The application of Ausmelt technology to base metal smelting, now and in the future

by P.N. Vernon* and S.F. Burks†

Synopsis

Ausmelt top entry submerged lance technology offers a cost-effective means of carrying out a range of base metal smelting operations with minimum impact on the environment.

The system is capable of using a range of fuels depending upon local costs. Due to the intense, localised reaction zone, high energy efficiency is obtained and the physical size of the plant is relatively small compared to that of most competing technologies. Capital cost can thereby be minimised. The furnace is well enclosed, such that fugitive emissions and ingress of diluting air to the gas stream are both minimised.

The oxygen potential in the slag can be varied over a wide range such that the system can be applied in both oxidising and reducing duties.

Following a general description of the technology, the paper discusses Ausmelt plants already in operation. The application of the technology for the provision of additional smelting capacity, for the improvement of converting operations and for slag cleaning is then described. A brief explanation of how these processes could be applied at southern African smelters is given and the paper closes with an assessment of novel Ausmelt applications for this geographical region, such as zinc recovery from sulphides.

Introduction to Ausmelt technology

Intensive smelting by the use of a top entry lance in a slag bath was developed by the CSIRO in Australia in the early 1970s. Key motivations in the early work were to recover values from slags and to smelt tin concentrates[1]. This work led to the granting of a patent to the CSIRO for the Sirosmelt Top Entry Submerged Lance (TSL) smelting system[2].

Dr. J. Floyd, who had headed the team at CSIRO, founded Ausmelt in 1981. Licences have been granted by the CSIRO to two companies, Ausmelt Ltd and Mount Isa Mines Ltd for the commercialisation of the Sirosmelt system. Both these companies have introduced further technological development and both now offer the system to the market on a world-wide basis. The latter company has concentrated upon the processing of copper and lead materials drawing on its own operational experience.

Figure 1 illustrates the basic features of an Ausmelt furnace. It is a simple structure with a high throughput to volume ratio such that furnace capital cost is usually lower than for most other furnace designs for similar throughput. As a broad indication the following specific throughput ranges apply to the smelting of a typical copper sulphide concentrate.

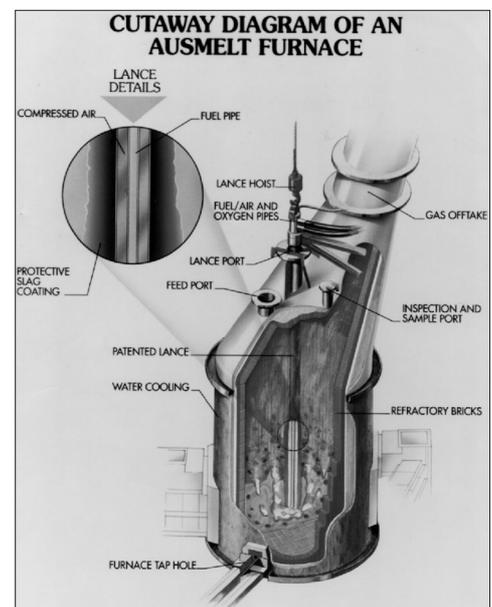|	Tons/day/m^2 of hearth
Reverberatory furnace	4–8[3,4,5]
Flash furnace	9–12[5]
Ausmelt furnace	50–100[6]

Figure 1—Cutaway diagram of an Ausmelt furnace

* Ausmelt Consultant, 1 Midhurst Way, Constantia, 7800.

† PGM and Base Minerals, Bateman Minerals & Industrial Limited, P.O. Box 25937, East Rand, 1462.

The application of Ausmelt technology to base metal smelting

The furnace structure consists typically of a vertical steel cylinder, water cooled on the outside and lined with a refractory suitable for the application. The roof of the furnace, which may or may not be water cooled, is normally an inclined cone leading to the off-gas duct system. The lance, which is the subject of various patents, enters through a port in the centre of the roof and is suspended from a suitable hoist system. In normal operation the tip of the lance is submerged in the slag bath such that violent splashing occurs. The splashing provides conditions such that rapid heat and mass transfer take place between the slag, the feed and the products of combustion. In this way high energy efficiency is obtained, thus minimising operating cost.

The patented[7] shrouded lance used in Ausmelt's technology allows injection of air into the region above the bath in which a cascade of slag provides excellent conditions for recovering energy to the bath from post conduction of metal vapours, carbon monoxide, hydrocarbon gases, etc, which are generated by reactions in the bath.

The fuel may be coal, oil or gas depending on site-specific costs. The combustion gas can be natural, or oxygen enriched, air. The fuel to oxygen ratio at the lance tip are readily controllable, as are the reactions in the bath. At one extreme the system has been operated at temperatures high enough and oxygen potentials low enough to reduce iron from oxides of iron. At the other extreme it has been operated at temperatures as low as 800°C and oxygen potentials high enough to cupel lead from silver. Solid feed normally enters through a second port in the roof. Where appropriate, molten material can be introduced via a launder and weir through the side wall. The furnace may be operated continuously or in batch mode. In the latter case, it is possible to carry out a series of operations sequentially in the same vessel, for example smelting at close to neutral conditions, converting under oxidising conditions followed by slag cleaning under reducing conditions. Alternatively these operations can be carried out in two or more furnaces in series. This opens important opportunities for the design of relatively low capital cost smelting circuits. Mounsey provides details of such applications for copper smelting at widely different throughputs[8].

Technology applications in non-ferrous metal smelters

General

The discussion which follows concentrates almost entirely on nickel, copper and platinum group metal smelters. The reason for this is quite simple: most non-ferrous metal smelters in southern and central Africa are involved in the recovery of these metals. Regional experience of and interest in base metal pyrometallurgy is therefore quite naturally focused on these metals. There are four important potential areas of application of Ausmelt technology.

Additional smelting capacity

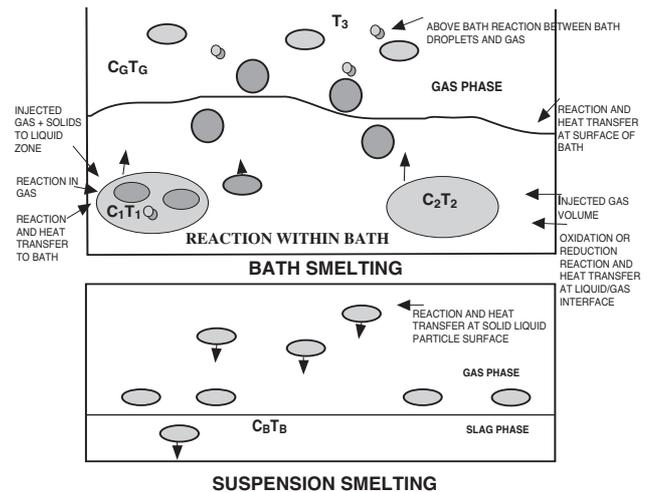As discussed by Floyd[9], Ausmelt technology employs a

Figure 2—Comparison of heat and mass transfer for bath smelting and suspension smelting after Floyd[9]

pneumatic bath smelting technique. This is illustrated in Figure 2. It has the following characteristics:

➤ Temperature and concentration differences between reactants and bath are relatively small, by comparison with suspension (e.g. flash) smelting techniques.

