind.

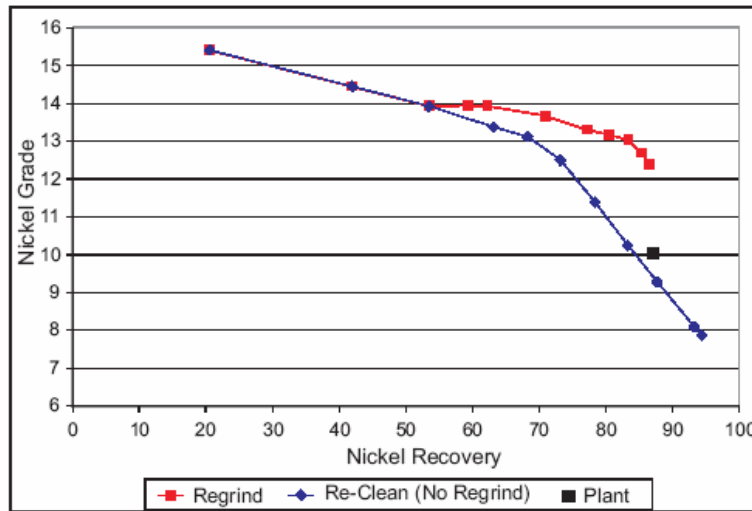
So the nickel recovery has been increased, and the process is more efficient. It could be even more efficient if we could then eliminate some of the additional MgO from the final concentrate, while still recovering the pentlandite. This is a liberation issue.

We were originally asked by what was then WMC to look at the potential for IsaSmelt for the Kalgoolie Nickel smelter, to handle the high MgO content. But the more we looked at smelting, the more we suspected that it would be easier to deal with the MgO in the concentrator.

So we worked with the Leinster operation to see whether we could improve the Nickel-MgO separation with inert regrinding in an IsaMill.

Grind or Smelt ?

- Nickel – MgO separation at Leinster



Pilot testwork on coarse cleaner scavenger concentrate

The answer is yes. This graph is from D.Seaman et al, *“Process Design of a Re grind Facility at the Leinster Nickel Operation to Improve Concentrator Recovery”*, AUSIMM, 9th Mill Operators Conference, Freemantle 2007.

The graph shows the results of pilot work conducted at Leinster. The coarse cleaner scavenger concentrate is shown with and without IsaMilling. The regrinding is effective in significantly increasing the Nickel concentrate grade at the same recovery. Most of the increase comes from removing MgO, as shown by the next graph.

Big impact MgO - and smelting energy

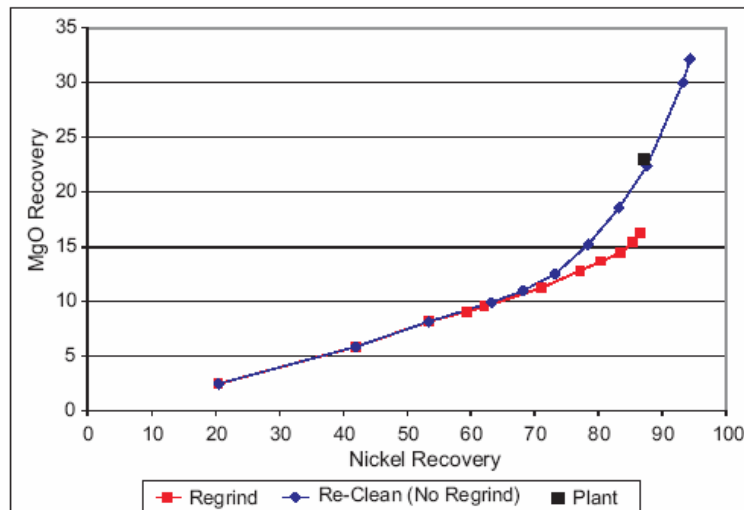
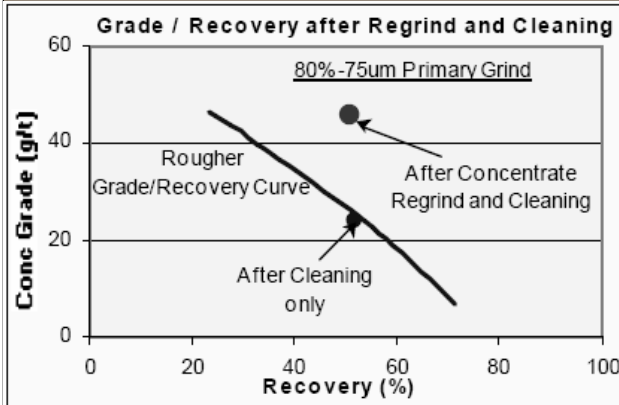


FIG 9 - MgO to nickel selectivity with and without regrind.

In this case, MgO can be removed from the concentrate without any loss of recovery with relatively little regrinding energy. This requires much less energy than smelting it out from concentrate.

Case Study : Anglo Platinum WLTR



The next example is from Anglo Platinum. This mill is their first installation, at the Western Limb Tailings Retreatment Plant. In many ways this was typical of operations that needed a step change in technology – old mill tailings that had been in dams for up to 100 years, fine grained and with altered surfaces. The ability of the IsaMill to efficiently liberate, and provide clean new surfaces to flotation, was enabling technology for this operation.

