Improving fine sulfide mineral recovery in Independence Group's Jaguar Mine zinc circuit

R Smiles[1] and B Lumsden[2]

1. Production Metallurgist, Kanowna Belle, Kalgoorlie Operations, PO Box 1662, Kalgoorlie WA 6430. Former Plant Metallurgist, Independence Jaguar Pty Ltd. Email: rsmiles@nsrltd.com
2. Technical Director, Ausmetec Pty Ltd, 47/176 South Creek Rd Cromer, NSW 2099. Email: barrylumsden@ausmetec.com.au

ABSTRACT

Independence Group's Jaguar Mine treats a polymetallic ore producing a copper concentrate and zinc concentrate. Effective separation of the sulfides requires relatively fine grinding with flotation feed P80 of about 75µm. Zn losses to final tails are greater than 60 per cent and <32 µm.

When magnetic conditioning was first installed in 2010 it showed about an 8 per cent reduction of zinc in final tail and on some ores a similar benefit for silver as well.

Current testwork is showing about a 12 per cent reduction in zinc and silver in final tail, consistent with the original testwork. Sizing of the final tail during the tests showed that the reduction of zinc and silver losses were only in the <32 µm fraction, as would be expected from an aggregation process. However, the most surprising result was about a 4 per cent reduction in zinc and silver in the plant feed with a >99 per cent statistical certainty. The reduction in zinc and silver in the feed is also only in the <32 µm fraction. Therefore, because the magnetic conditioning of Zn flotation feed cannot impact plant ore feed grade the hypothesis is that the magnetic conditioning is reducing the fine mineral from downstream processes, like filtering and thickening, returning to the plant feed in the recycled process water. This hypothesis is consistent with plant observation of dirty concentrate thickener overflow and measurements of solids in the overflow, as well as the average % Zn grade in cyclone overflow that correlates with the magnetic conditioning ON and OFF days. This paper presents these plant test results.

INTRODUCTION

Independence Group (IGO) operates the Jaguar Base Metals Project (Jaguar Operation), located approximately 60 km north of Leonora, in the north-east Goldfields.

The project comprises several deposits which have been mined historically including the Teutonic Bore deposit in the 1980s; the Jaguar deposit 2007-2014; and the Bentley deposit, which is now the main source of ore to the Jaguar Base Metals Concentrator.

The Bentley zinc-copper-silver-gold massive sulfide deposit was discovered in 2008 and brought into production as an underground mine in 2011. The Bentley mine ore's value resides in the sphalerite, chalcopyrite and silver minerals. The ore is processed through the concentrator at approximately 500 000 t/a, yielding a copper concentrate with payable silver and gold and a separate zinc concentrate with payable silver.

The processing plant comminution train consists of a single stage crushing circuit utilising a jaw crusher, followed by a SAG and Ball Mill each in closed circuit with classifying hydrocyclones. The product is a flotation feed slurry with a target P80 of 75 µm.

Sequential flotation separates the copper concentrate first, followed by the zinc concentrate. Two stirred media detritors operate in closed circuit with classifying hydrocyclones, preceding each flotation circuit's cleaning cells. The product is a copper cleaner feed and a zinc cleaner feed each with a P80 of approximately 10-20 µm. The concentrates are dewatered using thickening and filtration, with the final copper concentrate containing between 23-25 per cent Cu and the final zinc concentrate containing 47-50 per cent Zn. Figure 1 shows a simplified process flow diagram for the Jaguar concentrator.

A review of the cyclosized historical monthly composite samples of the final plant tails, as shown in Figure 2, indicated that approximately 70-80 per cent of the zinc metal losses to the tails stream are consistently in the -33 µm fraction, with approximately 60 per cent in the -11 µm size fraction. Ausmetec's Proflote unit uses magnetic aggregation to increase recovery of fine paramagnetic minerals, such as the chalcopyrite and sphalerite ores processed at Jaguar. Svoboda (1987) details the magnetic susceptibility of some minerals found in the Bentley ore, and these are listed in Table 1.

In 2010 a plant trial was conducted to test the effectiveness of the Proflote magnetic conditioning technology in increasing the recovery of copper into the copper concentrate and zinc into the zinc concentrate. The trial showed a statistically significant improvement in the recovery of both. This trial was conducted while the Jaguar mine supplied the ore feed to the processing plant, and no further trials had been conducted since the Bentley ore became the sole source of feed to the concentrator. There are currently three Proflote units installed in the Jaguar concentrator; at the copper rougher feed, the zinc rougher feed, and the zinc cleaner feed, also shown in Figure 1.