➤ The bath is well stirred by the injection of gases and reactions are therefore very rapid.

➤ Reactions and heat transfer occur predominantly in a zone above the bath where, due to violent splashing, slag, charge and other reactants are in intimate contact.

➤ Coarse feed, up to 100mm in diameter and damp material can be fed to the furnace because solids have a long residence time in the bath, compared with suspension smelting.

➤ By altering the composition of feed solids, fluxes, fuels and gases, a very wide range of different process conditions can be generated in the furnace, from highly reducing right through to highly oxidising.

These characteristics are quite different from those of alternative high intensity techniques which utilise suspension smelting. There are three main reasons why Ausmelt is often the selected technology when smelters expand.

Minimal modifications to feed and gas handling systems

In Southern Africa, most existing smelters use either submerged arc electric furnaces or coal-fired reverberatory furnaces. Historically, feed preparation has been relatively rudimentary, with damp concentrate being fed to the furnace without preliminary calcining or drying to zero moisture[10,11,12]. Oxygen enrichment has not been widely used and offgas flowrates are high. In consequence, the addition of an Ausmelt furnace to an existing smelter in order to boost production will often require minimal modification to the existing feed system, fuel supply or gas handling equipment.

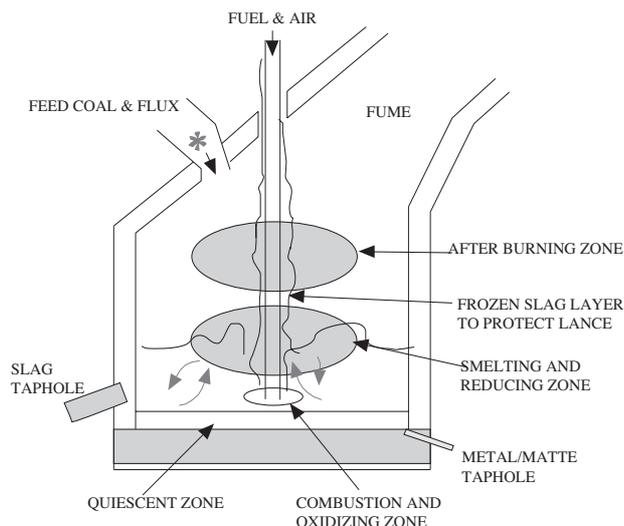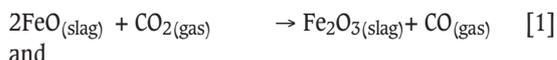# The application of Ausmelt technology to base metal smelting

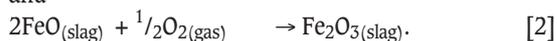**Figure 3—Reaction regimes within the Ausmelt furnace**

Flexibility of metallurgical operation

In the Ausmelt furnace, there are several distinct reaction zones, which are illustrated in Figure 3. The types of reactions illustrated all occur in the case of smelting a high iron sulphide feed to form a matte or alloy and an iron-rich slag.
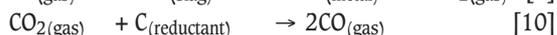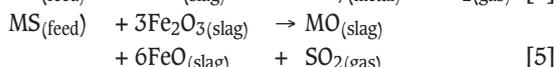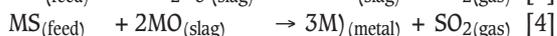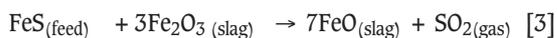
➤ At the mouth of the lance, combustion and oxidation reactions take place in the slag phase, in a very limited zone which does not penetrate the bath to a significant extent. During gas rise, oxidation occurs according to the reactions:

$$2FeO_{(slag)} + CO_{2(gas)} \rightarrow Fe_2O_{3(slag)} + CO_{(gas)} \quad [1]$$
and
$$2FeO_{(slag)} + {}^1/_2O_{2(gas)} \rightarrow Fe_2O_{3(slag)}. \quad [2]$$

➤ In the dynamic interfacial and splash zone a number of smelting and reducing reactions occur:

$$FeS_{(feed)} + 3Fe_2O_{3\,(slag)} \rightarrow 7FeO_{(slag)} + SO_{2(gas)} \quad [3]$$
$$MS_{(feed)} + 2MO_{(slag)} \rightarrow 3M)_{(metal)} + SO_{2(gas)} \quad [4]$$
$$MS_{(feed)} + 3Fe_2O_{3(slag)} \rightarrow MO_{(slag)}$$
$$+ 6FeO_{(slag)} + SO_{2(gas)} \quad [5]$$
$$C_{(reductant)} + Fe_2O_{3(slag)} \rightarrow 2FeO_{(slag)} + CO_{(gas)} \quad [6]$$
$$C_{(reductant)} + MO_{(slag)} \rightarrow M_{(metal)} + CO_{(gas)} \quad [7]$$
$$CO_{(gas)} + Fe_2O_{3(slag)} \rightarrow 2FeO_{(slag)} + CO_{2(gas)} \quad [8]$$
$$CO_{(gas)} + MO_{(slag)} \rightarrow M_{(metal)} + CO_{2(gas)} \quad [9]$$
$$CO_{2(gas)} + C_{(reductant)} \rightarrow 2CO_{(gas)} \quad [10]$$

➤ Above the bath, splashed slag will react with the gas components rising from the bath, and afterburning reactions to remove CO, H_2 and coal volatiles from the waste gases will also occur.

