Magnetic Conditioning of Sphalerite at Xstrata's Mount Isa Zinc Operations

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ABSTRACT

Plant tests of magnetic conditioning have shown increased flotation recovery of paramagnetic sulfide minerals (chalcopyrite, sphalerite and pentlandite) in the -38 µm size fraction within rougher and cleaner flotation circuits. A statistical plant test was undertaken in the Mount Isa zinc flotation circuit where magnetic conditioning was tested simultaneously in both the rougher circuit and the cleaner retreat circuit (cleaner scavenger). This test resulted in a normalised increase of 1.60 per cent in the rougher circuit zinc recovery and simultaneously a normalised increase of 4.60 per cent in the cleaner retreat circuit zinc recovery – to a very high level of statistical confidence.

Interestingly, in a novel approach, it was possible to verify the plant test results in two ways. Firstly, detailed MLA analysis of the tails confirmed the statistical plant test results and showed that the greatest effect of magnetic conditioning was on the sphalerite in the C3 - C6 size fraction, where there was a reduction of around 15 per cent in zinc in tails. Moreover, there was a reduction of around 15 per cent in liberated sphalerite across all -38 µm size fractions, but only a seven per cent reduction in non-liberated sphalerite in the tails. Secondly, plant modelling showed that increasing the rougher zinc recovery would cause an increase in zinc feed grade to the cleaner retreat circuit. The increase in the zinc feed grade to the cleaner retreat circuit with magnetic conditioning was demonstrated to a very high level of statistical confidence.

INTRODUCTION

Mount Isa lead-zinc concentrator

Xstrata Zinc's Mount Isa Mine's operations are one of the world's largest producers of lead, zinc and silver. The initial lead-zinc-silver ore deposits were discovered in 1923, while processing of the orebody began in 1931. The current lead zinc processing plant was commissioned in 1966 and has been subjected to various modifications and upgrades over the years to ensure that the plant maintains its financial viability.

Over the past ten years there have been significant modifications to the concentrator. These upgrades include the installation of two milling circuits, the installation of IsaMills to the lead and zinc flotation circuits and a large increase of flotation capacity, with a focus on the zinc flotation circuit. These changes are detailed by Munro and Young (2001).

Zinc flotation circuit

The zinc circuit at the lead zinc concentrator is continually evolving due to varying production demands. At the time that the trial was run, the circuit was configured in the arrangement shown in Figure 1. The zinc roughing circuit consists of eight Outotec tank cells; the primary rougher consists of the first two cells, while the other six are treated as secondary roughers.

The primary rougher concentrate reports to three zinc columns; the concentrate from these columns reports to final concentrate. The secondary rougher concentrate is treated by four Outotec tank cells in the zinc recleaners. Where the recleaner concentrate feeds the recirculating cleaners (banks of Wemco cells) and concentrate from these cells reports to the final concentrate.

The tails from the columns combine with the tails from the cleaners and are classified, with the underflow reground through a series of Isamill's and the overflow reporting to the retreat circuit. The retreat circuit has a roughing stage with the concentrate reporting to the retreat cleaning circuit, with the concentrate from these cells reporting to the final concentrate. The tails from the retreat rougher and retreat tail report to final tails.

Figure 2 shows the particle sizings of the zinc circuit. The feed shows that the targeted grind size for zinc concentrate is in the region of 60 mm. It is interesting to note that the P80 of the final concentrate is in the region of 25 mm, reinforcing the need of the retreat circuit to liberate the engrained sphalerite.

The reagents used at the lead zinc concentrator within the zinc circuit, are copper sulfate as the sphalerite activator, sodium ethyl xanthate (SEX) as the collector and methyl isobutyl carbonyl (MIBC) as the frother.

