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ENVIROPLAS TECHNOLOGY FOR THE RECOVERY OF LEAD  
AND ZINC FROM LEAD BLAST FURNACE SLAGS

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## ABSTRACT

The extraction of zinc and lead from liquid slags from lead blast and Imperial Smelting Furnaces direct into a lead splash condenser may offer an economically attractive alternative to fuming zinc and lead as oxides, since these oxides require further treatment to produce metal.

Mintek conducted four campaigns during 1994/95 on the 5,6 MVA multi-purpose demonstration-scale pilot plant to test the production of zinc metal direct from lead blast furnace slags (LBFS) and other sources such as residues and EAF dusts.

Typically the plant was operated at 1 t/h of slag, which was either fed direct as solid feed or premelted in a dc plasma-arc furnace to simulate hot slag from a lead blast furnace and continuously transferred at about 1300° C via a launder to a second dc plasma-arc fuming furnace through an underflow weir. The latter furnace was batch tapped approximately every two hours to remove slag, and a limited quantity of metal (mostly iron) was tapped up to twice a day. The fuming furnace was also tapped continuously for several days at a time.

The results achieved prove that PW (Prime Western) grade zinc can be readily made using an ISP lead-splash condenser linked to a dc plasma-arc fuming furnace. The final quenched slag consistently meets US EPA TCLP leach criteria, which is a critical aspect of the process.

The pilot plant equipment proved to be reasonably reliable once the initial commissioning problems were overcome, and relatively few conceptual changes are envisaged at the full industrial scale.

The process has still to be optimized in terms of, for example, the following parameters:

- The optimum zinc fuming rate has to be established for design criteria, and should be over 50 kg/m<sup>2</sup>/h for industrial-scale operations. This would enable a furnace less than 10 m in diameter to treat up to 1 000 t/d of liquid slag containing 12 per cent zinc as oxide.
- The selection of the carbonaceous reducing agent has to be optimized in terms of reactivity, particle size, moisture and volatile contents to achieve high reaction rates with respect to a particular LBFS.
- Control of the extent of zinc and iron oxide reduction to achieve optimum energy efficiency by balancing feed rate and composition, power input, and process temperature.
- Limiting the potentially negative effects of magnetite formation during premelting and liquid transfer of LBFS, and of sulphur, cadmium, arsenic and iron in the fuming and condensing processes.

## 1 Introduction

Mintek decided to utilize its recently installed multi-purpose demonstration-scale dc plasma-arc facility to develop data from which it should be possible to design full-scale plants based on the ENVIROPLAS<sup>TM</sup> process<sup>(1,2)</sup>. Several organizations have attempted to implement technologies to condense zinc metal direct from various waste materials such as electric-arc furnace (EAF) dust, zinc/lead residues, and lead blast-furnace slags (LBFS). Problems have been experienced with the quality of the zinc metal produced, the continuity of operation of the condenser (zinc-splash, not lead-splash condensers, have been used in most instances), back-reactions in the cross-over between the furnace and the condenser causing blockages, and high refractory lining wear at the slag line. Account was taken of these previously experienced difficulties in the design and operation of Mintek's facility.

The opportunities for Enviroplas technology can be grouped into three areas, namely ENVIRODUST for EAF and AOD dusts, ENVIROSLAG for lead and ISP furnace slags and ENVIRORES for zinc/lead calcine leach residues (either first neutral or final leach).

There are many common features among these different materials, especially regarding the fuming and condensation considerations. However, the pretreatment is very different in that LBFS are preferably fed in a liquid form, possibly via a holding furnace; EAF dust is dehalogenated first and fed direct as solid; while zinc calcine leach residues are roasted or premelted to selectively adjust the composition prior to liquid transfer to the fuming furnace. These process routes are illustrated in Figure 1.

To date, most of the testwork has concentrated on LBFS, since they present a commercially and technically attractive proposition. Most LBFS are reasonably free from major impurities and require much less energy when fed hot. The Doe Run Company of the USA has made a firm commitment to the development and

commercialization of the Enviroplas technology in association with Mintek to address this opportunity.

Mintek has conducted four campaigns on two different LBFS on the 5,6 MVA multi-purpose demonstration-scale pilot plant (constructed in 1993) to test the production of zinc metal direct from LBFS. This paper gives a description of the pilot plant and presents a brief overview of the results achieved. It also discusses some of the further optimization work still necessary to define the most effective process and furnace design.

