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STATISTICAL PLANT TRIALS – EFFICIENTLY COMBINING CONCENTRATE GRADE AND METAL RECOVERY RESULTS

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ABSTRACT

Statistical metallurgical plant trials are becoming more widespread, as a valuable tool for increasing plant profitability. Generally, a single parameter, like metal recovery varies under the trial condition while all other variables such as average metal feed grade or average metal concentrate grade are equal for the two test conditions during the period of the test. Metal recovery is usually the measured variable because concentrate grade is fixed by smelter terms, and plants operate to maximise recovery at the required concentrate grade. However, in all flotation plants there is a relationship between concentrate grade and metal recovery, and under the same conditions increasing one results in a decrease in the other. At MMG's Rosebery mine the zinc concentrate produced is generally above smelter specifications so zinc concentrate grade can vary during a test. During trialling of magnetic conditioning in the Rosebery zinc circuit the difference in both zinc recovery and zinc concentrate grade were analysed. The analysis of changes in zinc grade and recovery during the trial raised some interesting questions about the relationship between concentrate grade and recovery. A paired statistical method was developed and tested to combine in each pair the change in concentrate grade and recovery in a single result that could be analysed by a paired t test. This method was found to be very sensitive to combined, varying changes in concentrate grade and/or metal recovery. It was also evaluated on plant test results from another flotation plant to verify its applicability in other plants.

INTRODUCTION

All mineral separation processes are less than 100 per cent efficient: some valuable mineral is lost to the tailing and some non-valuable mineral reports to and dilutes the concentrate. Given the size of the mineral processing industry small improvements in separation efficiency can generate large financial returns. If, for instance, every copper processing operation could increase its recovery by 1 per cent then based on 20 Mt/yr of copper produced this would produce 200 000 extra tons of copper per year or about USD1.5billion in extra copper per year each year. Small changes generate large benefits.

However, it is well-documented that detecting small changes in a mineral processing plant is difficult, and it is widely recognised that only statistical plant tests will detect these changes. This is because of inherent variability in plant separation efficiency due to ore variability and the many operational variations. A number of excellent methods for conducting and analysing data from plant tests specifically applied to metallurgical plants have been published (Napier-Munn, 1995; Napier-Munn 1998; Napier-Munn and Meyer, 1999; Napier-Munn, 2008; Napier-Munn, 2010).

For all mineral processing plants there is generally a financial benefit in increasing both aspects of separation efficiency – the purity or grade of the concentrate produced and the metal recovery. The technical and financial trade off between grade and recovery is dependent on the ore characteristics and the prevailing metal prices, treatment costs and concentrate transport costs. Nevertheless both have value for a processing operation.

Most processing plants, particularly at today's metal prices operate to a set concentrate grade; or a tight concentrate grade range and maximise their recovery in this grade range. The financial focus undoubtedly is recovery, at a saleable concentrate grade. When a process change is introduced and evaluated by a statistical test there is a matrix of possible outcomes. Current practise is to make a technical decision based on a selected level of confidence, and then a financial decision based on the cost- benefit analysis. The selected level of confidence in mineral processing is usually 95 per cent, however, in mineral processing a lower level of confidence (90 per cent) can be selected if the cost benefit of the change is overwhelming, or if the downside risk of the change is low, or if there are a large number of data pairs (Napier-Munn, 1998; Napier-Munn and Meyer, 1999).

The matrix of possible plant test result scenarios are given in Table 1.

The term "No Change" signifies that there is no change at the selected level of confidence. But outcomes at levels of confidence below the selected level does not mean there is no difference – positive or negative, rather that any difference is not detected at the selected level of confidence with the number of data points collected. Collecting more data may show a difference at the chosen level of confidence, but further data collection and long testing periods can be expensive financially and in management and metallurgical time. Reducing plant trial times and refining decision making are important plant test considerations.

There are a range of plant test result scenarios where it would be beneficial to have a method to combine concentrate grade and metal recovery difference results to determine whether there has been an overall change in the grade - recovery response at the selected level of confidence – that is a different grade- recovery curve. It would be even more beneficial if this method could statistically analyse the combined result with a simple, efficient statistical test like the paired t test.