In 2016 a plant trial was conducted to monitor and assess the effectiveness of the Zn rougher and cleaner Proflote units based on plant performance and determine whether it is beneficial for IGO to continue utilising these units at the Jaguar Operation. The results of this trial confirm with high statistical confidence that the Proflote units improve the recovery of zinc and silver into the zinc concentrate, without detriment to the concentrate grade, and to such a degree that the benefits outweigh the costs of the unit.

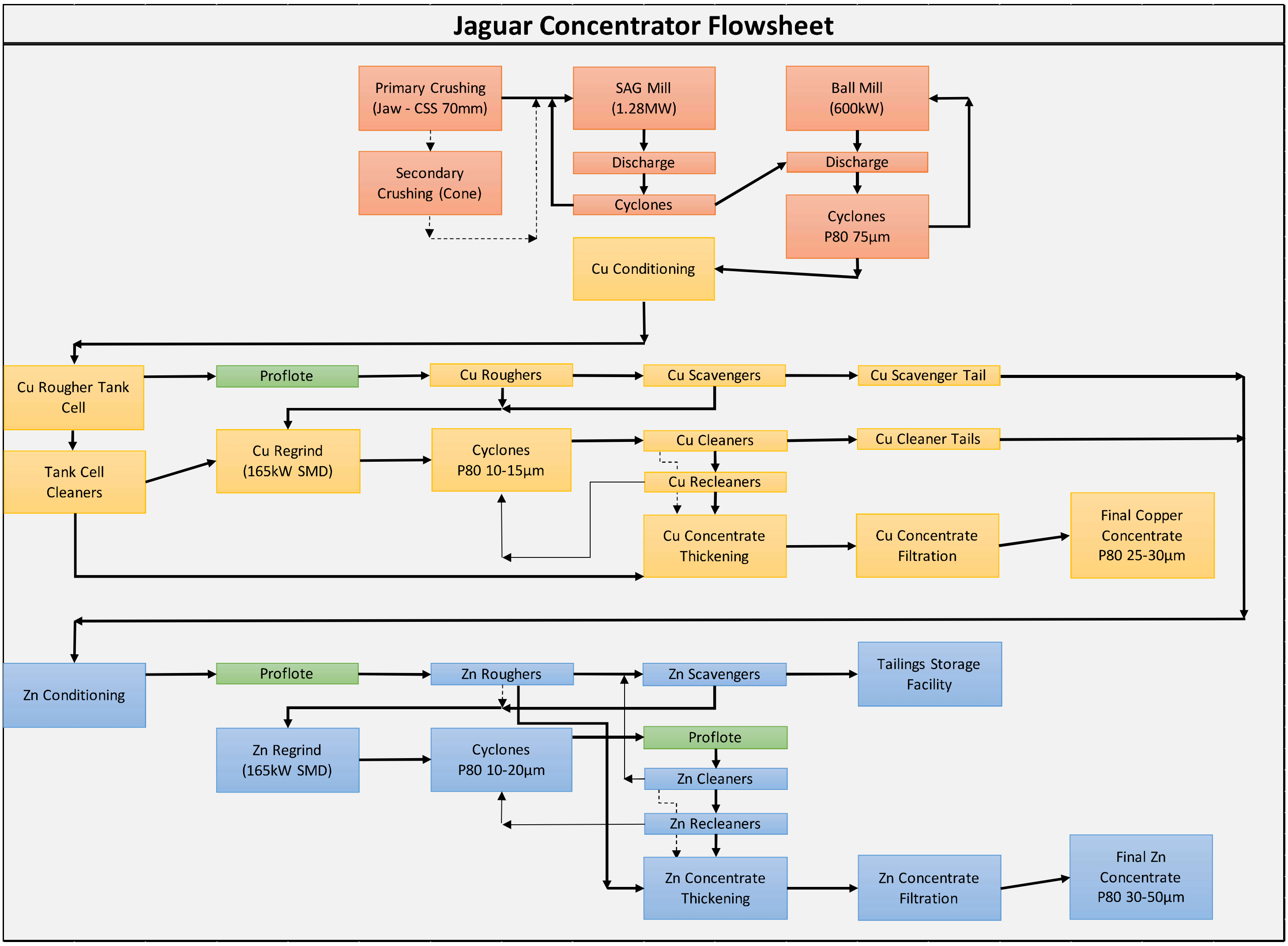

Figure 1 – Jaguar process flow diagram.

