

The 3,2 MVA Plasma Facility at Mintek

by

T.R. Curr, K.C. Nicol, J.F. Mooney,
A.B. Stewart, and N.A. Barcza
Council for Mineral Technology
South Africa

Synopsis

A description of the background to, and motivation for, the installation of a 3,2 MVA transferred-arc plasma furnace at the Council for Mineral Technology (Mintek) is given, followed by a detailed account of the facility itself from the handling of the raw materials to the disposal of the products. The system is capable of using a water-cooled torch or a hollow graphite electrode as a plasma-generating device in a transferred-arc configuration. The power supply is a d.c. Thyristor-controlled unit.

Mintek has expended considerable effort on making the system as flexible as possible, as well as providing comprehensive control and data-logging features, so that the facility can be of the greatest possible use as a tool in research and development.

INTRODUCTION

Because of its large reserves of chromium and manganese ores, South Africa has a large installed capacity (1200 MVA) of conventional submerged-arc electric smelting furnaces for the production of ferro-alloys¹. The Council for Mineral Technology (Mintek) started examining the potential of thermal plasma for applications in the field of pyrometallurgy in 1976², particular attention being paid to the use of plasma as the source of the high temperatures required for the processing of ferro-alloys³.

In 1979, Mintek, in conjunction with Middelburg Steel and Alloys (Pty) Ltd (M.S.&A.), undertook a series of campaigns on the smelting of high-carbon ferrochromium in a 1400 kVA transferred-arc furnace at Tetronics Research and Development Limited (T.R.D.)⁴. Their object was to study the potential advantages of a d.c. transferred-arc thermal plasma for the direct treatment of chromium-ore fines, i.e., without costly agglomeration.

The testwork at T.R.D. was successful enough to convince Mintek and M.S.&A. that a local plasma pilot plant should be established to support the ferro-alloy industry's rapidly growing interest in this technology. At that time (1981), the only plasma furnace at Mintek was a small-scale 100 kVA three-phase a.c. diffuse-plasma system, similar in design to the Extended Arc Flash Reactor (E.A.F.R.) at Toronto University⁵. Mintek's furnace had been used with fair success to melt several materials, such as silicon fines, ferrochromium, and ferromanganese fines, and limited smelting tests had been carried out on the production of the

last two commodities. The potential for scale-up of this furnace design, however, appeared to be limited because of the operating problems experienced with the inclined hollow graphite electrodes⁶.

The 100 kVA power supply to the diffuse-plasma furnace was therefore modified during 1981 to provide direct current by the installation of a water-cooled three-phase diode bridge; also, a small-scale furnace with a configuration similar to the transferred-arc design of T.R.D. was installed so that the high-temperature chemistry of various pyrometallurgical processes could be investigated. Numerous tests were subsequently carried out with water-cooled plasma torches and hollow graphite electrodes (cathodes), and the furnace design evolved to a stage where campaigns lasting many days can be undertaken on a regular basis⁷. The melting and smelting of various ferro-alloys were studied, and successful results were consolidated by the filing of patents⁸⁻¹¹.

In 1981, Mintek decided to install a larger plasma pilot plant since it realized that, if industry were to be convinced of the true potential of plasma technology, a local demonstration-scale furnace would be required. The object was, then, the determination of whether a new process, which would be superior to the conventional submerged-arc process, would be feasible technically and economically. The testing of the amenability of various local raw materials, particularly chromite fines, to efficient processing by the transferred-arc technique was therefore the major requirement. Operation at power levels of between 1 and 2 MW

was necessary, as was the attainment of consistent metallurgical results and the design of a suitable power supply, furnace, and infrastructure. The transferred-arc furnace was chosen because this configuration affords better control over the process chemistry than the non-transferred-arc approach¹², and because the former has a geometry similar to that of the conventional submerged-arc furnace, and existing plants would be able to accommodate a change to the new technology with relative ease.

The design of the major items of equipment, which are based primarily on the T.R.D. water-cooled plasma system⁴, was finalized during 1982. However, the potential usefulness of the hollow graphite electrode as a plasma source for d.c. transferred-arc applications came to the fore during that time, both from ASEA's work¹³ and from tests at Mintek⁷. It was therefore decided that suitable equipment should be incorporated in the facility so that a 100 mm hollow graphite electrode could be used.

In June 1983, a preliminary commissioning campaign, which yielded a great deal of valuable performance data and experience, was undertaken. The initial insulating lining chosen for high thermal efficiency was found to be unsatisfactory and was replaced with a more conductive lining. This change, as well as a host of minor improvements, is currently being implemented, and this paper describes the facility as planned for operation during 1984, highlighting the innovative or unconventional aspects of the equipment.

LAY-OUT

The 3,2 MVA plasma facility is housed in one of Mintek's six pilot-plant bays, each of which provides two 5 t overhead cranes, compressed air, steam, cooling water, and power at 380 V as normal services. A deionized cooling-water circuit, bulk nitrogen and argon gases, an 11 kV power supply, and a hydraulic ring main with a maximum power of 7,5 kW were installed subsequently to meet the additional service requirements of the plasma facility.

The overall flow of materials, electrical power, and products is shown schematically in Figure 1. All the equipment, except the transformers and the gas-cleaning plant, is housed indoors, while the feed and product materials are currently stored out-of-doors in bulk.

