IsaMill- 1:1 Direct Scaleup from Ultrafine to Coarse Grinding

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Abstract

The IsaMill has been used commercially in concentrator plants for over 15 years. Improvements in ceramic grinding media, mill design and wear components have advanced the IsaMill to the point where it can readily accept F_{80}'s of +300 microns. One thing that has not changed since the early days of development is the robust 1:1 scaleup of the mill from the laboratory to the mine site. This paper examines Xstrata Technology's efforts to both improve the grinding capability of the IsaMill and the work that has gone into ensuring the accuracy and precision of independent laboratories across the world that perform IsaMill signature plot scaleup work. Common issues encountered in design testwork are discussed in an effort to promote proper scaleup among all suppliers.

Introduction

Each year independent mineral processing laboratories around the world perform over 100 signature plots to provide an energy scaleup number for Xstrata Technology's IsaMill. 8 laboratories around the world are now certified every two years to ensure the reliability of their work and the robustness of their technique. This is a time consuming process to gather and split the concentrate sample, run replicate tests and ship out concentrate and media to the individual laboratories around the world. Once the testwork has been done any non-conforming laboratories must be inspected to determine any deviation from normal. The total cost of the program exceeds A$50,000. However, the results provide a level of confidence in the testwork being done that ensures every test can result in a process guarantee without Xstrata Technology being involved in the actual testwork. Through this partnership with independent laboratories improvements have been made to the signature plot procedure to reduce error wherever possible and the range of media sizes tested has increased with improved knowledge of the inner workings of the M4 4 litre IsaMill.

Section 1. IsaMill scaleup testwork

Historically IsaMill testwork was done in-house by MIM and then Xstrata Technology. However, as testwork is not a core business and the interest in signature plot testwork increased it became desirable to have external independent laboratories take on this workload.

The testwork itself is relatively simple and repeatable as long as the standard procedure is followed. This repeatability increases with practice.

Figure 1 and Table 1 represent the repeatability possible by someone with limited experience running the M4 (Larson 2012). The margin of error for these five tests is about 3.2% from the average energy to 10 microns. Each individual error from average is shown in the table.

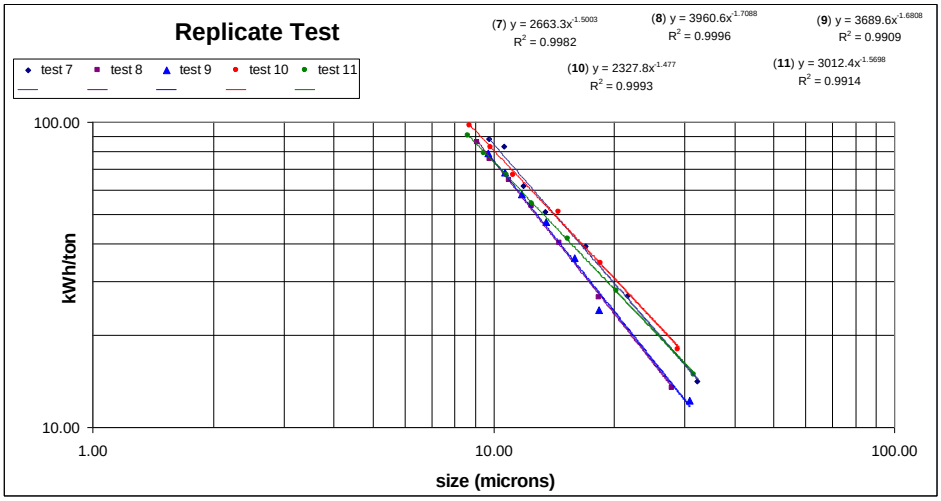

Figure 1. Copper concentrate replicate test

Energy to 10 microns (kWh/ton)				
Test 7	Test 8	Test 9	Test 10	Test 11
84.16	77.44	76.94	77.62	81.12
+5.91%	-2.54%	-3.17%	-2.31%	+2.09%
Mean 79.46 kWh/ton				
Standard Deviation 3.11				

Table 1. Copper concentrate replicate test energy to 10 microns

Figure 2 and Table 2 represents the repeatability of the first standard sample, with a margin of error of 6.8% from the average of the repeatability tests. This was done for the 2009/2010 standard sample.