Mineral	Reported Magnetic Susceptibility(Svoboda 1987) $M^3kg^{-1}x10^{-9}$
Chalcopyrite	1595.9
Bornite	100.5
Marmatite/sphalerite	38-5900
Cassiterite	2136.3
Pyrite	1-5
Quartz	-5.7

Table 1 – Magnetic susceptibility of some minerals.

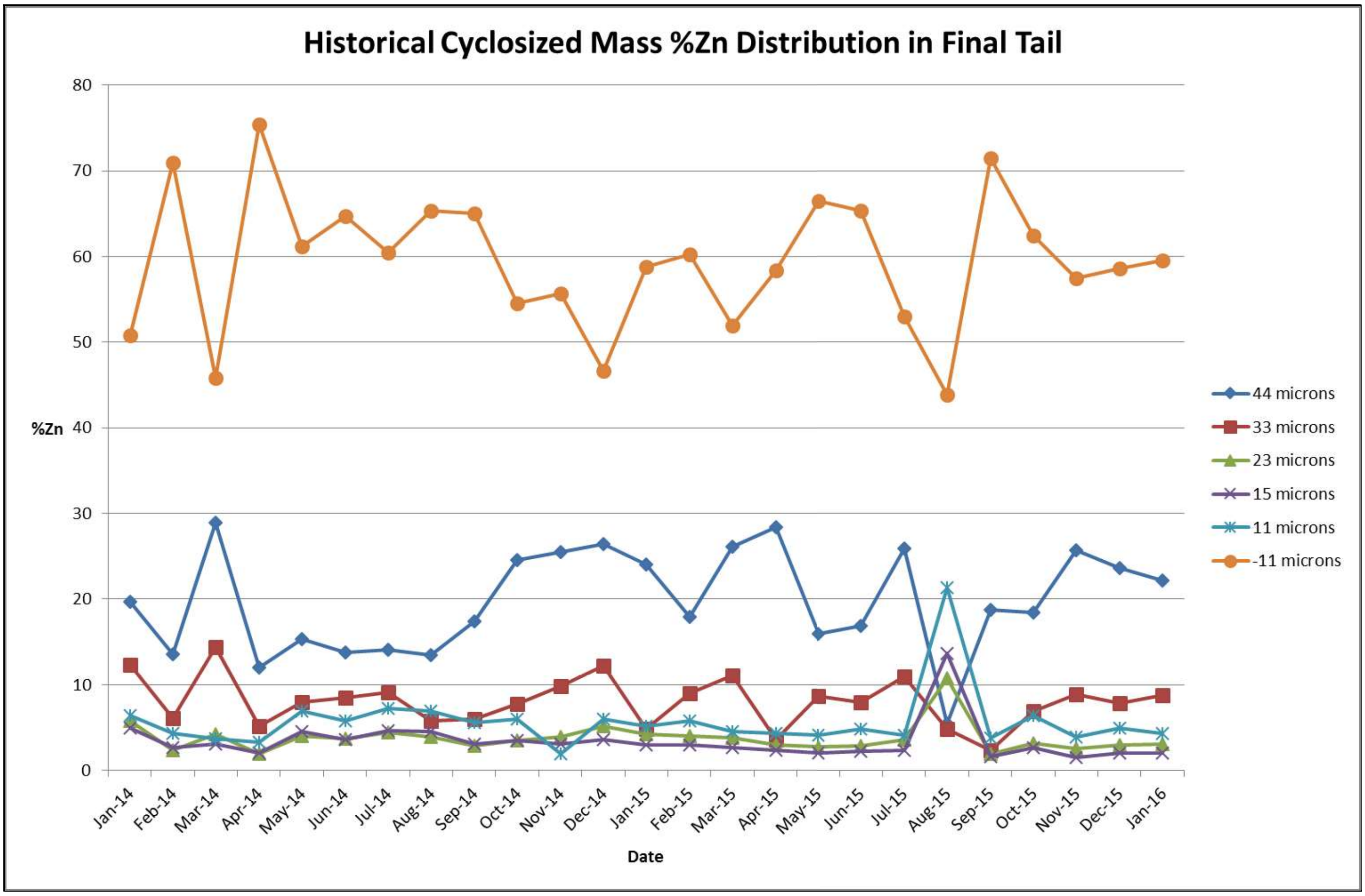

Figure 2 – Zinc distribution in historical cyclosized final tails samples.