This arrangement was selected because it provides the most flexibility in the feeding, powering, and controlling of the furnace, and can accommodate the inevitable changes that a research facility demands. In comparison with a more mechanized system, this layout places some restrictions on the flowrate of feed materials and liquid products, but is nevertheless capable of continuous operation at 1 to 1,5 MW power on a 50 per cent duty cycle or for up to 3 days at a 100 per cent duty cycle. The manpower requirements on a three-shift basis for the overall system are twelve operators and supervisors, and nine semi-skilled staff. In a typical

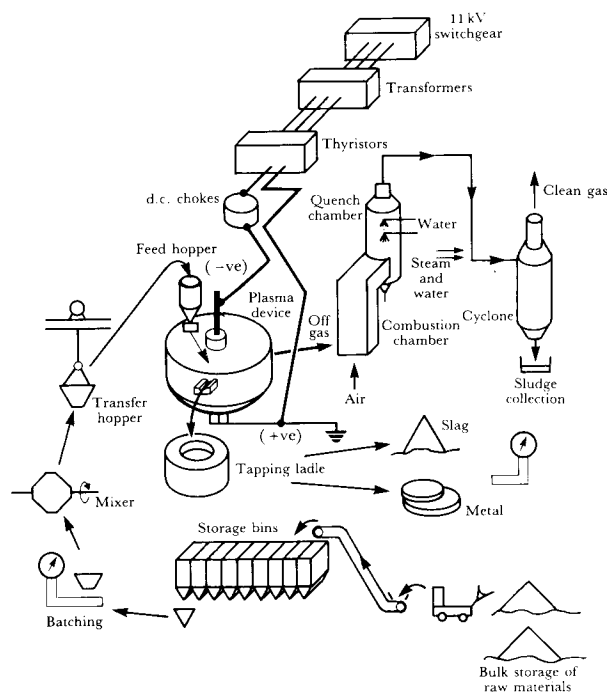


Figure 1. Schematic layout of the 3,2 MVA plasma facility

campaign, approximately 60 t of feed material are smelted in a 5-day week.

The power supply was designed to be very flexible, and up to 2,7 MW can be supplied, if necessary. The control system is also very flexible, and can accommodate changes via a programmable controller. The system for the handling of the off-gases was designed to meet safety and emission standards rather than for flexibility of operation, but there is scope for some variation in the position of the gas off-take port in the furnace.

The furnace

The furnace to be used during 1984 is shown in cross-section in Figure 2.

The selection of an internal diameter of 1,5 m at the hearth line was based largely on experience gained at T.R.D.⁴ on their 1,4 MVA furnace. At 1,5 MW, the power density on the hearth will be 0,85 MW/m², which is somewhat higher than the 0,50 MW/m² typically used in submerged-arc furnaces for the production of ferro-alloys. The use of power densities as high as 2,0 MW/m², as discussed elsewhere⁷, is not being considered on this scale until it can be successfully demonstrated at the 100 kW level because of the large capital expense involved in such a change.

A hearth-to-roof height of 1,2 m was chosen so that, at a maximum envisaged arc length of 600 mm, the distance from the tip of the electrode to the roof would be similar. This would minimize the possibility that an alternative path for the current (stray arc) would be established. It was estimated, from the work done at T.R.D.⁴, that an arc

PLASMA FACILITY AT MINTEK

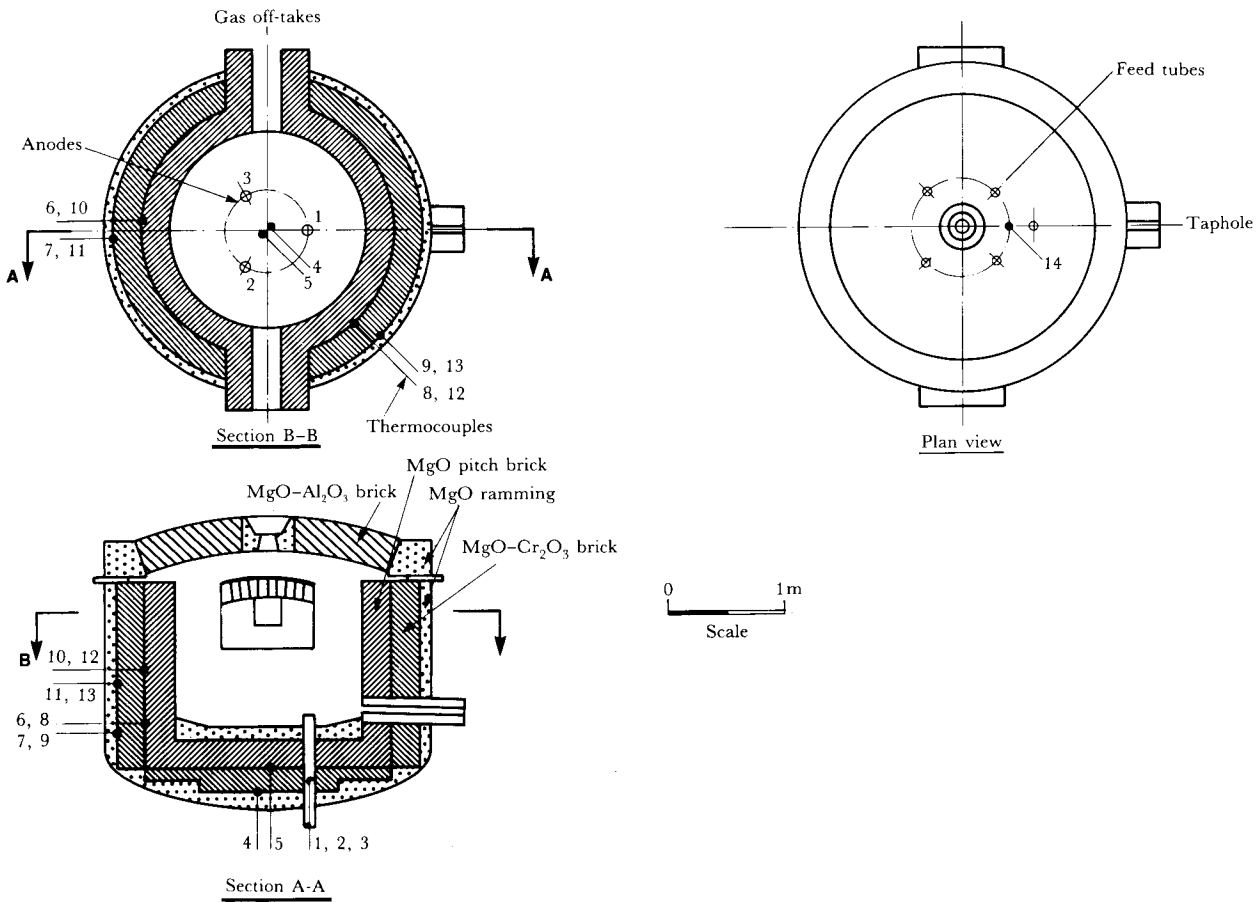


Figure 2. The 3,2 MVA plasma furnace

length of 600 mm would achieve a difference in potential of 500 to 600 V, which was considered adequate for the operation of a transferred-arc plasma. Provision was made for the height of the roof to be raised by 150 mm (by the installation of a spacing ring) should longer arc lengths require investigation.