In this round of testwork 7 different labs were certified. The criterion was to fall within 5% of the average energy of 42.8 kWh/t to a P_{80} of 15 microns from the XT replicate tests. Of the 7 laboratories certified, five were completed with their first try, one on their second and one on their third. In the case of the latter, there were issues with their Malvern laser sizer sub-sampling that was fixed after a visit to audit their procedure. The energies reported by the seven labs averaged 41.5 kWh/t.

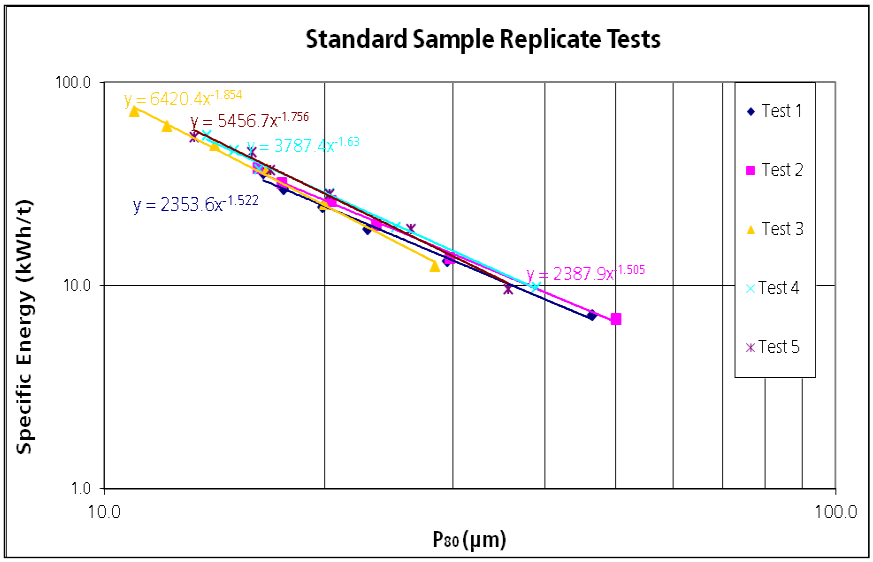

Figure 2. 2009/2010 standard sample replicate test (Villadolid 2009)

	Test 1	Test 2	Test 3	Test 4	Test 5	Average
Energy to 15 microns(kWh/t)	38.14	40.58	42.38	45.81	47.01	42.78
Error from average energy	10.9%	5.2%	.9%	7.1%	9.9%	6.8%

Table 2. 2009/2010 standard sample replicate test target energy and error

Figure 3 and Table 3 are the replicate tests for the most recent standard sample done in 2011/2012. This has a margin of error of 2.1 % to 12 microns and is performed by an XT engineer with the most recent practice of anyone performing signature plot tests. In this case the standard for the labs to maintain certification was adjusted to +/- 5% of the average energy rather than the +/- 2.1% shown possible by the replicate tests.