HISTORICAL TESTING

Magnetic conditioning has been shown at many plants and on a range of sulphide minerals, to increase the flotation recovery of <38 µm paramagnetic minerals. These have been published and include studies by: Englehardt, Ellis and Lumsden, 2005; Rivett, Wood and Lumsden 2007; Wilding and Lumsden 2010; Zoetbrood, Vass and Lumsden 2011; Lacouture *et al* 2016. Less than 38 µm, liberated, paramagnetic, minerals will selectively aggregate if magnetised by a high gradient magnetic field. Aggregated particles will have greater momentum, therefore, increasing their collision efficiency with the bubble and increasing the flotation recovery and the flotation kinetics of these aggregated fine paramagnetic minerals. Generally, in sulphide flotation the diluent minerals in the ore, pyrite and gangue, are not strongly paramagnetic and are therefore, unaffected by the magnetic field.

In 2010 the Jaguar plant was treating Jaguar ore and magnetic conditioning was evaluated in both the copper and zinc circuits (Wilding and Lumsden, 2010). This plant evaluation, using a paired "t" test, showed that magnetic conditioning substantially reduced the losses of paramagnetic chalcopyrite and sphalerite to tails. It also improved the chalcopyrite selectivity in the Cu circuit, reducing sphalerite reporting to copper concentrate (probably through reduced entrainment of aggregated fine sphalerite). A further stage of plant testing, installing the magnetic conditioning on the zinc regrind cyclone overflow in the zinc cleaner circuit showed a further 1 per cent increase in zinc recovery. Interestingly this cleaner testwork showed that the silver recovery could also be increased to zinc concentrate on some of the ore types treated at Jaguar. This could be because some silver sulphide minerals, like freibergite or tennatite-tetrahedrite are also paramagnetic, (Holloway, Clarke and Lumsden 2008) or it could be silver associated with the paramagnetic sphalerite.

It was at Jaguar that magnetic conditioning clearly demonstrated that not only was it selective against non-paramagnetic minerals, as would be expected, but that it was selective between paramagnetic minerals. Results were consistent with homogeneous aggregation, rather than heterogeneous aggregation of paramagnetic minerals. Therefore, the magnetic conditioning in the Cu circuit not only reduced the Cu losses to the Cu tail, but also reduced the zinc in copper concentrate and increased the zinc recovery in the zinc concentrate. This has now been demonstrated at a number of other sites where separation of two paramagnetic minerals occurs (Musuku, Muzinda and Lumsden, 2015; Lacouture *et al* 2016).

From the publication by Wilding and Lumsden (2010) the key metallurgical improvements achieved with magnetic conditioning were in the copper circuit were: a 10 per cent reduction in average copper in final tail to 99 per cent level of confidence; a 7 per cent reduction in zinc grade in copper concentrate to 93 per cent level of confidence; a 1.8 per cent increase in zinc recovery to zinc concentrate to 99 per cent level of confidence; and a 10 per cent reduction in zinc in final tail to 97 per cent level of confidence.

Subsequently, the magnetic conditioning remained ON continuously in the copper circuit and a second installation was carried out in the zinc circuit. The results in the zinc circuit were: a further 8 per cent reduction in zinc in final tail to 97 per cent level of confidence and a 1 per cent increase in zinc recovery to zinc concentrate to 98 per cent level of confidence. The 2016/17 trial on the Bentley ore reflects similar results.

EXPERIMENTAL

The magnetic conditioning in the zinc circuit is currently installed on both the zinc rougher feed and the zinc cleaner feed (zinc regrind cyclone overflow). The test on Bentley ore was initiated in late 2016 as a 2 day ON, 2 day OFF test with consecutive ON/OFF and OFF/ON days paired. The magnetic conditioning was turned ON or OFF automatically every 48 hours at the same time the shift composite samples were retrieved from the plant multi stream analyser (MSA) for analysis.

The shift samples for the copper tail and final tail for the two consecutive ON or OFF days were composited and then sized at 32 μm and the two size fractions were assayed. While cyclosizing these samples could have been undertaken to look at a wider range of size fractions, the resources were not available to do this on a routine basis, and it was decided that the separation at 32 μm would give a good indication of the Proflote’s effect on the fines fraction.

The trial was initiated in September 2016 and concluded in February 2017.

RESULTS AND DISCUSSION

The plant and sizing results were paired and analysed using a paired ‘t’ test to measure the level of confidence in the differences in the averages. There were 106 days of data, or 53 pairs. The plant results showed no change in the zinc concentrate grade with both ON and OFF having a zinc concentrate grade of 47.9 per cent zinc.

