IMPLEMENTATION OF MAGNETIC CONDITIONING IN TWO-STAGE SEQUENTIAL Cu-Zn FLOTATION SEPARATION

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ABSTRACT

The implementation of new technology to mineral separation operations requires rigorous testing to confirm the technology's technical and economic benefit. The Jaguar Mine owned by Jabiru Metals is located in Western Australia and sequentially separates a copper concentrate and then a zinc concentrate. Fine grinding (80% of zinc in tail is < 25µm) is required to achieve efficient mineral separation. All mineral losses are therefore contained in fines so improvements in metal recovery must focus on those finely ground minerals. Magnetic aggregation technology has been shown to increase the recovery of fine paramagnetic minerals so it was an appropriate technology to evaluate at Jaguar.

Testwork commenced in the copper circuit and it was found that there was a substantial reduction of copper in copper tail and an increase in zinc recovery to the zinc concentrate. The increase in zinc recovery in the latter zinc circuit was an interesting result and initiated the second stage of testwork that was to install and test a second magnetic conditioning unit in the zinc circuit. This showed a further increase in zinc recovery. Magnetic conditioning technology has now been fully evaluated in the plant and is now part of the Jaguar flowsheet.

INTRODUCTION

The Jaguar Project is located between Leonora and Leinster in eastern Western Australia and comprises two underground mines: Jaguar and Bentley. Jaguar, the initial mine, has been in production for over three years while the Bentley mine is due to come on stream in the second half of 2011. In 2010, the resource measured 4.7 million tons of 2.1% copper, 7.2% zinc and 98 g/t silver. The copper and zinc flotation flowsheets are shown in Figures 1 and 2, respectively. Design throughput is 400,000 tpy. The cyclone overflow P80 target is 45 µm and the flotation feed is composed of 38% solids.

MLA analysis shows that the main sulphide mineralogy is chalcopyrite, sphalerite, pyrite and pyrrhotite. Sulphides comprise about 60% of the feed, and the main non-sulphide gangue mineral is quartz. In the flotation feed, over 80% of the chalcopyrite is less than 38 µm and the chalcopyrite in tail is primarily less than 10 µm, with a mean size of 4 µm. While pyrite and pyrrhotite dilute the concentrate, the main diluent in copper concentrate is fine sphalerite, about 67% is liberated, and the rest is locked with chalcopyrite.

More than 80% of the sphalerite in feed is less than 38 µm and this is overwhelmingly liberated. Accordingly, sphalerite losses to final tail are very fine, with 80% of sphalerite less than 25 µm. With such a fine grind, all mineral losses are fine. Improving mineral separation efficiency at Jaguar by definition requires improving fine mineral separation efficiency. After the plant was commissioned and optimised the metallurgical team actively investigated methods and technologies to increase separation efficiency.

Fine Sulphide Mineral Separation

Few methods have clearly demonstrated in the plant that the selective flotation of fine sulphide minerals can be substantially increased. Holder [1] has shown that high intensity conditioning can increase plant fine mineral recovery, but generally this is an expensive, high power consumption approach that accordingly has not been widely utilised. Others [2-4] have shown that floc-flotation, a combination of high reagent dosage and long conditioning times, can also increase fine sulphide mineral recovery in the laboratory. However, like high intensity conditioning, floc-flotation also appears to be a relatively expensive option. One method that is installed in Australia is split flotation as described by Torrisi and Smith [5]. This is an operational strategy, rather than a technology, whereby the fine mineral, generally mineral less than about 20 µm, are floated in a fines flotation circuit and the coarse mineral are floated in a coarse circuit. The flotation conditions, such as reagent dosage and pH are optimised for the mineral size. While this has an expensive capital cost – building a separate fines flotation plant – it nevertheless has proved successful and cost effective. In effect, the Jaguar operation is already a split float plant, without a coarse circuit but only a fines circuit.

Magnetic Conditioning of Sulphide Flotation Feed

Published studies [4] demonstrate that selective aggregation will increase fine sulphide mineral recovery. The key requirements with this approach are that the aggregation be selective and cost effective. There are a number of published studies of magnetic aggregation of paramagnetic minerals that show that at magnetic inductions readily available from permanent rare earth magnets, paramagnetic minerals will aggregate [6-7]. Over the last decade, this method has been applied to paramagnetic sulphide minerals as a conditioning stage for flotation. These plant studies have clearly shown that magnetic conditioning of sulphide flotation slurry will selectively increase the flotation recovery of paramagnetic sulphide particles less than 38 µm. There are published studies of magnetic conditioning of the paramagnetic sulphides of copper [8-11], paramagnetic sulphides of lead [14], paramagnetic sulphides of zinc [9, 12], and paramagnetic sulphides of nickel [13]. These publications discuss the various paramagnetic sulphides and the theory of magnetic aggregation of sulphides for flotation. They demonstrate that metal recovery of paramagnetic sulphide particles less than 38 µm can be selectively increased by 0.5% to 4%, either at the same grade or at an increased grade.