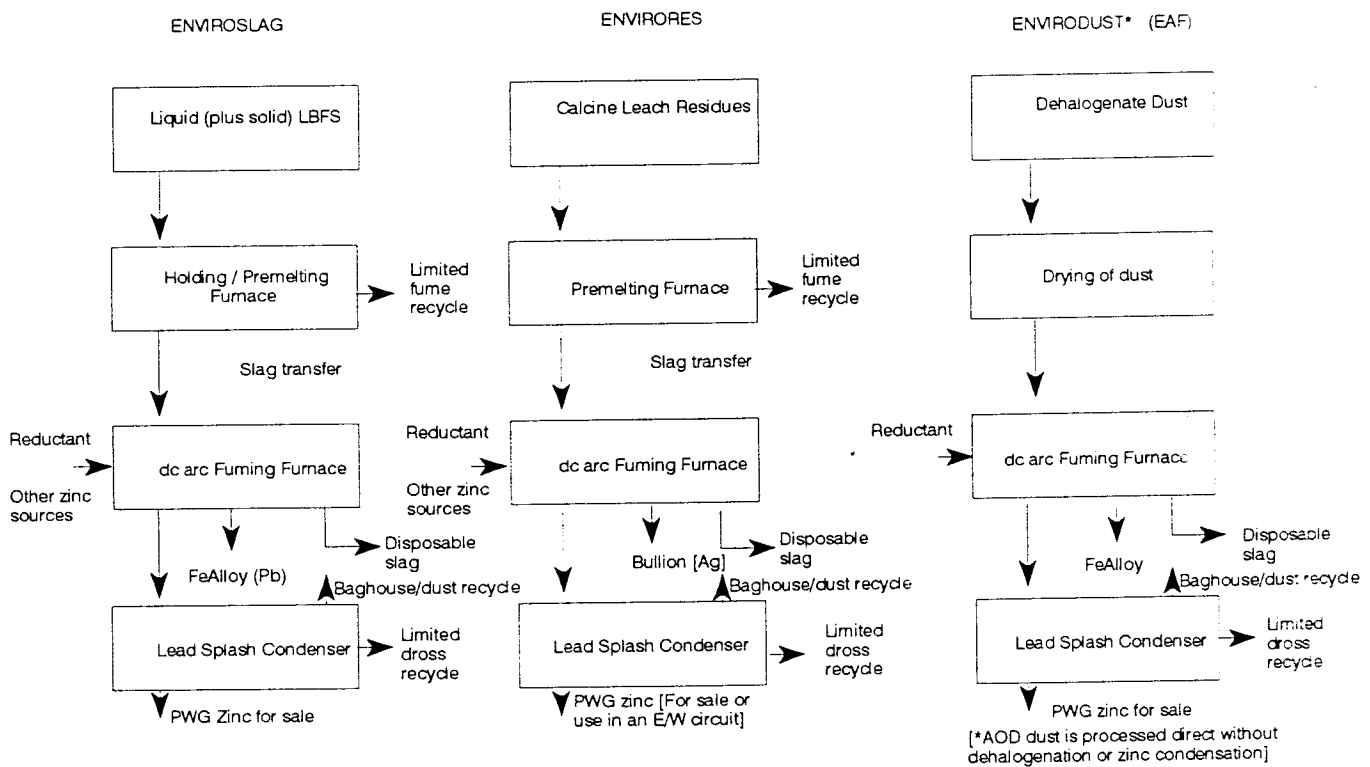


Figure 1. ENVIROPLAS™ Process Flowsheets for Slags, Residues, and Dusts

## 2 The Multi-Purpose Demonstration Plant

A schematic diagram and photograph of the Mintek demonstration plant are presented in Figures 2 and 3 respectively. The general arrangement comprises two plasma-arc furnaces served by a 5,6 MVA dc power supply, raw-material feed system, an ISP lead-splash condenser, a combustion chamber, and a gas cleaning system. Dry granulated LBFS was remelted in the first furnace (premelter) and hot slag was continuously fed, via a transfer launder and underflow weir, into the second furnace (fuming furnace).

This arrangement was employed to simulate the proposed industrial practise of feeding hot LBFS from the blast furnace, via a holding furnace, into a plasma-arc furnace.

Both premelter and fuming furnace consisted of a refractory-lined spray-cooled cylindrical shell 2,5 m in diameter, with a water-cooled roof in the shape of a truncated cone. Chrome-magnesite bricks were used to line the hot face of the sidewalls, such that a refractory thickness of 0,25 m and 0,13 m (for later campaigns) was obtained for the metal and slag regimes respectively. The flat part of the roof contained the feed port and a central entry port for the graphite electrode (cathode). The off-gas port was located in the side of the conical roof. The anode consisted of a number of steel pins vertically positioned in the hearth refractory and attached at their lower end to a circular steel plate, which, via radially extending arms was linked to the furnace shell and further to the anode busbars. The fuming furnace differed slightly from the premelter in that an additional taphole was provided for metal, and an underflow weir was incorporated in the side of the shell to receive molten slag.

A transfer launder was used to complete the connection of the premelter and fuming furnace, and a small chamber (weir box) was incorporated externally to the underflow weir to receive a continuous stream of hot slag. The fuming furnace was linked to the lead splash condenser through a short refractory-lined elbow (the cross-over).

The condenser assembly consisted of the condensing chamber with a single rotor (impeller), the lead circulation pump, the cooling launder with two immersible banks of cooling pins, the flux bath, and the zinc separation bath. The body of the condenser consisted of a refractory-lined steel box occupying a space of approximately 5 m by 5 m. The largest segment was the condensing chamber (2 m wide, 4 m long and 2 m high) into which the rotor was inserted through the roof. The condenser contained a 21 t inventory of lead and was designed for a zinc condensing rate of between 110 and 350 kg/h. This condenser design was supplied by ISP and is a smaller version of the ISP condensers that are employed, at several plants world wide, in combination with the Imperial Smelting Furnace (ISF) for the smelting of mixed zinc and lead sinter.

A reverse-pulse bag filter with a fan capacity of 6 500 Nm<sup>3</sup>/h served the premelter, while the gas-handling system behind the condenser comprised a refractory-lined combustion chamber, water-cooled ducting, a radiant gas cooler and a reverse-pulse bag filter with a capacity of 27 000 Nm<sup>3</sup>/h.

The 5,6 MVA power supply consisted of two transformers and two six-pulse rectifiers. The rectifiers may be configured in 12-pulse arrangement to deliver a maximum of 10kA to the fuming furnace, or two separate 6-pulse systems delivering a maximum of 5kA per furnace. The plasma-arc furnaces were fully controlled using a PLC, and a PC-based SCADA (Supervisory Control and Data Acquisition) system provided the user interface. Manual or semi-automatic operation was also available.

