Metallicon
PROCESS CONSULTING (PTY) LTD

Zincore Metals - Summary of Yanque Preliminary Pilot Plant Test Work

Project Report

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SUMMARY OF THE FINDINGS OF THE PRELIMINARY PILOT PLANT TEST WORK CONDUCTED ON THE SAMPLE FROM THE YANQUE DEPOSIT

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Executive Summary

A pilot plant campaign was recently conducted on an ore sample from the Accha deposit. Following on the successful completion of the Accha pilot plant campaign a similar campaign was conducted on a sample of ore from the Yanque deposit.

Earlier laboratory test work conducted on samples of the Yanque ore at the Mintek laboratories in South Africa indicated that zinc recoveries in the order of 70% could be achieved utilising a process of fuming whereby the oxides of zinc and lead are collected in the off-gases resulting from the process. The test work also showed that, unlike the Accha ore, the Yanque ore tended to melt at temperatures in excess of 1050 degrees Centigrade.

The objective of the Yanque pilot plant campaign was to determine whether the recoveries could be replicated and whether the melting phenomenon previously observed would be a problem.

Four sample areas on Yanque were identified by the geological team and a total of 8.7 tonne was submitted to SGS laboratories in Lima, Peru for crushing, blending and splitting. The samples were then delivered to the plant at Pacasmayo for test work on the pilot scale Waelz kiln.

The pilot plant produces a calcine product and a discard slag that are both collected for analysis and any further test work. Zinc and lead report to the calcine product as zinc oxide and lead oxide respectively

Two sets of tests were conducted namely:

- A parameter test programme during which the effect of various parameters on the zinc and lead recovery and grade to the calcine product were determined.
- A continuous test programme where the optimum test conditions identified in the first set of test work was used to determine the variability in the recovery and grade of the zinc and lead in the calcine product.

The results of the parameter test work indicated that zinc and lead recoveries of circa 91% and 98% respectively could be achieved. As in the laboratory tests the parameter tests were hampered by the fact that the gangue phases in the ore started melting at higher temperatures, with longer residence time and with higher anthracite consumption. This in

effect prevented the programme from yielding the optimal conditions that would result in higher grades and recoveries.

The continuous test programme was operated at parameter settings where melting was not apparent during the parameter test phase of the work. It was however noted during the course of the continuous campaign that melting of the charge did occur under certain conditions. The results of the continuous test programme that was operated over 96 hours yielded an average zinc recovery to the calcine of 78.3% with a calcine zinc grade of 51.53% (64% zinc oxide). The lead recovery was 91.2% and the calcine lead grade of 13.7% (14.75% lead oxide). A calcine product containing 65.2% zinc and lead metal combined can therefore be produced or, expressing the zinc and lead as their respective oxides, the calcine product contains 88.75% of zinc oxide and lead oxide.

Unlike the Accha test work the Yanque test work did not yield a classical grade-recovery curve, illustrating the negative effect of the melting of the gangue phases on the grade and recovery.

This pilot plant test work produced approximately 83 kilograms of calcine product. This calcine product can be used together with the 500 kilograms of calcine product produced during the Accha campaign for further pyrometallurgical and hydrometallurgical test work to establish the cost of further downstream processing.

The pilot plant campaign is deemed to have been successful in that:

- The results exceed the results obtained in the laboratory;
- The melting of the gangue phases in the kiln was apparent but it appeared that under certain conditions this could be controlled;
- The pilot plant produced more calcine product for further downstream test work;
- A better understanding of the effect of the operating parameters was developed;

The concentration of the chlorine of 0.35% in the calcine product is of the same order of magnitude as that produced for the Accha sample. The fluorine content in the calcine product of 3.21% is however significantly higher than that achieved for Accha, indicating that a secondary calcine step will certainly be needed.

Analysis of the parameter test work and the results obtained indicate that under certain conditions the charge did not melt. Furthermore, fundamental analysis of the mineral system has indicated that minor alteration of the constituents of the charge would effectively reduce the prevalence of melting. It is recommended that further test work be conducted in the laboratory to identify the gangue phases causing the melting of the gangue phases. Once this has been established test work will indicate what avenue to follow in addressing this phenomenon. Once this has been established, further work can be conducted to optimise the results for the treatment of the Yanque material with the aim of generating information for process design.