However, when the Jaguar test was initiated in the copper circuit, all the published studies of magnetic conditioning were on mineral separations where one paramagnetic mineral was being separated from a diamagnetic ore (some ores also contained a small amount of ferromagnetic mineral). But at Jaguar, two paramagnetic minerals are separated; firstly one paramagnetic mineral (chalcopyrite) and then in the second stage a second paramagnetic mineral (sphalerite). So in effect, a paramagnetic mineral separation was being undertaken in the copper circuit. Critically, the separation aim in the copper circuit is to maximise the recovery of one paramagnetic sulphide (chalcopyrite) and minimise the recovery of the other paramagnetic sulphide (sphalerite). It was possible that the aggregation in the copper circuit was heterogeneous (chalcopyrite and sphalerite) rather than homogeneous (chalcopyrite-chalcopyrite). This would then reduce rather than increase the flotation selectivity. While heterogeneous aggregation had not been observed elsewhere, this could have been due to very low concentrations of the secondary paramagnetic mineral. At Jaguar, however, the chalcopyrite and sphalerite in feed are both around 10%.

Work published since this Jaguar tests was also initiated [10] on a sequential chalcopyrite-sphalerite flotation circuit and has shown that copper-zinc selectivity improved in the copper circuit with magnetic conditioning. Aslan and co-workers [10] suggest that this is due to homogeneous aggregation resulting in increased chalcopyrite recovery and reduced sphalerite recovery in the copper circuit. The reduced sphalerite recovery is most likely due to reduced entrainment of the aggregated fine sphalerite in the copper concentrate. A second interesting aspect that was investigated in this work was whether a single magnetic conditioning of the flotation feed was sufficient for the entire dual stage separation processes, or whether sequential magnetic conditioning before each separation stage was required to maximise the benefit.

Magnetisation of paramagnetic minerals is a reversible process [6], heat and elapsed time after magnetisation causes the magnetic dipoles in a paramagnetic mineral to lose their alignment. Jaguar mine is in an area where the summer maximum ambient temperature can reach well in excess of 45°C, so slurry temperatures would exceed this. Further, there are a number of pumping stages the slurry must pass through between the copper feed and the zinc flotation circuit, so given that paramagnetic aggregates are not as strongly bound as ferromagnetic aggregates, their sustainability through the circuit to the zinc flotation is unknown. Some previous work [15] had suggested that some of the paramagnetic aggregates survived pumping and the Jaguar testwork could confirm this previous result.