Table 2 shows 5 scenarios where such a method would be beneficial. In the first there is an increase in the grade and recovery, though neither is to the selected level of confidence. If concentrate grade and recovery could be combined then the combined result may meet the selected level of confidence. In the second and third scenario there is an increase in one parameter at the selected level of confidence, but a decrease in the other parameter at the selected level of confidence. In the fourth and fifth scenario there is an increase in one parameter at the selected level of confidence, but a decrease in the other parameter below the selected level of confidence. However, further testing and data collection may result in both parameters being different at the selected level of confidence, and the negative cost may outweigh the positive cost benefit.

There are other scenarios where such a method would also be of benefit in understanding the test in more detail. For instance, suppose in the first part of the test there was an increase in recovery at a slightly lower grade, whereas in the second part of the test there is a lower increase in recovery but to a higher concentrate grade. Could it be determined that there was a change in test performance?

The principal problem is to develop or utilise a method that compares concentrate grade recovery curves (the overall concentrate grade-recovery response) so that the total flotation response between 2 test conditions can be paired for the efficient statistical paired t test.

A study of the literature shows two methods that address this grade-recovery problem, and offer solutions, though neither with a simple paired t test. One method (Napier-Munn, 1998) is a statistical method that compares the concentrate grade – metal recovery lines for test conditions to determine whether there is a statistical difference in the lines. The second method (Lotter et al, 2010) uses metallurgical modelling to equate and normalise the grade between two conditions so that only the recoveries are different and so can be compared.

Comparison using concentrate grade – recovery correlation lines

The most satisfactory method for statistically comparing two test conditions where the concentrate grade and recovery vary over the test is the method of Napier-Munn (1998). Napier-Munn develops a statistical method to compare recovery-grade regression lines for two conditions to evaluate whether there is a statistical difference between the two conditions. While the paper explores the use of this method for comparing feed grade recovery regression lines, Napier-Munn shows its potential application to concentrate grade and recovery for a lead separation. It is a very useful method where other methods are not applicable; for instance where historical data is being tested. This method can be applied to compare the concentrate grade and recovery for two conditions. The serious limitation of this method is that it is not an efficient statistical method of comparison. It is appropriate where other methods won't apply, but as Napier-Munn emphasises it requires far more data than a paired t test. In an example in Napier-Munn's paper a paired t test gives the result to a 95 per cent level of confidence using only about one third of the data that is required for a regression analysis.

Modelling

Lotter et al (2010) ran a block statistical plant trial in the Raglan Ni-Cu-PGM concentrator comparing plant performance of PAX and PIBX. The raw plant results show that the PIBX gave a 0.5 per cent higher nickel recovery at a 0.58 per cent higher nickel in concentrate grade at about 9 per cent lower nickel in feed. The data is then adjusted for feed and concentrate grade differences to give an adjusted 1.04 per cent higher recovery at the same feed and concentrate grade. The data adjustment is done using Bilmat metallurgy modelling software. However, the ANOVA statistical analysis is undertaken on the tail grade, not on the adjusted recovery result. So the modelling may equate the mean recovery for two conditions but does not as far as the paper shows lend itself to a statistical comparison of the adjusted recoveries for the two conditions.

A statistical comparison of tail grades show that the tail grade is lower with PIBX to a very high level of confidence. Plotting final concentrate grade and final nickel recovery 'seems' to indicate (though not statistically) that the grade recovery performance with PIBX was superior to PAX.

It is interesting to note that there was good plant/ore stability at Raglan. PAX grade recovery data was the same to a high level of confidence over a 6 month period.

Lotter et al (2010) have shown that provided the plant is stable and the models accurately reflects the plant then modelling can be used to equate the difference in grade and recovery between 2 conditions, but not necessarily statistically.

However, modelling itself presents problems in plant testing. Modelling is based on estimates and approximations often by iteration, based on the collection of large quantities of data that are taken on average to represent the circuit. Therefore, unless large quantities of data are collected for both test conditions the same model data must be used for both test conditions – which provides another approximation. The more estimates and approximations used the less robust the data the more likely that greater quantities of data are needed to get a result to the required level of confidence.

