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Title:- MINTEK'S ROLE IN THE DEVELOPMENT OF PLASMA-ARC TECHNOLOGY BASED ON A GRAPHITE CATHODE.

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Mintek's role in the development of plasma-arc technology based on a graphite cathode

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ABSTRACT

The lack of a plasma-arc torch of proven design capable of operating in the 20 to 60 kA range resulted in intensive research at Mintek. A direct-current (d.c.) transferred plasma-arc pilot-plant furnace utilizing a graphite cathode was developed. This technology resulted in the installation of a 16 MVA d.c. transferred plasma-arc industrial facility for the smelting of ferrochromium. The fact that this furnace has recently been uprated successfully to 40 MVA justifies the use of a graphite cathode.

1. INTRODUCTION

Mintek's direct involvement in plasma-arc technology started in 1979 with the development of a process for the production of ferrochromium. A TRD (Tetronics Research & Development Ltd) water-cooled direct-current (d.c.) transferred plasma-arc torch was used to supply the thermal energy to the process. An open-bath furnace configuration was used - in contrast to the conventional submerged-arc furnace, which employs three self-baking graphite electrodes and operates with three-phase alternating current (a.c.) The plasma-arc torch was precessed mechanically to distribute the arc attachment zone in a circle over the surface of the bath, thereby spreading the energy input. The fine feed was fed direct onto the liquid surface of the bath of slag and metal in the furnace hearth.

Successful metallurgical results were achieved at a power level of about the 400 kW in the TRD 1.4 MVA plasma-arc furnace /1/. The need for the investigation and optimization of the process chemistry and the scaling up of the process to a larger pilot-plant level gave rise to the erection of pilot-plant facilities at Mintek during the early 1980s. The first plasma furnace, installed at Mintek in 1980, was a 100 kVA three-phase a.c. diffuse plasma system with three inclined graphite electrodes. The electrodes had small centrally located holes through which a plasma-stabilizing gas was introduced. The design of this furnace was similar to that of the Extended Arc Flash Reactor at the University of Toronto /2/.

Although satisfactory operation was achieved with this furnace, perceived scale-up problems with the inclined electrodes resulted in its conversion, by the addition of a diode bridge, to a d.c. transferred plasma-arc furnace with a vertical non-precessive water-cooled plasma-arc torch. In 1981, when serious doubts arose at Mintek as to whether water-cooled plasma torches could be scaled up rapidly enough for the identified requirements of industry a hollow graphite electrode was added to the 100 kVA facility as an option to the water-cooled torch.

The need for demonstration-scale testwork at about the 1 MW power level was also realized during 1981, and Mintek started to design a 3.2 MVA power supply and infrastructure for a larger pilot-plant furnace. /3/.

An extension of the 3.2 MVA facility, which was initially designed and used only for the testing and development of water-cooled plasma-arc torches for use on the furnaces at Mintek, was subsequently converted into an additional plasma furnace, rated nominally at 200 kW. Although this furnace was an afterthought, it proved to be the main work-horse of Mintek's plasma programme over the past six years.

2. MINTEK'S PILOT-PLANT FACILITIES

2.1 The 3.2 MVA Plasma furnace

Mintek's original 3.2 MVA (nominally 1 MW) plasma furnace was installed and commissioned during 1983. Between 1984 and 1986, a number of campaigns were carried out, which, although successful, highlighted a number of shortcomings on the facility. During 1988, the facility underwent a major reconfiguration, which increased its versatility and incorporated a number of technological improvements. The basic modifications are shown in Fig. 1.

The original supporting structure of the furnace was fixed, and was specific to the furnace. This was replaced by a bogey-and-rail system. The furnace-support bogey is versatile in that it can accommodate different furnace shells or reactors. The bogey rests on rails, which allow the whole furnace to be moved into the pilot-plant bay for easy access.