This was the development site for the big M10,000 IsaMill – this unit is 2.6 MW and operates with sand media, the same mill model is now rated at 3 MW with ceramic media.

This is a fine grinding mill, operating on a difficult stream. But Anglo Platinum realised that the advantages of IsaMilling didn't stop with these difficult fine grained applications. They saw that the ability to improve liberation, and at the same time improve flotation selectivity, had much wider application to their mainstream applications.

The Big Picture at Anglo



- **Installing 64 MW of IsaMill**
- **Coarse grinding scavenger feed**
 - F80 100 microns, P80 50 microns
 - Liberate gangue to increase PGM recovery
- **Regrinding rougher concentrate**
 - P80 25 -35 micron
 - Increase concentrate grade
- **Higher recovery and higher grade**
 - Significantly increased smelter capacity
 - Significant reduction in processing energy

The end result is that Anglo Platinum have embarked on a major program to fit IsaMills to their concentrators, in a combination of mainstream grinding and regrinding duties. This program will significantly improve both recovery and concentrate grade. The increase in concentrate grade means a significant increase in capacity through existing smelting, and significant reduction in overall processing energy.

The mainstream mills will grind from typically F80 100 microns to P80 45 to 60 microns, and will treat rougher tail/scavenger feed. Each mill will process around 300 t/h of solids.

The regrind mills will treat rougher concentrate, and will regrind to P80 15-20 microns before cleaning.

It is clear that the IsaMill is now a mainstream grinding and regrinding mill, not a niche fine grinding mill.

Transforming Circuit Design and Energy Efficiency



We can build plants which :

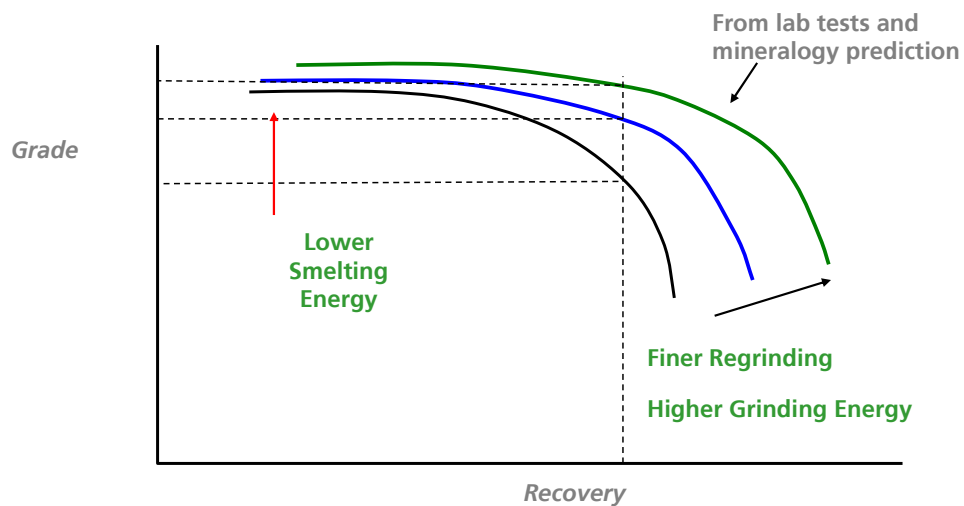
- Use half the power
- use a fraction of the footprint and height
- Deliver better results – grade and recovery

We already have the tools :

- Laboratory grinding and flotation
- Quantitative mineralogy
- Smelting thermodynamics
- Efficient regrinding technology

To summarise, we think we already have all the tools we need to double the energy efficiency of processing. We just need to use them together in the right way.

We have the tools to get it right



This is an illustration of what we can currently do. We can use laboratory tests to develop a range of grade/recovery curves at different grinding and regrinding sizes.

We can use quantitative mineralogy to help us design and interpret these tests, and interpolate between them.

We can predict the grinding energy needed to create the different grade/recovery curves.

We can use simple smelting thermodynamics to calculate the different smelting energy needed for the different concentrates.

This gives us enough information to find the most efficient operating point; the lowest energy trade off between grinding and smelting for that ore.

Challenge to Researchers :



Develop a standard “energy index” to rank ores

- Develop grade/recovery curves at different grinds
- Calculate grinding energy and smelting energy for different options
- Use for new ores, and benchmark existing plants

Reduce the energy of *processing*, not just energy of *grinding*

So in closing, I issue a challenge to researchers. If we have the tools, why don't we use them in the right way to optimise energy efficiency.

I think the previous concepts can be captured in a relatively simple “energy index” to describe an ore. For a long time the industry has used the Bond Work Index to summarise grinding energy needs. Even though there are much more sophisticated grinding models, we still find a single index to be useful.

So why don't we develop a modern energy index, like the Bond Index, but to include grinding and regrinding energy, the grade recovery curve, and basis smelting thermodynamics. A simple measure that for each ore predicts how much energy will be needed to produce metal (or final product). And a simple technique to indicate the lowest energy route for that ore, the best trade off between grinding and smelting/refining.

The same index and technique could be used to benchmark our existing operations – how do we perform against the estimate of the most efficient way to treat the ore.

Our focus is to improve the energy efficiency of processing, not just the energy efficiency of grinding.