Analyses of literature methods

Both methods outlined in the literature have their possibilities; however, both have some deficiencies. The method used by Lotter et al (2010) to adjust recoveries to the same final concentrate grade for the two conditions is a data adjustment method and is only as good as the model, the data set, the estimates and the approximations. Adjustments by modelling can increase the variability in the data because of the error bars in modelling. At Raglan modelling was suitable with steady ore and operation, but this is not necessarily applicable to all sites. Only the final average concentrate grades were adjusted by Lotter, not each individual pair. Modelling each individual pair may be much more complex and time consuming. Also, as far as can be seen a statistical analysis of the adjusted recoveries was not carried out, whether this is because it is not possible or whether a statistical analysis of other parameters (in this case tail grade) was preferred.

The concentrate grade recovery correlation method of Napier-Munn is definitely suitable, though as Napier-Munn (1998) identifies it is a less efficient statistical method than the paired t test, and that test efficiency is an important technical and financial consideration.

A novel method – the financial method

During a recent plant test at the Rosebery Mill the question of how to combine concentrate and recovery data was investigated by the authors. One of the investigators proposed a novel approach to resolving the question. The proposal was to combine the data financially rather than technically. A defensible argument can be made for a financial comparison of concentrate grade and metal recovery – every mine is assessed on financial outcomes (or perhaps the triple bottom line) rather than technical outcomes. Valuing a 1 per cent change in grade or recovery is at the fingertips of plant management. Therefore, in these scenario situations why couldn't the statistical analysis of a plant test be financial, based on the technical results? This method allows the efficient paired t test to be used and no estimates or approximations are required.

An example is generated for a mineral processing operation where for each pair of results; a 1 per cent increase in grade has a value of an extra $5 and a 1 per cent increase in recovery has a value of an extra $10.

The data is not real and has been chosen for illustration, nevertheless it can be seen from the data in Table 3, based on the assumptions made that neither the increase in recovery, or the increase in grade is to a high level of confidence (low'‘t'), however, the overall financial benefit is to an exceedingly high level of confidence (‘t' is 3.84). This data fits scenario 1 (Table 2) where there is a small increase in both grade and recovery though at a low level of confidence, and so the test condition would be seen as having no benefit. But based on a financial comparison combining the concentrate grade and recovery, the benefit is valuable and to a very high level of confidence. Using a purely technical analysis of plant performance the test condition would be rejected, but clearly combining the grade and recovery into a financial benefit shows a clear financial benefit to the plant. It can be said that to a 99 per cent level of confidence there is on average a $2.7 daily increase in financial benefit.

This paper utilises plant test data from plant testing of magnetic conditioning and compares the test conditions with a paired t test of concentrate grade and metal recovery and combines these in a financial comparison. The first test is a test of magnetic conditioning on the Rosebery zinc flotation plant and the second is of a test of magnetic conditioning in a second flotation plant in the cleaning circuit.

For both operations tested the value calculation is relatively simple. Other sites may have more complex calculations particularly if precious metals are recovered and payable, or where there are penalty elements. However, the method still holds for more complex financial calculations they just require a more complicated financial spreadsheet.

Magnetic conditioning

While the method was developed for comparing and equating the concentrate grade and metal recovery for two test conditions the data was generated from a plant test of magnetic conditioning to increase the selective recovery of fine paramagnetic minerals.

Magnetic conditioning as a method to increase the recovery of <38µm paramagnetic minerals is well documented (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). The method is based on magnetising the flotation slurry and the resulting selective aggregation of the paramagnetic sulphide mineral. This technology has been shown to increase the recovery of a range of paramagnetic sulphide minerals from chalcopyrite/bornite, sphalerite, pentlandite and a paramagnetic galena. It has also been shown to increase the concentrate grade and recovery of the targeted mineral (Aslan, et al, 2010; Holloway, Clarke and Lumsden, 2008; Engelhardt, Ellis and Lumsden, 2005)

Plant flow sheets

The Rosebery flowsheet is given in Figure 1, showing where the magnetic conditioners were installed. In the second plant the magnetic conditioners were installed in the cleaning feed in the cleaning circuit, where cleaner tail reports to final tail.

EXPERIMENTAL

A randomised paired ON OFF plant test was carried out over about 2 months with daily shift samples collected and analysed.

The main work on which this paper is based was carried out at the Rosebery mine in Tasmania. The statistical analysis method was also tested with results from another flotation plant in Australia, where a randomised ON OFF plant test was also employed.

RESULTS AND DISCUSSION

Rosebery plant test

A summary of the plant test results (26 pairs – 52 data points) and statistical analysis of the ProFlote magnetic conditioning device are given in Table 4.