The author, a professional engineer registered on the international register of professional engineers in accordance with the Washington Accord, has made visits to the various sites in Peru to assess the standard of the work performed. This has included the SGS laboratory where the samples were prepared, the site laboratory that produced the assays during the pilot plant campaign and the pilot plant site. In all cases the standard of work was found to acceptable and of a high standard.

Contents

1. INTRODUCTION

Following the successful completion of the pilot plant tests on the Accha ore a similar campaign was conducted on four samples of ore from the Yanque deposit on a Waelz kiln pilot plant owned by Cementos Pacasmayo S.A.A., in Pacasmayo, Peru. Laboratory tests had been conducted on a sample of the Yanque ore at the Mintek laboratories in South Africa.

The first stage of the pilot plant campaign consisted of a series of 14 tests to consider the effect of various parameters on the performance of the pilot plant. This was followed by a continuous run over a number of days to determine the variability of the results and generate a grade recovery curve of the calcine product indicating the range of recoveries and grades that could be expected.

Metallicon Process Consulting (Pty) Ltd (Metallicon) was commissioned by Zincore to develop and execute the pilot plant work. This follows on the successful completion of the initial laboratory test work produced by Metallicon at the Mintek research facility in South Africa. Metallicon is a specialist process consulting company that, although based in South Africa, have conducted metallurgical studies throughout the world and have previous experience working on projects in South America.

Metallicon have a long-standing relationship with Hatch, a privately owned international engineering projects company with offices worldwide. In order to provide ongoing support to the pilot plant Hatch was able to provide Metallicon with experienced metallurgical engineers to oversee the pilot operation. The pilot plant was operated by staff from the site under the guidance of Metallicon with the Hatch engineers being the Metallicon site representative..

This report is a summary of the findings of the Yanque pilot plant campaign and describes the sample preparation, pilot plant infrastructure and contains findings developed from analysis of the data.

2. OBJECTIVE OF THE PILOT PLANT TESTS

The objectives of the pilot plant test work can be summarised as follows:

- To confirm the findings of the Mintek laboratory test work;
- To test whether the melting of the ore observed in the laboratory would be realised in the pilot plant kiln
- To study the effect of varying feed grade;
- To study the effect of various operating parameters;
- To generate design criteria for future engineering design;
- To gain a better understanding of the anthracite consumption as this has been identified as a major operating cost;

- To generate sufficient calcine product for downstream test work;
- To determine a relationship between the recovery of Zinc to the calcine and the grade of zinc in the calcine.

3. SUMMARY OF LABORATORY TEST WORK

The laboratory test work conducted at Mintek is summarised in a previous Metallicon Report (No. ZIN001-001) published in April 2010.

The findings of the laboratory test work were that the Yanque ore was amenable to a fuming process and that recoveries of circa 70% could be achieved. It was however found that there was a tendency for the Yanque material to melt in the crucible once temperatures exceeded 1050 degrees Centigrade.

For that reason one of the major objectives of this test programme is to determine whether a similar behaviour will be evident in the continuous Waelz kiln, and what range of recoveries could be expected.

4. SUMMARY OF TEST PROCEDURE

4.1 Sample Tested

Four sources of ore were identified with the aid of the geological team and approximately 8.7 tonnes of sample was collected from the Yanque deposit.

The grades of the samples are summarised in the following table.

Ore	Analysis			
	Zinc [%]	Lead [%]	Iron [%]	SiO_2 [%]
1	5.74	2.23	1.77	52.77
2	12.47	2.04	3.85	43.51
3	10.12	1.77	3.91	48.06
4	21.29	3.92	3.65	35.42

Based on the assay analysis of the geological samples and the current understanding of the Yanque ore body it was decided to prepare a blend of the ore available to represent the average feed grade of the ore-body i.e. circa 10%. For this reason a blend of ore types 2 and 3 was used as the primary sample used in the pilot plant test work. A series of tests was conducted on each ore during the test programme to quantify the effect of ore type on the metallurgical performance.