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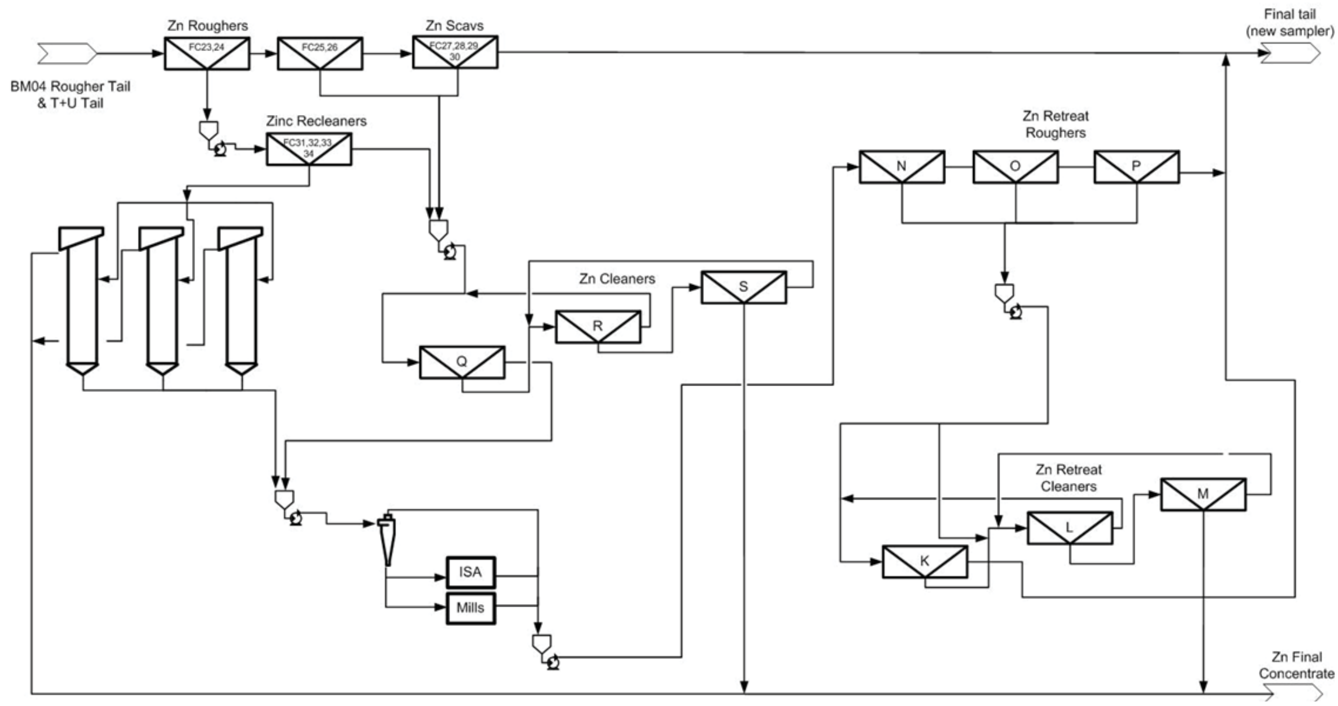

FIG 1 - Lead zinc concentrator zinc circuit.