➤ Metal or matte droplets formed at the slag surface will continue to react as they fall through the slag, and then at the slag : matte interface. The interface reactions can be accelerated by lowering the lance. As the metal or matte droplets fall further they enter a small quiescent zone at the bottom of the furnace which aids matte/slag separation.
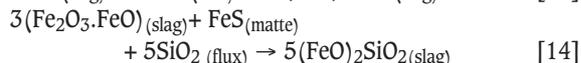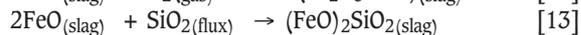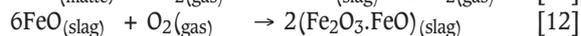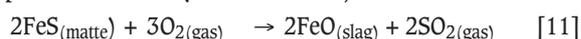
Because of the multiple reaction zones, the Ausmelt furnace can be used for a large number of different pyrometallurgical processes. As far as basic smelting operations are concerned, Ausmelt can, in theory, be used to smelt high grade sulphide concentrates autogenously, or increasing amounts of fuel can be added to smelt materials containing less sulphur or even no sulphur at all. It is also possible to generate mattes with varying iron and sulphur contents, making it possible to assist the subsequent converting operation as required.

Small 'footprint' of Ausmelt furnaces

The third reason why Ausmelt is often favoured for smelter expansions is the small floor space needed for an Ausmelt installation by comparison with an alternative type of furnace with the same smelting capacity. As noted previously, the specific smelting rate per square metre of hearth area is an order of magnitude greater for an Ausmelt furnace than for a reverberatory unit. In most smelters, additional buildings and ancillary equipment are added over a period of time, crowding the original access areas, utilising expansion allowances for a different purpose from that originally intended, and generally complicating the life of the plant operators. In many old smelter plants, it is often extremely difficult to implement further modifications in the available space. Ausmelt generally offers a distinct advantage in such cases since the main constraint on an Ausmelt installation is available height rather than floor space.

Converting

The following fundamental reactions are involved in converting furnace mattes containing copper, iron, sulphur as well as (in some cases) nickel and cobalt:

$$2FeS_{(matte)} + 3O_{2(gas)} \rightarrow 2FeO_{(slag)} + 2SO_{2(gas)} \quad [11]$$
$$6FeO_{(slag)} + O_{2(gas)} \rightarrow 2(Fe_2O_3.FeO)_{(slag)} \quad [12]$$
$$2FeO_{(slag)} + SiO_{2(flux)} \rightarrow (FeO)_2SiO_{2(slag)} \quad [13]$$
$$3(Fe_2O_3.FeO)_{(slag)} + FeS_{(matte)}$$
$$+ 5SiO_{2\,(flux)} \rightarrow 5(FeO)_2SiO_{2(slag)} \quad [14]$$

The iron in the furnace matte is therefore removed in a fayalite slag, while sulphur is oxidised to sulphur dioxide gas. Converter matte or blister copper are the desired products containing the metal values.

The standard converting unit throughout the copper and nickel industries has been the Peirce-Smith converter for many decades. This tilting, cylindrical converter is very robust and some steel shells have probably been in use for close to fifty years. However, the characteristics of the unit process, as listed, demonstrate its disadvantages:

➤ Tuyères are used to introduce air into the converter. Severe refractory wear occurs along the line of the tuyères, necessitating the replacement of at least this portion of the brick lining after only a few months.

➤ The converting operation is highly exothermic. It is therefore necessary to add cold solid material to the converter (reverts and flux), to remove as much heat as possible in waste gas, and to interrupt the converting operation periodically in order to keep the temperature down.

The application of Ausmelt technology to base metal smelting

➤ The tuyère pipes block rapidly and have to be kept clear by punching frequently with a rod.

➤ The operation is batch in nature, with ladles of molten material being charged to and removed from the converter at regular intervals. The large number of materials handling operations needed naturally imposes a limit upon process efficiency, and the transfer of molten matte in open ladles results in significant loss of sulphur dioxide in fugitive emissions, constituting an environmental hazard.

➤ A considerable amount of cold air leaks into the converter waste gas system at the open junction between the converter mouth and the waste gas hood. This increases the flowrate and reduces the sulphur dioxide concentration of gas to the sulphuric acid plant which is usually provided to treat gas from the converting operation.

➤ In order to minimise fugitive emissions of sulphur dioxide from the converter mouth, secondary hooding, with dedicated air fans, has been retrofitted to many converting operations as environmental emission standards have become stricter. Secondary emission capture systems collect very large volumes of cool gas containing low concentrations of sulphur dioxide. It is difficult and costly to remove the sulphur dioxide from this type of gas stream using standard scrubbing techniques, and the treatment and discharge to atmosphere therefore presents a problem. Furthermore, a solid effluent disposal problem is created.

➤ By design, Peirce-Smith converters are highly oxidising process units. While they are effective in removing iron and sulphur from furnace matte, their inflexibility causes some problems when converting nickel/copper sulphide mattes. These problems mainly arise as a consequence of the downstream refining processes, which usually require the converter matte to contain low iron (< 2%) or low sulphur (< 10%) content, or both. As iron content decreases, cobalt begins to oxidise and is transferred from matte to slag[13, 14, 15]. As sulphur concentration decreases, solid nickel oxide reports to the slag in the converter. This greatly increases slag viscosity and makes matte : slag separation less effective. In neither case is it possible to reverse these reactions in the oxidising environment of the converter and it is therefore necessary to transfer converter slag to another vessel in order to carry out a slag cleaning operation.

A number of pyrometallurgical technologies have been proposed over the past few years as possible replacements for Peirce-Smith converters. Ausmelt is one of these. In a converting application, it would have the following advantages over the conventional units:

➤ The oxidising reactions can be controlled more effectively by altering the composition of the lance gas.

➤ The operation can tolerate wide fluctuations in furnace matte (feed) composition since the unit can be operated as a smelting furnace as well as a converter.

➤ Refractory life should be better than in a Peirce-Smith converter. Even in small Ausmelt units involving high temperatures and multiple semi-batch processes, refractory life of about 5 months has been demonstrated in normal operation.

➤ Either molten, or wet granulated solid furnace matte can be charged to the converting furnace, and it can be operated in either batch or continuous mode. Excellent control of the temperature in the unit and of the speed and completeness of reaction is therefore possible.

➤ The conventional converter aisle and overhead gantry cranes could in theory be eliminated, if molten transfer is no longer required. Although it is difficult to imagine that an existing converter aisle could be scrapped, new smelters could certainly be constructed with provision for continuous transfer of furnace matte in molten or solid form from furnace to converter. This is to be employed at the Zhong Tiao Shan smelter discussed later in this paper.

➤ The waste gas from an Ausmelt converter will probably contain greater than 10% sulphur dioxide by volume at a temperature of about 1300°C. The potential exists to produce more sulphuric acid than can be achieved using Peirce-Smith converters, because of the greatly reduced dilution with cold air.

➤ There is very little leakage of gas either into or out of an Ausmelt furnace. Secondary waste gas hooding is not normally necessary.