4.2 Sample Preparation

The original samples from site contained large rocks and the sample was not homogenous. Furthermore the sample was not packaged in such a way so as to allow for a homogenous feed to the pilot plant. For this reason the four samples were delivered in sealed containers to SGS in Lima, Peru. This SGS laboratory specialises in the preparation, blending, splitting and analysis of samples from various sources.

The sample was crushed to less than 3mm, sampled, assayed and split into 50 kg bags.

The SGS laboratory was inspected by the author and the procedures and standards were found to comply with international best practise. The quality control and sample tracking procedures were particularly well managed.

4.3 Pilot Plant Test Work

The prepared sample was delivered to Pacasmayo where the sample was to be put through a pilot scale Waelz kiln. The operation of the pilot plant is being conducted by local staff from the Bongara zinc plant under the supervision of a Hatch metallurgist.

A bag of fine sample is mixed with anthracite and formed into pellets. The pelletising is done without the use of binder however one of the parameters that will be considered in the test work programme is whether binder will improve process efficiency by increasing the pellet resistance to breakage.

The photograph in Figure 1 was taken of the drums containing the Accha sample used in the previous test programme. Similar drums were used to store the Yanque samples. The photograph also illustrates the ore-anthracite pellets that are fed into the kiln. The pellets containing the Yanque ore and the requisite amount of anthracite were manufactured in the laboratory under controlled conditions.

Figure 1 : Sample drums and pellets of the feedstock

4.4 Health and Safety

The author is happy that all the necessary safeguards were in place during the pilot plant campaign. During a visit to the pilot plant it was noted that the operators were equipped with the necessary personal protective equipment. The plant all had all the necessary safety guards, hand rails and kick plates in place.

It must also be noted that the plant was also kept is a very clean state and this is normally a challenge for pilot plant operations.

4.5 Plant Description

A schematic of the pilot plant is shown in the following figure.

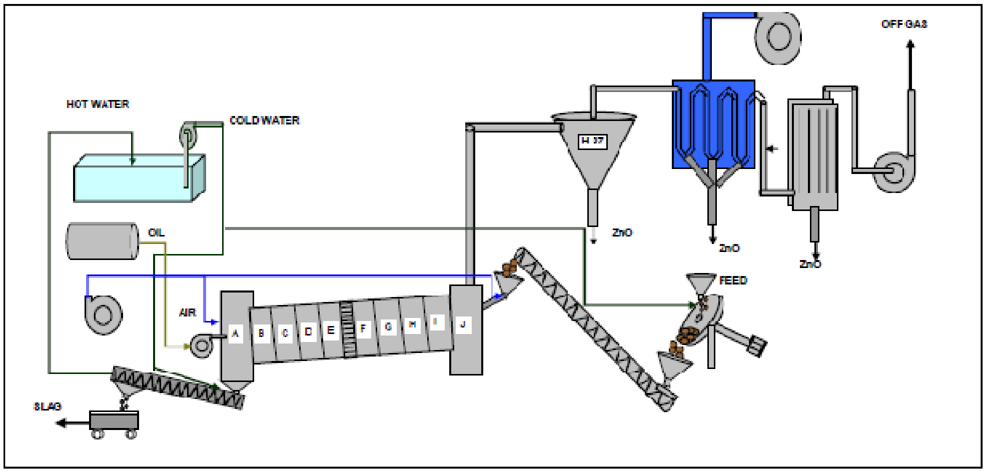

Figure 2 : Schematic of the Waelz Pilot Plant (courtesy of Hatch)

A picture of the pilot plant kiln is shown in the picture below.

Figure 3 : Waelz Pilot plant

The pilot plant Waelz kiln is four metres in length with an internal diameter of 0.3 metres. The kiln is fitted with a variable speed drive and the speed of the kiln can be varied from 1.5 to 2.0 revolutions per minute. The kiln is inclined at an angle of approximately 2.4 degrees from the horizontal. The slope of the kiln and the speed of rotation were used to control the residence time of the material in the kiln.

The pilot plant is meant for continuous operation and is fitted with an automatic feeder that is meant to regulate the feed to the kiln. The feeder design was found to accumulate feed sample and it was decided to direct feed the feed sample manually at regular intervals. The average feed rate used initially during the test work was 15 kilograms per hour. Gas was introduced to the kiln through a regulated gas lance.