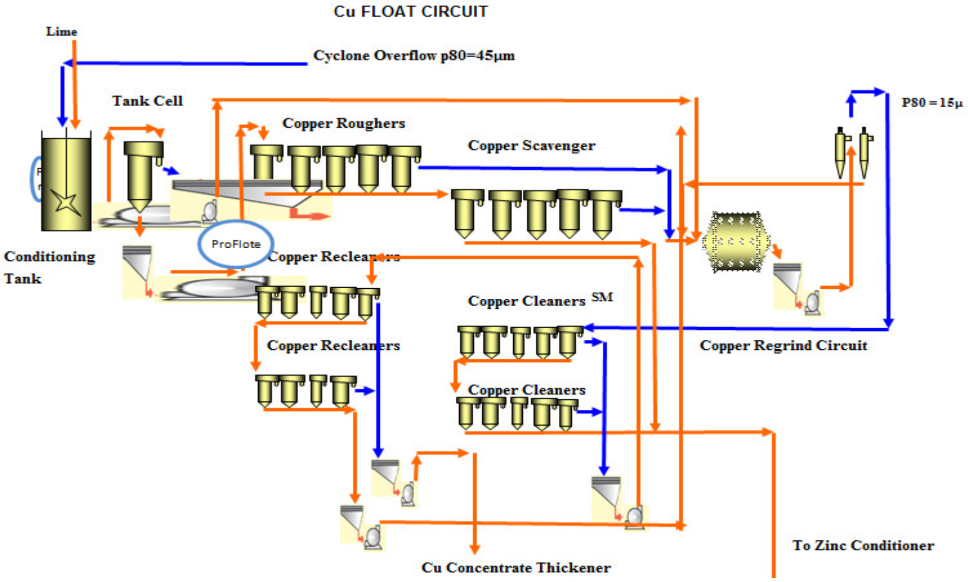

Figure 1 – Jaguar operations copper flotation flowsheet

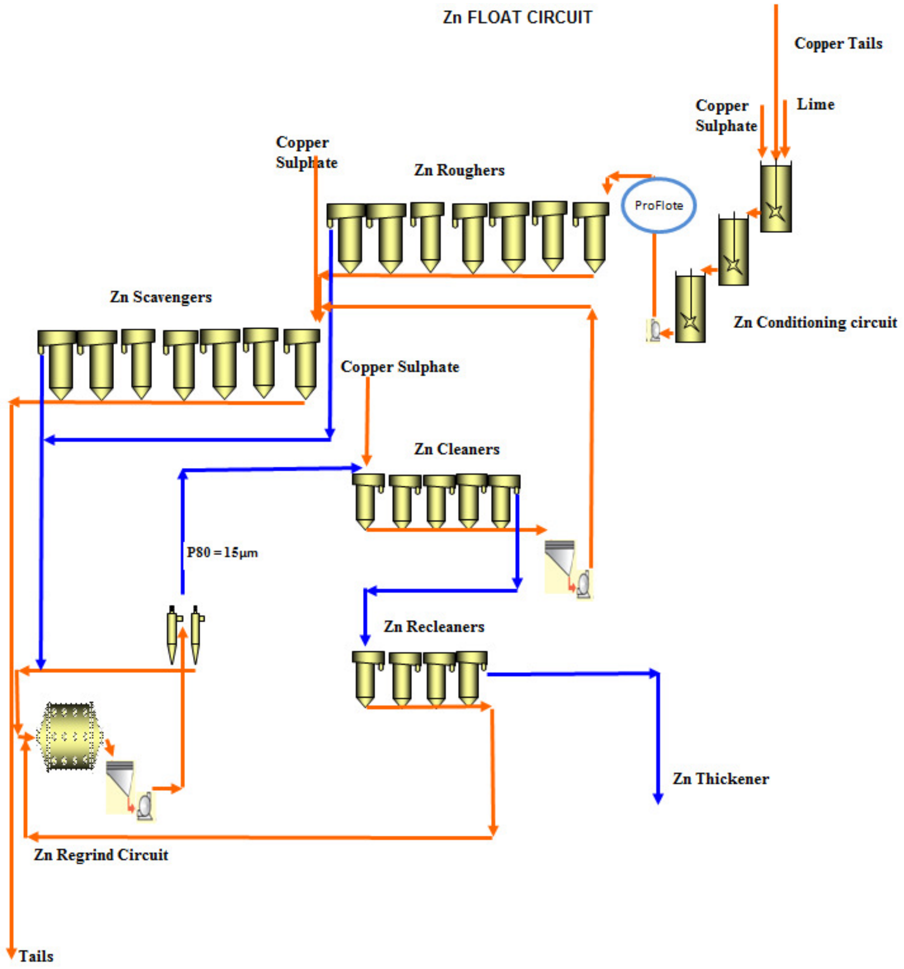

Figure 2 – Jaguar operations zinc flotation flowsheet

EXPERIMENTAL

The experimental plant testing was carried out in two stages, initially on the copper circuit and then on the zinc circuit. A photograph of the ProFlote magnetic conditioning device is shown in Figure 3.

Experiment 1 – Copper Circuit

The magnetic conditioning unit was installed in line on the feed to the copper rougher circuit. The statistical test was operated on a day-ON, day-OFF basis. When the equipment is turned OFF, the magnets are withdrawn from the slurry. There are two shift samples for each 24-hour period so the data was paired by comparing a night shift (NS) with the following day shift (DS). This scheme is summarised in the following schedule:

Day 1	NS	ON	Pair 1
Day 2	DS	OFF	Pair 1
	NS	OFF	Pair 2
Day 3	DS	ON	Pair 2
	NS	ON	Pair 3

This method ensured that there was equal number of ON and OFF night shifts and day shifts, that there was an equal comparison of ON or OFF shifts leading and following, and that the switching ON and OFF was random relative to plant operation. Because of significant variability in ore, a large number of pairs were required to reduce the standard deviation and to determine whether any differences were to a high level of confidence. The test ran for a total of 162 shifts, 81 ON and 81 OFF.

Experiment 2 – Zinc Circuit

For the zinc test, the magnetic conditioning unit was installed in line on the feed to the zinc rougher. The ON-OFF regime was the same as the regime used in the copper circuit. Because the zinc test was carried out after the copper test, the magnetic conditioning unit remained ON in the copper circuit while the unit in the zinc circuit was switched ON and OFF. The ore feed was also variable during the test and the test operated for 124 shifts, 62 ON and 62 OFF.

