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Enhancing Magnetite Returns – The Benefits of IsaMilling

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ABSTRACT

With the expansion of magnetite projects in Australia has come the opportunity to take advantage of newer technologies that were not necessarily available when the magnetite industries of North America and Europe were maturing. One of these technologies is the IsaMill, originally developed for the economic treatment of ultra-fine grind (UFG) duties of Mount Isa Mines. As understanding of the IsaMill has increased, so too has the ability to process coarser feeds while maintaining the same energy efficiency advantage and tight product size distribution that originally made the IsaMill so attractive. In the case of magnetite the hard non-elastic ceramic grinding media is ideally suited to the grinding duty when compared to steel grinding media. The centripetal separator and naturally steep product size distribution curve provide a mill discharge that maximises the critical concentrate grade. This paper analyses the effect of the IsaMill grinding technology on the full-scale Ernest Henry Mine (EHM) magnetite operation along with pilot and lab scale demonstrations of optimisation. Issues encountered and the solutions to maximise the mill throughput and quality are examined in an effort to promote better understanding across the industry.

INTRODUCTION

In 2011, Ernest Henry Mine (EHM) started processing the magnetite from their copper/gold concentrator tailings. The flow sheet for this plant is shown in Figure 1.

The inclusion of the IsaMill was at the time unique for magnetite processing. The decision was made after comparative tests of an M4 IsaMill and a pilot 40 L tower mill. The results of this comparison are shown in Figure 2 (Burford and Niva 2008).

The crossover of energy efficiencies between the tower mill and IsaMill is common and will depend on feed size, ore hardness and media sizes employed. The same trend is seen in Figure 3 comparing a ball mill with an IsaMill for a different magnetite project (David, Larson and Le, 2011).

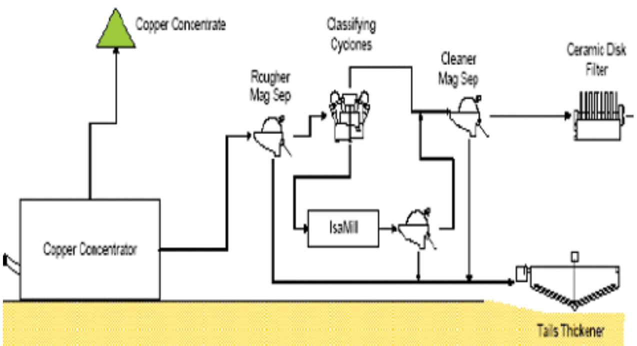

FIG 1 - Ernest Henry Mine magnetite flow sheet overview (Siliezar, Stoll and Twomey, 2011).

Since the time of the initial test work, and further developments have been made benefitting IsaMill operations in the manufacturing of reliable larger ceramic beads. While the EHM comparison test work was done with 3.5 mm ceramic beads 5 or 6+ mm beads are now commonly offered by a variety of manufacturers. This ensures a more complete top size reduction vital for magnetite operators to make final silica grade and also further reduces the already low amount of ultra-fines created which could complicate downstream processing with their propensity to lead to fine liberated silica entrainment in magnetic concentrates. The ceramic media has an advantage over steel media in that it is far less elastic and transfers energy more efficiently to the ore rather than just being deformed.

ISAMILL PERFORMANCE

During the first year the IsaMill was typically receiving a F_{80} of 250 - 300 microns (compared to a design feed size of ~150 microns) and an absolute top size in excess of 1 mm. Cenotec ceramic media with a top size of 6.5 mm was used in the IsaMill with the goal of being able to better break the coarse end of the feed.

Fortunately the deviation from design was realised prior to commissioning. This feed was similar in size to that tested at AMMTEC in May 2011. Some limited survey results are plotted on Figure 4 showing the AMMTEC signature plot with the good scale-up correlation typical of IsaMill installations. The mill net power draw (gross power – 80 kW) was also used as the AMMTEC results are expressed in net energy required.