A thickness of 460 mm was chosen for the brick lining to allow two rows of standard-length bricks of high thermal conductivity to be installed. This conductive lining was selected to maximize the lining life.

A shell temperature of 275 to 295 °C, based on a hot-face temperature of 1750 °C, was calculated during the design stage. The domed roof, made of brick 230 mm thick, is designed to dissipate the radiation from the molten bath even more rapidly than the side walls. This approach was derived from previous work at the 100 kVA level⁷, which showed that the roof refractories suffered much greater damage than the side walls above the slag line. A water-cooled annular panel is used to dissipate the power (50 to 70 kW) radiated from the roof, so providing a comfortable working surface above the furnace. A domed bowl employed for the hearth yields maximum strength and depth (660 mm) in the central portion of the hearth. The same type of brick as used in the side walls is used in the hearth, with a layer of rammable high-grade

magnesia as the working surface to minimize the penetration of the metal between the bricks.

Three stainless-steel bars of 90 mm diameter are used to establish the anode connection required for the transferred-arc mode of operation. They are spaced symmetrically on a pitch-circle diameter of 600 mm. This configuration was selected to avoid the placing of a current path under the central 'hot-spot' that could be expected if a central hollow-graphite electrode were utilized. (The following section describes the possible arrangements for the plasma device.) After the present testing on a smaller scale has been completed, the conducting-hearth approach used by ASEA¹⁴ may be employed to give a current path that is even more distributed.

A single central port in the roof, which is lined with a pitch-impregnated, fired, rammable magnesia refractory, is used to accommodate the various plasma devices. This central 'plug' can be replaced during operation without any disturbance to the brickwork of the roof.

Four feed ports of 50 mm diameter were cast into the roof on a pitch-circle diameter of 800 mm. A removable water-cooled metal tube is employed in each port to reduce the likelihood that the feed will sinter and subsequently block the feed ports while passing through the hot roof. The feed locations were selected so that the feed can be distri-

buted as evenly as possible across the molten bath, it being assumed that reaction takes place in a thin layer on the surface of the molten bath. Provision was made for material to be fed down the plasma device direct to the central region of the bath in a concentrated fashion, as proposed by ASEA for the Elred process¹³. With this method, very rapid reaction rates, and therefore energy-consumption rates, in the 'arc root' region of the plasma are envisioned. Two off-gas ports are installed symmetrically on either side of the furnace to provide a smooth removal of the potentially large volumes of products (0,9 m³/s) with as low a port-gas velocity as is structurally practicable. It was necessary for the ducts to be placed horizontally in the side walls, in spite of the attendant disadvantage of particle 'fall out' and potential blockage of these ducts, because of space limitations on the furnace roof. In future configurations, water-cooled ducts of much smaller outside dimensions could be mounted in the roof, but this was avoided since the emphasis at this stage is simplification of the furnace operation and control. A water-cooled valve in each duct is used to control the furnace pressure. These ducts are water-cooled externally because of the high thermal conductivity of the bricks used and the restrictions on the thickness of the refractories imposed by the space available for each duct.

The tap-hole of the furnace is located 100 mm above the hearth so that a 100 mm 'heel' of metal will be retained after each tap to enhance the distribution of the thermal energy of the plasma over the hearth. This is particularly important on the 100 kVA scale when a hollow graphite electrode is used, since the plasma arc can attach itself directly

above one of the anodes and cause dangerous overheating. The retention of a metal heel diminishes the extent of this overheating in the event of such an asymmetrical arc attachment. The furnace can be tilted hydraulically by 20° from the horizontal for the metal 'heel' to be removed if necessary, and is mounted on four load cells so that any changes in furnace mass that may provide useful information on the extent of metal penetration and 'heel growth' can be monitored.

Thermocouples are placed as shown in Figure 2, particular emphasis being placed on the monitoring of the condition of the side wall at the slag line, the roof, and the anodes. Cooling by air is provided for each anode individually in case of local overheating, but the alarm level has yet to be well established. The thermocouples are generally located in pairs to measure a temperature difference and hence a heat flux that can be checked with a heat flowmeter and measurements of the shell temperature. A port in the roof 550 mm from the centre is provided for the measurement of temperature with a water-cooled radiation pyrometer mounted permanently to give a direct view of the molten bath.

The plasma-generating devices

As previously mentioned, the Mintek 3,2 MVA furnace was designed to allow the use of the following two types of plasma-generating devices:

- the water-cooled transferred-arc torch, and
- the hollow graphite electrode.

For both of these devices, the positive leg of the d.c. supply was connected to the bath of the furnace via the anodes, and the negative leg was connected to the plasma device (Figure 3).