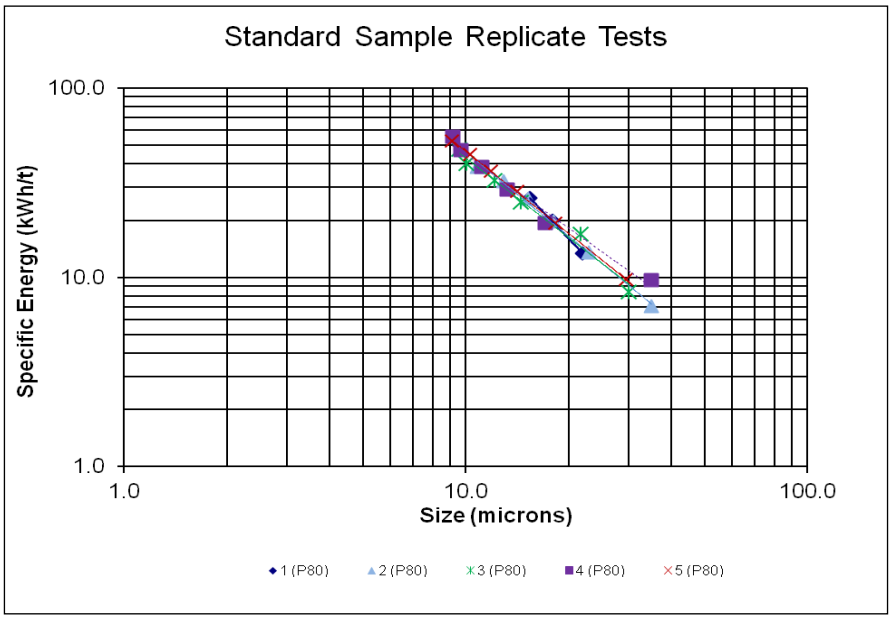

Figure 3. 2011/2012 standard sample replicate test (Villadolid 2011)

	Test 1	Test 2	Test 3	Test 4	Test 5	Average
Energy to 12 microns(kWh/t)	35.71	35.12	33.15	35.15	35.71	34.97
Error from average energy	2.1%	.4%	5.2%	.5%	2.1%	2.1%

Table 3. 2011/2012 standard sample replicate test target energy and error

Section 2. Common sources of error

The IsaMill signature plot test will have an average margin of error of about +/- 5% under ideal conditions to common IsaMill product sizes. Standard techniques have been set in an effort to minimize this error.

The energy meter will have an error of about +/- 1% according to the common manufacturers of energy meters in use. The slurry flow measurement will have an error of about .5 seconds, or 1-1.5% depending on flow. The density measurement will have an error of about 1%. The actual timing of each pass will have a margin of error of about 1%. As each pass requires about 6-7 minutes to complete, an error of 2-3 seconds on calling the tank empty is a minimal error. The remaining measurement error is due to any sizing or sampling inconsistencies in the Malvern laser sizer.

These errors are almost inevitable, improper technique will only serve to amplify them. Some errors encountered while doing laboratory audits include the following (this is not to single out any particular lab for criticism but to promote proper techniques among all labs).

2.1 Flow measurement

Improper flow measurement can greatly increase the margin of error of a test. Flow can either be measured with a 1 litre Marcy scale cup or with a suitably large graduated cylinder. With the Marcy scale cup it is relatively straight forward as the time is measured for slurry- not froth- to discharge from the holes marking the 1 litre point. In this case time/volume is actually being measured.

With a graduated cylinder time/volume cannot be used as the froth will obscure where the slurry actually reaches the line for the volume of interest. In the case of using a graduated cylinder to measure slurry flow the slurry must be directed into the cylinder for a given amount of time and then the level analysed when the sample has settled. In this case the measurement is in volume/time.

2.2 Density measurement

The density sample is taken in the middle of each pass. This requires that the feed sample is properly mixed to avoid feed density segregation between the beginning and end of the pass. For this reason all tanks used for IsaMill signature plots must have internal baffles and a mixer capable of suspending .5mm material of an SG of 4-5. Failure to use baffles can cause segregation and also centrifuging of the sample as it nears the end of the pass, starving the feed pump of slurry and artificially extending the pass and increasing the measured energy consumption.

The slurry density sample is never to be calculated by using the Marcy scale, but rather by a wet/dry mass. The Marcy scale can overestimate the slurry density if flow is allowed to continue into the cup even after overflowing. It can also underestimate the slurry density if material is allowed to spill and less than 1 litre of slurry is measured.

2.3 Sample sizing

The sizing of the individual pass samples can be wrought with errors that are sometimes hard to detect. For this reason Xstrata Technology has general guidelines for Malvern use during scaleup tests. All subsamples should be mixed in a baffled beaker and samples taken with an adjustable micro-pipette. Use of magnetic stirrers should be avoided as the magnetic bar can be interfered with by the sample pipette. Baffles must be used to prevent segregation between the middle and outside of the sample container. The adjustable pipette is needed to ensure that all slurry drawn is actually put into the Malvern. In the case of magnetite testwork screen sizing is preferred to avoid the possibility of magnetic agglomeration affecting the laser sizer results.