➤ Cobalt and nickel losses to slag can be controlled more effectively both by limiting the oxidation potential during the converting operation and by carrying out a batch slag reduction cycle following converting (elaboration follows).

Slag reduction

During smelting of copper and nickel sulphides, most metal losses occur because of entrainment of sulphides in the slag. This is generally addressed by incorporating a settling zone into one end of the furnace. In the prevailing quiescent conditions in this zone, matte separates effectively from slag and collects in the bottom of the furnace, allowing a discard slag to be generated. Alternatively, slag or a mixture of matte and slag may be transferred from the reaction vessel to a dedicated settling furnace, with the same objective.

There is however a second, chemical, mechanism by which slag losses occur. During converting a significant percentage (50–100%) of cobalt in furnace matte is oxidised into the converter slag, along with a small percentage of copper and nickel[12,13,14].

According to Matousek[13], the partition of cobalt and iron between matte and slag in various smelting and converting operations can be represented graphically as shown in Figure 4. The Figure shows

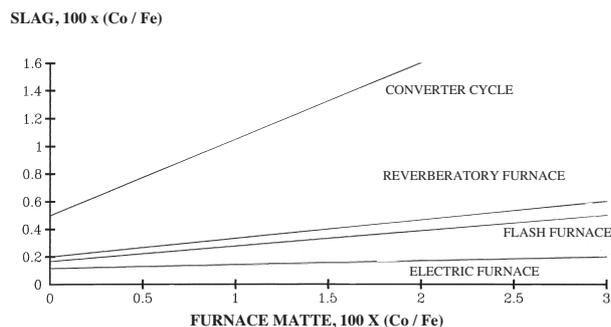# The application of Ausmelt technology to base metal smelting

SLAG, 100 x (Co / Fe)

Figure 4—Cobalt in pyrometallurgical systems after Matousek[13]

quite clearly that while cobalt is recovered effectively to matte during neutral or reducing smelting operations, significant losses to slag occur under oxidising conditions.

There are two possible methods of increasing overall cobalt recovery in smelters which have converting operations. Firstly, converter slag in nickel smelters can be reduced in the smelting or slag cleaning furnace, from which the furnace matte is recycled to converting. Cobalt gradually accumulates in the smelter circuit. If the cycle is always operated successfully then the cobalt eventually leaves the circuit in the converter matte. This type of circuit is, however, unforgiving of operational disturbances, which usually result in cobalt reporting to the discard furnace slag. It is also inapplicable in the case of copper smelters, in which blister copper completely free of cobalt is produced, and all cobalt in the smelter feed is lost to discard slag.
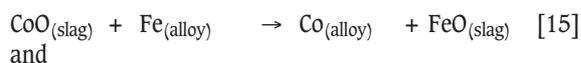
The second method of recovering cobalt from slags is to produce a secondary alloy or matte in the slag cleaning furnace, by reducing the cobalt (and iron) oxide either with carbon or a sulphide such as pyrite. In this case, a product containing most of the cobalt from the converter slag is certainly generated, but it often contains at least 50% iron.[16] This material is not suitable for feeding to a conventional base metal refinery. It requires a hydrometallurgical process tailored to the removal of iron in order to generate a marketable cobalt product.

Ausmelt technology is suited to both of the slag reduction processes previously described. In smelters using an Ausmelt furnace as a converter, a batch cycle can be set up in which *the same furnace* will be used, firstly to convert furnace matte and then subsequently, to reduce cobalt from the converter slag. At the end of the reduction phase of the cycle, matte or alloy will be left in the furnace, a new batch of furnace matte will be added, and another converting phase will commence. Periodically, matte or alloy from the reduction furnace will be removed as a separate intermediate product.
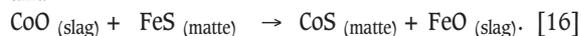
In a smelter where an Ausmelt furnace is retrofitted solely as a slag cleaning unit, it will operate in continuous mode. The final control over oxidising potential which can be achieved in an Ausmelt furnace means that it can be used to produce either matte or

alloy, and can process converter slag within a fairly wide composition range.

In general[16] the reactions to be expected are:

$$CoO_{(slag)} + Fe_{(alloy)} \rightarrow Co_{(alloy)} + FeO_{(slag)} \quad [15]$$

and

$$CoO_{(slag)} + FeS_{(matte)} \rightarrow CoS_{(matte)} + FeO_{(slag)}. \quad [16]$$

Some of the advantages of an Ausmelt furnace in this application compared with a slag resistance electric furnace are listed below:

➤ Energy supply is independent of slag composition. The slag chemistry can therefore be optimised to recover metals rather than to obtain the best electrical characteristics.

➤ Temperature is near to constant through the bath, and can be increased by the use of fuel in order to reduce slag viscosity and density.

➤ The furnace is much smaller and possibly less expensive to maintain.

Sulphur Capture

As noted earlier, Peirce-Smith converter operations lose a significant percentage of the sulphur entering the converting circuit in furnace matte as fugitive emissions of sulphur dioxide. There are two sources of fugitive emissions: open matte ladles, and the open mouth of the converter. It is both difficult and expensive to reduce these emissions to any significant degree, and at best it is likely that secondary hoods will simply vent the dilute gas through a tall stack into the atmosphere. As environmental legislation becomes stricter, it seems inevitable that Peirce-Smith converters will gradually be replaced with more modern units. Quite apart from the metallurgical benefits of the Ausmelt process, an Ausmelt furnace used in a converting operation will certainly recover more sulphur than conventional converters, since both mouth leakage and losses from molten transfer will be reduced. In principle, ladle transfer could be completely eliminated from new smelters.

Ausmelt furnaces, because they have an independent fuel source and can therefore be operated at temperatures of greater than 1600°C under controlled conditions, can also be used to desulphurise converter matte[17]. Sulphur content of nickel–copper mattes can be reduced to 6–10% or even to about 2%. This is sometimes a requirement of the downstream hydrometallurgical operation. By removing the sulphur in the pyrometallurgical step, it can be converted to sulphuric acid or sulphur which can be used for leaching or can be sold. Conversely, in the refinery, sulphides will dissolve to form sulphuric acid which will then have to be neutralised, often using expensive reagents such as caustic soda.

Existing Ausmelt operations and current projects

Ausmelt plants in regular commercial operation are shown in Table I.