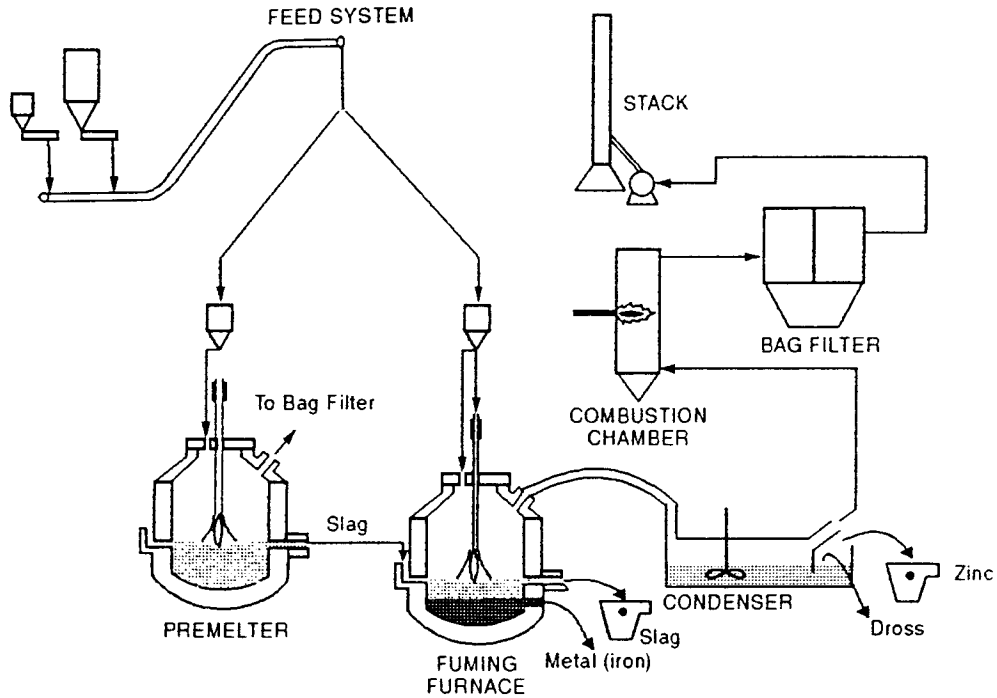


Figure 2. Schematic diagram of the demonstration plant

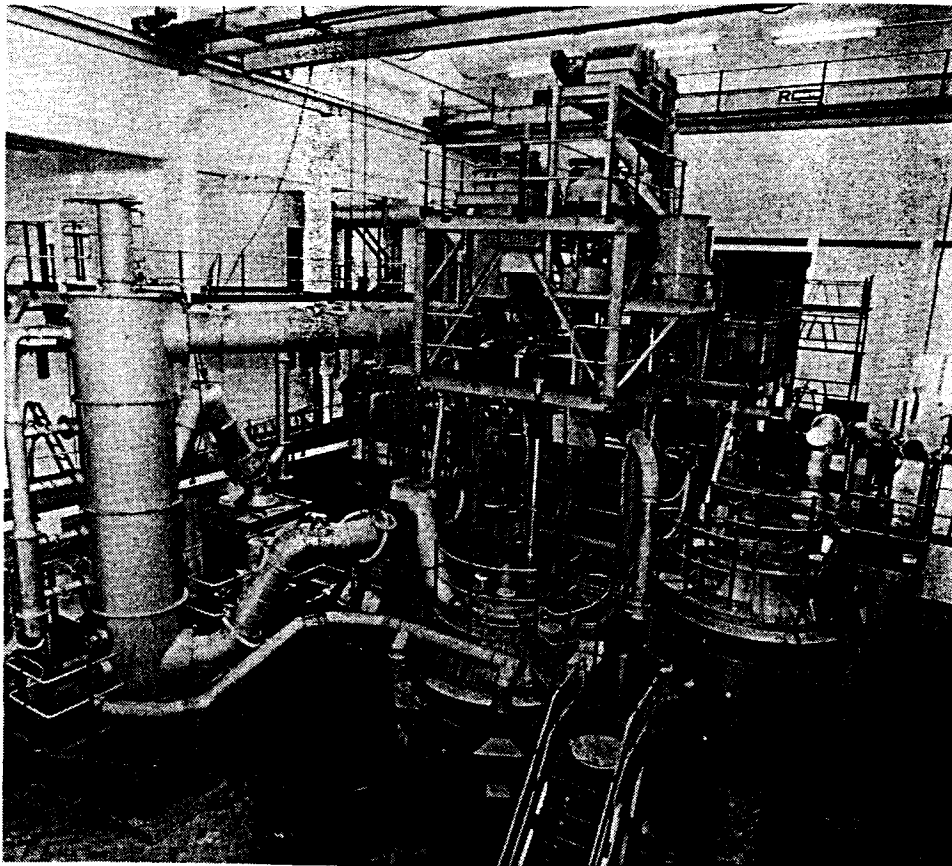


Figure 3. Photograph of the demonstration plant, showing the feed system, the two plasma furnaces, the lead splash condenser (left background), and the combustion chamber (left foreground)

### 3 LBFS Test Campaigns - Operating Criteria and Process Variables

The six main objectives for the fuming campaigns were to

- produce disposable slags that pass the toxicity characterization leaching procedure (TCLP) tests of the US Environmental Protection Agency (EPA)
- demonstrate that PW grade zinc metal can be produced
- prove the feasibility of liquid slag transfer into a sealed furnace
- determine fuming kinetic rates and condenser condensing efficiency values
- provide design data for commercial installations
- demonstrate that it should in principle be possible to achieve an economically viable process.

This last objective required the establishment of optimum operating conditions such as a condenser efficiency of about 70 to 80 per cent at this scale and about 80 to 90 per cent extraction of zinc from typical LBFS.

The process variables of major interest for the fuming furnace were reductant level and operating temperature. Coke additions were calculated to give at least 90 per cent extraction of zinc without excessive reduction of iron. This facilitated the minimization of coke usage, energy consumption and gas handling, since minimal volumes of CO are generated. However, coking levels must be sufficient to ensure a CO:CO<sub>2</sub> ratio such that zinc does not re-oxidise in the condenser. Theoretical considerations show that a minimum temperature of about 1350°C is required for 90 per cent zinc extraction. Above 1500°C there is a diminishing return in terms of zinc extraction, a risk of unacceptable refractory erosion and contamination of the fume with undesirable species. Further, the operating temperature must sustain a fume entry temperature to the condenser of at least 1100°C to minimize back-reactions. The selectivity of zinc reduction is also temperature- dependent, and any iron that is produced is not carbon-saturated and could not be tapped at 1350°C. Consideration of these factors indicates a desirable operating temperature in the range 1450 to 1500°C.

Four campaigns were carried out to address the commissioning of the plant, the development of the process technology, the demonstration of reliable equipment performance and the behaviour of different slags.

The granular LBFS was premelted in the first plasma-arc furnace (premelter) and hot slag was fed continuously from the premelter, via a transfer launder and underflow weir, into the second plasma-arc furnace (fuming furnace). Metallurgical coke was also fed to the fuming furnace through a feed port located in the roof or via the hollow electrode. The coke addition was about 30 kg per ton of LBFS. During certain periods of the smelting campaign, the premelter was switched off, the underflow was closed with refractories, and granular LBFS was fed directly to the fuming furnace. With the three

units (premelter, fuming furnace, and condenser) in line, the premelter was typically operated at a power level of 650 kW (200 V, 3,25 kA), and the fuming furnace was run at about 700 kW (175 V, 4 kA). When the premelter was not used, the fuming furnace was operated at power levels of around 1,2 MW. During short periods of the campaigns, the fuming furnace was run at 2,5 MW with feed rates of up to 3 t/h. The zinc and lead oxides contained in the slag were reduced to their metals and volatilized in the fuming furnace. Residual or 'spent' slag was tapped from the fuming furnace when about 2,5 t of LBFS had been fed to the premelter, i.e. at intervals of around 2 hours. Zinc was tapped once or twice per shift from the condenser, during periods when steady operation was achieved. Drosses were regularly removed from the cooling launder as they were generated. Gases and dust passing through the condenser were burnt in the combustion chamber and further cleaned in the bag filter. Fumes were removed continuously from the bag filter.