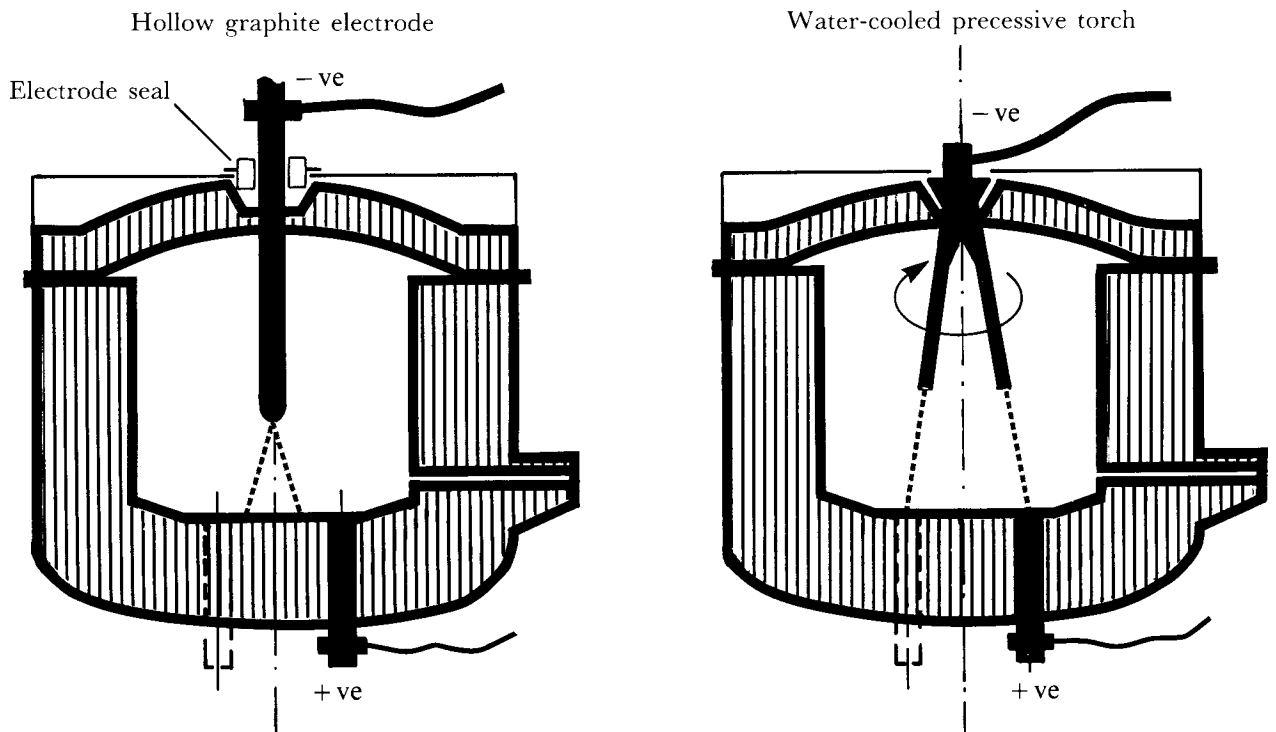


Figure 3. Schematic arrangement of plasma-generating devices

These two plasma devices represent the two extremes of development philosophies. The water-cooled d.c. transferred-arc torch is complex, and its initial capital cost is relatively high. It is therefore preferable for the torch to be protected from overcurrents by the fast response of a Thyristor-driven supply. Torches have not yet been operated industrially at currents higher than 12 kA, but the cost of consumables (e.g., cathode wear) is expected to be low compared with the cost for graphite electrodes. The hollow graphite electrode is a major consumable item (2 to 4 kg per ton of metal) that requires a large diameter for high-current operation, but can be easily operated on a power supply rectified by a diode bridge. This type of system can utilize the on-load tap-changing transformers that are used with conventional furnaces.

The water-cooled torch

The water-cooled transferred-arc torch, which is based on a plasma torch developed by T.R.D.⁴, was designed and constructed at Mintek from locally supplied materials. It was designed to operate up to 3600 A and up to a maximum voltage of 1500 V (Figure 4).

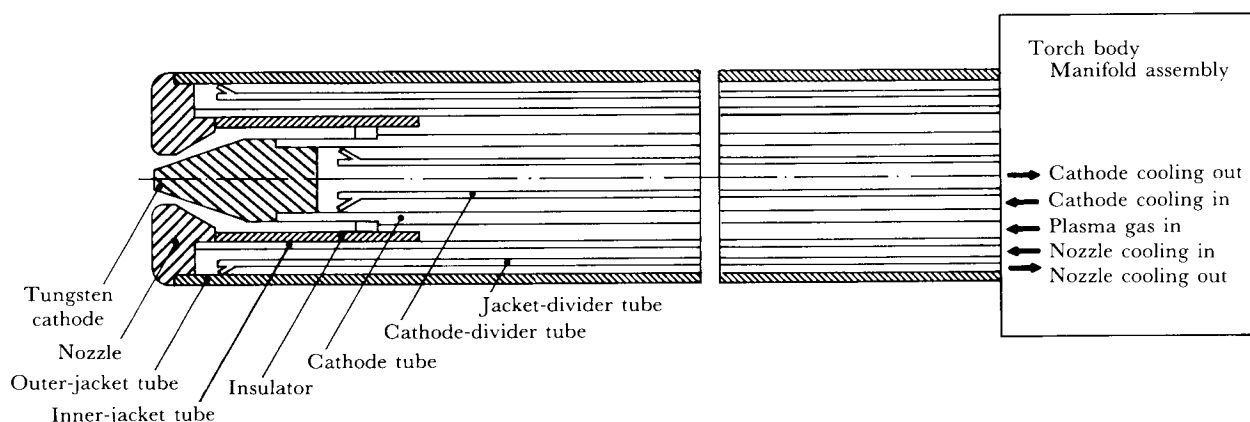


Figure 4. The water-cooled plasma torch used by Mintek

The thoriated-tungsten cathode is fitted into a current-carrying copper tube, and the assembly is cooled with pressurized deionized water. The dimensions of the cathode and the cooling required depend on the current range likely to be used.

The jacket assembly is fabricated from standard copper tubes terminating at the nozzle, which forms an annulus round the tungsten cathode. The jacket assembly is cooled with pressurized deionized water, the flowrate required depending on the furnace temperature and the length of the torch being used. The exact details of the plasma torch are proprietary to T.R.D., but a total power loss of between 30 and 60 kW would be expected from this device.