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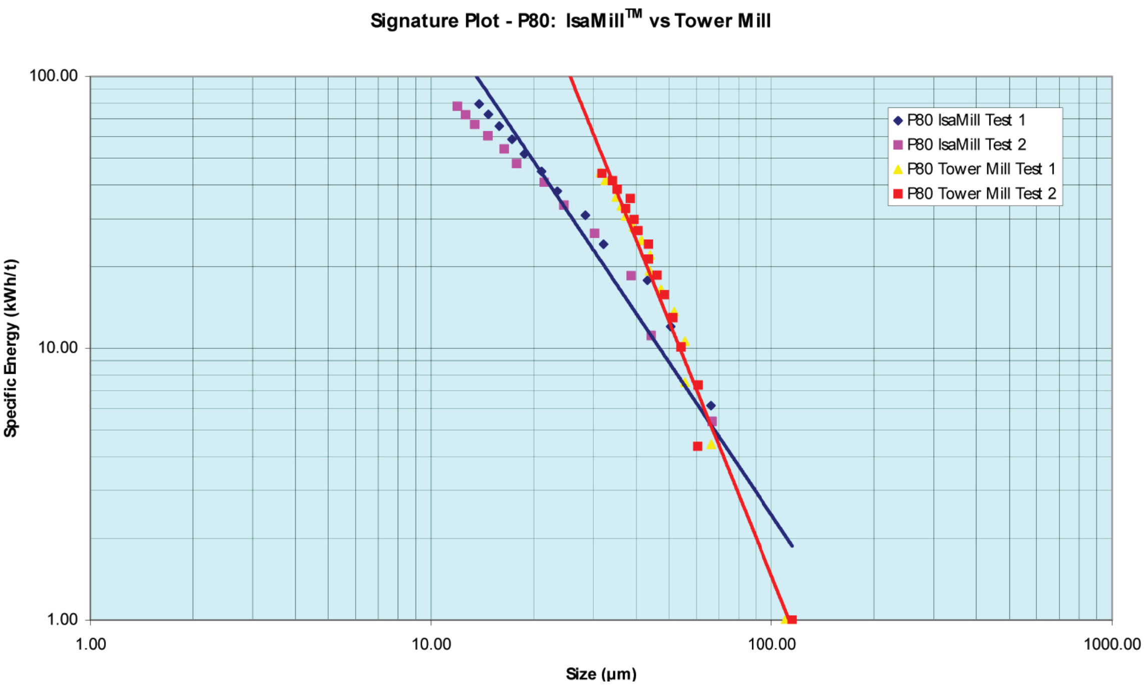

FIG 2 - Comparison of IsaMill and tower mill.

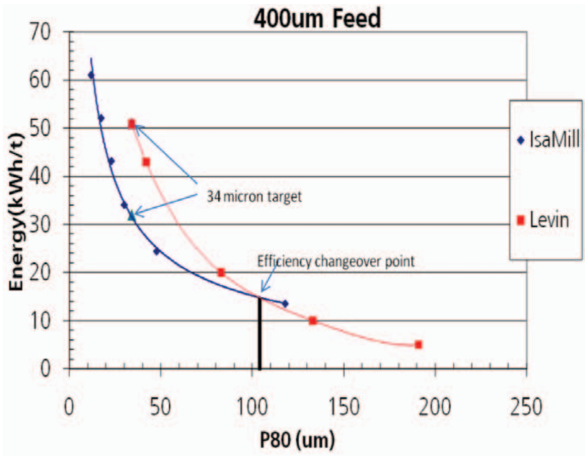

FIG 3 - IsaMill/Levin test comparison.

FIG 5 - The Ernest Henry Mine 3 MW M10 000 IsaMill.

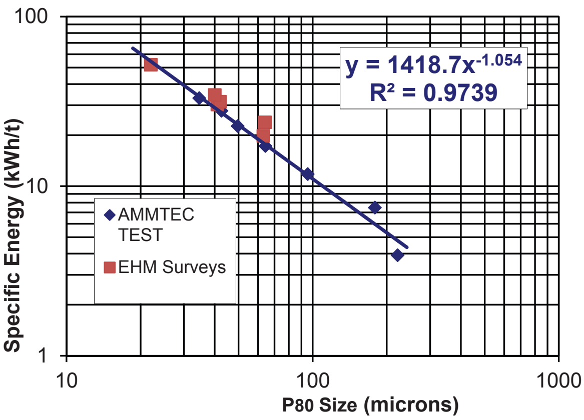

FIG 4 - AMMTEC signature plot with Ernest Henry Mine M10 000 survey data (Larson, 2011).

The AMMTEC tests were performed with a top size 6 mm of Cenotec CZM media while the plant uses 6.5 mm Cenotec.