In one case a labs standard sample P_{80} energy was coming out higher than acceptable but the line for the P_{98} signature plot energy matched what would be expected from the replicate test, as did the mill net power draw. After examination it was determined that faulty sub-sampling for the Malvern was the cause. In this case the Malvern was located across the room from the sample mixer and a bulb pipette was used to take the Malvern sample. As the obscuration level of the Malvern determines how much sample is discharged, the combination of excess sample and segregation in the bulb resulted in the top size being segregated to the bottom and ultimately biasing the Malvern sample. By using an adjustable micro-pipette only the amount of slurry actually needed is sampled and all of it discharged into the Malvern, preventing any segregation biases.

The Malvern itself is basically a black box poorly understood by much of industry. Without proper care readings can be sporadic and inaccurate without the user knowing. There are specific settings for minerals but the one setting that is most commonly wrong is the absorption value. This can commonly range from .01-1 depending on the Malvern model. Xstrata Technology generally recommends that this setting be placed at .1 so that particles of .3-1 microns are measured and accounted for. By setting the absorption improperly sub 1 micron particles will not be measured. For most applications this may not be a major problem but for some IsaMill applications that size range can make up 10-20% of an ultrafine size distribution.

2.4 Viscosity

Excess viscosity can also have detrimental effects to energy efficiency if not fully understood and appreciated. Xstrata Technology has started to provide all new operating sites and M4 laboratories with a Marsh funnel. The Marsh funnel is a simple yet effective tool for quickly determining the viscosity of slurry without the need to stop a test to perform more complex rheology measurements. It consists of just a funnel and a one quart (.946 Litres) container. One quart of water takes about 28-30 seconds through the funnel.

Typically in a M4 signature plot test the net power draw will drop from pass to pass. This is simply an effect of the material being ground finer and thus being easier to mix. It was found over the course of several M4 and M20 test programs that a set of conditions existed where this power draw would start to increase. Comparing to Marsh funnel readings taken during these same passes it was found that this increase in power draw correlated to Marsh funnel times of about +38 seconds for the one quart of slurry to pass through the funnel. This time limit will change with media size, as more of a void space between larger media won't be as sensitive to viscosity changes but this aspect has not yet been fully investigated.

(Wikipedia, 2008, http://en.wikipedia.org/wiki/Marsh_funnel)
The Marsh funnel is not a rheometer, because it only provides one measurement under one flow condition. However the effective viscosity can be determined from following simple formula.

$\mu = \rho (t - 25)$

where μ = effective viscosity in centipoise
ρ = density in g/cm³
t = quart funnel time in seconds

This is by no means meant to be a precision measurement. It does though act as an invaluable tool when each pass through the IsaMill only allows for 6-7 minutes for all measurements and it must be decided quickly if water is to be added to dilute the next pass.
Each pass through the IsaMill is separately accounted for with an individual energy so each pass at a different density does not affect the others.

Figure 4. Marsh Funnel

2.5 Sample mass and segregation

The standard for most materials is to provide 15 kg of dry solids for each M4 signature plot. The correct amount of solids is critical to ensure that steady state is reached and a representative discharge is sampled without coarse solids being segregated and held in the mill. This requirement will be the same for all stirred mill tests where a continuous discharge sample is collected. An example of this is shown below in Figure 5 by Gao testing different feed masses in a 40 litre pilot Tower Mill. The smaller sample mass shows less energy required to reach equivalent particle sizes. Although this result may look good it is not realistic compared to the test done with more sample. For this reason Xstrata Technology recommends that to ensure proper scaleup, testwork is done with 3-4 x solid volume than mill void volume. For common sulphide ores this results in 15 kg of total mass. For something like magnetite with a higher solid SG more material is required. If a very coarse product and low energy is desired more sample still may be required to ensure steady state is reached in the first pass and that there is enough time per pass for the operator to reliably take all measurements with the high flowrate. If screen sizings are to be done where more mass is removed during each pass more starting mass will be required.