The application of Ausmelt technology to base metal smelting

Table I
Ausmelt Commercial Plants

	Location	Client	Feed Rate Tonnes/Yr	Feed Type	Commissioning Date
1.	Pt Pirie, Australia	Broken Hill Associated Smelters	1500	Lead/Silver retort metal	1990
2.	Eiffel Flats, Zimbabwe	Rio Tinto Zimbabwe	7500	Cu/Ni residue	1992
3.	Onsan, Korea	Korea Zinc Co. Ltd.	90 000	Pb/Zn slag	1992
4.	Bindura, Zimbabwe	Anglo American Corp.	12 000	Copper Sulphide residue	April 1995
5.	Onsan, Korea	Korea Zinc Co. Ltd	120 000	Zn residue	August 1995
6.	Hackenohe, Japan	Mitsui Mining and Smelting Co.	100 000	Zn/Pb slag	1994
7.	Pisco, Peru	Funsur/Minsur SA	30 000	Tin Concentrates	March 1996

Table II
Plants being Commissioned or Constructed

	Location	Client	Feed Rate Tonnes/Yr	Feed Type	Commissioning Date
8.	Ghatsila, India	Hindustan Copper Ltd	72	Precious metals anode slimes	In progress
9.	Nordenham, Germany	Metaleurop	122 000	Primary & secondary lead materials	In progress
10.	Tsumeb, Namibia	Gold Fields of South Africa	120 000	Primary & revert lead materials	In progress
11.	Zhong Tiao Shan, Peoples Republic of China	CNIEC	200 000	Primary copper concentrates	June 1998
12.	Portland, Victoria Australia	Alcoa of Australia	12 000	Spent potlining	June 1997

Example two in that table illustrates the application of an Ausmelt furnace to close the circuit at a nickel refinery, as described by Markham, Mwenye and Vernon[18]. The objective of the operation is to partially de-sulphidise the residue from an Outokumpu atmospheric leach process down to 5–6% sulphur, at which level it is suitable for grinding and releaching. The existence of the Ausmelt furnace allows this refinery to offer a comprehensive custom smelting and refining capability for low sulphur nickel-copper alloy.

Example four in Table I is the first application of Ausmelt technology for the converting of copper sulphide to blister copper. The feed material is a copper sulphide residue from the non-oxidative pressure leaching of nickel-copper sulphides. Schwarz and Richardson describe the rationale for the pyrometal-lurgical treatment of this residue at Bindura[19]. The application of Ausmelt technology followed from that. The residue is smelted and the resultant molten matte is then treated under oxidising conditions to convert the sulphur to sulphur dioxide and the copper to blister. The blister copper is tapped into a ladle and transferred to an anode furnace. The slag remaining in the furnace is high in oxidised copper. Conditions at the lance are then adjusted and lump coal is added to reduce that copper. A low copper, disposable slag is then tapped. Platinum group metals are recovered in anode slimes when the anode copper is refined.

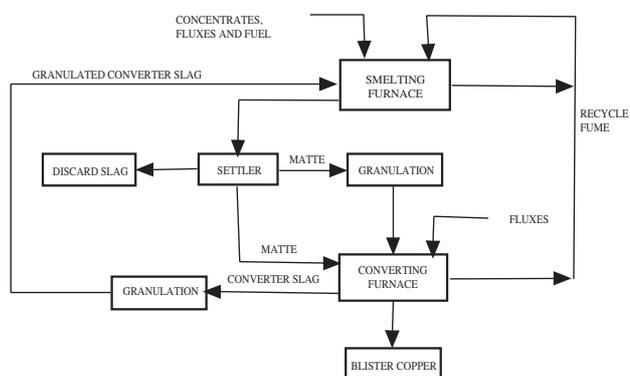The process in example five was jointly developed

Figure 5—Two-furnace copper smelting

by Ausmelt and Korea Zinc and, for the first time, provides a viable solution satisfying all environmental needs, to the problem of treatment of leach residues in the zinc industry. The role that Ausmelt technology plays in the overall Korea Zinc Process is described by Choi[20].

Table II shows plants that are either being commissioned or which are under construction. Items nine and ten are examples of the replacement of older technology (sinter plants and blast furnaces) by a single advanced, environmentally acceptable, item of equipment. A feature of the design of these plants is

The application of Ausmelt technology to base metal smelting

the wide range of different feed materials that can be accommodated within the same furnace. Some of the many different operating procedures possible are described by Short, Sutton and Swayn[21].

Example eleven, the Zhong Tiao Shan copper smelter, is the first application of top submerged lancing technology to all of the steps required in copper smelting in a single plant and as such is a landmark in smelting development. Figure 5 is a simplified block flow diagram of this plant, which is at present under construction. The chemistry of the process is no different from that in any other copper smelter as described earlier. The most important feature of the plant is the transfer of the primary smelting furnace matte, via a settler, to the converter by launder rather than ladles. An alternative routing for that matte is to granulation such that matte can be stockpiled. In this way the smelting and converting operations are decoupled, so that smelting can continue steadily throughout the converting cycle and also during converter downtime. Converter slag is granulated for return to the smelting furnace, again eliminating the use of ladles. This plant will produce 35 000 tonnes per year of blister copper from 200 000 tonnes per year of concentrate.

Potential new southern African applications

The following section is based entirely on literature references, not on communication of any kind with the operating companies potentially concerned.

Platinum Group Metal (PGM) smelters

Mostert and Roberts[11] described the operation of the Waterval Smelter of Rustenburg Platinum Mines in 1973. The following key points are of relevance to this paper:

➤ The charge system at that time incorporated partial drying to 7% moisture followed by pelletisation and further drying to 2% moisture. This would be ideal feed for an Ausmelt furnace.

➤ The furnace operation did not include a slag reduction process. Two mechanisms for recovery of metal (nickel, copper, platinum group metals and cobalt) returned from the converter to the furnace would therefore have existed. Firstly, metals in the form of entrained matte sulphides or alloys would be recovered to some extent, by settling to allow matte: slag separation by density difference. Secondly, metals present in oxides would be partially reduced by iron sulphide in the feed to the smelting furnace. It should be noted that settling in this type of operation is only moderately effective because of high slag viscosity resulting from the presence of magnetite. Reduction of oxides is quite effective in the case of nickel and copper, but cobalt oxide minerals in converter slag generally report to furnace discard slag unless a specific reduction process is implemented.

➤ The furnace gas flowrates were very high, resulting in gas with sulphur dioxide concentration of 0.4%. Even the converter gas concentration was reported to drop to 2.5% SO_2 from time to time.

➤ Peirce-Smith converters were used to remove iron and sulphur from the furnace matte.

Ward[10] as well as Plasket and Ireland[12] and Watson and Harvey[22] described the Western Platinum and Impala Platinum Smelters in more recent papers. Fundamentally the process at these smelters was and is the same as at Rustenburg, and more recent press releases indicate that this is also true of the Crocodile River, Northam and Hartley Platinum operations. Cobalt levels in converter matte have been reported to be about 0.35% Co compared with corresponding iron content of about 0.5%[22].