Figure 5 shows the actual 3 MW M10 000 installed at EHM. The feed enters on the left of the picture at the non-drive end and discharges from the drive end where it is then sent to the regrind magnetic separators.

Also included in Figure 6 is an example of the IsaMill product size distribution. Considering the coarseness of the feed the steepness of the product size distribution is more than acceptable. Much of the coarse material in the product appears to be silica reporting to the discharge due to density differences with the finer higher specific gravity magnetite. The regrind magnetic separators concentrate during this survey contained zero material above 106 microns and minimal material above 75 microns.

IMPROVING THE ISAMILL FEED

As not all of the tails are currently processed, there is an opportunity to improve the grinding capacity of the magnetite circuit. This could be achieved by screening the rougher magnetic separator feed, concentrate or the cyclone underflow at 150, 212 or 300 microns and returning the oversize to the main copper concentrator. From an early survey shown in Table 1 it can be seen that this size fraction

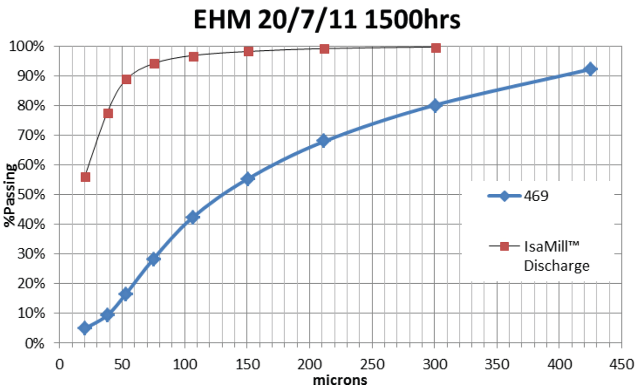

FIG 6 - Ernest Henry Mine M10 000 IsaMill feed and discharge product size distributions.

TABLE 1

Magnetite regrind fresh feed 24-7-11.

Size fraction (µm)	Cumulative % passing	% copper	% iron	% silica
850	99.25	0.42	15.41	43.83
600	96.31	0.44	14.84	43.62
425	89.46	0.49	15.61	42.98
300	79.62	0.43	16.91	41.05
212	69.72	0.22	23.07	38.27
150	58.15	0.10	36.74	22.87
106	43.25	0.05	51.23	13.75
75	30.06	0.03	54.31	9.11
53	18.92	0.05	58.71	5.99
38	10.48	0.05	61.66	3.74
20	5.40	0.11	64.20	3.31
-20		0.15	49.66	8.60

grades about 0.45 per cent copper and 40 per cent silica. This has the potential to improve the overall copper recovery of the EHM concentrator and reduce the amount of silica reporting to the magnetite cleaner circuit. In addition to any potential benefit in increased copper recovery, removing this material would reduce the wear on the IsaMill, increase the throughput of the IsaMill and improve downstream grade and filtering performance by reducing the amount of silica being fed to the IsaMill and potentially being turned into silica slimes.

It is an option at EHM to improve grade (assuming the liberated silica entrainment is controlled) by screening the rougher magnetic concentrate. This would result in a finer more homogenous feed to the IsaMill and also reduce the amount of coarse middling material discharging from the IsaMill. It would be expected that as a result the specific energy required would decrease to <20 kWh/t from the current 30 - 35 kWh/t. It would also increase the iron grade of the regrind feed by five to ten per cent Fe. The amount of actual magnetite processed through the IsaMill would increase from about 55 t/h to over 90 t/h under this scenario compared to the coarsest feed scenario. This has the potential to improve the concentrate grade without alternative treatment such as finer Derrick screens on the final concentrate. A setup for 300 micron, 212 micron or 150 micron screening of the rougher magnetic separator concentrate prior to the cyclones or IsaMill feed would also be more manageable than the finer Derrick screens. About half of the silica present and two-thirds of the non-magnetic material would be removed by a 300 micron screen. By not sending the material to IsaMill in the first place this non-magnetic material would not be able to be turned into fines more susceptible to entrainment further downstream.

The results of screening under four different sampled scenarios spanning three months is included in Table 2. By installing a 212 micron Derrick screen prior to the IsaMill on the rougher magnetic separator concentrate an improvement in actual magnetite throughput of about 30 - 40 per cent could conservatively be expected.

TABLE 2

Ernest Henry Mine IsaMill prescreening scenarios.