It was found during the test programme that the degree of melting could be reduced by increasing the feed rate to the kiln from 15 kg/hr to 17 kg/hr. This change is not seen as a problem as the tests were conducted on a comparative basis.

Fume generated in the kiln was extracted and the calcine product collected in a system consisting of a cyclone, baghouse and extractor fan. The calcine product collection arrangement is shown in the next photograph. The discard slag product was also collected from the discharge end on the kiln and sent for sample preparation and assay.

Figure 4 : The calcine collection system

The pilot plant is fitted with thermocouples and the necessary equipment was available to be able to record temperatures of the kiln shell and various other items on a routine basis. The routine recording of the temperature in the baghouse is shown in the photograph below.

Figure 5 : Monitoring the temperature in the baghouse

4.6 Parameter Test Work

The first set of test work was done to establish the ideal operating conditions for the different samples. As stated in an earlier section of this report it was found during the parameter tests that an increase in feed rate from 15 kg/hr to 17 kg/hr resulted in a reduction in the amount of melting of the ore within the kiln.

Once the effect of the various parameters was understood a series of tests was conducted on an ore blend equivalent to a grade of 10% zinc to confirm the findings observed on the other two samples.

The parameters tested were:

- Plant feed rate;
- Residence time;
- Anthracite ratio to ore;
- Temperature;

- Zinc content;
- Pellet binder.

Each test is run over a day as the residence time of a single test can be up to six hours. Samples are collected at various intervals and only once the plant has reached steady state.

The samples were submitted to the assay laboratory where they were split and assayed. The author inspected the assay laboratory and found that it was operated at a high standard and that the necessary quality control procedures were in place.

4.7 Continuous Pilot Plant Test Procedure

Once the effect of the various parameters was understood the optimum operating conditions were identified for the purpose of conducting a continuous pilot plant campaign.

The objective of the continuous pilot plant campaign was to confirm the design parameters for future engineering design. Furthermore, operating the pilot plant over a long continuous period provided the opportunity to determine the variability in the pilot plant operation and develop a relationship between the recovery of zinc and lead to the calcine product, and the grade and zinc and lead respectively in the calcine product.

It also afforded the team the opportunity of increasing the inventory of high quality calcine product for future metallurgical test work required in defining the downstream processes required to produce a saleable product.

5. RESULTS AND DISCUSSION

5.1 Results of the Parameter test work

Throughout the parameter test programme it was evident that the melting of material in the kiln was going to present a challenge.

In all cases where the residence time of the material increased or the ratio of anthracite exceeded a critical point the material was found to melt. It was also found that at a feed rate of 15kg/hr excessive melting of the ore occurred within the kiln. It was decided to increase the feed rate to 17 kg/hr and it was found that the degree of melting reduced.

The results do indicate that the zinc recovery can exceed the 70% achieved in the laboratory with a maximum of 93.1% being achieved during the parameter test work.

5.1.1 Calculation of the Recovery

Metallicon visited the plant in the week of 7 June 2010 and it was apparent that using sample masses for the calculation of recovery was not a true reflection of the recovery. This is more so the case for Yanque where material was being lost in the “crust” formed as a result of the melting of the gangue phases.

For this reason it is recommended that a version of the “two-product formula” is used for the calculation of the zinc recovery. The formula used is widely used on metallurgical operations where the availability of accurate mass flows is not possible. Reference to the use of the “two-product formula” can be found in most metallurgical text books.

The expression used to calculate the zinc recovery for the previous Accha test work made use of the zinc (Zn) and iron (Fe) analysis. Evaluation of the iron analysis for the Yanque test work indicated poor metal accounting for the iron and a discrepancy in the iron analysis from test to test. For this reason an alternative expression had to be developed.

The modified expression developed by Metallicon considers the assays for zinc (Zn) and lead (Pb) in the calculation of the zinc recovery, and the use of lead (Pb) and iron (Zn) in the calculation of the lead recovery. As an example the expression used for the zinc recovery is:

$$Recovery\ of\ Zinc = \frac{C_{Zn}}{F_{Zn}} \times \frac{F_{Zn} - \frac{F_{Pb}}{S_{Pb}} S_{Zn}}{C_{Zn} - \frac{C_{Pb}}{S_{Pb}} S_{Zn}}$$

where:

C_{Zn} is the Zn assay in the calcine
F_{Zn} is the Zn assay in the feed
S_{Zn} is the Zn assay in the slag
F_{Pb} is the Fe assay in the feed
S_{Pb} is the Fe assay in the feed

In the calculation of the lead recovery the values for the zinc are substituted with the values for the lead, and vice versa.