A new sealed six-component feed system, capable of handling dry feed materials ranging from 100 μm to 12 mm, was installed. As a result, a wider range of metallurgical processes can be evaluated, since a large number of components (up to six) can now be fed simultaneously to the furnace. The overall gas-tightness of the furnace has been dramatically improved through the sealing of the feed system by the use of a double-hopper seal with a pneumatically activated ball valve, enclosed conveyors, and flexible bellows. Each of the main feed hoppers, which have a volume of 900 litres, are fitted with an independently controlled vibratory feeder. This versatile feed system can distribute the feed either around the graphite cathode or down the centre of the cathode, and can deliver up to 2 t of total feed recipe to the furnace every hour.

The outer diameter of the furnace shells that can be accommodated has been reduced considerably, and hence the mass of refractory material and the cost of a furnace reline have both decreased. However, no corresponding reduction in the maximum power levels or feed rates has resulted, despite the decrease in the internal diameter of the hearth, since higher power and feed fluxes can be attained satisfactorily. Table I compares the original 1 MW furnace and the new furnace options.

The power supply consists of two six-pulse thyristor drives, each capable of supplying 750 V at 1800 A. Each drive can be run separately for low powers (e.g. 100 to 400 kW), or they can be run together in the twelve-pulse mode in series to supply 1500 V at 1800 A, or in parallel to supply 750 V at 3600 A. The drives can be operated in two different modes, namely constant current or constant voltage. The power supply has been described in detail elsewhere /3/.

During the campaigns conducted on the original 1MW furnace, an overall control and operating strategy was evolved, and it was found that accurate control of the feed rate and the power to the furnace was essential /4/.

2.2. The 200 kW Plasma and Fluidized-bed Facility

The 200 kW plasma facility, although rated for operation at 200 kW, utilizes the 3.2 MVA power supply and can therefore operate at substantially higher power levels than 200 kW. The furnace has an internal and outside diameter of 0.5 and 0.8 m, respectively. The support structure of the furnace consists of a bogey-and-rail system, incorporating two hydraulic cylinders, which enable the shell to be tilted during pouring.

The feed system consists of six 100 litre hoppers, each fitted with an independently controlled vibratory feeder. The system is capable of feeding dry materials ranging from 100 μm to 6 mm either down the centre of the graphite cathode, or around it, or both.

The situation of the fluidized-bed reactor directly above the 200 kW furnace allows the combined operation of the two units to be investigated. The combined configuration of the furnace and fluidized bed is shown in Fig. 2. The single-stage fixed fluidized-bed reactor has an internal diameter of 280 mm and a freeboard internal diameter of 450 mm. The depth of the bed is controlled at 350 mm by virtue of the location of the overflow pipe, leaving a 1.3 m freeboard. A pair of sealed tubular vibratory feeders deliver material onto the surface of the bed in the reactor. The small amount of material elutriated from the bed is collected in a cyclone separator, and can be introduced to the furnace together with the particles that overflow from the bed /5/.

Recently, a new conical water-cooled roof was installed, replacing the flat roof design of old. This design decreases the high degree of erosion of refractory material from the roof that occurred when the freeboard above the bath was reduced by the build-up of feed material that sometimes occurs. The furnace shell and new conical roof are shown in Fig. 3.

2.3. Sealed Plasma Facilities

Mintek has two sealed plasma facilities, namely the 50 kVA and 100 kVA units, which have been used primarily for fuming or vapour-phase processes, e.g. the production of zinc and magnesium /6/.

The 50 kVA facility has a 50 kVA d.c. power supply, and a reaction vessel with a production capacity of about 1 kg of magnesium per hour. The unit is normally operated at 60 V and 700 A, which provides for a power supply of approximately 40 kW.

The furnace, which is shown in Fig. 4, comprises a steel shell, a single graphite cathode, a cylindrical copper-anode connection, a water-cooled combustion chamber, and a small bag filter. The assembly is made gas-tight by means of water-cooled flanges equipped with rubber sealing rings. The cathode is a composite electrode. The top section consists of water-cooled copper, and is attached to the bottom (graphite) section by means of a copper nipple. The feed system comprises of a vibratory and a spiral-type feeder, and two sealed hoppers.

The test equipment shown in Fig. 5 includes the same 50 kVA plasma furnace in combination with a condensing unit for the collection of vapours.