All four of the Ausmelt technology applications discussed earlier could be incorporated in these PGM smelters. Since there is known to be excess total electric furnace smelting capacity available, it seems unlikely that any South African PGM producer will be planning a smelting expansion in the near future. However, replacement of Peirce-Smith converters, converter slag reduction to improve cobalt recovery, and improved sulphur capture are all measures which could be investigated profitably by PGM producers. Should they do so, Ausmelt technology would be a contender in all cases.

Nkana smelter, Zambia

Press releases have indicated that a very large slag stock pile at the Nkana smelter is being treated on a small scale to recover cobalt by slag reduction[23]. Current arisings of slag also contain cobalt in significant quantities. The Nkana smelter utilises coal-fired reverberatory furnaces fed with damp concentrate[24]. The feed and fuel systems could be used almost without modification to feed an Ausmelt furnace, which in this case could certainly be considered as a replacement or supplement for the ageing reverb furnaces.

A dedicated Ausmelt furnace could be used to treat dump slag in order to recover cobalt, and Ausmelt technology could also be used either to replace the Peirce-Smith converters or to recover cobalt from slag. Ausmelt carried out testwork on this slag during 1994 and produced matte containing cobalt[23].

Other copper smelters

O'Kiep and Palabora[25] use reverberatory furnaces which could possibly be replaced by Ausmelt furnaces both in order to improve operational efficiency and to improve sulphur capture. Both of these smelters as well as Mufulira in Zambia[26] and Selebi Phikwe in Botswana[27] use Peirce-Smith converters which will eventually be replaced. It is believed that at least two of the above operations contain cobalt in sufficient quantities to warrant a dedicated recovery process. Only Palabora recovers sulphur dioxide from waste gas by means of a sulphuric acid plant and a weak gas scrubber. There is therefore great potential to improve sulphur capture aided by the use of more modern smelting technology.

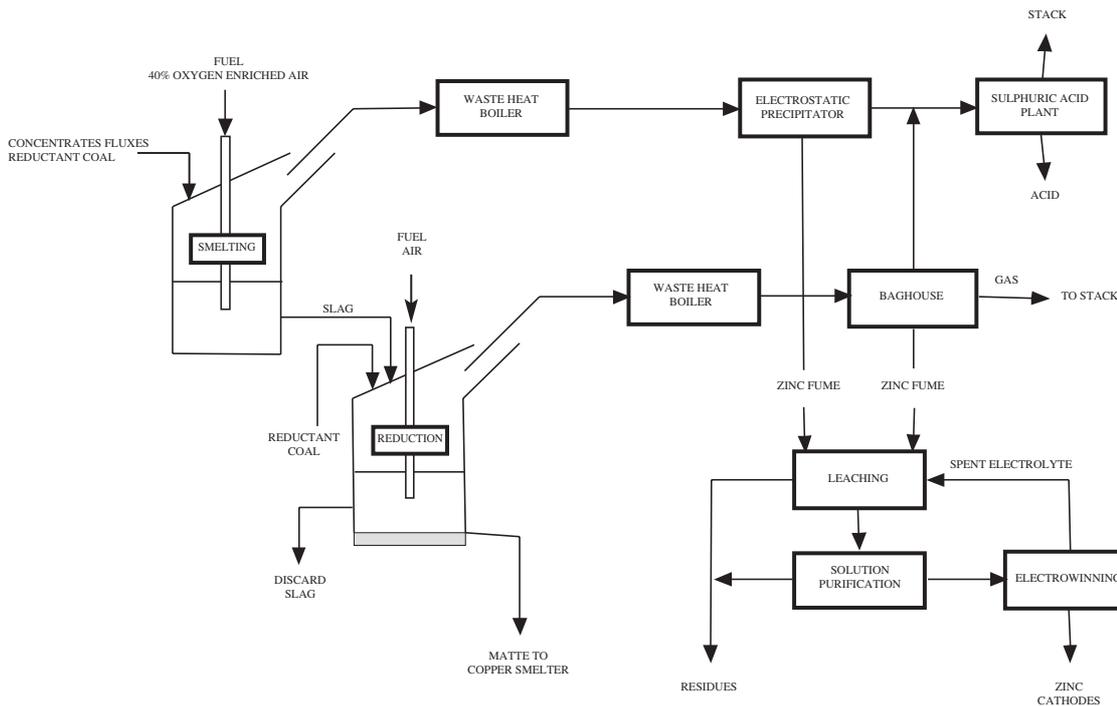# The application of Ausmelt technology to base metal smelting

Figure 6—Process flowsheet for smelting of zinc concentrates

In summary, therefore, process improvements making use of Ausmelt technology are possible at virtually every copper, nickel and PGM smelter in Southern Africa. While other technologies could well be suitable for some of these applications, Ausmelt exhibits a great deal more flexibility than most technologies. It is conceivable that three Ausmelt furnaces could be used in a single smelter for the entirely separate and distinct activities of smelting, converting and slag reduction. In all cases these furnaces would achieve high recoveries of sulphur dioxide befitting a modern smelter.

Zinc sulphide concentrate processing

Most sources of zinc are sulphide deposits in which the zinc is in association with other sulphides. Most commonly the sulphides are of lead, copper and iron, but zinc also associates with lesser, but important quantities of silver, cadmium, arsenic and other elements. These sulphides are normally separated, with varying degrees of success depending upon the mineralogy of the deposit; by flotation to yield separate lead, copper and zinc concentrates for distinct downstream treatment.

Zinc metal is produced from sulphide concentrate, either by the Imperial Smelting Process or, more commonly, by a roast–leach–electrowinning route. In the hydrometallurgical route it is necessary to remove virtually all impurities ahead of electrolysis. In particular iron must be excluded. A number of methods of achieving this exist; discussion of which has no place in this paper, other than to note that these high iron residues all carry with them substantial quantities of zinc. The paper by Choi (op. sit.) discusses aspects of this subject and how Ausmelt technology can be utilised to deal with these residues.

A completely different approach is also possible. Let us assume that the concentrate has an analysis of approximately:

Zinc	55%
Copper	2%
Iron	5%
Sulphur	30%

Let us also assume that high sulphur capture is essential. Under these circumstances Ausmelt technology can be used as illustrated in the flowsheet in Figure 6.