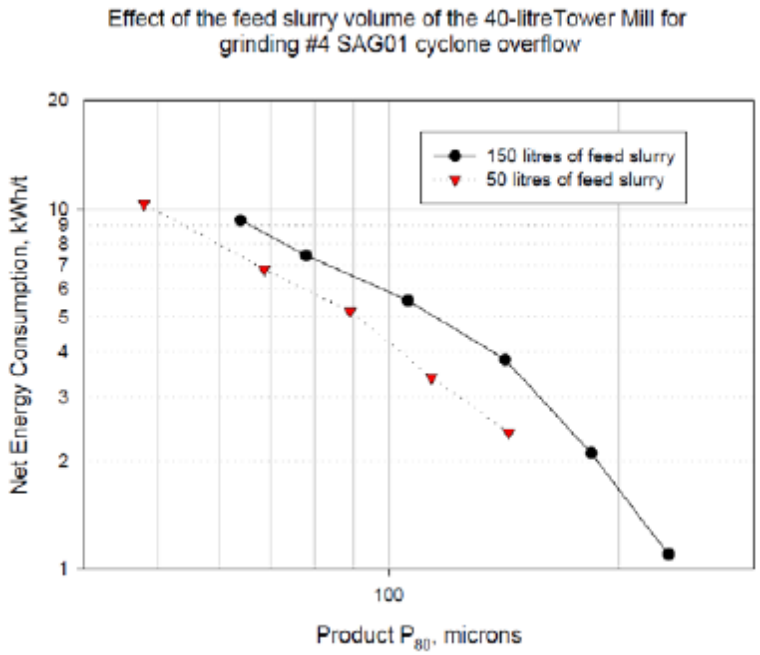

Figure 5. Effect of varying feed solids mass in a pilot tower mill (Gao)

Not all stirred mill test programs follow these guidelines however. Published conditions below compared to the IsaMill signature plot standard show recommended solid volumes of less than half of that used to size an IsaMill and barely enough solids to equal the total mill void space. (Nippon Eirich 2009 and Rahal, Erasmus and Major 2011)

Mill Type	Mill Open Volume(L)	Sample Mass	Solid Volume(L)	Ratio
M4 IsaMill(4L)	**1.35**	**15kg**	**5.00**	**3.70**
Nippon-EirichNE008(8L)	**~2.35**	**10kg**	**3.33**	**1.42**
Nippon-EirichKM-5(120L)	**~35.20**	**150kg**	**50.00**	**1.42**
Knelson-Deswik10(10L)	**~4.72**	**20kg**	**6.67**	**1.41**

Table 4. Regrind mill test volume ratios

Section 3. Larger grinding media

One of the most significant advances in IsaMill technology over the last 5 years has not come from Xstrata Technology itself but from media suppliers around the world. The original UFG IsaMills were run on either sand or slag, a major limitation to the coarseness of the feed that can be processed. Even the first widely used ceramic media in an IsaMill was limited to an effective size of 3.5mm. While progressing up the feed coarseness scale, there were still limitations as to what this was capable of grinding. In recent years 5 to 6.5mm high quality ceramic media has become available that has greatly increased the efficiency of grinding coarser material in the IsaMill. This media has also resulted in product size distribution curves that are much sharper and more efficient to process downstream. An example of this from Anderson, et al, is shown in Figure 6 for MRM ore. At an equivalent energy and feed size the 5-6mm media gives a much sharper size distribution curve with the top size completely ground.