The Rosebery plant gives very consistent results so a high level of confidence for a number of variables can be achieved. There is a clear recovery benefit with magnetic conditioning with a 0.65 per cent increase in zinc recovery and a 0.13 per cent reduction in zinc in tail. The two test conditions give similar mean zinc in concentrate from similar mean zinc in feed.

An economic analysis of the test results can be made and a decision as to the economic viability of the process made. The difference in zinc recovery (and zinc in tail) is clear the difference in zinc in concentrate is negligible.

A sharp observation was made and commented on when the results were analysed at the end of the test. It was suggested that during the test that the magnetic conditioning performance declined through the trial. On a straight comparison of recoveries this may be a true observation the mean increase in zinc recovery declined from 0.82 per cent in the first half to 0.50 per cent in the second half. While the change in mean difference is small, given that the results show a very steady plant operation this may be a valid observation. A number of factors that may have contributed to this difference were considered, such as ore source; though none could be identified. If the zinc in concentrate is considered there was a slight increase in the mean difference in zinc in concentrate with magnetic conditioning during the two halves of the trial from a 0.18 per cent lower difference in mean zinc in concentrate to 0.30 per cent higher mean zinc in concentrate. Neither of these paired differences was to a high level of confidence.

Therefore, based on the first and second half of the test is a +0.82 per cent recovery at -0.18 per cent lower concentrate grade (13 pairs) equal to a +0.50 per cent recovery at +0.30 per cent concentrate grade (13 pairs).

Financial method of comparing grade – recovery curves

Generic smelter terms, rather than Rosebery's contracted smelter terms were used to make a financial analysis of the data. These were USD250/t of concentrate as the concentrate cost ex plant and USD2200/t as the zinc price, with payment for 85 per cent of zinc in concentrate. The daily financial return can be calculated and a paired t test carried out on the pairs, in the same way it is carried out on the technical data. The analysis is based on a zinc feed to the zinc circuit of 245 t/day. The results are given in Table 6.

Table 6 shows that for each period of the trial; total, first half and second half the data is showing an increase in financial return with the magnetic conditioning and that for all three periods the paired t test gives a high level of confidence.

Interestingly, the difference in financial return for the two periods is similar, there appears to be no difference in the financial return for the two parts of the trial, therefore, there is no deterioration in the financial performance of the magnetic conditioning over the test period.

One assumption that was required when utilising this financial method was that the metal feed (zinc in this case) to the circuit needs to be constant for each data point. That is, the financial return, but not the technical grade - recovery result for any circuit is heavily influenced by the feed tonnage and feed grade. So a small increase in metal feed of 5 per cent or less, heavily affects the financial outcome of a circuit, but has little influence on the grade – recovery outcome. If real metal tonnes were used in the circuit then these slight variations of up to 5 per cent would swamp a 1 per cent change in grade – recovery. This leads to large standard deviations and the financial analysis becomes an analysis of the metal feed to the circuit, not the grade-recovery changes in the circuit. Therefore, the feed to the circuit for each data point is fixed, in this case 245 t/day of zinc, so that the financial analysis measures variations in technical performance of recovery and concentrate grade.

An improved financial method that requires no fixed metal feed assumption is to calculate the financial return per unit of metal entering the circuit (Napier-Munn, 2011).

Correlation lines method

The method of Napier Munn (1998) was used to look at this data.

The graph of zinc concentrate grade against zinc recovery for magnetic conditioning ON and OFF is given in Figure 2.

Using the method of Napier-Munn the correlation coefficients and the t values are given in the Table 7.

It can be seen that the correlation coefficients are low and with a low t value (low level of confidence). This method is not applicable to this amount of data; a significantly longer test would need to be run to get to a higher level of confidence.

An alternate comparison is to use the upgrade ratio (per cent Zn conc / per cent Zn feed) instead of the concentrate grade. The zinc upgrade as it varies with recovery is given in Figure 3.

This data appears to have a better fit and the relevant correlation coefficients and t's are in the Table 8.

There is a strong correlation and a high statistical t for the correlation co-efficient. The mean distance between the lines is 0.73 per cent, the increase in recovery with magnetic conditioning at the same zinc upgrade to 99 per cent level of confidence. This appears to be a better comparison of plant performance than a concentrate grade – recovery correlation, probably because there is some variability in head grades during the test.