Conditions in the primary smelting furnace are mildly oxidising such that sulphur is driven off as SO_2, copper and iron are dissolved in the slag as oxides, and lead (as well as other volatile metals) are collected in the fume. The zinc enters the slag up to a concentration of about 20% and the remainder leaves the furnace as zinc oxide fume.

In the second furnace the temperature is increased to about 1350°C and coal is added to reduce the oxygen potential in the slag. Under these conditions the zinc is driven out of the slag as the metal. It is oxidised in the freeboard of the furnace by secondary air introduced down the lance shroud pipe. The heat from the strongly exothermic reaction

$$Zn_{(fume)} + {}^1/_2 O_{2(gas)} \rightarrow ZnO_{(fume)} \qquad [17]$$
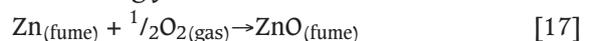
is partially recovered in the bath by radiation and in the spashing action. The zinc level in the final discard slag is likely to be determined economically, but can be less than 1%.

Advantages of this process route are:

➤   Iron is separated from the zinc at the front end of the process.

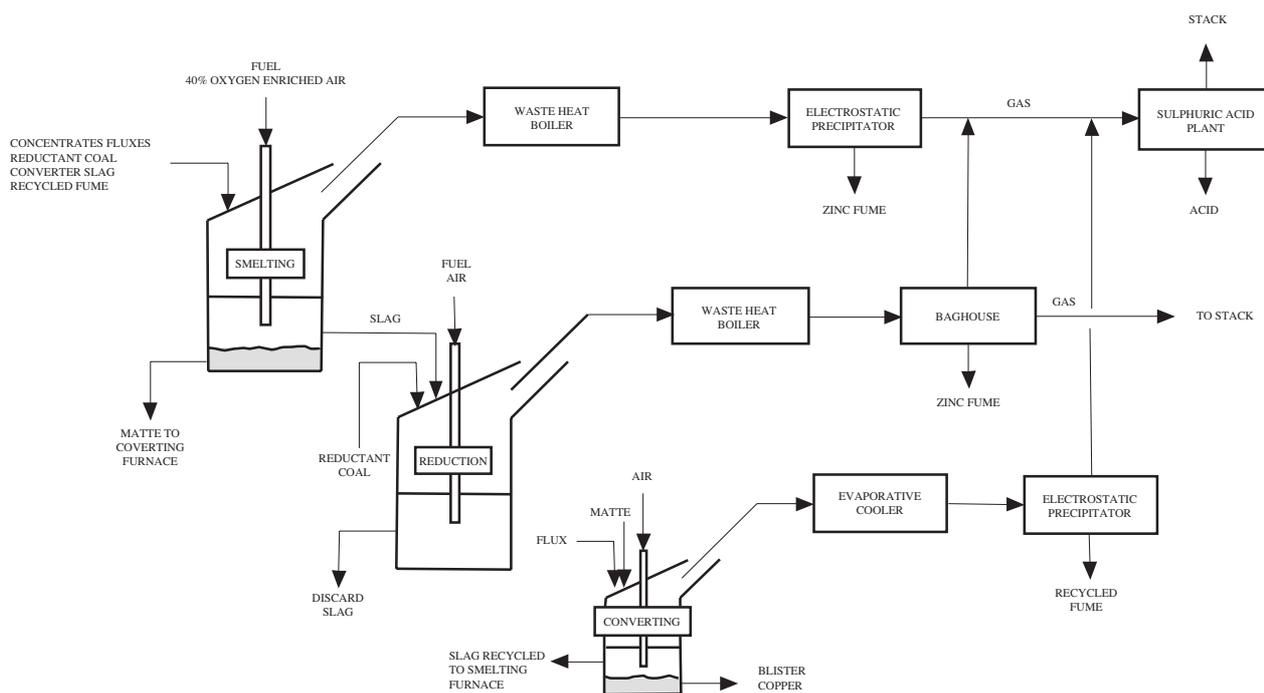# The application of Ausmelt technology to base metal smelting

Figure 7—Process flowsheet for smelting of bulk copper—zinc concentrates

➤ High concentration of SO$_2$ results in the feed to the acid plant.
➤ Smaller zinc oxide leaching and solution purification facilities are required than in a roast–leach–electrowinning plant of similar capacity.

Application to a bulk zinc-copper concentrate

A logical development from the zinc concentrate treatment described above is to eliminate the need for differential flotation and to make a single concentrate that might have the analyses:

Zinc	45%
Copper	10%
Iron	5%
Sulphur	30%

In this case the plant approaches the copper smelter discussed earlier in this paper combined with zinc fuming. The flowsheet shown in Figure 7 applies.

Conclusions

The paper has described some of the present applications of Ausmelt technology in base metals smelting and refining and has identified some of the potential applications for the future.

Process improvements making use of Ausmelt technology are possible at virtually every copper, nickel and PGM smelter in southern Africa. While other technologies could well be suitable for some of these applications, Ausmelt exhibits a great deal more flexibility than most techniques. It is conceivable that three Ausmelt furnaces could be used in a single smelter for the entirely separate and distinct activities of smelting, converting and slag reduction. In all cases these furnaces would achieve high recoveries of sulphur dioxide befitting a modern smelter.

Ausmelt technology is also very applicable in South Africa for the processing of zinc sulphide concentrates. A zinc oxide product containing little or no iron can be generated. While further hydrometallurgical processing is required, the impurity removal process is simpler than that required in existing roast–leach–electrowin or pressure oxidation–electrowin operations.

Ausmelt and Bateman have a collaborative agreement applicable in several countries under which it is possible to provide a comprehensive service for the design and construction of complete plants. The two companies have co-operated since 1991 on the production of cost estimates and studies for a number of projects in southern Africa and elsewhere.

References

1. FLOYD, J.M. *Metallurgical Applications of High Temperature Submerged Combustion*, Paper to Institute of Fuels Conference, Adelaide, South Australia, Nov. 1974. 12 pp.
2. FLOYD, J.M. Submerged injection of gas into liquid pyrometallurgical bath, *US Patent* No. 4 251 271, 17 Feb. 1981.
3. MCDONALD, A. and VERHELST, D. Pyrometallurgical operations at Hudson Bay Mining and Smelting Co. Ltd. *CIM Bulletin*, vol 87. No. 984. 1994. pp. 97–102.
4. CASLEY, G.E., MIDDLIN, J., and WHITE, D. Recent development in reverberatory furnace and converter practice at the Mount Isa Mines copper smelter. *Extractive Metallurgy of Copper*, Chap. 6. 1976. pp. 117–138.
5. MECHEV, V.V. On status and trends of copper industry development in the U.S.S.R. *Copper 91—Cobre 91*, vol. IV. 1991. pp. 91–105.
6. FOUNTAIN, C.R., TUPPURAINEN, J.M.I., WHITWORTH, N.R., and WRIGHT, J.K. *The Paul Queneau International Symposium—Extractive Metallurgy of Copper, Nickel and Cobalt*. vol. II. X. C.A. Landoldt, (ed.). TMS, Warrendale, PA. 1993. pp. 1461–1473.
7. FLOYD, J.M. Top submerged injection with shrouded lance *International Patent Application* WO91/05214, 18 Apr. 1991.
8. MOUNSEY, E. Economic and technical evaluation of Ausmelt process systems for copper bearing materials. *Cobre 95*. 1995.