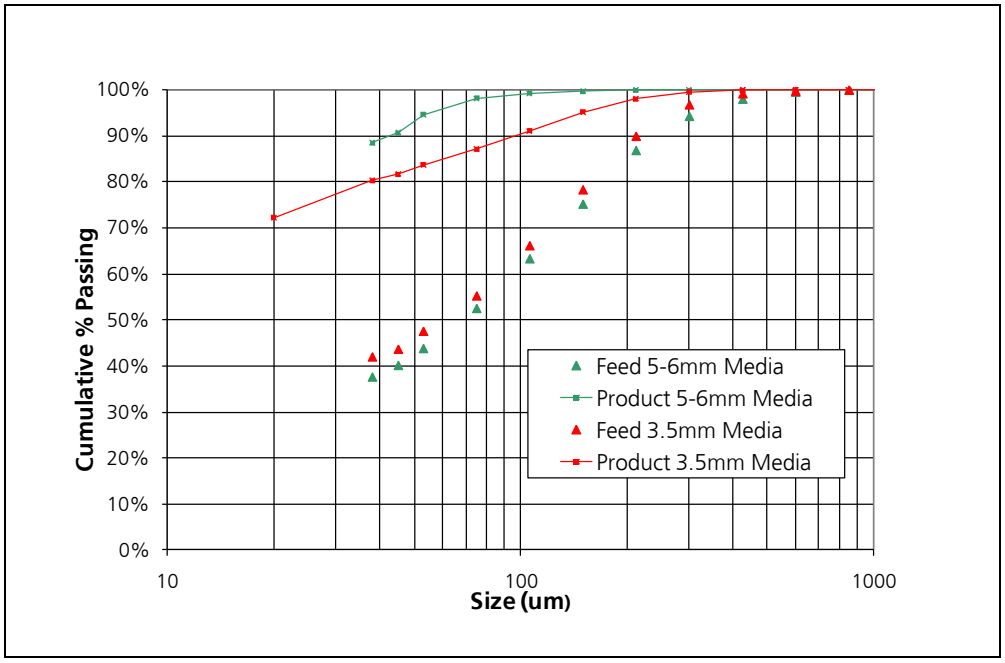

Figure 6. Performance of 3.5 mm Media at 16 kWhr/t and 5-6 mm at 16 kWhr/t

In the case of the Ernest Henry Mine magnetite circuit the mill feed during startup was regularly between an F_{80} of 300-350 microns with a top size approaching 1mm. Due to the coarseness of this stream a 6.5mm ceramic media manufactured by Cenotec was chosen to ensure top size breakage. Signature plot work was done on the cyclone underflow of the rougher magnetic separator at AMMTEC prior to starting this circuit. The comparison between the AMMTEC signature plot (blue) and the EHM commissioning surveys (red) are shown below in Figure 7. In this case the test ore and commissioning ore were taken months apart and the media top size is 6mm for the AMMTEC test and 6.5mm for the EHM M10,000 but the scaleup to the mill target of 45 microns still falls within the 5% margin of error associated with the test. In this case the net energy for the M10,000 to grind to a P80 of 42 microns is 29.9 kWh/t versus 28.8 kWh/t.

It is currently unknown how large of a media can be tested in a standard M4 IsaMill and still scale to full size mills. At some point the wall effect will become apparent and the power draw will increase due to media shearing between the disc tip and mill shell. This has not happened at 6mm.

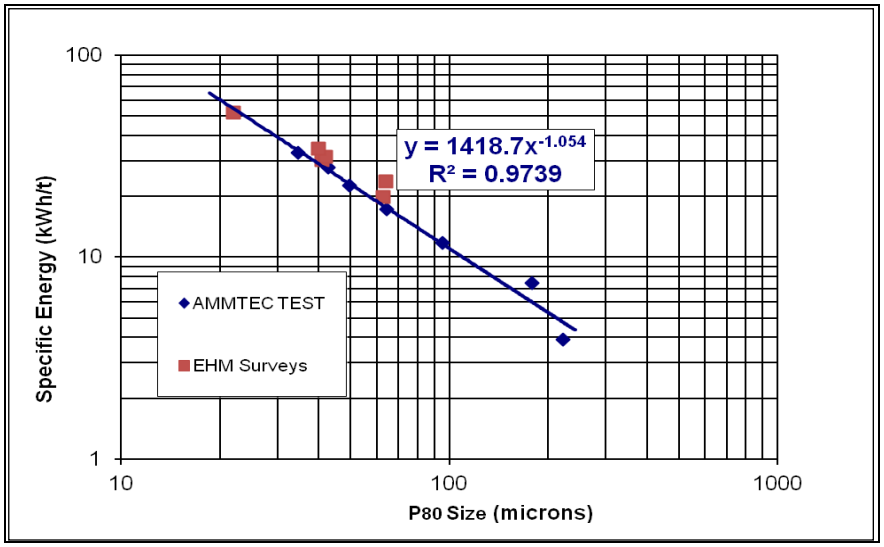

Figure 7. EHM M10,000 vs. AMMTEC M4 scaleup (Larson 2011)

Despite being a 6.5mm top size and needing to grind coarse abrasive magnetite slurry the Cenotec media at EHM has remained very round and worn at a rate of 8-9 g/kWh. Figure 8 shows this media after being emptied into the media bin one month into operation. At this point the media would have turned over slightly more than 1 time.