However, when using this method to compare the concentrate upgrade – recovery lines with and without magnetic conditioning for the two halves of the test then the correlation coefficients are substantially lower and the t values are reduced to as low as 0.73 – well below acceptable levels of confidence. Therefore, unlike the financial method this method cannot be used to accurately determine whether there is a difference between the two halves of the test. This analysis shows the sensitivity of this method to quantity of data (as Napier-

Munn, [1998] identifies). Perhaps if the test had been doubled or tripled in length then this method would have been suitable.

Modelling the Rosebery concentrate grade recovery results

A number of modelling approaches for the Rosebery results were considered. Careful consideration of the Rosebery ore and plant led to the conclusion that it was very difficult to accurately model and adjust the recovery result to a fixed concentrate grade, by modelling or by any test, particularly with the accuracy and certainty that was required for the sort of analysis attempted here. In normal plant operation there is too much variability to make an adjustment and trying to do so would introduce inaccuracies and variability into the results. Lotter et al (2010) for his modelling had 42 and 46 data points for each of his test conditions and the variability in the nickel concentrate grade –recovery results were lower than the variability at Rosebery. Moreover, Lotter does not use the modelling to determine the statistical difference between the two conditions, but to get an overall value of the recovery benefit at the same grade.

Conclusion from Rosebery Testwork

The existing published methods are not sufficiently sensitive or accurate to allow the combination of the concentrate grade and recovery results to determine whether there is a change in magnetic conditioning performance between the first and second halves of the plant test. However, the straightforward financial combination of flotation recovery and concentrate grade using a simple paired t test is sufficiently sensitive and accurate to make this determination.

Second plant test results

A recent plant test of magnetic conditioning at a second site gave results that were directly applicable to this method. All the data is normalised to avoid providing specific confidential data.

The results for the entire trial period of 39 pairs (78 days) are given in Table 9.

The increase in metal concentrate grade was to a high level of confidence and the increase in recovery while very valuable was to a lower level of confidence. The combined increase in grade and recovery was substantial; metallurgically and financially. Depending on the level of confidence selected – 90 per cent or 95 per cent this data set matches scenario 1 or 2 in Table 1.

It was observed that the trial also fell into two sections, both showing a better grade recovery performance with the magnetic conditioning, but at different points on the grade-recovery curve. In the first half of the test there was an increase in metal recovery to a high level of confidence, at a slightly lower concentrate grade at a very low level of confidence. In the second half of the test there was an increase in metal concentrate grade to a high level of confidence at a slightly higher metal recovery though at a low level of confidence. In both halves of the test the magnetic conditioning is giving a superior grade recovery curve but it is moving on that curve so that in the first part the increase is shown in recovery and the second in grade. The results for the two halves of the test are given in Table 10.

For the total data set, depending on the selected level of confidence the difference in concentrate grade alone (96.6 per cent) or concentrate grade and metal recovery (92.2 per cent) can be incorporated in undertaking the financial analysis. Alternatively further data can be collected to determine whether the increase in recovery will achieve a higher level of confidence.

On the basis of the testwork of the entire test – 96.6 per cent level of confidence of an increase in grade and 92.2 per cent level of confidence increase in recovery it was decide to carry out a financial paired difference on the data for the entire test and also for the two halves of the test to see whether there was a paired difference in the financial performance for the two halves.

The following generic financial smelter terms for the metal concentrate were used.

- Payment for 85 per cent of metal
- Shipping costs of AUD250/t concentrate
- Assumption 10 t/shift of metal in feed
- LME price of metal at time of writing (AUD)

The results are shown in Table 11.

It can be seen that to 98.6 per cent level of confidence the magnetic conditioning over the entire period of the trial is increasing the financial return by a normalised AUD1.7 per day. The non-normalised dollar value for this is very large. This result is calculated to a very high level of confidence and is substantially more than the cost of the magnetic conditioning and so justifies it's installation.

There are a few further observations that can be made. The financial benefit is similar for both parts of the test, and that there is not a substantial change in the financial performance of magnetic conditioning over the period of the trial. The increase in financial benefit in the first half of the trial is to a high level of confidence, but in the second half it is to a lower level of confidence, due to higher variation in the plant performance leading to a higher standard deviation in this period (about 50 per cent higher) and a smaller financial benefit.