9. FLOYD, J.M. *The Paul Queneau International Symposium—Extractive Metallurgy of Copper, Nickel and Cobalt*, vol. TMS, Warrendale, PA. I. R.G. Reddy and R.N. Weizenbach, (eds.). 1993. pp. 473–488.

10. WARD, V.C. Electric smelting—some process, control and design aspects: the smelter, Western Platinum Ltd., Marikana, Transvaal, South Africa. *The Metallurgical Society of AIME*. 1978. Paper A78–28.

11. MOSTERT, J.C. and ROBERTS, P.N. Electric smelting at Rustenburg Platinum Mines Limited of nickel-copper concentrates containing platinum group metals. *J. S. Afr. Inst. Min. Metall.*, Apr. 1973, pp. 290–299.

12. PLASKET, R.P. and IRELAND, D.A. Ancillary smelter operations and sulphuric acid manufacture at Impala Platinum Limited. *J. S. Afr. Inst. Min. Metall.*, Aug. 1976, pp. 1–10.

13. MATOUSEK, J.W. *The Paul Queneau International Symposium—Extractive Metallurgy of Copper, Nickel and Cobalt*, vol. I. TMS, Warrendale, PA. pp. 129–142.

14. GRIMSEY, E.J. The behaviour of cobalt during nickel smelting and converting. *Aus. Inst. Min. Metall. Proceedings*, no. 1, 1994, pp. 77–80.

15. GRIMSEY, E.J. *The Paul E. Queneau International Symposium—Extractive Metallurgy of Copper, Nickel and Cobalt*, vol I. R.G. Reddy and R.N. Weizenbach, (eds.). TMS, Warrendale, PA. 1993. pp. 1239–1251.

16. JONES, R.T., HAYMAN, D.A., and DENTON, G.M. Recovery of cobalt, nickel, and copper from slags, using DC-arc furnace technology. *International Symposium on Challenges of Process Intensification—35th Annual Conference of Metallurgists.* Montreal, Canada. 1996.

17. BALDOCK, B.R., CHARD, I.L., FLOYD, J.M. *et al. The Paul Queneau International Symposium—Extractive Metallurgy of Copper, Nickel and Cobalt*, vol. II. TMS, Warrendale, PA. 1993. pp. 1081–1100.

18. MARKHAM, P., MWENYE, T., and VERNON, P.N. The smelting of nickel-copper leach residues. *XVth CMMI Congress,* Johannesburg, SAIMM, vol. II. 1994. pp. 295–302.

19. SCHWARZ, J. and RICHARDSON, M.R. Process options for modification of the Outokumpu refinery circuit at BSR Ltd. to improve base and platinum group metal recoveries. African Mining Conference, Harare. 1991.

20. CHOI, Z.Y. Evolution of iron separation processes in zinc smelting at Korea Zinc. *Iron in Hydrometallurgy*, CIM. 1996.

21. SHORT, W.E., SUTTON, D.J., and SWAYN, G.P. Commercial application of Ausmelt's top submerged lance technology in the lead industry. *Lead into the future*. IMM London. (1996). pp. 193–204.

22. WATSON, G.B. and HARVEY, B G. A common-sense approach to process improvements to electric smelting of nickel-copper concentrates at Impala Platinum. *Non-Ferrous Pyrometallurgy: Trace Metals, Furnace Practices and Energy Efficiency*. Met. Soc. Of CIMM. 1991. pp. 289–304.

23. BURKS, S.F. Cobalt recovery at Nkana. *Bateman Global Review,* Nov. 1995. p. 6.

24. GIBSON, N. Smelting developments at Rhokana Corporation Limited. *Technical Proceedings of the Northern Rhodesia Section Seventh Commonwealth Mining and Metallurgical Congress*, W.G. Watts, (ed.). Northern Rhodesia Section, IMM. 1961.

25. EDGE, D.A. Copper matte converting practice at Palabora Mining Company. *Copper and Nickel Converters*, R.D. Johnson. (ed.). 1979.

26. BLAIR, I.S., HUMPHRISS, J., JOYCE, B.P., and WARNOCK, J.L. The introduction of electric smelting technology to Mufulira, Zambia. *Extractive Metallurgy of Copper*, TMS—AIME, New York. 1976.

27. HALL, R.A. and HIGHCOCK, G.A. On-line developments at the BCL Smelter. *CIM Bulletin*, vol. 88, no. 991. 1995. pp. 89–96. ◆

R50 million surface drilling contract for Cementation Mining*

Cementation Mining has started work on a surface drilling contract valued at approximately R50 million in the Target and Sun prospect areas in the Free State Province. The contract was awarded by Avgold on an open tender basis.

This is the largest deep surface exploratory drilling project currently underway on the African continent. The site is located between Allanridge and Bothaville and work involves drilling 32 holes in 20 months totalling some 70 000 metres. Commencement date was 10 February 1997.

The exploration is the forerunner to the possible establishment of a major new gold mine. Cementation Mining carried out preliminary prospect drilling work on the site in the early 1990s and the current contract includes reef cuts from some previously drilled holes.

About 15 Sullivan 50 drill rigs with a depth capability of 3 500 to 4 000 metres will be used for this contract. A total workforce of around 200, including management, will be employed on site.

'Deep hole gold exploration has little application elsewhere in the world. South Africa has experienced an extremely quiet period in recent years,' says Jimmy Erasmus, manager of Cementation Mining's Drilling

◄ *A typical deep hole exploration drill rig used by Cementation Mining*

Division. 'However, we have kept our fleet of drill rigs in good order in case of an opportunity such as this.'

Erasmus adds that Cementation Mining's drilling operation has been awarded several smaller surface drilling contracts by various companies in the past few months, indicating an upswing in the industry. 'We have observed increased confidence and activity in the mining industry since the second half of last year.' ◆

* Issued by: Lynne Hancock Communications, P.O. Box 180 Witkoppen, 2068.