5.1.2 Effect of Anthracite Ratio on Zinc Recovery

The laboratory test campaign already identified the consumption of anthracite as a major cost item in the future operation. For that reason it was imperative that a more robust relationship between ore and anthracite tonnage needs to be developed. This was successfully done for the Accha sample tested previously. The result of the Accha test work was a model describing the relationship between the zinc recovery and the anthracite:zinc ratio.

Preliminary analysis of the data has shown that the application of an exponential relationship will be able to describe the relationship observed in Figure 6.

An exponential relationship was developed using the results of the parameter test work for the 25%, 15% and 10% samples and the constants solved for using the Solver add-in available in Microsoft Excel.

The analysis of the anthracite at Pacasmayo has indicated that the anthracite has an active content of 85%. The values for the anthracite have been changed accordingly by multiplying the anthracite masses by a factor of 85%.

The results at different anthtracite ratios for Yanque have been plotted on the Accha graph as illustrated in Figure 6.

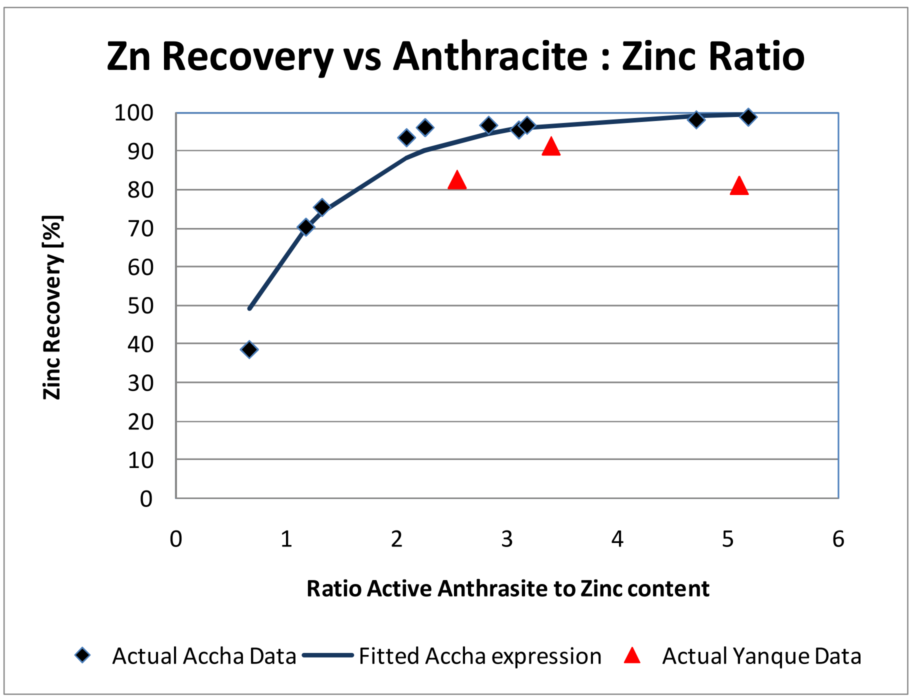

Figure 6 : Plot of zinc recovery versus ratio of active anthracite to zinc content

The zinc recovery for Yanque is lower than that observed for Accha for similar conditions. The use of an anthracite ratio of 6 (active carbon ratio of 5.1) resulted in the charge melting in the kiln. This resulted in the loss in recovery observed in Figure 6.

Although the expression developed will suffice in relating the zinc recovery to the anthracite consumption for the financial model, Metallicon is of the opinion that this empirical expression is the first step to developing a robust model.