The plasma gas, usually argon or nitrogen, flows through the annulus formed by the nozzle round the cathode. The plasma arc is initiated by

a high-frequency, high-voltage spark; but the tip of the plasma device must still be placed within 50 mm of an anode contact, which can be either a graphite rod acting as a transfer medium or the molten bath itself. The water-cooled plasma torch for the 3,2 MVA Mintek furnace is of a fixed length chosen to suit the requirements of the particular process under investigation. The torch precesses at an angle of 10° at 60 r/min to distribute the energy over the surface of the melt.

As an aid in the development and testing of the plasma torch, a test rig was built, which allowed open-arc and small-scale furnace tests to be carried out.

The early testwork consisted of open-arc trials in which the anode was a carbon block connected by flexible cables to the positive busbar. During consecutive runs, the arc length was gradually increased to 450 mm, and the current was taken up to 1600 A. Because of the heat generated and the effect of the hot gases on the service lines, the individual open-arc trials were of short duration, but 0,5 MW could be realized.

So that the energy produced could be contained, the second stage of the torch trials was conducted on a small-scale furnace of 800 mm diameter,

lined with a basic refractory and with a pitch-bonded graphite roof similar to that of the 100 kVA system⁷. The energy produced by the torch was absorbed by the melting down of a metal heel within the furnace. To keep the power level low, a short arc length that gave a running voltage of 100 V was used, and the current was increased to 2750 A, at which level it ran steadily.

The hollow graphite electrode

This electrode consists of fine-grained, prebaked graphite with an outer diameter of 100 mm and a length of 1200 mm. A hole of 10 mm diameter drilled down the centre along the entire length of the electrode allows the injection of the plasma gas. To prevent any oxidation of the electrode at its point of entry into the furnace, a water-cooled, gas-tight gland seal is used (Figure 5) with a nitro-

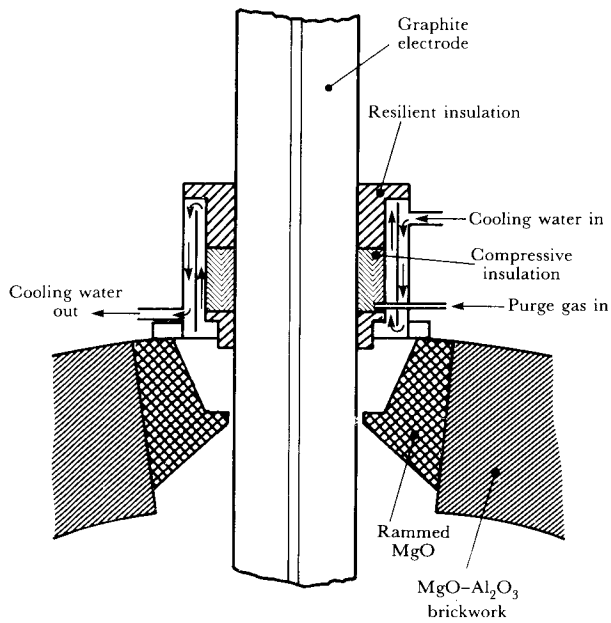


Figure 5. The electrode-to-roof seal

gen purge. The seal also isolates the electrode from the roof. The negative electrical connection is made onto a water-cooled electrode clamp that can be lowered or raised hydraulically to allow the length of the plasma arc to be varied during operation. To establish the plasma arc, the electrode is lowered until it makes contact with the conductive melt within the furnace, and then raised.

The power supply

In the design of the power supply, the first consideration was maximum flexibility in the voltage and current ranges, and the second, assured arc

stability. Transferred-arc systems require a high-current, low-voltage mode of operation, whereas non-transferred-arc systems require a low-current, high-voltage mode. To accommodate these two different systems, a power supply consisting of two six-pulse Thyristor drives, each capable of supplying 750 V at 1800 A, were installed (Figure 6). These drives can be run separately to provide two supplies (for example, to supply two independent plasma devices), or in the twelve-pulse mode either in series or in parallel configuration to provide 1500 V at 1800 A for the non-transferred arc or 750 V at 3600 A for the transferred arc.

Four air-cored chokes are included in the negative leg of each drive to ensure the maximum arc stability, even under cold furnace conditions, as well as to protect the Thyristors from overcurrent surges. The required inductance can then be selected as a multiple of 0,25 mH up to a maximum of 1 mH, simply by variation of the number of chokes in the circuit. During commissioning, it was found that, with a graphite electrode of 100 mm diameter, one choke was sufficient to ensure arc stability. Several Thyristor devices were damaged during commissioning owing to the large back e.m.f.s. generated by the chokes (especially at the 1 mH level). RC (resistive-capacitive) suppressor networks as well as free-wheeling diodes were installed to prevent a recurrence.

The drives can be operated in two different modes of operation, namely constant current and constant voltage. In each instance, the required operating values are selected by setpoint potentiometers located in the control desk.

The feed system

This system consists of two parts: preparation of the feed material from the raw materials, and the actual feeding arrangement on the furnace.