Figure 8. Cenotec 6.5mm ceramic media charge at EHM after 1 month (Larson 2011)

Advances in the size of media available and the confidence that it will scale from a standard M4 test has led to other test programs to take advantage of IsaMill technology in new grinding duties. Work performed by AMMTEC from David, et al, shown below in Figure 9 demonstrates the energy efficiency of the IsaMill when taking a coarser magnetite feed and grinding to a target of 34 microns. This efficiency gain over the ball mill increases as the grind goes finer. This would further promote the possibility of running the IsaMill either

alone at a small scale or in series with a ball mill with 300-400 micron F80's and being efficient to grind products below 60-70 microns.

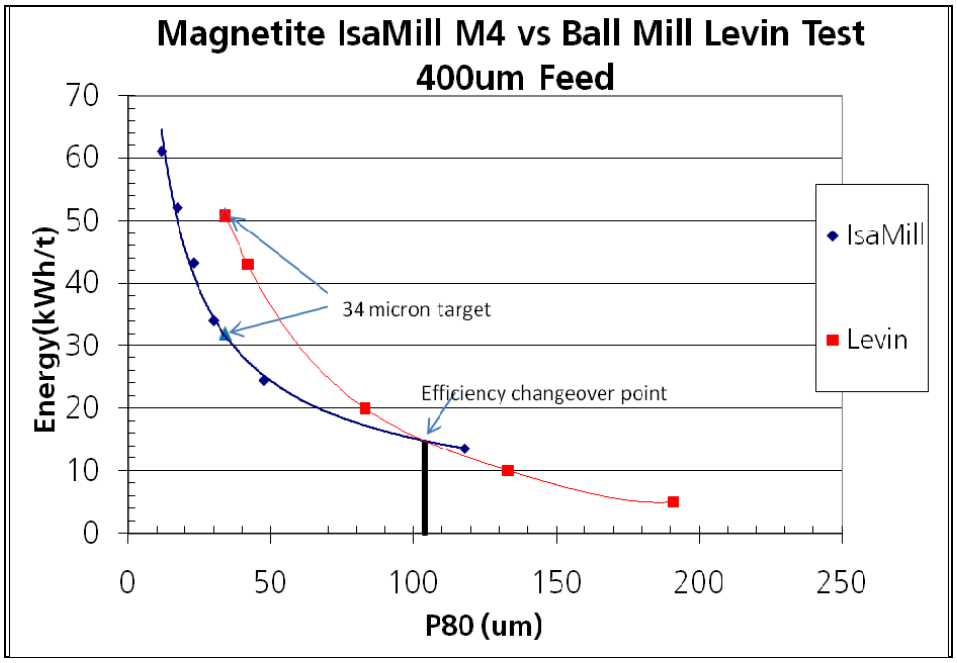

Figure 9. IsaMill/Levin test comparison (David, Larson, Le 2011)

Similar to the MRM results with the sharper product size distribution the magnetite results (Figure 10) showed no material over 106 microns in a 37 micron P_{80} and very little over 75 microns. The P_{98}/P_{80} ratio in the IsaMill is typically a positive factor even with smaller grinding media but the use of 5mm media on feeds typically served by 3.5mm media can improve this further. In the case of magnetite this results in less oversize middlings and an improved concentrate grade.

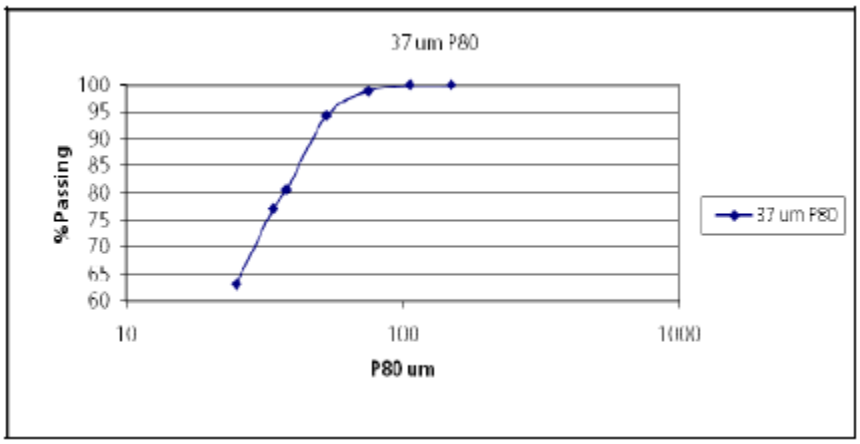

Figure 10. IsaMill magnetite product size distribution curve (David, et al)