But perhaps one of the critical conclusions from this test is that if the plant had only carried out a technical analysis and selected 95 per cent level of confidence, then the plant had the option of extending the test to collect more data to see if 95 per cent confidence level could be reached in the recovery data, or base its financial analysis on the grade data alone. The value of a 1 per cent grade increase is much less than a 1 per cent recovery increase. Therefore, grade benefit is only about 28 per cent of the total financial benefit of the combined concentrate grade and recovery that was determined by the financial method - and this financial method benefit was to 98.6 per cent level of confidence.

Alternatively the test could have been extended for a further 3 months to get more data, but every day the magnetic conditioner is OFF to achieve an OFF pair the plant is 98.6 per cent certain of losing about AUD5000/day. If the test was extended for another 30 pairs, then the plant can be 98.6 per cent certain of losing 30 x $5000 (AUD150, 000) – a very expensive exercise. Even more expensive when the test cost and management/technical time is considered.

CONCLUSION

It is acknowledged that when running plant tests it would be beneficial under a number of scenarios to be able to incorporate the concentrate grade and recovery results into a single result. The methods currently published do have some limitations, they either require some assumptions and modelling for statistical analysis or they use less efficient statistical methods (correlation lines). Combining the financial result of changes in recovery and grade for each data point allows an efficient paired t statistical test to be employed of the two test conditions that can incorporate changes in concentrate grade and recovery.

The financial method has been applied to two plant tests of magnetic conditioning and this application has shown that the method is efficient in determining small but valuable differences in plant performance.

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List of Figure Captions

List of Table Captions

TABLES

Table 1

Plant test result scenarios.

Scenario	Grade result	Recovery result	Technical decision	Financial decision
1	Increase	Increase	Positive	Cost benefit analysis
2	Increase	No Change	Positive	Cost benefit analysis
3	Increase	Decrease	Inconclusive	Cost benefit analysis
4	Decrease	Increase	Inconclusive	Cost benefit analysis
5	No Change	Increase	Positive	Cost benefit analysis
6	No Change	No Change	Inconclusive	Cost benefit analysis

Table 2

Different plant test scenarios where a grade – recovery test would be beneficial.

Scenario	Concentrate grade result	Recovery result	Technical decision	Financial decision
1	Increase – low level of confidence	Increase – low level of confidence	Inconclusive	Cost benefit analysis
2	Increase – high level of confidence	Decrease – high level of confidence	Inconclusive	Cost benefit analysis
3	Decrease – high level of confidence	Increase – high level of confidence	Inconclusive	Cost benefit analysis
4	Decrease – low level of confidence Increase	Increase - high level of confidence	Positive	Cost benefit analysis
5	Increase - high level of confidence	Decrease – low level of confidence Increase	Positive	Cost benefit analysis

Table 3

Plant test results compared financially.

Pair	Test condition change in concentrate grade	Test condition change in metal recovery	Test condition financial difference concentrate grade	Test condition financial difference in recovery	Nett financial difference
1	+1.0	-0.4	+5.0	-4	+1.0
2	-0.2	+0.6	-1.0	+6	+5.0
3	-0.5	+0.4	-2.5	+4	+1.5
4	+0.2	+0.5	+1	+5	+6.0
5	+0.6	-0.2	+3	-2	+1.0
6	+0.8	-0.3	+4	-3	+1.0
7	0	+0.2	0	+2	+2.0
8	-0.1	+0.6	-0.5	+6	+5.5
9	0.5	-0.1	2.5	-1	1.5
Mean	0.21	0.14			2.7
‘t’	1.21	1.08			3.84

Table 4

Rosebery plant test results.

	per cent Zn feed	per cent Zn conc	per cent Zn tail	per cent Zn recovery
Magnetic conditioning ON	11.98	56.0	0.78	94.73
Magnetic conditioning OFF	12.26	55.9	0.91	94.08
Difference	0.28	0.1	0.13	0.65
‘t’	Low	low	3.13	3.63
Level of confidence	Low	low	99 per cent	99.9 per cent

Table 5

Test results two halves of the test.