To control the smelting operation, the theoretical energy requirements (kWh/t LBFS) for each furnace were calculated, and the energy losses were measured, using cooling-water flowrates and temperatures. The operating power levels of the furnaces were then determined for selected feed rates. The main control parameters for running the furnaces were the tapping temperatures, which were measured with an optical pyrometer, and the percentages of zinc in the tapped slags. It was the aim at the outset of the campaign to attain zinc levels in the final slags of below 1,8 per cent, to achieve zinc extractions of about 90 per cent. The designed tapping temperatures of the premelter and fuming furnace were 1300 and 1450°C respectively. These temperatures were selected to minimize zinc losses in the premelter, to ensure sufficient fluidity, and to achieve a high degree of zinc extraction. During the campaigns, gradual changes were made to the 'setpoints' of energy losses and specific energy requirements to attain the desired tapping temperatures.

The general rules for operation of the condenser and its cooling system were based on temperature control around 500°C. When the pump sump temperature was too high (or low), the lead pump speed was increased (or decreased). When the return launder temperature was too high (or low), the cooling pins were immersed (or withdrawn). Propane burners were also used when the launder temperature was too low. The temperature of the gas entering the condenser was monitored. In order to maintain a sufficiently high temperature (over 1100°C), air was sometimes introduced to the furnace off-gas, where it combusted the CO, with the evolution of energy. Control parameters other than temperature were pressure, rotor speed, and rotor immersion. The pressure in the condenser was kept slightly positive (around 5 mm H<sub>2</sub>O), to avoid ingress of air, which could oxidize the zinc vapour and cause accretions.



#### 4 Results from LBFS tests - Mass and Energy Balances and Condenser Performance

In 1988, initial testwork on fuming LBFS was carried out on Mintek's 1 MW (3.2 MVA) pilot plant. The results have been reported elsewhere<sup>(3)</sup>.

During the four smelting campaigns in the current programme, a total of about 1000 t LBFS were processed. Typical analyses of the LBFS were 14% ZnO, 3% PbO, 25% FeO, 25% SiO<sub>2</sub> and 20% CaO. Metallurgical coke was used as the reducing agent. The carbon content of the coke was about 80 per cent, and 20 to 40 kg coke were used per ton of LBFS.

Zinc oxide contents in the slags tapped from the fuming furnace of about 1,5 per cent at best could be achieved, giving a zinc extraction efficiency of about 90 per cent. However, higher values in the slag than the target of less than 2 per cent were obtained when operating conditions were not adequately controlled, as shown in Figure 4. The data shown in this figure are for solid feeding of low-sulphur slags. The PbO contents of the residual slags were usually below 0,2 per cent, and all the slag samples submitted for toxicity leaching TCLP tests and even those of about 0,6 per cent PbO, were found to be in conformance to US EPA regulations.

About 20 t of zinc metal was tapped from the ISP condenser, and the weighted average composition was confirmed to meet PW grade specifications. Zinc mass balances were performed for periods of fairly consistent operation. About 850 kg residual slag, 50 kg zinc metal, 45 kg condenser dross and 10 kg fume were produced per ton of LBFS. The condenser dross contained about 60 per cent lead and 16 per cent zinc. A better drossing procedure would reduce the amount of lead metal removed with the dross. For selected periods of continuous operation lasting for more than 40 hours, zinc condensing efficiencies of 70 to 80 per cent were attained, which is a reasonable performance for a single-rotor condenser system. This gives an overall zinc recovery of about 60 to 70 per cent on a zero-recycle basis.

Energy balances were carried out for the premelter and fuming furnace, using selected taps of uninterrupted operation. The calculated specific energy requirements, based on total power consumption levels per ton of LBFS and on measured heat losses, were 330 and 190 kWh per ton of LBFS for the premelter and fuming furnace respectively. Thermal efficiencies of both furnaces were around 60 per cent. The operating temperature of the premelter was around 1300°C while the tapping temperatures of the fuming furnace were around 1450°C.

Problem areas still to be addressed included low rates of zinc fuming and extraction that occurred under conditions where magnetite-rich slag was produced in the premelter and transferred to the fuming furnace causing the build up of a solid layer and the use of relatively unreactive reductants. More detailed results will be presented at the 1995 TMS Fall Extraction and Process Meeting in the USA<sup>(4)</sup>.