The relationship depicted in Figure 6 is given below. The expression had a correlation coefficient of 0.983:

$$Zinc\ Recovery = 100 \times \left(1 - \exp\left(-1.02 \times \frac{\%\ Active\frac{Carbon}{100} \times Mass\ anthracite\ [kg]}{Mass\ zinc\ in\ feed\ [kg]}\right)\right)$$

It must be noted that the refractory installed on the pilot kiln is not ideal and that an outside heat source in the form of gas burner was used. The results can be used for determining the cost of anthracite however further work must be done to model/describe the energy balance in the kiln.

The gas lance arrangement is shown in the following photograph.

Figure 7 : Gas lance on slag end of kiln

5.1.3 Optimum Process Parameters

A total of 14 tests were run on the Yanque sample in order to gain an understanding of the effect of the various operating parameters.

The test work was constrained to the blend of ore 2 and ore 3, with single tests being performed on ores 1 to 4. The optimal settings for the various parameters that yielded the best zinc recoveries to the calcine product are tabulated below.

Parameter	Setting
Residence time [hours]	6
Feed rate [kg/hr]	17
Pellet binder required	NO
Anthracite ratio [kg anthracite/kg zinc]	4
Temperature [^{o}C]	1150

5.1.4 Results Achieved in Parameter Test Work

The parameters in discussed in section 4.6 were varied in order to determine the optimum conditions for the recovery of zinc and lead from the Waelz kiln. A test programme was developed and the various parameters were tested on the blend of ore 2 and 3. The best recoveries achieved were 93.1% for zinc and 98.7% for lead. These results are significantly better than the results obtained in the laboratory.

Analysis of the different tests realised that the silica content of the samples tested ranged between 32% and 65%. This is a matter of concern as it indicates that the blending process applied either at the SGS laboratories or on site was not done properly.

The major contaminants are chlorine, fluorine, cadmium and arsenic and the concentrations in the calcine are circa 0.35%, 3.21%, 0.07% and 0.08% respectively. The results are very variable and high values are observed for tests that have poor zinc recoveries i.e. insufficient dilution of contaminants by zinc and lead in the calcine. The chlorine and arsenic levels in the Yanque calcine product are lower than those achieved for the Accha calcine. The fluorine content is however significantly higher than that for Accha where the fluorine was only 0.5%.

5.2 Results of the Continuous Pilot Plant Campaign

It was found after 24 hours that the molten buildup within the kiln was limiting the flow of material within the kiln. The kiln was run within feed for 8 hours with anthracite only after which the temperature of operation was reduced from 1150 degrees Centigrade to 1050 degrees Centigrade.

The melting of the gangue phases did result in a loss in recovery and a zinc recovery of 78.3% and a lead recovery of 91.2% were achieved.

In conducting the continuous pilot plant test the pilot plant was operated at the optimum conditions identified and samples were taken every two hours to determine the variability in the results.

The calcine zinc grades and zinc recoveries varied throughout the continuous run. The variability in the results is illustrated in the grade-recovery curve below. This relationship was generated from the assay of the samples taken on a two hourly period.