Final tail

In the 2010 plant evaluation of magnetic conditioning, a benefit was seen in the reduction in metal in the final tail. Magnetic conditioning gave a very similar result in 2017 on Bentley ore. The key final tail results are in Table 2.

There was a 10-15 per cent reduction in the zinc and silver assay in the final tail - this is similar but slightly larger than the reduction in zinc in tail on Jaguar ore. The reduction in metal assay in tail is at a 95 per cent level of statistical confidence, therefore, it can be concluded that the result is due to the magnetic conditioning.

Table 3 summarises the sizing results for the final tail. There was a reduction in the zinc and silver in the <32 μm fraction in the final tail, but no change in the zinc and silver in the >32 μm in the final tail. The improvement in the <32 μm fraction, is consistent with magnetic aggregation. The magnitude of the difference for zinc in the <32 μm fraction is closer to 20 per cent, greater than for the overall sample, as would be expected, but the confidence is lower partly due to greater variability in the sizing sample and the fewer data pairs.

	% Zn final tail	ppm Ag final tail
Magnetic conditioning ON	0.75	51.4
Magnetic conditioning OFF	0.84	57.3
Difference	0.09	5.9
Level of confidence	99.9%	99.9%

Table 2 – Average zinc and silver assays in final tail.

	Size fraction final tail assays			
	<32 µm %Zn	<32 µm ppm Ag	>32 µm % Zn	>32 µm ppm Ag
Magnetic conditioning ON	0.707	59.2	0.69	41
Magnetic conditioning OFF	0.853	65.5	0.66	40
Difference	0.145	6.2	0.03	1
Level of confidence	92%	94%	low	low

Table 3 – Average zinc and silver assays in final tail size fractions.

Plant feed

During the statistical analysis of the test results, an unexpected phenomenon became apparent. It was observed that the average feed grade of zinc and silver was around 5 per cent lower in the plant feed when the magnetic conditioning was ON, compared to when it was OFF. The lower zinc and silver in feed was to 99 per cent confidence and the results are given in Table 4.

The lower zinc and silver content in plant feed resulting in lower zinc and silver in zinc circuit feed (copper tail) was to 99 per cent certainty. The question is; how can a downstream process such as the Proflote have an effect on the upstream plant feed with such a high degree of certainty? The original test work on Jaguar ore in 2010 was reviewed and a reduction in zinc in plant feed with magnetic conditioning was also noted but to a lower (about 90 per cent) level of confidence.

The ON and OFF zinc feed (also upstream of the zinc circuit magnetic conditioning) was sampled and sized (however the plant feed was not sized) and the results are given in Tables 5 and 6. This showed there was only a reduction in the <32 µm metal in zinc feed with magnetic conditioning 'ON' and no measurable impact on the >32 µm zinc.

This corresponding reduction in the <32 µm fraction, to 94 per cent confidence for zinc and 98 per cent confidence for silver suggests that there is a mechanism whereby the magnetic conditioning change is feeding back into the plant feed. The only plausible hypothesis was that there was a returning stream that was carrying <32 µm mineral back to the plant feed, and that the amount of <32 µm metal in this stream was reduced when the magnetic conditioning was operating. This can only be a process water stream because there are no other feedback mechanisms from the zinc circuit to the plant feed.

	%Zn in plant feed	ppm Ag in plant feed
Magnetic conditioning ON	7.58	130
Magnetic conditioning OFF	8.09	136
Difference	0.51	6
Level of confidence	99.9%	99%

Table 4 – Average zinc and silver assays in plant feed.

	Size fraction Zn float feed assays			
	<32 µm %Zn	<32 µm ppm Ag	>32 µm %Zn	>32 µm ppm Ag
Magnetic conditioning ON	7.84	86.9	4.67	52.5
Magnetic conditioning OFF	8.37	96.3	4.71	54.9
Difference	0.52	9.3	0.04	2.4
Level of confidence	94%	98%	low	low

Table 5 – Average zinc and silver assays in zinc feed size fractions.

	%Zn in plant feed		%Zn in final tail	
	1st Day	2nd Day	1st Day	2nd Day
Magnetic conditioning ON	7.62	7.35	0.76	0.73
Magnetic conditioning OFF	7.82	8.19	0.85	0.83
Difference	0.2	0.84	0.09	0.1
Level of confidence	low	99.9 %	90 %	99 %

Table 6 – Average zinc assays in plant feed for second ON and OFF days.