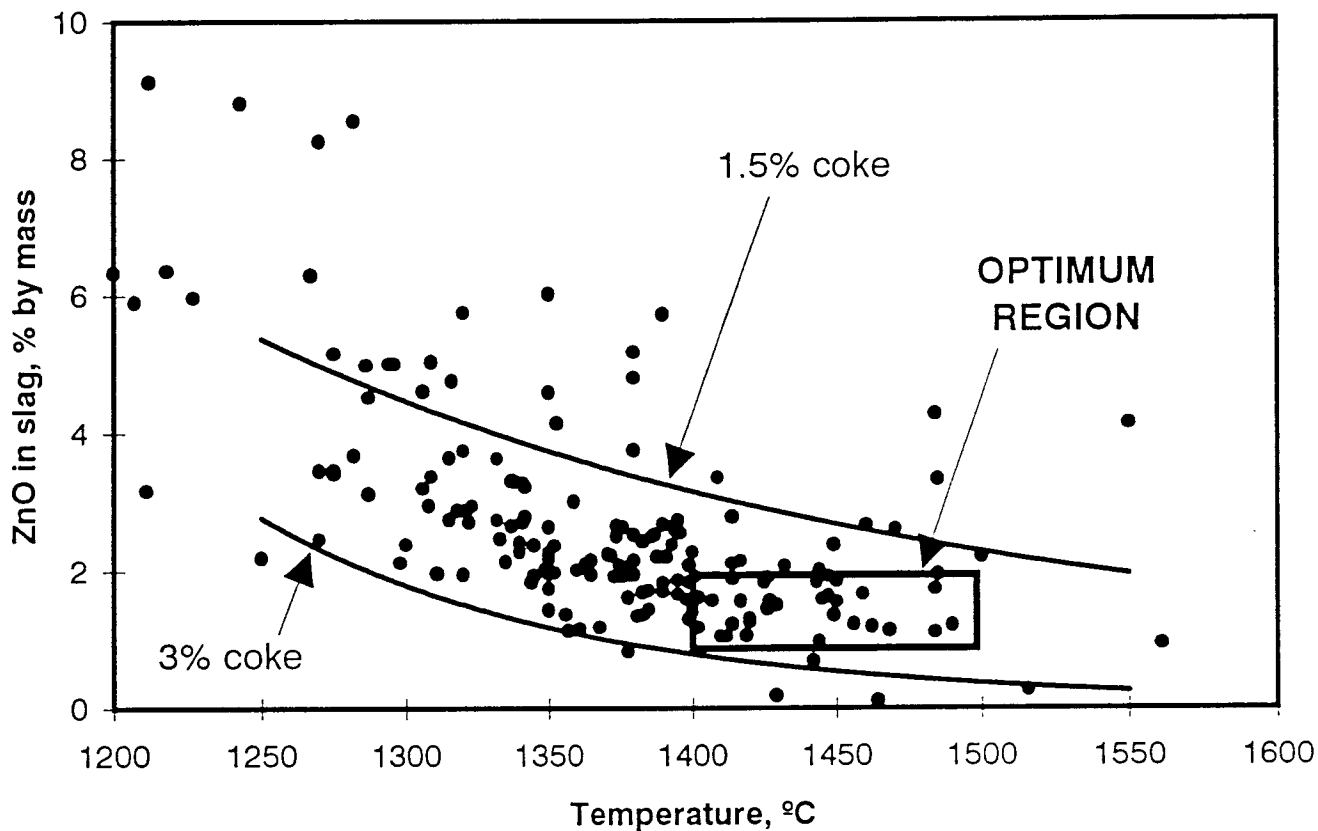


Figure 4. Zinc oxide content of slags tapped from the fuming furnace, as a function of tapping temperature. Curves calculated using Pyrosim (5)

## 5 Theoretical Considerations

A theoretical evaluation of the results was made to identify the best approach to process and equipment optimization. The key factors in achieving the necessary kinetics are common to any process, and in this case are:

- adequate temperature at the reaction interface between the reductant (coke) and the slag
- adequate mixing to provide heat and mass transfer to the reaction interface, and bulk stirring
- adequate reactivity of the reductant.

These three topics are discussed in some detail below.

### Temperature at the reaction interface.

The kinetic model in the paper by Robertson *et al*<sup>(6)</sup> allows the calculation of the effect of temperature on the rate, and some results are given below. Of course, the absolute values of the rate depends on the value assumed for the effective mass transfer coefficient (EMTC). This empirical rate parameter can only be quantified by large-scale testwork, and includes the effects of:

- any increase in the reaction area above the nominal bath area (for example by mixing of the solid reductant into the bulk of the slag),
- the high temperatures in the arc-attachment zone, and
- the mixing caused by the electromagnetically driven flows induced by the arc current.

Based on testwork to date<sup>(6)</sup> the EMTC was taken to be in the range 0,04-0,12 cm/s in the liquid slag. The ratio of the gas-to-slag MTCs was assumed to be constant at 2000, because of the much higher diffusivity in the gas phase.

The slag composition assumed was close to the desired slag composition from the plasma furnace, containing about 2 per cent ZnO and 1 per cent sulphur. The slag model used indicated that at this high sulphur level (and at the oxygen potentials calculated), about half of the zinc in the slag would in fact be present as ZnS. However, for simplicity, all the zinc in the slag is reported as "ZnO", as is common practice with chemical analysis results.

Figure 5 shows the bulk and interfacial ZnO concentrations in the liquid. The driving force (difference between bulk and interfacial concentrations) required for ZnO diffusion in the liquid slag is as high as 0,7 per cent at 1500°C, so the rate would become liquid-phase-controlled if the bulk zinc concentration were to be much below this value.

Figure 6 shows the effect of temperature on the Zn(g), CO and CO<sub>2</sub> at the gas/slag interface and in the bulk gas phase forming in contact with the coke. The driving forces in the gas phase are all quite small, the limiting driving force being that for the CO<sub>2</sub> to diffuse into the bulk gas and then to the coke surface, where it reacts to form CO. The need for a reactive coke arises particularly because of the low CO<sub>2</sub> concentrations calculated. The coke reactivity must be sufficient for the CO<sub>2</sub> to react as quickly as it is formed when its bulk concentration is only around 3 per cent or less. This information on the expected CO<sub>2</sub> level in the gases in the vicinity of the coke is essential in devising tests to assure adequate reductant reactivity before the reductant is used in the furnace. Mintek is well aware of the importance of coke reactivity

It is important to note that the results of Figures 5 and 6 are not affected by the absolute magnitude of the EMTC - hence they provide a most valuable insight into the process, irrespective of the degree of agitation actually imposed. The results do depend on the ratio of the MTCs and on the thermodynamic data used for the reactions, but these data are fairly accurately known.