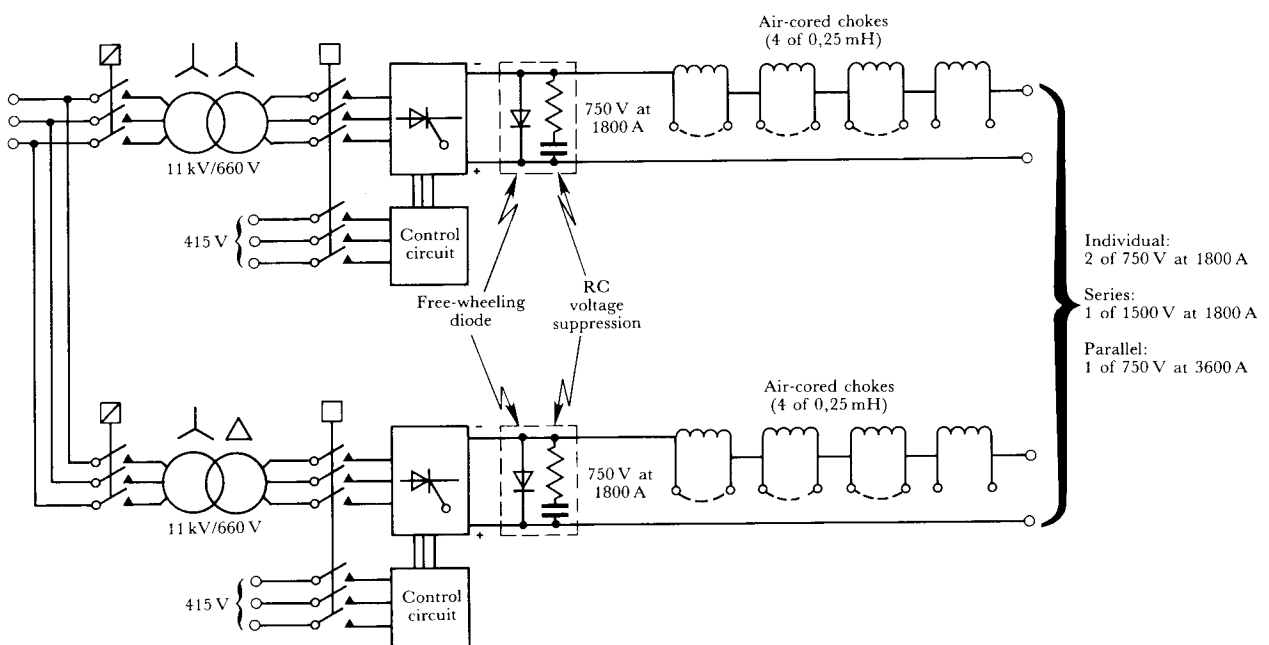


Figure 6. Schematic representation of the power supply

Preparation of the feed

The raw materials, sized and dry, are delivered in bulk and stored in covered bunkers. A front-end loader and a mobile pocket-belt elevator are used to transport the raw materials to twelve 1,5 m³ storage bins. The batches are weighed manually on a weighing car into a transport hopper, which is loaded into a double-cone rotating mixer. A tramp screen (10 mm) is used at the mixing stage, and, after 2 to 5 minutes of mixing, the prepared batch of 250 kg is discharged into a transport hopper and conveyed by the overhead crane to the furnace hopper. This system, although labour intensive, allows for a good control of the batching and can accommodate rapid changes in the feed recipe. Both these requirements are particularly vital to the successful operation of a research facility. Three men and a supervisor can achieve a maximum feed-preparation rate of 1,25 t/h in this way, so that, for a duty cycle of 100 per cent on the furnace, it would be necessary for the prepared feedstock to be stockpiled.

Metering and distribution

The present feeding mechanism on the 3,2 MVA plasma furnace is depicted in Figure 7. The feed system is required to deliver prepared mixtures of feed at a known controlled rate (in the range 100 kg/h to 1,5 t/h) evenly and steadily to four points of the furnace. The feed material is in the size range 0,1 to 10 mm, and the system must be sealed so that hot furnace gases cannot escape into the atmosphere or into the feed hopper, where they might cause an explosion.

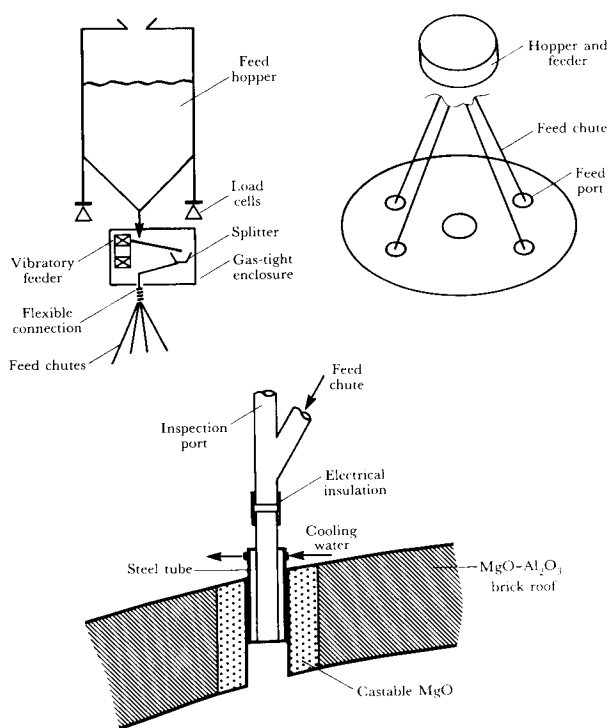


Figure 7. Schematic arrangement of the feed system

The feed hopper is mounted on three 2 t load cells, and has a capacity of approximately 0,25 m³. An enclosed vibratory feeder with a capacity of 2 t/h is mounted below the hopper with an integral four-way splitter that feeds four feed pipes through a flexible stainless-steel bellows to isolate the system for weighing purposes. The vibratory feeder is controlled by a dedicated controller, described later in this paper. The four feed pipes are connected to the feed ports by ball-and-socket joints and a telescopic section for ease of removal and adjustment. These ports include a vertical opening for inspection and a side-entering feed stream, followed by an electrical-insulation bush and the water-cooled metal insert through the refractory roof. The insulation is designed to prevent a stray arc inside the furnace from travelling to earth via water-cooled inserts and the feed system.