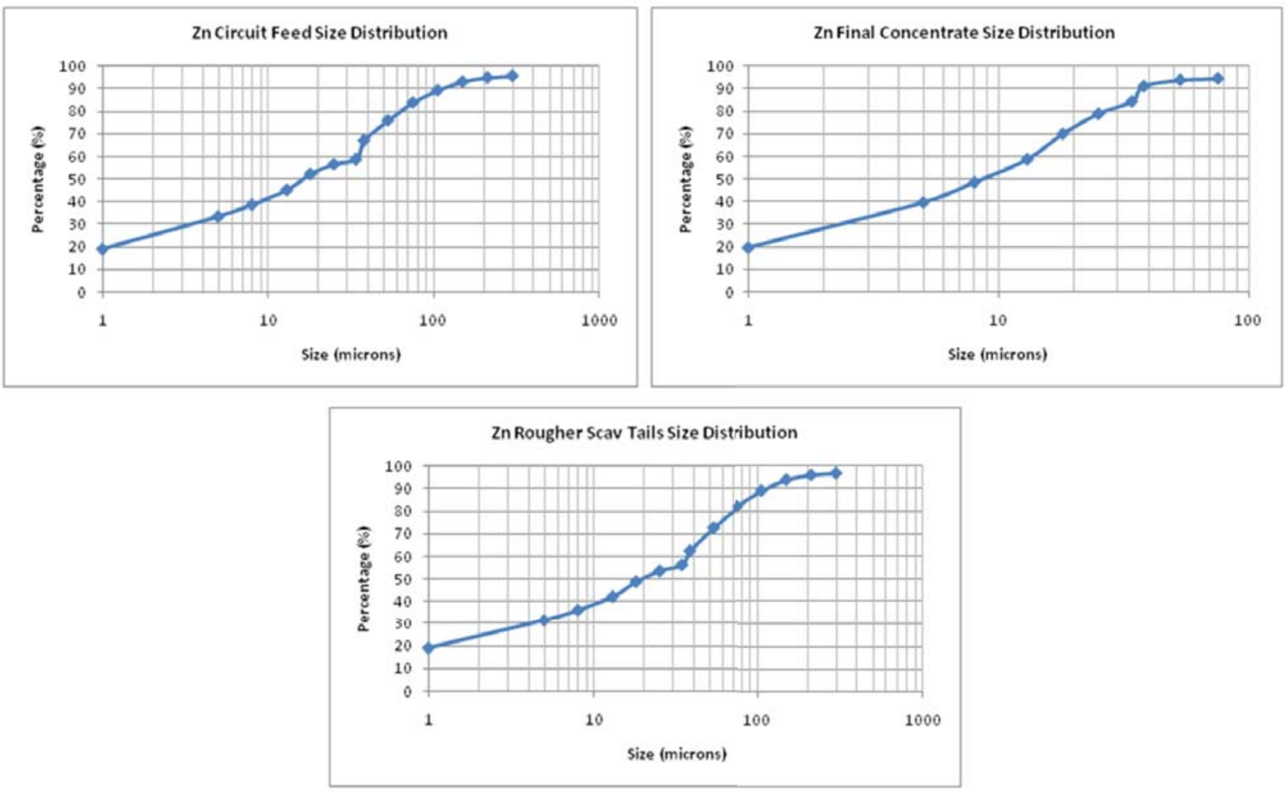

FIG 2 - Particle sizings within the zinc circuit.

Mount Isa Mine mineralogy

There are two main ore deposits treated at the lead zinc concentrator, the Mount Isa deposit and the Hilton deposit.

The Mount Isa deposit (Black Star open cut mine) galena [PbS] and sphalerite [(Zn,Fe)S] is distributed within fine and coarse grained pyrite [FeS] and pyrrhotite [Fe1-xS] which is structured in bedding parallel bands.

The primary silver minerals are freibergite [$(Ag,Cu)_{12}(Sb,As)_4S_{13}$] and tetrahedrite [$(Ag,Cu,Fe)_{12}Sb_4S_{13}$] which are commonly associated with the galena. A majority of the orebody is dolomite and quartz in siltstone layers and veins.

The Hilton Deposit (Handlebar Hill open cut mine and George Fisher underground mine) shares the same general ore structure as the Mount Isa deposit with similar galena, sphalerite, pyrite and pyrrhotite mineralisation located within various thicknesses of bedded shales and siltstones (Capes, Grant and Neindorf, 2006).

Magnetic conditioning

The use of magnetic conditioning to selectively aggregate fine paramagnetic minerals to increase their flotation recovery has been well documented for the paramagnetic minerals; chalcopyrite, bornite, sphalerite (that contains iron – marmatite), galena (that contains iron) and pentlandite (Aslan *et al*, 2010; Bott and Lumsden, 2009; Engelhardt, Ellis and Lumsden, 2005; Fleming, Wood and Lumsden, 2010; Holloway, Clarke and Lumsden, 2008; Rivett, Wood and Lumsden, 2007; Wilding and Lumsden, 2011; Zoetbrood, Vass and Lumsden, 2010). Generally, it has been shown that magnetic conditioning reduces the loss of fine paramagnetic mineral to the tail by at least ten per cent. The sphalerite at Mount Isa is strongly paramagnetic because it contains iron in the sphalerite matrix. However, other paramagnetic minerals like pyrrhotite also exist within the Mount Isa ore.

Figure 2 shows that 65 per cent of the zinc in tail less than 38 µm; increasing zinc recovery requires targeting the fine mineral which magnetic conditioning can do.

EXPERIMENTAL

The application of magnetic conditioning was achieved by installing magnetic conditioning units into predetermined flotation cells within the zinc circuit. The magnetic conditioning devices consist of high strength rare earth magnets arrayed within a stainless steel assembly (Rivett, Wood and Lumsden, 2007). To prevent build up of ferromagnetic particles the magnets are automatically cycled out of the slurry to remove this build up that reduces magnetic field intensity.

Because the aggregates are broken in regrinding it was necessary to install the magnetic conditioning units in the retreat cleaners as well as the rougher scavengers. The complexity of the circuit determined that the trial would be broken down into three sections; the rougher-scavenger circuit, the retreat rougher circuit and retreat cleaner circuit. These have been highlighted within Figure 3, in the dotted boxes.

Figure 3 shows the plant trial sections and sampling points.

The retreat circuits had reliable representative sampling points (outlined within Figure 3 – the dots within the outline) to monitor the affect during the trial. The greatest difficulty was in sampling the rougher scavenger circuit as it was only possible to get two representative samples of the circuit; the circuit feed and circuit tailings. The rougher scavenger concentrate grade was calculated for the trial from other plant streams. The trial was a paired t-test on the calculated recoveries over three months, whilst examining the confidence in the results as the trial progressed.