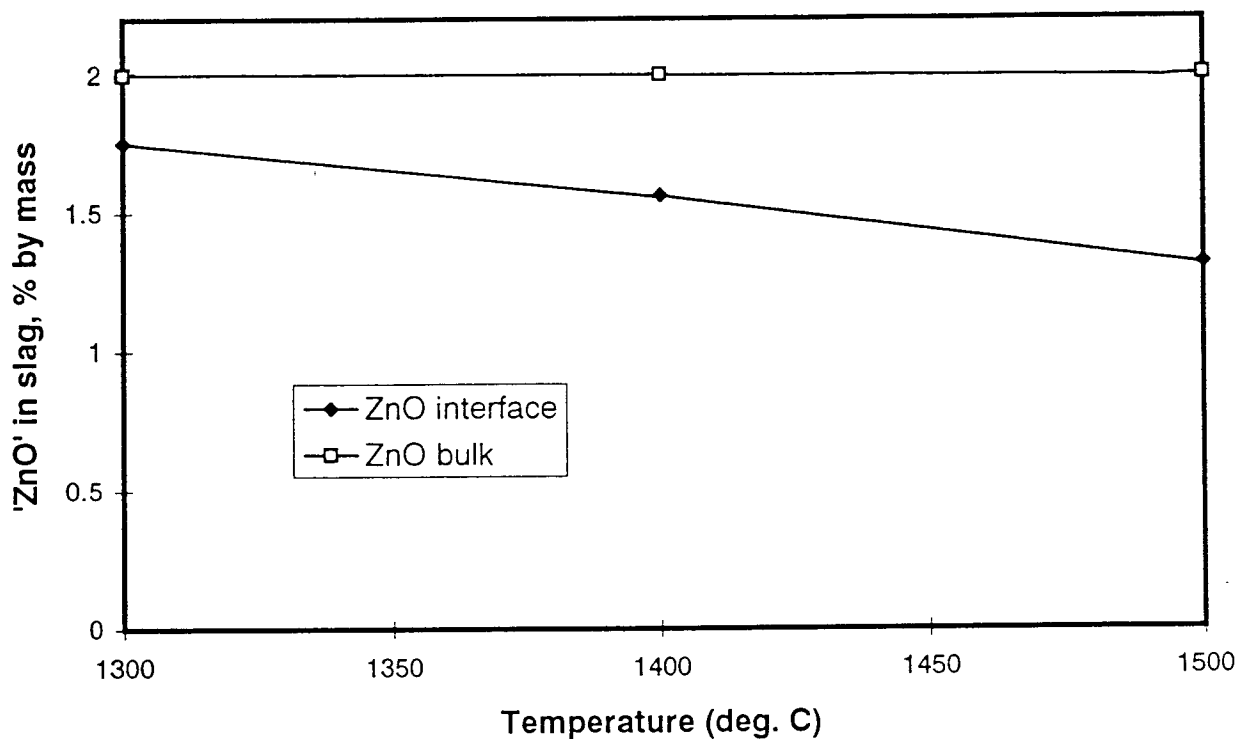


Figure 5. Calculated concentration of 'ZnO' in the liquid slag phase at different temperatures.

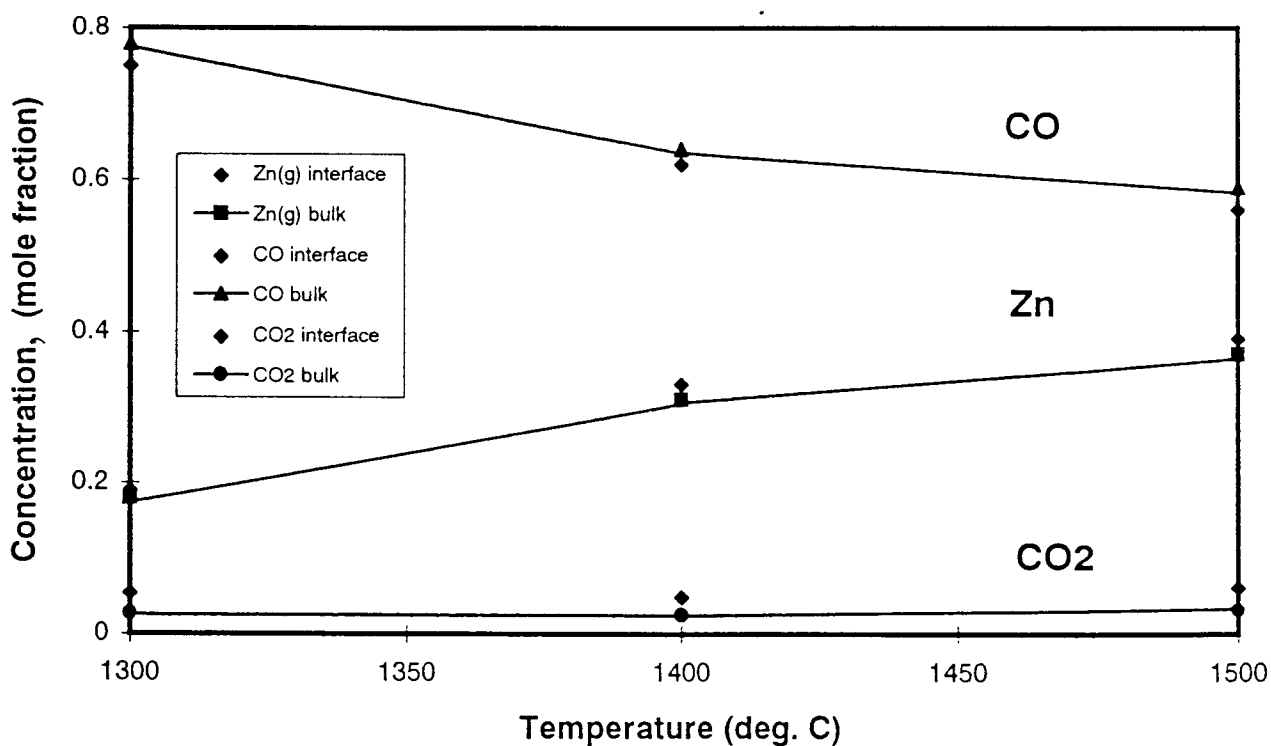


Figure 6. Calculated concentrations in the gas phase for Zn(g), CO, and CO<sub>2</sub> at different temperatures

Figure 7 is a plot of the rate of zinc volatilization as a function of temperature and the EMTC. The figure shows that, at a given value of the EMTC, the rate is expected to increase by almost three times as the interface temperature is increased from 1300 to 1500 °C, purely as a result of the more favourable chemistry.

It can be seen from Figure 7 that the required rate of zinc production of at least 50 kg/m<sup>2</sup>/h can be obtained, but the requirements for interface temperature and the EMTC are quite stringent. One combination would be an interface temperature of 1400°C and an EMTC of 0,12 cm/s. This is a very high value for a mass transfer coefficient and implies very good mixing at the gas/slag interface. Results of actual fuming rates are close to those predicted in Figure 7, under favourable conditions.