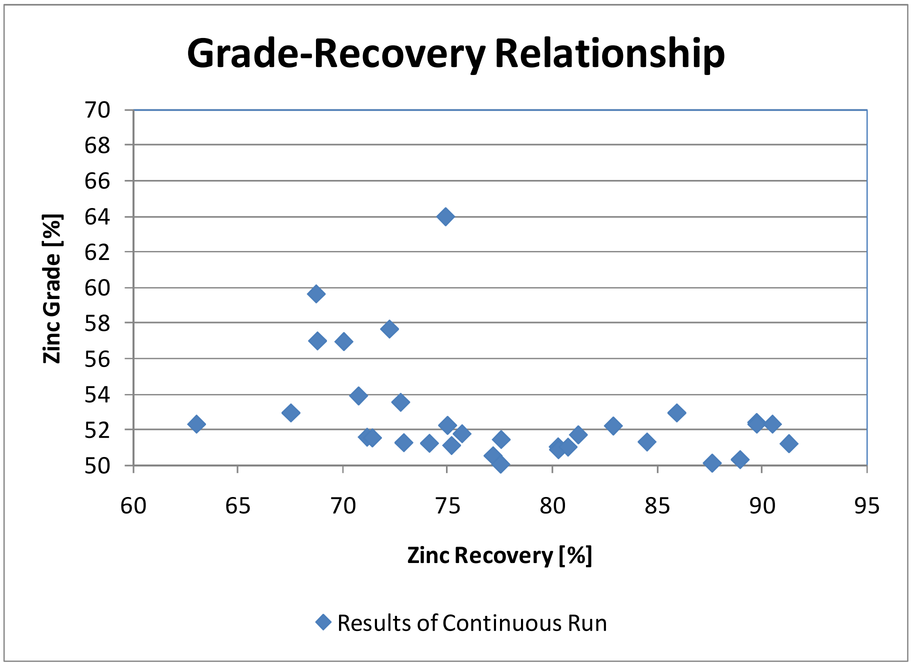

Figure 8 : Grade-Recovery Relationship for the Continuous Run

The above is not what would have been expected and illustrates the recovery loss resulting from the melting of the gangue phases in the kiln.

5.3 Calcine Inventory

The calcine produced during the tests has been collected and properly bagged for future test work. A total of 83 kilograms of calcine material was produced. This is in addition to the 500 kilograms produced for the Accha campaign.

The grade of the calcine is variable and sufficient mass is available of the different qualities to test the susceptibility of downstream processes to variable calcine grade.

6. CONCLUSIONS

The pilot plant campaign performed on the Yanque samples can be regarded as a success and has met the objectives originally specified on commencing the programme. Zinc recoveries in excess of 90% were achieved with lead recoveries exceeding 98%.

The optimisation of the operating parameters was hampered by the melting of the charge within the kiln. The melting of the gangue phase in the kiln for various conditions can partly be attributed to high silica content in the ore. The fact that the silica content of the samples tested varied between 32% and 65% is a matter of concern in that it indicates that either the primary sample blending at SGS was not done properly or the site blending of ores 2 and 3 was not done properly.

The best zinc recovery achieved in the parameter test work was 93.1% with a lead recovery of 98.7%. The grade of the calcine product for this test was 61.89% zinc and 11% lead. If it is assumed that the zinc and lead occur as zinc oxide and lead oxide respectively the concentration of zinc oxide will be 77.04% and the concentration of lead oxide will be 11.84%, yielding a combined concentration of 88.89%.

It was however noted that the melting phenomenon was only evident under certain conditions. If this phenomenon can be controlled it is expected that the recoveries of both zinc and lead will increase.

The continuous run yielded an average zinc recovery of 78.3% at a calcine grade of 51.53% zinc (64% zinc oxide). The lead grade in the calcine product for the continuous run was found to average 13.70% (14.75% lead oxide) with a lead recovery of 91.2% to the calcine product.

The major contaminants are chlorine, fluorine, cadmium and arsenic and the concentrations in the calcine for the test with the best recovery discussed above are 0.35%, 3.21%, 0.07% and 0.08% respectively. The chlorine and arsenic levels in the Yanque calcine product are lower than those achieved for the Accha calcine (chlorine 0.66% and arsenic 0.17%). The fluorine content of 3.21% is significantly higher than that for Accha where the fluorine was only 0.71%.

The anthracite consumption is significantly lower than initially expected. The model relating zinc recovery to the ratio of zinc feed grade and anthracite appears to be applicable to the Yanque ore however this will have to be proven once the melting of the Yanque ore has been addressed. As with the Accha sample a ratio of 4 kilogram of anthracite is required per kilogram of zinc in the feed.

The pilot plant campaign has produced 83 kilograms of calcine for further test work. The calcine is of varying grade lending itself to variability test work for the design of downstream processes.

Unlike the grade-recovery relationship developed for the Accha sample the grade-recovery relationship resulting from the continuous test work does not resemble a classical grade-recovery curve. This can be attributed to the effect of the melting of the gangue phases in the kiln and the resultant loss of zinc to the slag.

The fact that the melting of the charge occurred under specific conditions indicates that the opportunity exists to control the melting. Fundamental analysis of the system has indicated that the constituents of the charge can be altered to prevent melting of the charge. It is recommended that further test work be conducted in the laboratory to identify the gangue phases causing the melting of the gangue phases. Once this has been established test work will indicate what avenue to follow in addressing this phenomenon. Only once this has been established can further work be conducted to optimise the results for the Yanque deposit and for the purposes of process design.