A randomised block design, on a two-day-on, two-day-off basis was used, with performance judged upon the difference in calculated recoveries between the on and off days. To prevent any additional operational bias it was determined that only one metallurgist would know the operational state that the magnets were in throughout the trial.

The samples for analysis were collected composites, with each point within the circuit being sampled through a mineral liberation analyser (MLA) and an on stream analyser (OSA), where sample cuts were taken every 15 minutes for a 24-hour period. When sample pumps failed the pairs had to be eliminated from the trial, narrowing down the data set for analysis. If there was a significant process disruption that could affect the status of the trial, eg shutdowns, broken sample pumps. The pair would be eliminated so as not to create any additional bias within the results.

Figure 4 shows the installation in the retreat banks.

RESULTS AND DISCUSSION

Rougher scavenger results

The rougher scavenger is the first block within the experimental trial. Ten of the magnetic conditioning units were placed in the first cell in the rougher bank.

The results in the rougher scavenger circuit are summarised in Table 1.

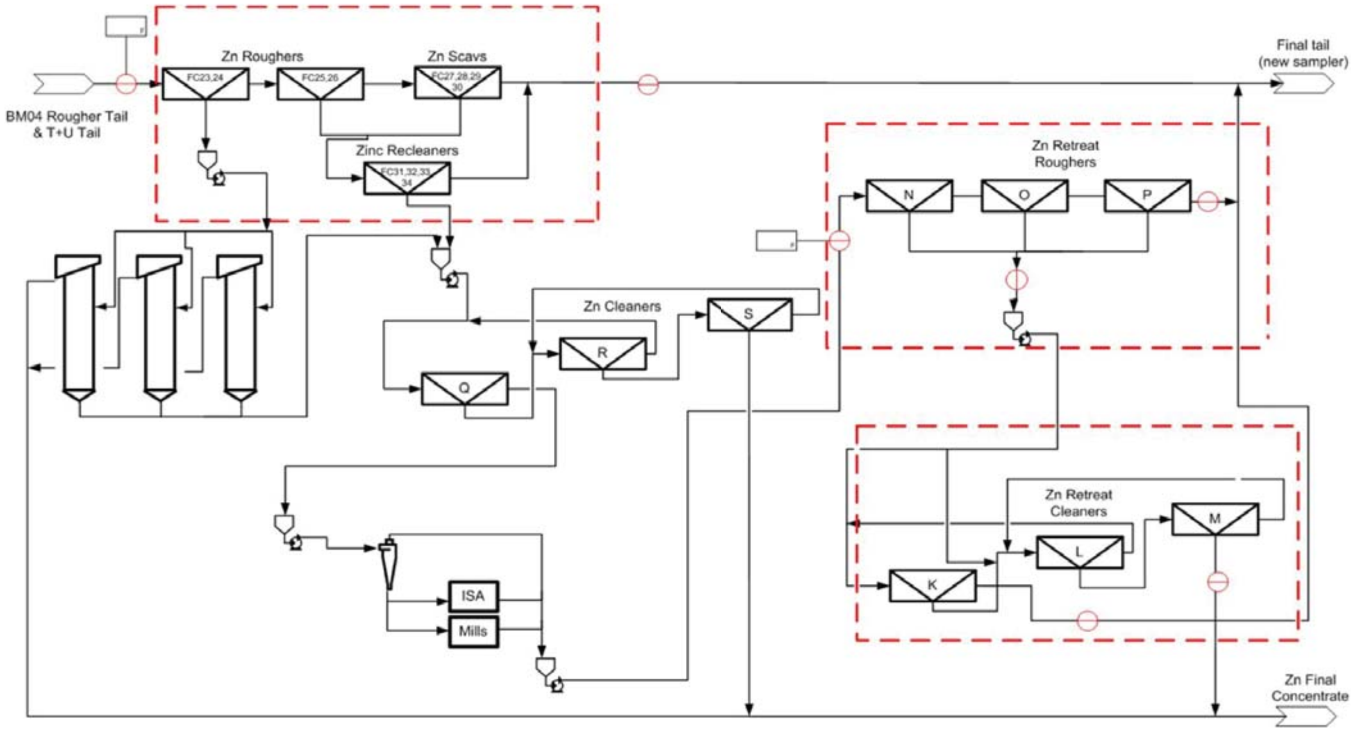

FIG 3 - Plant trial sections and sampling points.

FIG 4 - Magnetic conditioning installations in the retreat bank.

TABLE 1

Rougher-scavenger magnetic conditioning results (normalised).