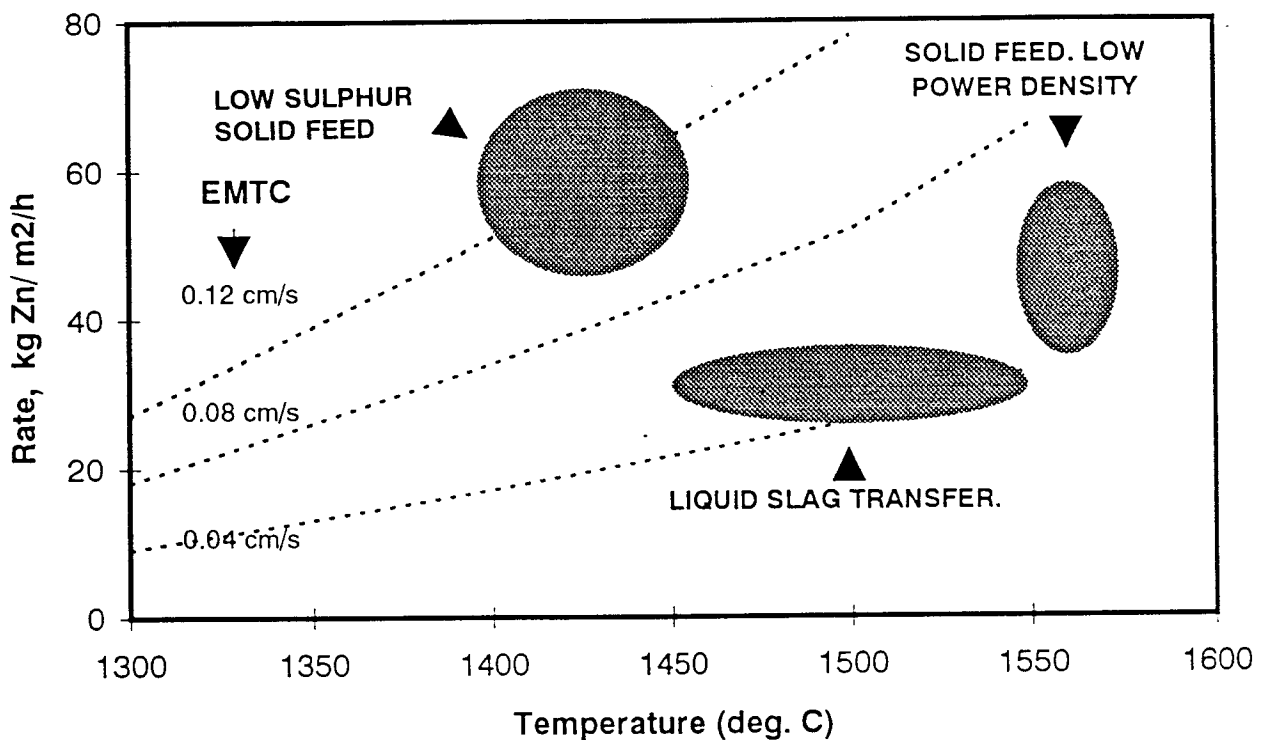


Figure 7. Volatilization rates vs temperature. Theory and experiment.

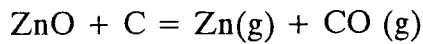
(Rate - kg Zn per unit surface area of the bath per hour)

### Mixing

As mentioned earlier, adequate mixing is necessary for at least three reasons

- Heat transfer to the reaction interface.

The overall reaction:



is extremely endothermic, with a  $\Delta H$  at 1400 °C of 349 kJ/gmole of zinc. At the required zinc-production rate of at least 50 kg/m<sup>2</sup>/h, this corresponds to a required heat flux density of 74 kW/m<sup>2</sup> to the interface to provide the reaction heat. This heat transfer must presumably occur by convection from the hotter bulk slag flowing from the arc attachment zone. Assuming an effective heat-transfer coefficient of 1 kW/m<sup>2</sup>K (again a relatively high value<sup>(7)</sup>, requiring good mixing) leads to a required driving force of 74°C. Therefore a bulk slag temperature of about 1475 °C is required for the reaction interface temperature to be 1400 °C. This explains the bulk slag temperature of 1400 °C or higher found by Mintek to be necessary for the required rate of LBFS fuming<sup>(6)</sup>.

- **Mass transfer to the reaction interface**

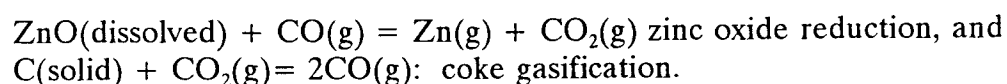
This step was dealt with in some detail by Robertson *et al.*<sup>(6)</sup>, who concluded that the satisfactory test results reported by Mintek conducted in the 3,2 MVA (1 MW) furnace with low-sulphur LBFS, charcoal reductant, and solids feeding, could be explained by an EMTC of 0,08 cm/s, at a bulk slag temperature of 1500 °C. Clearly therefore, if any change in the mode of operation were to result in reduced mixing, the required zinc extraction performance would not be met.

- **Bulk stirring of the bath**

Stirring is necessary to prevent stratification of liquid in the slag pool. Stratification is more likely to be a problem when the furnace is operated with liquid slag transfer using the underflow weir than during feeding of cold solids to the slag surface. During transfer the liquid slag feed is at a lower temperature, and is thus denser and more viscous than the (presumably hotter) slag in the fuming furnace.

- **Reactivity of the reductant**

The mass-transfer model of the process developed by Robertson *et al.* assumed that the ZnO reduction reaction occurs in two steps:



The coke gasification step must be fast enough to keep up with the rate of generation of CO<sub>2</sub> by the zinc oxide reduction step. In the fourth campaign at Mintek on the treatment of LBFS, there was a noticeable difference between the reactivities of two cokes used, which were improved by crushing. Coke selection has also been reported as being an important factor in the satisfactory operation of dc plasma furnaces for the production of ferrochromium.

For the tests<sup>(6)</sup> carried out on the 3,2 MVA scale using charcoal as a reductant there was no evidence of any influence of a slow carbon gasification step. Charcoal is generally the most reactive form of carbon.