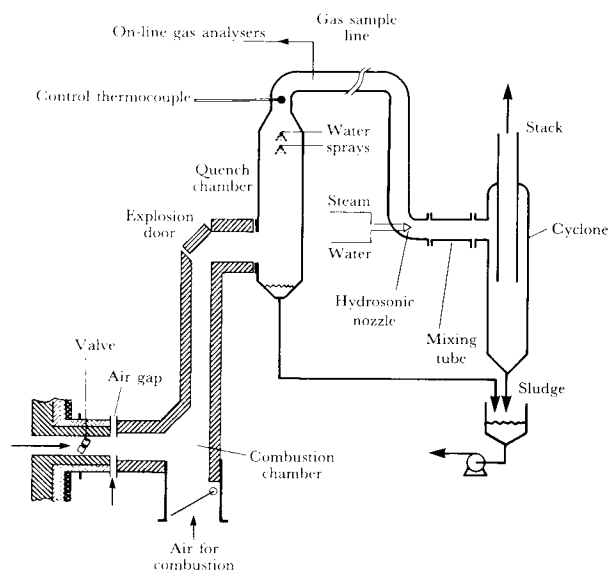
The steelwork and feed system of the furnace are earthed for safety so that only the water-cooled inserts need to be treated as electrically live. A nitrogen purge is employed in the enclosed vibratory feeder to prevent furnace gases from rising up the feed pipes, and the feed material in the hopper provides the upper seal. A stand-by rotary-vane feeder is provided, together with a splitting chamber, but this tends to produce surges in the feed rate by virtue of its 'bucket' type of operation. This makes control of the pressure in the furnace very difficult owing to the rapid evolution of gases when smelting mixtures are being fed.

Product handling

Gaseous products

The gases typically produced during smelting are carbon monoxide and hydrogen, both of which are highly combustible and potentially explosive in combination with air at low temperatures. The intermittent use and changeable nature of a research facility make the treatment of off-gases followed directly by flaring (as commonly practised in industry) too hazardous. The furnace off-gases are therefore combusted almost immediately after leaving the furnace in two vertical, brick-lined combustion chambers. Air is drawn in through a 10 to 15 mm 'slip-gap' between the furnace off-gas duct and the combustion chamber. This gap allows the furnace mass to be determined accurately and the furnace itself to be tilted without any physical disconnection. The second, and major, ingress of air is through an adjustable gas damper at the bottom of the combustion chamber (Figure 8).

After combustion, the hot gases are drawn into quench chambers made of corrosion-resistant steel (type 3CR12) and fitted with two spray nozzles. A temperature controller (referred to later in this paper) maintains a temperature between 200 and 300 °C in the chamber, which allows unlined ducting to be used for all the downstream processing instead of bulky and heavy refractory-lined ducting. The quench chambers produce a relatively small amount of sludge, which is directed to the main gas-cleaning plant.



Note: Only one furnace port, combustor chamber, and quench chamber are shown

Figure 8. The off-gas handling system

A hydrosonic scrubber¹⁵ is used as the main gas-cleaning element on a plant located outside the pilot bay, and draws gas from both quench chambers. The device, which is designed for operation at 700 to 800 kPa, consists of a steam nozzle that provides the system with suction and mixes the dust particles with water droplets from subsidiary water-spray nozzles in a mixing tube. The water droplets and the cleaned gas are separated in a cyclone that vents the gas and collects the sludge. The sludge is then sent to a slimes dam by an intermittently operating sludge pump. The major advantage of the steam-driven system over a fan-operated one is the absence of moving parts, and therefore low maintenance costs.

The combusted gas stream is sampled continuously after it leaves the quench chamber, and is analysed for carbon monoxide, carbon dioxide, hydrogen, and oxygen. This provides a constant check on the extent of combustion, and an alarm is triggered if a dangerous build-up of carbon monoxide or hydrogen occurs. A flushing purge of nitrogen is then provided to drive inert gas into the furnace and hence through the off-gas system. No provision is made for an automatic ignition of the off-gases, because they leave the furnace at temperatures well above those at which spontaneous ignition would occur.

High-temperature liquids

Molten slag and metal are tapped into small ladles of 0.3 m³, which are allowed to cool. The ladle is then tipped in a stand by the overhead crane, and the slag and metal are separated by hand, weighed, sampled, and stockpiled. This system can accommodate a large variation in the ratios of the slag to the metal, and therefore in the tapping volumes, but is limited to furnace powers of 1,0

MW and less. At higher powers, the tap-to-tap time would approach 45 minutes or less, and a continuous tapping system would have to be implemented.

CONTROL AND INSTRUMENTATION

A flexible means of overall control over the furnace is provided by a programmable logic controller (P.L.C.) that not only performs the various interlocking and alarm-monitoring functions, but also has computational and control features. A data logger records all the furnace variables to provide snapshot, averaged, and shift reports. The recorded data can then be transferred and analysed elsewhere.

The arc power and the resistance are computed and displayed by the P.L.C. Its main control function is to ensure that material is fed at a constant selected rate to the furnace. This it achieves by monitoring the signal from the load cell of the feed hopper and calculating the loss in mass per unit of time. This value is compared with the setpoint value (in kilograms per hour) that is entered by the operator, and the resulting error is used to drive the feeder.

A pressure transmitter of very low range (0 ± 250 Pa) is used in monitoring the furnace pressure. A periodic purge with nitrogen ensures that the sensing line remains clear, as well as providing a blockage alarm. To control the furnace pressure, the operator varies the amount of suction on the furnace by changing the angular position of the hydraulically driven off-gas valves until a slightly positive operating pressure is obtained. Two thermocouples that are situated in the top of each of the quench chambers are linked to ON/OFF controllers to provide control over the flow of cooling water to the sprays that are used to quench the combusted gas.

A novel linear-displacement transducer¹⁶ with a 1 m stroke is used in monitoring the electrode position, and thus providing an indication of the arc length. B- and K-type thermocouples monitor the temperatures of the refractories and anodes. Thermocouples situated in the gas off-take ducts are used to measure the gas temperature. There is a close correlation between these temperatures and the temperature of the bath, although they are affected by the position of the gas valves. A dual-wavelength radiation pyrometer mounted on the roof of the furnace provides an indication of the temperature of the bath. Compared with simple single-wavelength devices, this type of system is relatively insensitive to smoke and to changes in emissivity, but reflections from the arc can have a significant effect on the measurement.