	Total % Zn recovery	<38 µm % Zn recovery	<38 µm % Zn in tail
Magnetic conditioning ON	101.6	100.8	92.2
Magnetic conditioning OFF	100.0	100.0	100.0
Difference	1.6	0.8	7.8
Paired 't'	3.05	1.79	7.09
Level of confidence	>99 per cent	94.7 per cent	>>99.9 per cent

It must be remembered that there is no concentrate sample taken so the recovery is calculated from the mass flows and feed and tail assays. Because mass flows can be more variable this could increase the standard deviation of the recovery data, however, because small changes in concentrate grade assay do not substantially affect the recovery calculation the affect on recovery is not large. Very high levels of confidence for the trial were achieved for some of the parameters, reflecting a low standard deviation in the data.

Interestingly, and as expected there was no difference between ON and OFF in zinc feed grade, zinc concentrate grade, the recovery of >38 µm zinc and the recovery or assays of lead and iron. The only difference to a high level of confidence was in the <38 µm zinc recovery and tail assay and the total zinc recovery.

During the trial a trend was observed that when the magnetic conditioning was operating there was an increase in mass flow (kg/s) and zinc mass flow (kg/s) to the concentrate. This data was collected and the daily mean mass flow of concentrate and zinc to concentrate was analysed at the end of the test. Although there was a five to ten per cent increase in the mean mass flow and mean zinc flow in concentrate, the high variability in this flow measurement resulted in the level of confidence in the difference being low. This increase in zinc flow to concentrate was also reflected in a similar increase in the <38 µm zinc concentrate mass flow.

The observation of this increased rougher scavenger concentrate flow was further reinforced by the zinc head grade of the retreat circuit. When the magnets were turned ON within the rougher scavenger bank a higher grade of zinc reported to the head of the retreat circuit – this will be discussed in more detail in the next section.

Retreat results

Before flow enters the retreat circuit it has been reground through the Isamills to a very fine P_{80} of 14 µm – ideal feed for the ProFlote units. Ten of these units were placed in the retreat circuit (six within the roughers and four within the cleaners).

The retreat circuit showed a substantial performance improvement both overall as a retreat block (roughers and cleaners) and within the cleaners. While there was a one per cent increase in zinc recovery in the retreat rougher, it was not to a high level of confidence.

The results are summarised in Table 2.

TABLE 2

Retreat magnetic conditioning results (normalised).

	Total retreat % Zn rec	Retreat cleaners % Zn rec
Magnetic conditioning ON	104.6	103.6
Magnetic conditioning OFF	100.0	100.0
Difference	4.60	3.6
't'	2.39	2.32
Level of confidence	98.7 per cent	98.5 per cent

The increase of 4.60 per cent in zinc recovery for the total retreat circuit and 3.6 per cent increase in recovery in the retreat cleaner are to a very high level of confidence, which showed that magnetic conditioning is increasing zinc recovery in the retreat circuit. The results show how effective magnetic conditioning can be when the feed stream is well-suited to the process.

Concurrent with the results in the rougher scavenger circuit, there was no difference in concentrate grade, or iron and lead results.

Mineral liberation analyser results

To understand the mineralogical affect of the magnetic conditioning an ON and OFF composite of the rougher scavenger tail was sent for MLA analysis.

The MLA analysis showed that the magnetic conditioning reduced the zinc in the tail for all <38 µm fractions but that it was most pronounced in the C3 - C6 fractions (approximately 1 - 20 µm). Table 3 gives the zinc assay data by size fraction. The data shows that the reduction in zinc in the C3 - C6 zinc assay is about 15 per cent. About 50 per cent of the weight of the sample is in the CS3 - CS6 fraction, with little weight in the CS1 - 2 fraction.

TABLE 3

Mineral liberation analyser results of rougher scavenger tails.

	CS7	CS6	CS3-5	CS1-2
Magnetic conditioning ON % Zn assay	0.77	0.37	0.52	1.46
Magnetic conditioning OFF % Zn assay	0.80	0.42	0.60	1.50

The MLA also gives the liberation of the sphalerite of the ON and OFF tail sample. Despite the fineness of the sample most of the sphalerite in the rougher scavenger tail is not liberated. The magnetic conditioning has the greatest affect on the liberated sphalerite. There is a 15 per cent reduction in liberated sphalerite over the whole sample with magnetic conditioning, and about a seven per cent reduction for the non-liberated fraction. The non-liberated sphalerite can still be up to 90 per cent of the sphalerite in the sample fraction. This is visually represented by the Figures 5 and 6 which shows where the percentage of liberated sphalerite is compared on the various cyclosising fractions.

The effects of magnetic conditioning can be clearly seen between Figures 5 and 6. The substantial reduction in the proportion of 100 per cent sphalerite in the tail between the two conditions is the key indicator that confirms the statistical trial results. This is visually represented within the graphs by the decrease in liberated sphalerite and the increase in proportion of non-liberated fines within the ON tail.