## 6 Discussion

In commissioning campaigns 1, 2 and 3, on the 5,6 MVA pilot-plant at Mintek, most of the tests in which satisfactory conditions of temperature and operation were achieved were carried out with low-sulphur LBFS, solid slag feeding, and a metallurgical coke. As described earlier, these tests gave adequate kinetics, and did not suggest that there were likely to be any real barriers to achieving the required kinetics on the larger scale. In the midst of this work some successful tests were indeed carried out on slag transfer and using solid Doe Run slags (with their higher sulphur content), but only for a limited number of taps.

Liquid slag transfer has a major effect on the process in a number of ways. The following comparison is between slag transfer and solids feeding.

- The total power requirement is lower, because energy is not needed to heat or melt the solid slag. The lower power input is expected to reduce the mixing introduced by magnetohydrodynamic (MHD) effects in the bath. The MHD stirring will predominantly be determined by the arc current, which in the tests at Mintek was substantially higher during the solids feeding period. Currents used at Mintek in the fourth campaign were generally 4 kA during liquid slag transfer and 8 kA during solids feeding.
- With a liquid slag feed there is far less dust in the environment above the bath, so that radiation heat transfer from the bath surface to the roof and sidewalls is high. This provides another heat load on the reaction interface, which will lower its temperature further. Radiation from the bath surface to the roof and sidewalls could easily double the heat load on the interface. The results of the fourth campaign showed conclusively that the heat losses to the roof were substantially reduced (by a factor of two) during solids feeding, when the roof was presumably shielded by dust.
- As explained earlier, there is a greater likelihood of segregation in the bath during slag transfer.
- In campaign 4, particularly during transfer of Doe Run slag, there was a problem with magnetite formation in the pre-melter and in the transfer launder<sup>(8)</sup>. This was an additional complicating factor, which actually led to the accretion of magnetite over a significant part of the hearth at one stage of the campaign.

It is clear, from Mintek's results on solid slag feeding with a low sulphur LBFS, that satisfactory kinetics can be obtained. However it is equally clear from the experimental results and from the theoretical analysis<sup>(6)</sup> (which has been "calibrated" against experimental data on the 100 kVA and 3,2 MVA scales, again with solid slag feeding and with (reactive) charcoal as the reductant), that the conditions for satisfactory rates of zinc volatilization are

quite difficult to achieve. These conditions are a high slag temperature, good mixing, and a reductant with a high reactivity. This emphasizes the need to conduct testwork at both a bench and demonstration pilot-plant scale, on individual slags and using appropriate reductants, to determine the rate and extent of zinc extraction.

## 7 Conclusions and Recommendations

- The slags produced readily met US EPA TCLP leach criteria, even when the lead content was about 0,6 per cent which is above the target value of 0,2 per cent.
- Prime Western grade zinc has been reproducibly attained from two different LBFS with acceptable condenser efficiency up to 80 per cent which, considering the small scale of operation (1 t/h slag), would extrapolate to an efficiency of probably over 90 per cent on a full-scale plant.
- Zinc fuming rates of over 50 kg/m<sup>2</sup>/h (up to almost 70 kg/m<sup>2</sup>/h) were achieved at temperatures of about 1425°C when solid slag feed was used direct into the fuming furnace.
- Zinc extraction rates from the slag and zinc oxide levels in the slag were not satisfactory when liquid slag feed was used.
- Further optimization of the process and equipment design is still required so that a cost-effective furnace design can be achieved for the full scale plant, and to ensure consistent operation at acceptable rates of zinc removal.
- Zinc extraction rates of more than 50 kg/m<sup>2</sup>/h, and preferably approaching 100 kg/m<sup>2</sup>/h are required to limit the diameter of the industrial-scale furnace to less than 10 m for typical LBFS at a throughput rate of about 1000 t/d. Further testwork to achieve higher rates consistently from liquid slag feed is underway.
- Co-processing of LBFS and EAF dust with about 20 per cent Zn or ZnO to increase the zinc throughput is being evaluated as a means of increasing the potential economic performance of the technology.
- The results show why it is necessary to thoroughly test the extraction of zinc and lead for a particular LBFS on the demonstration scale prior to designing a full-scale plant.



## 8 Acknowledgements

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## 9 References

- 1 Schoukens, A.F.S., Shaw, F, and Chemaly, E.C., "The Enviropas process for the treatment of steel-plant dusts", *J.S.Afr.Inst.Min.Metall.*, Vol.93, No.1, January 1993, pp. 1-7.
- 2 Barcza, N.A., Hutton, C.J., Freeman, M J., and Shaw, F., "The treatment of metallurgical wastes using the Enviropas process", *International Symposium on Extraction and Processing for the Treatment and Minimization of Wastes*, 1994 TMS Annual Meeting, 27 February - 3 March 1994, San Francisco, pp. 941-962.
- 3 Schoukens, A.F.S., Nelson, L.R., and Barcza, N.A., "Plasma-arc treatment of steel-plant dust and zinc-containing slag - theoretical and practical considerations", *Recycling of Lead and Zinc, the Challenge of the 1990s, Proceedings of an international conference organized by the International Lead and Zinc Study Group Sub-Committee on Recycling*, Rome, June 1991, pp.361-370.
- 4 Schoukens, A.F.S., Denton, G.M., Jones, R.T., "Pilot-plant production of Prime Western grade zinc from lead blast-furnace slags using the Enviropas process", to be presented at the *TMS Fall Extraction and Processing Meeting*, Point Clear, Alabama, 12-16 November 1995, 11p.
- 5 Jones, R.T., "Computer simulation of metallurgical processes", *APCOM 87, vol.2.*, South African Institute of Mining and Metallurgy, 1987, pp. 265-279.
- 6 Robertson, D.G.C., Nelson, L.R., Narayana Swamy, K., "Kinetic simulation of the zinc fuming of lead blast furnace slags in center-fed, hollow graphite electrode, DC plasma-arc furnaces", *Metallurgical processes for the Early Twenty-First Century*, TMS, Warrendale, PA, 1994, pp.283-306.
- 7 Bird, R.B., Stewart, W.E., and Lightfoot, E.N., *Transport Phenomena*. John Wiley, New York. 1960, pp.393.
- 8 Floyd, J.M., Conochie, D.S., Grave, N.C., (1979), "Measurement of oxygen potentials in slags in a nickel smelter using disposable tip EMF cells", *Proc. Aus. IMM*, No. 270, June 1979, pp.15-23.