There was no difference in zinc concentrate grade between magnetic conditioning ON and OFF, with both at 47.9 per cent zinc and while the silver in concentrate was slightly higher when magnetic conditioning was ON, it was not significant to high confidence.

At 65 t/h, and 60 per cent of the zinc feed mass <32 µm, a 0.5 per cent difference in zinc assay in plant feed is about 200 kg/h of zinc. The possible feedback mechanism is via the concentrate filtrate that reports to the process water via the zinc concentrate thickener overflow. The zinc thickener overflow can be directed to the process water tank, or to the tails hopper which reports to the tailings dam. Water is returned to the process water tanks via a decant pump. At 65 t/h plant feed, there is about 80 m^3/h of process water, therefore, the calculated process water content is about 2.5 g/L of zinc, or about 4.2 g/L of sphalerite to give 200 kg/h of extra zinc. The losses to the Jaguar zinc thickener overflow have been documented for a number of years and instigated the replacement of the zinc thickener feed well (Thompson 2016). On days when the concentrate filter and thickener are not operating effectively the concentrate thickener overflow has been measured to contain about 4.0 g/L of solids and it is proposed that these solids are overwhelmingly sphalerite and are fine in order to appear in the thickener overflow. On other days the solids content of the zinc concentrate thickener overflow is lower. Nevertheless, the quantities are consistent with the observed difference in plant feed.

Suspicion fell on the zinc concentrate filter and the filtrate because the final zinc concentrate has a P80 of 30-40 µm. The filter cloth supplier suggested that losses through the filter of 5 µm -7.5 µm mineral could be 4 per cent, with losses below this size even greater. Moreover, the 200 kg/h of extra zinc is about 4 per cent of the approximately 4-6 t/h of zinc filtered at Jaguar. Again, the data is consistent with what is observed in the plant. This seems a logical and plausible hypothesis and there are periods at Jaguar where the process water is particularly dirty that would support this hypothesis. On dirty water days the zinc thickener overflow was found to contain significant zinc. This load can build as the fine sphalerite recirculates in the plant.

This hypothesis also has implications on the metallurgical accounting at Jaguar. The plant feed grade sample is measuring the recirculating zinc as fresh zinc. The feed grade when the magnetic conditioning was OFF was about 5 per cent higher than when ON. It also means that the concentrate assay is not accurate because it is measuring as recovered zinc, zinc that is actually being lost back to the plant feed. This zinc is actually being measured as reporting to concentrate but is just recirculating in the plant and a proportion would eventually recirculate out to tailings. This is most important when it comes to silver assays where the silver recovery calculation is very dependent on the zinc feed and tail assay to determine the weight of concentrate recovered. The use of these three sample assays introduce inaccuracies in metallurgical accounting due to the recirculating zinc unless allowance is made for the amount of metal recirculating.

Another possible route for the return of some fine zinc in the process water could be via the tailings. At Jaguar there is no tailings thickener and the tailings discharge is close to where the process water is extracted from the dam. When the magnetic conditioning is OFF there is more fine zinc in the tail and if settling in the tailings is insufficient then this can also recirculate back to plant feed. This recirculating zinc adds to the zinc assay in the feed. However, if it is recovered to zinc concentrate at a similar rate as in the first pass then for the metallurgical balance this increases the apparent zinc recovery, increases the apparent zinc feed grade and to a lesser extent increases the zinc in tail. Although the mechanism is different, this idea is not dissimilar to gold operations where gold in solution returning from the TSF to the plant in the process water needs to be measured and included in the metallurgical accounting.

The average zinc content of plant feed for the test sequence; first ON day, then second ON day, then first OFF day and then second OFF day, was cyclic. This is shown in Figure 3. The graph shows that with time the magnetic conditioning reduced the recirculating zinc (second ON day is lower than first ON day) and then the recirculating zinc increased with time as the magnetic conditioning was OFF (second OFF day was higher than first OFF day). The cycle is consistent with the thesis that recirculating zinc in process water was the reason for the lower zinc in feed with magnetic conditioning, allowing for residence time in the TSF and process water tank. Figure 3 shows that the average zinc content in tail followed a similar cycle, though less pronounced for the OFF days.

While there was no difference in zinc concentrate grade when comparing the first ON and OFF days, there was an increase in zinc concentrate grade with the second ON and OFF days, from 47.7 per cent zinc for OFF to 48.3 per cent zinc for ON. This was to more than 98 per cent level of confidence.