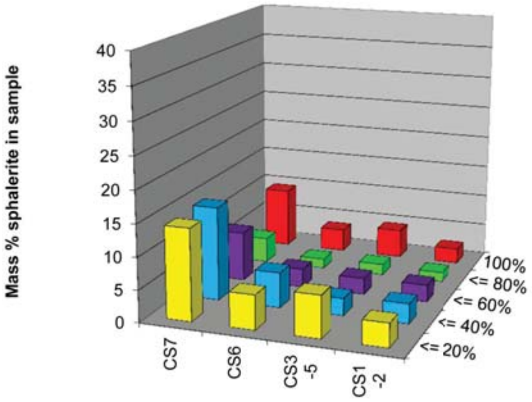

FIG 5 - Magnetic conditioning ON – Zn scavenger tail sphalerite liberation.

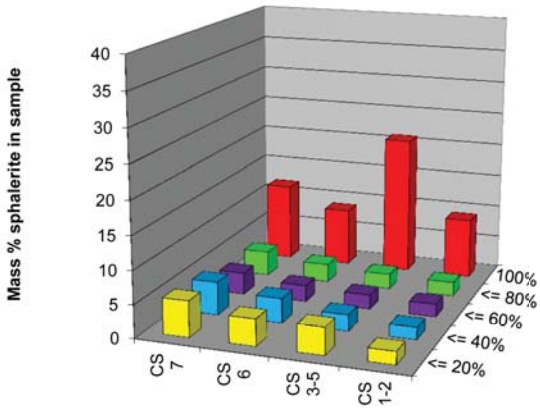

FIG 6 - Magnetic conditioning OFF – Zn scavenger tail sphalerite liberation.

Model of flows

What was extremely interesting and initially puzzling was that there was a large increase in zinc feed assay to the retreat circuit to a very high level of confidence. The retreat feed is the tails from the cleaner circuit. The result is given in Table 4.

This increase in zinc assay in the retreat circuit was observed in the plant. It is a puzzling result because a higher retreat feed (cleaner tail) would suggest that there was a decrease in cleaner recovery since the cleaner feed grade is similar for ON and OFF. However, a close study and modelling of the circuit and an understanding of the plant operation explains the result. This increase in retreat feed confirms the increase in zinc recovery in the rougher-scavenger circuit.

TABLE 4

Retreat rougher feed result.

	Retreat rougher feed % Zn
Magnetic conditioning ON	16.48
Magnetic conditioning OFF	14.97
Difference	1.51
't'	3.15
Level of confidence	99 per cent

The initial cleaning circuit (columns and cleaner [QRS banks]) operate to capacity with maximum recovery at final concentrate grade – this is why the retreat circuit is required because the columns and cleaner circuit have insufficient capacity for the zinc flow to cleaners. The rougher scavenger results indicated an increase in zinc and mass flow to the cleaning circuit, however, if the cleaners are operating at maximum capacity, this extra mass and zinc will report to the retreat feed (cleaner tail). This results in an increase in the feed grade to the retreat circuit when the magnetic conditioning in the roughers is operating.

The simple modelling shown in Figure 7 using averages of the measured plant test data available and estimates for other streams gives a very reasonable correlation between the actual retreat rougher zinc head grades and the actual rougher retreat head grade as shown in Table 5.

TABLE 5

Modelling of the retreat rougher feed for magnetic conditioning ON and OFF.

	Retreat rougher feed % Zn (actual)	Retreat rougher feed % Zn (modelled)
Magnetic conditioning ON	16.48	16.5
Magnetic conditioning OFF	14.97	14.6

It is satisfying to be able to understand and tie-in surprising results observed during a test, to the test and plant operation. This result also shows that the retreat test work strongly confirms the result in the rougher scavenger circuit and the observation of increased flows to the rougher scavenger concentrate.

Mineralogical composition

The lead zinc concentrator ore feed is a blend sourced from three different mines. The ore-blend was compared to magnetic aggregation performance to determine whether there was a relationship between ore source and performance. The ore source data for a particular 24-hour period is known to a good approximation, and an average bulk feed grade for each ore source is known so it is possible to calculate to a quite reasonable estimation the proportion of zinc units in the feed sourced from particular mines. The Black Star ore (Mount Isa Mine) and the George Fisher ore (Hilton Mine) provide on average greater than 90 per cent of the zinc units in the plant feed.