Figure 3 – ProFlote magnetic conditioning installation in the copper circuit

RESULTS AND DISCUSSION

Test 1 – Copper Circuit Testwork

The copper metallurgy results are summarised in Table 1 together with the paired statistical analysis results. The statistical test showed a large, i.e. 10%, reduction in copper in copper tail and copper in final tail to a very high level of confidence; particularly given the variability in the ore. The two measurements reinforce each other, clearly confirming that it is the magnetic conditioning that is causing the 10% reduction in copper in tail. The increase in copper recovery from the large reduction in copper in tail is not demonstrated to a high level of confidence. Given similar head grades of copper, this is mainly due to the much greater variability in the recovery data. The paired recovery standard deviation relative to the difference was about 3 times larger for the recovery data compared to the tail assay data. However, since copper can only report to concentrate or tail, 10% less copper in tail must mean this copper is in the concentrate.

There is no change in copper concentrate grade. Magnetic conditioning is demonstrating a superior grade recovery curve – an increase in selectivity. There is a clear reduction in copper in copper tail and copper in final tail of around 10 %. At a plant feed rate of 400,000 tpy, with a feed grade of 3% copper, this is about an extra 175 tons of copper per year.

Table 1 – Copper results in the copper circuit with magnetic conditioning

	%Cu in Conc.	%Cu in Cu Tail	%Cu in Final Tail	%Cu Rec in Cu Conc.
Mean ON	23.4	0.50	0.36	84.5
Mean OFF	23.4	0.54	0.40	84.0
Difference	0	0.05	0.04	0.50
Paired ‘t’	-	1.5	2.33	Low
Level of confidence	-	93.2%	98.9	Low

A statistical analysis of the zinc data in the plant is extremely interesting, in light of the questions this testwork raised regarding heterogeneous or homogeneous aggregation and strength of paramagnetic aggregates. The results are given in Table 2. There was a substantial improvement in zinc metallurgy in the plant to high levels of confidence. Zinc recovery to copper concentrate fell by about 7% in spite of an observed increase in copper recovery and a consequent increase in copper concentrate tonnage. This is a substantial increase in copper-zinc selectivity. This improvement in zinc metallurgy can further be seen in the 1.8% increase in zinc recovery to the zinc concentrate to a high level of confidence, which is coincident with an approximate 10% reduction in zinc in final tail, again to a high level of confidence. The zinc rejected in the copper concentrate is not rejected to tail, but recovered in the zinc concentrate.

Table 2 – Zinc results in the plant for magnetic conditioning to the copper rougher

	%Zn Rec in Cu Conc.	%Zn Rec in Zn Conc.	%Zn in Final Tail	%Zn in Zn Conc.
Mean ON	7.41	79.7	1.54	49.0
Mean OFF	7.96	77.9	1.71	48.9
Difference	0.55	1.8	0.18	0.1
Paired ‘t’	1.53	2.28	1.89	Low
Level of Confidence	93.6	98.8%	96.9	Low

It should also be noted that zinc recovered in the copper concentrate is a double financial loss, generating penalties in the copper concentrate and loss of payment by not reporting to the zinc concentrate. At a plant feed grade of 7% zinc, this reduction in zinc in tail represents about an extra 540 tons per year of zinc. Lead is present at low levels in the ore, and silver is also present and is an important revenue source for Jaguar. There was no change in the recovery of silver or lead to a high level of confidence.

The copper and zinc metallurgy results, when magnetic conditioning is applied to the copper circuit, answer a number of the questions raised our introduction. The reason for the better copper-zinc selectivity and the better zinc recovery must mean that the paramagnetic sphalerite is also being aggregated when magnetically conditioned in the copper rougher feed. This aggregation is not heterogeneous with the paramagnetic chalcopyrite but must be homogeneous with other sphalerite particles. The reduction in zinc recovery in the copper concentrate is most likely due to lower entrainment of magnetically aggregated paramagnetic sphalerite in the copper concentrate. This copper-zinc phenomenon has also been observed elsewhere [10].

The aggregated sphalerite is floating when activated by copper sulphate in the zinc circuit, giving an increase in zinc recovery to zinc concentrate. The reduction in zinc recovery to the copper concentrate is 0.55% of the zinc whereas the increase in recovery to the zinc concentrate is 1.8 %, which cannot be solely explained by the entrained zinc rejected from the chalcopyrite concentrate that is floated in the zinc concentrate, but also by the other fine sphalerite also magnetically aggregated in the copper rougher feed. These sphalerite aggregates are also sufficiently strong to survive the pumping stages between the copper rougher and the zinc rougher.