The recovery versus feed grade graph with and without magnetic conditioning is shown in Figure 4. At the same zinc feed grade there is an increase in zinc recovery to zinc concentrate. While the lines of best fit can be compared statistically, as Napier-Munn (2010) shows, this is not as powerful a statistical method as the paired 't' test, and usually many more data points are required to get high confidence. Nevertheless, the graph shows two parallel lines separated by a zinc recovery difference of 0.7 per cent at the same feed grade. This 0.7 per cent zinc recovery increase is to a confidence level of 90 per cent.

As the experiment was only designed to prove whether the Proflote unit had a positive effect on the zinc fines recovery, this interesting discovery of its apparent effect on the flotation feed was made only upon statistical analysis of the trial data results after the experiment had concluded. At the time this paper was written, Jaguar had not yet allocated further time and resources to corroborate findings or mitigate fines recirculation within the plant. Filter cloth type and recirculation of filtrate, along with changes to improve thickening efficiency could be investigated to alleviate this phenomenon.

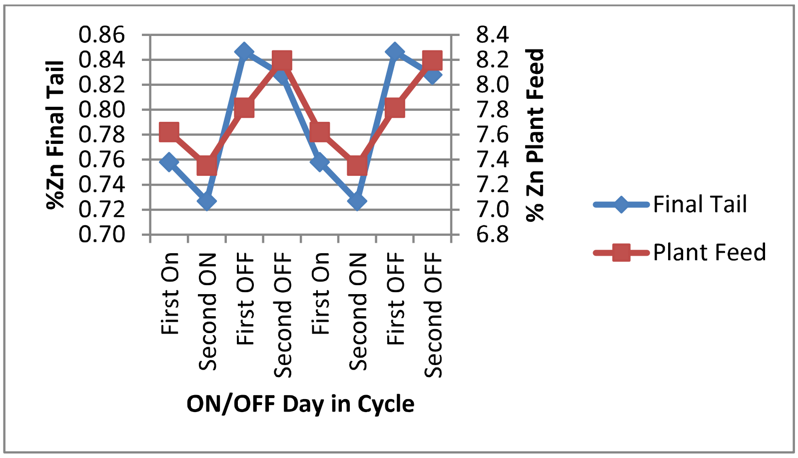

Figure 3 – Cycle of average % zinc assays final tails and plant feed for the test.