For both ore sources the proportion of zinc units per day was plotted against the zinc recovery performance (normalised) of the ON and OFF days in both the rougher scavenger and the retreat circuit. For Black Star the results are plotted in Figure 8 and for George Fisher in Figure 9.

A number of observations can be made from these graphs:

- The performance of ON and OFF show a similar trend on both ore types.
- The relative performance of ON and OFF for both ore types are similar with the ON and OFF lines generally parallel with ON giving better recovery than OFF at the same zinc distribution in feed.
- The recovery of zinc is similar in the rougher scavenger for both ore types.
- There appears to be no relationship between magnetic conditioning and ore type. This perhaps reflects the similarity in the ore as outlined in the paper.

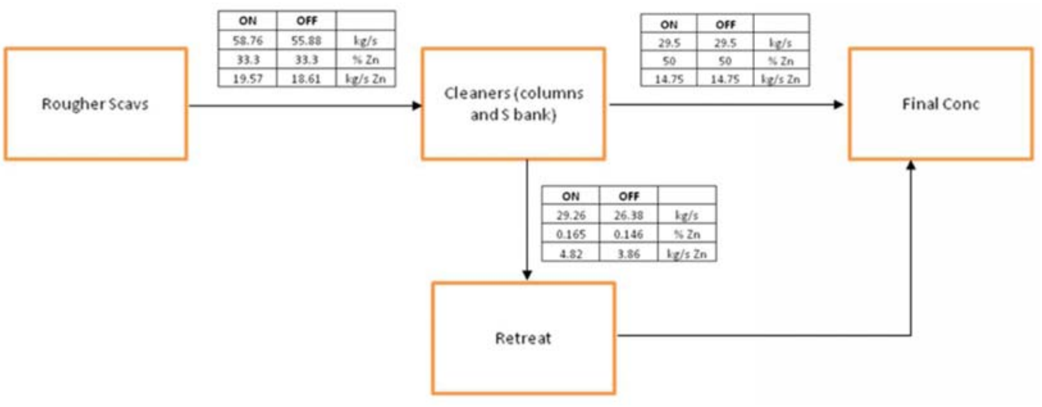

FIG 7 - Retreat circuit flow model.

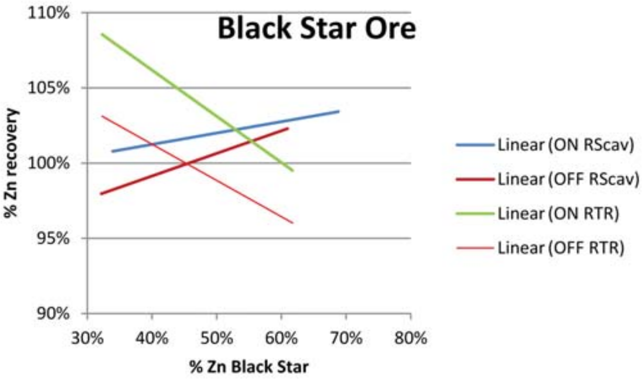

FIG 8 - Zinc recovery (normalised) relative to variations in zinc proportions from Black Star ore.

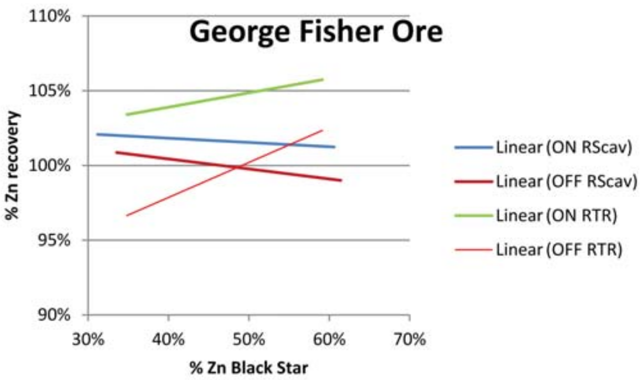

FIG 9 - Zinc recovery (normalised) relative to variations in zinc proportion from George Fisher ore.

- Perhaps the most interesting observations are not from comparing ore type against magnetic aggregation but from comparing ore type against circuit performance.
- Firstly, as Black Star ore zinc increases rougher scavenger recovery increases, but the opposite is true for George Fisher.
- Secondly, for both ore types the recovery trend in the retreat circuit is the opposite to the recovery trend in the rougher scavenger.
- It might be expected that the recovery-zinc source trend in the rougher-scavenger and retreat would be similar for each ore, either increasing or decreasing with ore source. The explanation for the opposite trends in the rougher-scavenger to the retreat may be a function of the circuit restraints particularly in the cleaner, rather than mineralogy. As the modelling shows when the rougher recovery increases (as it did with the magnetic conditioning) because the cleaner operates at capacity the extra zinc recovered in the rougher reports to the retreat circuit, and so the load in this circuit increases reducing residence time and zinc recovery.