	F_{80} (microns)	Energy (kWh/t)	Total throughput	Fe grade	Magnetite throughput	
Case 1					t/h	% improvement
Normal	300	30	93.3	42.3	54.8	
300 µm screen	180	23.8	117.6	49	80.1	46.0
212 µm screen	140	21.9	127.9	52.7	93.6	70.7
Case 2						
Normal	260	25.8	108.5	37.4	56.4	
300 µm screen	180	23.8	117.6	41	67.0	18.8
212 µm screen	140	21.9	127.9	43.6	77.4	37.3
Case 3						
Normal	155	22.7	123.3	46.4	79.5	
300 µm screen	120	20.5	136.6	49.2	93.3	17.4
212 µm screen	100	18.4	152.2	51.1	108.0	35.9
Case 4						
Normal	212	24.8	112.9	44.3	69.5	
300 µm screen	150	22.5	124.4	48.5	83.8	20.7
212 µm screen	125	20.9	134.0	52.5	97.7	40.6

In addition to the large amount of coarse material in the feed it was found by Davis tube analysis that 14 per cent of this feed was liberated non-magnetic material. Similar data from an earlier survey showed 20 per cent liberated non-magnetic material in the regrind fresh feed.

Fine screening in general has been used for over 40 years in Minnesota (Devaney, 1985). From Healey, already in 1972 Erie Mining Company Hoyt Lakes plant had 200 mesh (74 micron) Rapifine screens supplied by Dorr-Oliver Company to screen the final concentrate. The actual paper cited came from 1967. The results of this screening are shown in Table 3.

TABLE 3

Typical results from two-stage fine screening of finisher concentrate (Healy, 1967).

	% wt	% 325 mesh	% distribution of -325 mesh	% silica	% distribution of silica
Fine screen feed	100.0	88.5	100.0	8.5	100.00
Fine screen oversize	18.9	52.0	11.1	20.5	45.9
Fine screen undersize	81.1	97.0	88.9	5.7	54.1

EHM has recently commissioned pilot Derrick screen deck unit to prove the application for their plant. Table 4 shows the split of the iron around the screening pilot plant. The Derrick screen is widely accepted in the iron ore industry, though it is best known in application using finer screens in screening relatively coarse material (and thus lower grade) from final concentrate to improve iron grade.

The key points from Table 4 (Do, 2012):

- More than 90 per cent of the material in the stream was classified correctly.
- The per cent solids in the undersize is too low to constitute a feed to the IsaMill. This will require a magnetic densifying step prior to feeding the IsaMill.

A detailed study will need to be completed to identify the preferred location of the screening plant in order to maintain the proper feed density to the IsaMill with minimal

TABLE 4

Pilot Derrick screen preliminary results.

Test	Wash water (m^3/h)	Classified correctly (%)	Fines classified correctly (%)	Mass split to undersize (%)	% solids of undersize
1	0	93.2	94	84.8	41.38
2	42	95.3	97.5	88.9	35.75
Test	**Fe split to undersize (%)**	**Fe grade of feed (%)**	**Fe grade of undersize (%)**	**Fe grade of undersize (%)**	
1	94.5	45.5	50.7	16.5	
2	96.9	43.9	47.8	12.2	

extra costs. Even so this application for the Derrick screen appears ideal. Rather than screening low-grade material after processing it is done prior to grinding saving the energy that would otherwise be spent grinding non-magnetics down to 45 microns.

If the whole of the EHM plant were to be thought of in terms of only processing magnetite with the copper concentrator rejecting the pesky gangue copper and gold, this proposed flow sheet fits in very well. The semi-autogenous grinding (SAG) mill and ball mill are ideally suited for the coarser grinding duties so the coarse fraction of the Derrick screen product returns to the ball mill where it is more efficiently ground. This leaves the IsaMill to grind the finer, iron-rich particles. The grind from 150 to 45 microns is the most energy intensive part of the process so it is best that the particles being ground to the final product size have more value.

By screening the feed, the grinding results can be reliably predicted using the squared function for fines production developed for the IsaMill JKSimMet model. As 45 microns is the size of interest in this case, energy can be predicted from one case to another as long as the per cent passing 45 microns in the feed is known and it is assumed that the feed size distribution curves are relatively normal. This is shown in Figure 7. This will be further proven with a 20 L pilot IsaMill at site. In addition this will be used to optimise the media size prior to installing the screens in the full-scale application.