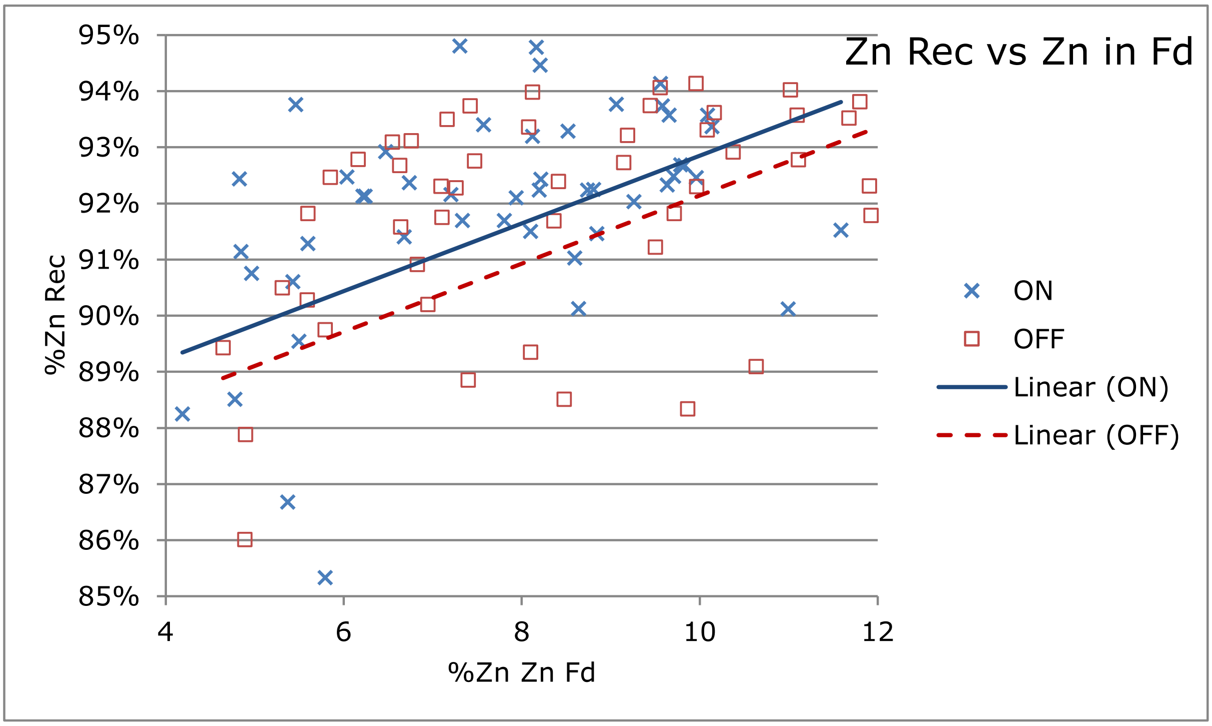

Figure 4 – % Zinc recovery at % zinc feed grade for both magnetic conditioning ON an OFF.

Financial considerations

Calculation of the increase in revenue due to magnetic conditioning is complicated by the recirculating metal values in the process water. However, assuming the fresh feed head grades are the same for both conditions, (magnetic conditioning ON or OFF) then the difference with magnetic conditioning is about 600 t/y of extra zinc at 99.9 per cent certainty. The high silver grades in Jaguar zinc concentrate (more than 200 g/t), guarantees that all the increased silver recovered is above the threshold payment grade. The estimated additional payable silver recovered (due to the lower silver in tail) is approximately 60,000 oz/y of silver. With these figures, the Proflote installations at Jaguar are saving IGO over AUD$ 2M annually in zinc and silver fines recovery.

CONCLUSION

The testing of magnetic conditioning at the Jaguar Concentrator in 2016-2017 has confirmed and reproduced previous plant trials that showed aggregating fine paramagnetic minerals selectively reduces their losses to tails. The value of this reduction in losses is substantially more than the cost of the Proflote units.

The evaluation of the plant trial data indicates a reduction in the amount of <32 µm metal in the cyclone overflow upstream of the magnetic conditioning. This upstream change can be explained by a reduction in recirculating zinc and silver in process water. The authors consider this phenomenon to be relevant to many processing plants and deserving of further investigation.

This reduction of recirculating metal via concentrate filtrate and/or thickener overflow has since been observed at another copper concentrator during the trial of magnetic conditioning. These trials support the theme of this conference of ‘Back to Basics’ to ensure all streams that impact on metallurgical accounting are identified, sampled and measured. Is recirculation of metal values in process water streams affecting the performance of your plant? Does magnetic conditioning offer you an opportunity to improve performance and basic metallurgical accounting?

ACKNOWLEDGEMENTS

The authors would like to thank Independence Group and the management at Jaguar for permission and support in presenting these results; as well as the metallurgy team, lab staff and operators who all assisted in running the trial.

REFERENCES

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

Holloway, B, Clarke, G, and Lumsden, B, 2008, Improving fine lead and Ag flotation recovery at BHP-Billiton’s Cannington mine, Paper presented at the 40th Canadian Mineral Processors Conference, Ottawa, January 2008.

Lacouture, B, Wilson, B, Oliver, J, and Lumsden, B, 2016. Improving fine sulphide mineral recovery at the Red Dog operation, paper presented to XXVIII International Mineral Processing Congress (IMPC), Quebec City, September 11-15.

Musuku, B, Muzinda, I, and Lumsden, B, (2015). Cu-Ni processing improvements at First Quantum’s Kevitsa mine, *Min Eng*, 88: pp 9-17.

Napier-Munn, T, 2010. Designing and analysing plant trials, in *Flotation Plant Optimization*: (ed: C Greet), pp 175-190 (The Australian Institute of Mining and Metallurgy: Melbourne).

Rivett, T, Wood, G and Lumsden, B, 2007. Improving fine Cu and gold flotation recovery – a plant evaluation, in *Proceedings of the Ninth Mill Operators’ Conference*, pp 223-228 (The Australasian Institute of Mining and Metallurgy: Melbourne).

Svoboda, J, 1987, *Magnetic Methods for the Treatment of Minerals*, (Elsevier: Amsterdam).

Thompson, M, 2016. Concentrate Thickeners Feed Well Replacement, in *Proceedings of the 13th Mill Operators’ Conference*, pp 273-278 (The Australasian Institute of Mining and Metallurgy: Melbourne).

Wilding, J and Lumsden, B, 2010 Implementation of magnetic conditioning in two stage sequential Cu-Zn flotation separation, in *Proceedings of the 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, paper presented at Processing of Nickel Ores and Concentrates, Falmouth, June 2010.