The conclusion from this analysis is that the magnetic conditioning performance is independent of ore source at Mount Isa. This may have been expected given that the sulfide mineralogy is similar between the two deposits.

CONCLUSION

Statistical testing confirmed that magnetic conditioning gave an increase of 1.60 per cent in the rougher circuit zinc recovery (normalised) and an increase of 4.60 per cent in zinc recovery within the cleaner retreat circuit (normalised). To further confirm the statistical results of the trial, MLA testing was completed on the tailings from the rougher circuit, which identified a reduction of up to 15 per cent of zinc in rougher scavenger tails.

Plant behaviour within the zinc circuit was modelled for the trial to understand the trends that had been observed, identifying that when the magnetic conditioning units were ON a higher volume of zinc reported to the retreat circuit (greater quantities of zinc is being recovered in rougher circuit). Identification of how the magnetic conditioning behaves against various orebodies showed that the performance was not limited to a specific orebody.

Due to the improved metallurgy with magnetic conditioning in the zinc circuit, a second trial has been planned in the SAG prefloat circuit at the lead zinc concentrator. About 18 per cent of zinc in plant feed is lost through entrainment of ultra fine zinc in the prefloat and lead concentrate. Trahar (1981) reports that losses by entrainment fall substantially as particle size increases, therefore agglomeration of this fine sphalerite should reduce their entrainment loss into these streams, increasing their recovery in the zinc concentrate. Similar reductions in entrained sphalerite have been postulated from magnetic aggregation test work at other sites.

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REFERENCES

Aslan, A, Hassoy, H, Boz, H, Lumsden, B and Geredeli, H, 2010. Implementation of magnetic conditioning technology, ProFlote to Cayeli Bakir Isletmeleri AS (CBI) concentrator, in *Proceedings of the XIIth International Mineral Processing Symposium*, pp 429-435, (Hacettepe University: Istanbul).

Bott, A and Lumsden, B 2009. Magnetic conditioning at the Hellyer tailings retreatment plant, in *Proceedings Tenth Mill Operators' Conference*, pp 247-254 (The Australasian Institute of Mining and Metallurgy: Melbourne).

Capes, G, Grant, D and Niendorf, L, 2006. Development of the George Fisher ore bodies, paper presented to Strategic versus Tactical Approaches in Mining, 8 - 10 March, Perth.

Engelhardt, D, Ellis, K and Lumsden, B, 2005. Improving fine sulfide mineral recovery – Plant evaluation of a new technology, in *Proceedings Centenary of Flotation Symposium 2005*, pp 829-834 (The Australasian Institute of Mining and Metallurgy: Melbourne).

Fleming, R, Wood, G and Lumsden, B 2010. Improving fine (<20µm) copper sulphide mineral recovery by magnetic agglomeration – Measuring the degree of agglomeration, in *Proceedings Procemin 2010*, pp 215-226 (Gecamin: Santiago).

Holloway, B, Clarke, G and Lumsden, B, 2008. Improving fine lead and silver flotation recovery at BHP-Billiton's Cannington mine, in *Proceedings 40th Annual Meeting of the Canadian Mineral Processors*, pp 347-362 (Canadian Institute of Mining, Metallurgy and Petroleum).

Munro, P and Young, M 2001. Lead-zinc-silver concentration practice at lead/zinc concentrator, Mount Isa Mines Limited, Mount Isa Queensland, in *Sir Maurice Mawby Memorial Volume*, second edition (ed: J T Woodcock and J K Hamilton) pp 498-504 (The Australasian Mining and Metallurgy: Melbourne).

Rivett T, Wood G and Lumsden B, 2007. Improving fine copper and gold flotation recovery- a plant evaluation paper presented, in *Proceedings Ninth Mill Operators Conference*, pp 223-228 (The Australasian Institute of Mining and Metallurgy: Melbourne).

Trahar, W, 1981. A rational interpretation of the role of particle size in flotation, *International Journal of Mineral Processing*, 8:289-327.

Wilding, J and Lumsden, B, 2011. Implementation of magnetic conditioning in two stage sequential Cu-Zn flotation separation, in *Proceedings Conference of Metallurgists*, pp139-148, (Metallurgy and Materials Society: Quebec).

Zoetbrood, D, Vass, P and Lumsden, B, 2010. Magnetic conditioning of pentlandite flotation – plant evaluation, in *Processing of Nickel Ores and Concentrates*, June 2010, Falmouth.