In this program the M4 was also run continuously in the pilot plant to confirm that the energy and product size distribution were not a result of coarse material segregation and to produce feed for the downstream processes. The M4 is ideally suited for this application as at a

common magnetite regrind energy of 10-15 kWh/t about 100 kg/hour can be processed through the mill.

The transition to 5mm media may also improve the energy efficiency of a process depending on the target P_{80}. In all cases whether comparing different technologies or just media size for a particular technology there is a cross-over point where one becomes more efficient than the other. In the cases in Figure 11 the larger media is more efficient to a coarser product size. When an application requires a finer grind and more energy there is enough residence time for the 3.5mm media to break down the coarsest incoming feed at the same rate it comes in. Compared to 5mm media it will remove smaller pieces at a time so needs more time to grind a coarser feed. This is ideal for a finer grind and high energy application. At a coarser product and lower energy the high flowrate may overwhelm the 3.5mm media and fill up the mill with coarse material.

This is shown in Figure 11 for two different platinum applications. At product sizes above 30 microns the 5mm media will be more efficient than the 3.5mm media. In this case the smallest media size capable of breaking the incoming feed is not necessarily the most efficient option.

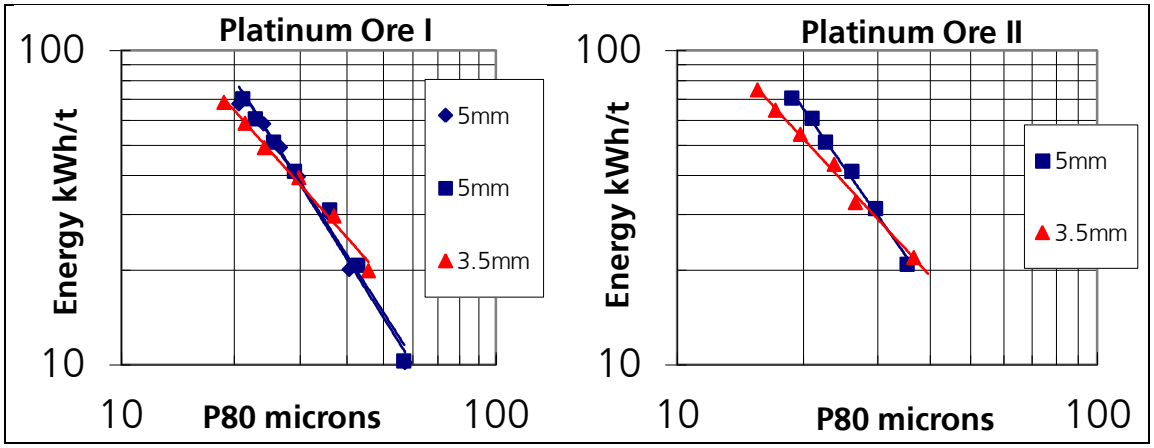

Figure 11. Comparison of 5mm and 3.5mm media for platinum ore (Larson 2010)

Use of +5mm media has the potential to improve energy efficiency and product size distribution for existing operations while increasing the range of feed sizes the IsaMill can treat in future applications.

Conclusions

By treating the independent mineral processing laboratories around the world as partners and involving them in advances in IsaMill technology Xstrata Technology has been able to maintain rigorous standards in the quality of scaleup work done by these labs. Advances in the ability to treat coarser feeds have not impaired the ability of large scales mills to still be accurately scaled from the standard 4 litre IsaMill. Large improvements in energy efficeincy and product size distributions can be realized by utilizing the 4 litre mill in the lab or pilot plant setting.

Acknowledgements

The authors would like to thank Xstrata Technology for permission to publish this work and assistance in writing it. We would also like to thank Xstrata Copper's Ernest Henry Mine for permission to publish the EHM magnetite IsaMill scaleup work and AMMTEC for performing this lab work.

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