	First half of test		Second half of test	
	per cent Zn rec	per cent Zn conc	per cent Zn rec	per cent Zn conc
Magnetic conditioning ON	94.53	55.61	94.94	56.38
Magnetic conditioning OFF	93.71	55.79	94.44	56.08
Difference	0.82	-0.18	0.50	0.30
‘t’	2.78	0.59	2.32	0.72
Level of confidence	99 per cent	low	98 per cent	low

Table 6

Financial comparison of magnetic condition test for two halves.

	Value USD/day of zinc		
	Total trial period	First half of trial	Second half of trial
Magnetic conditioning ON	329904	328487	331321
Magnetic conditioning OFF	327528	326010	329046
Difference	2376	2477	2275
‘t’	3.18	2.07	2.41
Level of confidence	99 per cent	97 per cent	98 per cent

Table 7

Correlation coefficients and t value for zinc concentrate grade recovery lines.

	Correlation coefficient	t value
Magnetic conditioning ON	0.20	1.00
Magnetic conditioning OFF	0.27	1.40

Table 8

Zinc correlation coefficients and recovery for plant test.

	Correlation coefficient	t value
Magnetic conditioning ON	0.58	3.52
Magnetic conditioning OFF	0.46	2.51

Table 9

Cleaning circuit plant test results of magnetic conditioning.

	per cent Grade of conc	per cent Metal rec
Magnetic conditioning ON	104.1	101.2
Magnetic conditioning OFF	100.0	100.0
Difference	4.1	1.2
‘t’	1.88	1.45
Level of confidence	96.6 per cent	92.2 per cent

Table 10

Results from the two halves of the test.

	First half of test		Second half of test	
	per cent Metal rec	per cent Grade of conc	per cent Metal rec	per cent Grade of conc
Magnetic conditioning ON	102.1	98.5	100.3	110.6
Magnetic conditioning OFF	100.0	100	100.0	100.0
Difference	2.1	-1.5	0.30	10.6
‘t’	2.14	low	low	2.86
Level of confidence	97.8 per cent	low	low	99.5 per cent

Table 11

Financial analysis of cleaner flotation results.

	Mean shift metal value normalised(AUD)		
	Entire test	First part of test	Second part of test
Magnetic conditioning ON	101.7	101.9	101.5
Magnetic conditioning OFF	100.0	100.0	100.0
Difference	1.7	1.9	1.5
‘t’	2.28	2.19	1.20
Level of confidence	98.6 per cent	98.0 per cent	87.7 per cent