One of the main advantages of the IsaMill is the steep product size distribution it produces. This is shown in Figure 8, where a 37 micron P_{80} results in a P_{98} of sub-75 microns and zero material over 105 microns (David, Larson and Le, 2011).

It could be expected that by reducing the feed top size a similar performance could be gained from the Ernest Henry M10 000. Figure 9 shows the product sizes from P_{80}s of 38 - 45 microns screening the feed at various sizes.

MAGNETIC SEPARATOR OPERATION AND UPGRADING

There is also room for improvement in the magnetic separator operation feeding the IsaMill. Some improvements have already been made, such as running the magnetic separators at a lower bath level. Magnetic separators are efficient on their own for recovery; the goal is to ensure that entrained silica is limited in the concentrate. By running at a high bath level and increasing the residence time it increased the amount of entrained non-magnetic material reporting to the concentrate. It is best to think of the magnetic separators as giant washing machines, where high flows of water are necessary to wash the silica from the magnetite. Figure 10 shows sanding in one of the regrind magnetic separators. By having the drums in contact with this bed of material it will result in it scooping up material with little selectivity. The picture on the right shows the same magnetic separator minutes later after opening the tailings valves.

In addition to running at low bath levels another change was to raise the drum levels. In the case of the regrind magnetic separators, virtually zero magnetite was in the tails stream but entrained non-magnetic was at over ten per cent of the concentrate. These results were with the separators running at a low bath level. With the drums raised, the tailings remained at below one per cent magnetite but the entrained non-magnetics dropped significantly to a point where the regrind magnetic separators were making a grade of about 68 per cent Fe. Most of the magnetite that will be lost under this operating mode will either be ultra-fine iron which is not efficient to filter or small pieces of magnetite in composites

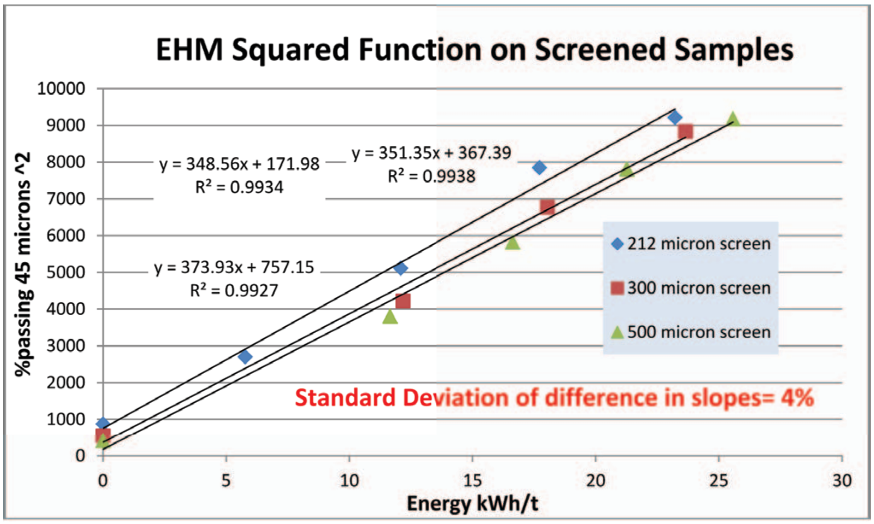

FIG 7 - Ernest Henry Mine production of 45 micron material.

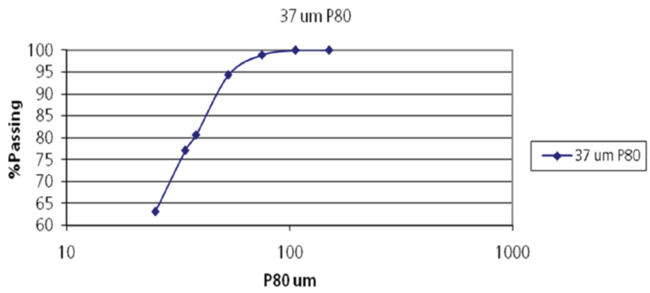

FIG 8 - IsaMill product size distribution curve.