Test 2 – Zinc Circuit Testwork

The statistical test of magnetic conditioning in the zinc circuit was carried out with the magnetic conditioner in the copper circuit permanently ON. The effect of magnetic conditioning the copper rougher feed on sphalerite recovery prompted testing independently in the zinc circuit. The important results are given in Table 3.

The 8 to 9% reduction in zinc assay in tails with magnetic aggregation is to a high level of confidence. This result is consistent with the 1.06% increase in zinc recovery recorded, but to a lower level of confidence (a similar relationship of confidence levels was observed in the copper circuit testwork). Both these results are consistent with the results achieved when magnetic conditioning was applied in the copper rougher circuit.

Table 3 – Zinc results in the zinc circuit for magnetic conditioning to the zinc rougher

	%Zn Rec in Zn Conc.	%Zn in Final Tail
Mean ON	73.59	1.56
Mean OFF	72.53	1.71
Difference	1.06	0.14
Paired ‘t’	1.30	1.86
Level of Confidence	90.1	96.6

Because magnetic conditioning of the plant feed is carried out twice in the case of the zinc rougher (once in the copper rougher feed and once in the zinc rougher feed), and since the second conditioning further increases the recovery, though to a lesser amount, it suggests that either the slurry residence time in the copper rougher conditioning is not sufficient to aggregate all the sphalerite that could aggregate, or a significant amount of the sphalerite aggregated in the copper rougher conditioning is broken down in the circuit (by pumping) before the zinc circuit and thus further magnetic conditioning is required. If the sphalerite aggregate breakdown is proportional to the recovery increase, then about 40% of the aggregates are dispersed through the circuit. The magnetic conditioning gave slightly lower zinc grade in zinc concentrate as shown in Table 4.

Table 4 – Zinc feed and concentrate assays

	%Zn in Plant Feed	%Zn in Zinc Conc.
Mean ON	7.21	47.08
Mean OFF	7.31	47.38
Difference	0.1	0.3
Paired ‘t’	Low	1.3
Level of Confidence	Low	90.0

This lower zinc-in-concentrate is probably not a difference due to the magnetic conditioning. It should be noted that the zinc-in-feed is slightly higher with the magnetic conditioning being OFF, and thus this higher feed grade most probably accounts for the higher concentrate grade; an analysis of the mean upgrade ratio (%Zn-in-conc./%Zn-in-feed) is identical for ON and OFF modes.

Moreover, there was no indication in the copper testwork that magnetic aggregation reduced the zinc concentrate grade. For the plant treating about 400,000 tpy of ore, this reduction in zinc-in-tail is about 420 tpy of extra zinc.

Another interesting result, that confirms the copper testwork (and the zinc testwork), but is not of commercial importance to Jaguar, is that the copper recovery to zinc concentrate with the magnetic conditioning in the zinc circuit was higher. With this second stage of magnetic conditioning, the recovery of copper to zinc concentrate was 6.7%, and without the second stage of magnetic conditioning it was 6.4%, with this difference being at the 90% level of confidence. There is no change in the metallurgy of the other minerals.

CONCLUSIONS

A number of very interesting conclusions can be drawn which advance the understanding of the magnetic conditioning technology.

Firstly, from an operational perspective, magnetic conditioning in the two circuits has demonstrated that fine copper and fine zinc selective flotation separation is improved. The result is a 10% reduction in copper losses to tail, lower recovery of zinc to copper concentrate, and combined, the two magnetic conditioning stages reduced zinc losses to tail by 18 to 20%. This is a substantial increase in metallurgical performance and financial outcomes. For Jaguar, this represents about 180 tons per year of extra copper and about 900 tons per year of extra zinc. At these metal recovery rates, the cost of the magnetic conditioning would be much less than 10% of the financial benefit.

The key criteria for an aggregation method to be successful are selectivity and cost effectiveness, and magnetic conditioning has demonstrated these two characteristics.

Secondly, the testwork has increased the understanding of magnetic aggregation technology. Magnetic conditioning does increase the selective separation of two paramagnetic minerals; chalcopyrite and sphalerite. The results are consistent with homogeneous aggregation of paramagnetic minerals, increasing the recovery of fine chalcopyrite in the copper circuit and aggregating and reducing the entrainment of fine sphalerite in the copper concentrate. However, a substantial proportion of the fine sphalerite aggregates survive the copper flotation circuit and the pumping stages to be recovered in the zinc concentrate. A second stage of magnetic conditioning further enhances the sphalerite recovery in the zinc circuit, most probably by re-aggregating some of the sphalerite aggregates that have become dispersed during the copper flotation stage.

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