FIGURES

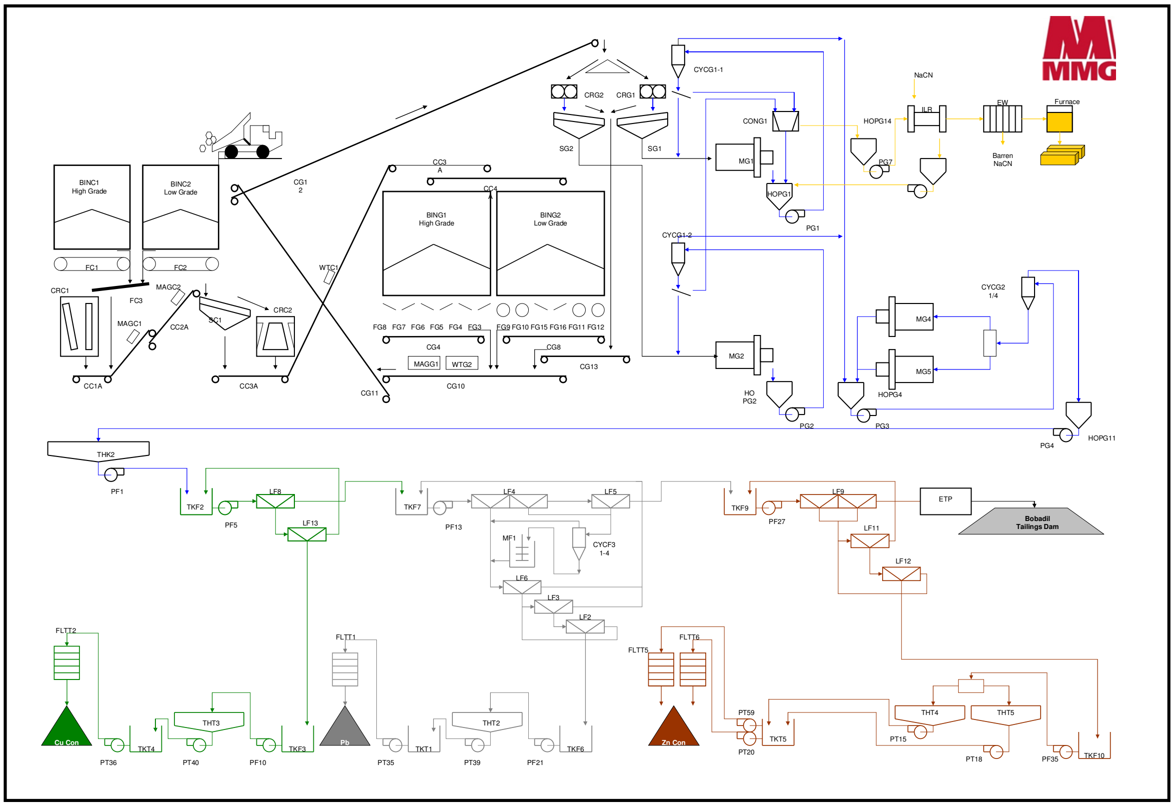

Fig 1 – Rosebery flotation flow sheet.

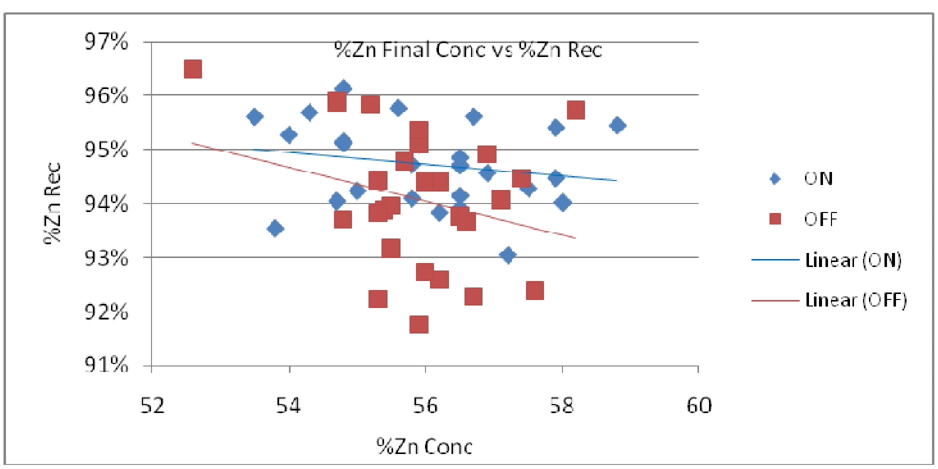

Fig 2 - Zn concentrate grade against zinc recovery.

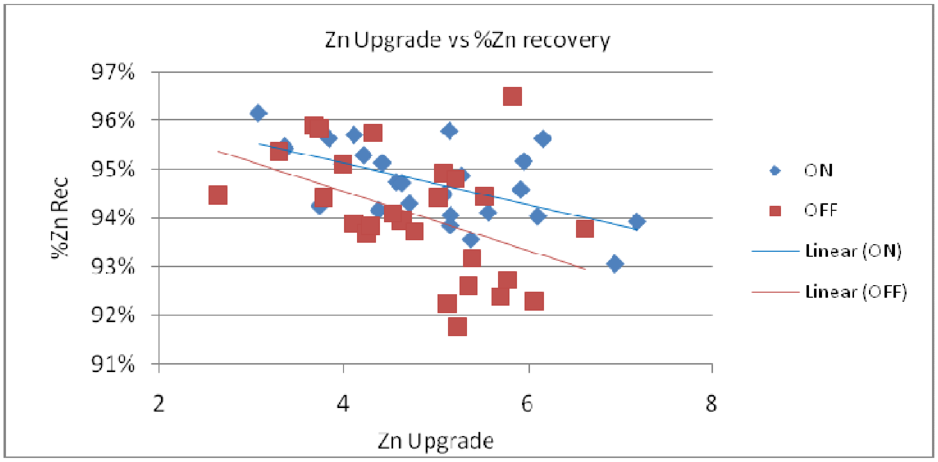

Fig 3 - Zinc upgrade against zinc recovery.