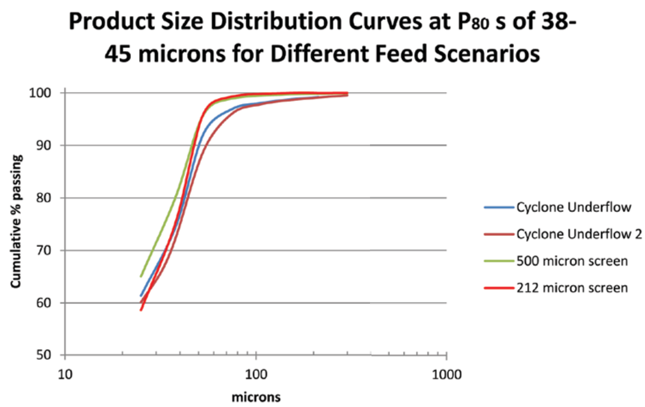

FIG 9 - Ernest Henry Mine IsaMill product size distributions at different feed size screens.

with much larger middling particles which will only act to lower the final concentrate grade. Any effort to recover either of these types of iron losses typically results in more of an increase in penalty in entrained silica than can be gained in improved iron recovery, and this is the reason most magnetite producers willingly sacrifice a small amount of recovery for a substantial improvement in grade. By raising the drum level it will also ensure that the drum is not rotating through a bed of settled solids, picking up silica and increasing the stress on the shaft. In addition results from a 19 July survey showed the incoming regrind feed was about 20 per cent liberated non-magnetic material. It should be noted that this was with the rougher magnetic separators bath levels still high.

Every effort should be made to reduce the entrainment of non-magnetic material in the regrind feed. By sending coarse silica particles to the IsaMill it is ensured that these will be ground down to create unnecessary silica slimes that are even more difficult to reject and negatively impact grade

FIG 10 - Regrind magnetic separator sanded (left) and with tailings valves open (right).

and filtering. Figure 11 shows a sample of the +300 micron size fraction of the regrind circuit fresh feed, with the lighter colour coarse non-magnetic material obvious.

FIG 11 - Regrind fresh feed oversize screened at 300 microns.

During the second extended visit to site dedicated to operations improvement the rougher magnetic separator drums were raised from 50 mm to 75 mm of their mechanical limit. Short surveys of the tailings stream after showed that the tailings only contained about one per cent magnetic iron after the adjustment. This is consistent with good practices around the world and typical rule of thumb operational goals for cobber magnetic separators. The next work to be undertaken on the rougher magnetic separator is to overhaul the distributor to even the slurry flow to the four banks of separators. Currently two of the banks receive most of the flow with the other two largely starved of feed. A general rule of thumb for sizing magnetic separators in North America is to have about 8 - 12 t/h of feed per foot of drum length (about 26 - 40 t/h per metre of drum length). Under ideal operating conditions and at a typical feed of 1400 t/h of fresh feed this would make the EHM separators undersized by about 50 per cent for the drums receiving the most feed.

Fixing the rougher magnetic separator distributor should allow EHM to further optimise the magnetic separators. There was a large amount of non-magnetic build-up observed under the drums that is likely contributing to liberated non-magnetic entrainment in the concentrate. Adjustments to the flow pattern and water addition are planned for the future to deal with this.

Further it is important to point out the necessity of differentiating between magnetic and non-magnetic iron in the tailings; the grades and recoveries of these two iron species should be reported separately. The total Fe in the tails was assayed at about eight per cent; however only 0.5 per cent of the total mass was recovered in the Davis tube of the tailings stream, indicating that over 96 per cent of the iron in the tails is in the form of hematite or other low/non-magnetic form of iron. No effort should be made to recover this, as recovering non-magnetic iron will also result in the recovery of other non-magnetic penalty elements such as silica. Analysis of tailings streams should be done by Davis tube, Satmagan or even a hand-held magnet and never solely by straight assay for iron so that the recovery of the magnetic and non-magnetic iron can be fully understood and targeted. In the case of running a Davis tube on the magnetic separator tails, an assay should be done on the magnetic portion. Previous work done on testing different drum heights likely came to faulty conclusions due to assays not being done on the Davis tube fractions.

CONCLUSIONS

The M10 000 IsaMill scaled reliably from 4 L lab tests, even with a coarse feed and large media size. The product from the IsaMill was a wider size distribution than desired but it would appear that the top size was mostly liberated light silica and did not negatively impact downstream grade control. The feed to the IsaMill can still be optimised by screening the coarsest fraction and by improving the magnetic separator performance to better reject coarse liberated gangue material. These steps will allow the IsaMill to process more material of a higher grade and improve EMH's overall magnetite production.

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