A good, reliable method for the measurement of the bath temperature is needed in the development of an overall furnace-control strategy. This will take the form of a balance between the feed rate and the power to ensure that the temperature of the bath is held at the required level. The accu-

rate control of the accumulated energy and feed on a tap-to-tap basis will also be an important part of this control strategy.

OPERATION OF THE FURNACE

The primary aim in the operation of the plasma furnace is the maintenance of steady temperatures, power, and feed rates during a run. Although operation with the hollow graphite electrode differs from operation with the water-cooled torch, these differences are largely related to the start-up and shut-down conditions.

The furnace is warmed by the use of a graphite electrode and a deep coke bed, which maintains contact with the anodes and sustains the reducing conditions that are best suited to the refractories chosen. A low power (approximately 30 to 60 kW) is maintained until the lining has come smoothly up to temperature. Once the temperature of the internal wall has reached approximately 1000 °C, metal fines, fluxes, and coke are added, and the power is increased gradually until a continuous metal bath or heel of 100 mm depth has been established across the hearth up to the taphole level. The heel provides electrical contact with the anodes, distributes thermal energy through the bath, and is usually maintained throughout any single campaign.

The choice of a water-cooled torch or a graphite electrode can be made at this stage of the start-up procedure.

For a water-cooled torch, a graphite rod, used as a temporary anode, is inserted through a side door in close proximity to the plasma torch. The high-frequency spark generator then initiates an arc that is extended manually down to the molten bath for final contact with the preferential anodes in the furnace. The torch can then be precessed at its chosen speed, and the Thyristors used to control the current, and hence the power to the furnace.

The graphite electrode is simply contacted briefly with the molten bath and then raised to any chosen position to establish the plasma arc, in exactly the same way as it was during the warming-up period. However, the power input in this instance can also be varied by the raising or lowering of the electrode to alter the arc voltage at any given current.

The temperature of the furnace is then raised to its desired level, which is maintained by variation of the power input with either of the plasma sources. This defines, at least to a first approximation, the energy losses from the furnace in the steady state. Feed can then be added to the furnace, which generates new conditions for the plasma arc, manifested as an increase in the arc voltage. A balance is then sought between the feed rate and the power, the calculations being based on the thermodynamic energy requirements of the process, which are known, and the assumption that a steady state is sustained. This is currently done by the operator, who uses the theoretical relation shown, for example, in Figure 9 and empiri-

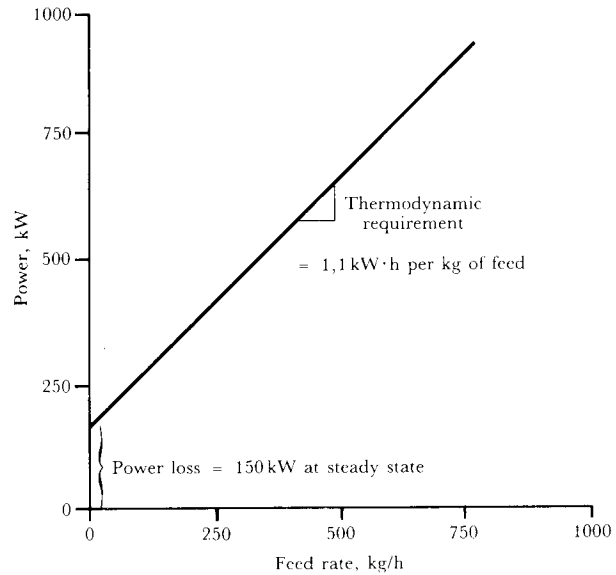


Figure 9. Typical relation between feed rate and power

cal measurements such as the temperatures of the lining, bath, anodes, and roof. The P.L.C. will perform this function automatically once the furnace behaviour has been established.

The pressure in the furnace is kept at slightly positive levels so that the loss of reducing agent due to the ingress of oxygen is minimized. This function could also be assumed by the P.L.C. at a later stage. The examination of dip samples from the bath ensures that the furnace conditions are correct for the successful tapping of the liquid products once a predetermined mass of feed has been added.

The primary difference in operation (as opposed to start-up) between the two plasma sources is that, with the graphite electrode, the arc length can be varied freely. However, this advantage is offset to some extent by the necessity for a regular measurement of the electrode length because of erosion of the graphite.

CONCLUSIONS

The confidence in plasma has rapidly reached the point at which two major South African producers of ferro-alloys, without waiting for further motivation or proof, have installed commercial-scale facilities.

In May 1983, Samancor Management Services (Pty) Ltd commissioned a 10,5 MVA system, based on the technology supplied by Voest-Alpine, using an industrially robust water-cooled d.c. transferred-arc plasma device^{17,18}. M.S.&A. completed the installation of a 20 MVA d.c. arc furnace in December 1983, which is based on the ASEA design originally developed for the Elred process^{14,19}. The former plasma furnace is used for the remelting of ferromanganese metal fines, and the latter for the melting and smelting of high-carbon ferrochromium alloys.

Thus, since its 3,2 MVA plasma furnace was designed and installed, Mintek has found that the need to justify and motivate the installation of industrial-scale plasma furnaces for the processing of ferro-alloys is less important than supporting the optimization of the recently installed furnaces. For example, the technology on control and instrumentation that Mintek developed for this facility has been largely transferred to the M.S.&A. 20 MVA furnace¹⁹.

The scope of the 3,2 MVA furnace can be broadened further to the testing of new process chemistry, which would be developed initially on the 100 kVA facility, but which would require demonstration on a scale sufficiently large to gain credibility. This will be the major contribution that the Mintek 3,2 MVA facility is destined to make to the local pyrometallurgical industry.

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