The 50 kVA sealed unit was scaled up to 100 kVA for the pilot-scale production of magnesium. The facility consists of a transferred plasma-arc furnace with a 100 kVA d.c. power supply, a sealed reaction vessel with a production capacity of about 3 kg of magnesium per hour, an externally heated (10 kW) condenser, and an air-tight feed system comprising two vibratory feeders and two feed hoppers. The general arrangement of this pilot plant is shown in Fig. 6.

The facility can accommodate about 40 kg of feed and is generally operated at a power level of 70 kW (700 to 900 A and 80 to 100 V).

A tilting-pot furnace, which is not completely sealed, can also be used on the 100 kVA facility

3. INDUSTRIAL DEVELOPMENTS

A 16 MVA d.c. transferred plasma-arc furnace for the production of ferrochromium was installed at the Krugersdorp plant of Middelburg Steel & Alloys in 1983. The process is based on the Mintek-patented concept for the melting and smelting of ferrochromium /7/. The furnace equipment was based on the ASEA Elred process, which was originally proposed for crude iron, but was adapted to ferrochromium production based on the operation of the pilot-plant facilities at Mintek.

After a rather slow start during 1984 and 1985, considerable progress was made with the technology and satisfactory operation was achieved in 1986. By 1987 the process and furnace were performing well, and during 1988 the average power level achieved was 12 MW, which was the maximum level obtainable with the 16 MVA power supply /8/. The production of ferrochromium was 18 000 t/a. Towards the end of 1987 Middelburg Steel & Alloys decided to uprate the furnace from 16 to 40 MVA so that ferrochromium production could be increased. Other considerations included the anticipated higher energy efficiency, together with the already demonstrated advantages with regard to cost and improved utilization of raw materials that give this plasma furnace a considerable advantage over the conventional submerged-arc furnace with regard to variable costs /8/.

The 40 MVA furnace was installed at the end of 1988. Fig. 7 shows the arrangement of the feed system, the furnace, and its transformer and power supply /9/. The electrical system comprises two 20 MVA transformers and two thyristor rectifiers each rated at 30 kA, i.e. 60 kA in total. The diameter of the furnace has been increased from 7.5 to 9 m, and the height from 3.7 to 4.7 m to allow a greater bath depth (a 1 m metal heel instead of 0.5 m). The furnace is fully computerized, and is controlled via set parameters from the operator's desk in the control room /9/.

The cost of this uprating was only about $10 million, since part of the infrastructure of the 16 MVA unit was utilized. The relative simplicity of the design also contributed to the low cost.

This development marks the installation of the world's largest d.c. plasma-arc furnace for the smelting of ferrochromium.

4. FUTURE INDUSTRIAL APPLICATIONS

Mintek has successfully applied d.c. transferred plasma-arc technology to the remelting of ferromanganese fines, and a 10.8 MVA Voest Alpine furnace has been installed at Samancor's plant in Meyerton. However, only limited progress has been made with the smelting of high-carbon ferromanganese. The two main problem areas are the low boiling point of manganese metal (2097°C), resulting in excessive losses of vapour, and the low voltage generated in the plasma-arc column owing to the presence of conductive manganese metal vapour. This, in turn, results in the need for longer arcs and causes higher energy losses. There is nevertheless a good possibility that these problems can be resolved, and a plasma furnace can be developed for the smelting of ferromanganese alloys from manganese ore fines. A graphite cathode will probably be used in such a furnace.

A novel plasma-arc process for magnesium metal has been tested successfully on a pilot-plant scale at Mintek, and the prospects for the scaling-up are promising. A semi-industrial-scale furnace has been designed jointly by Samancor and Mintek, and has recently been built. The furnace will be operated at 2 to 3 MW, and should provide information that can be used to scale the process up to a fully commercial operation. A graphite cathode has been used in this application, primarily for safety reasons.

5. SUMMARY AND CONCLUSIONS

Mintek has supported the intensive development of furnaces based on a graphite cathode by installing a variety of plasma-arc furnaces of the open-bath transferred plasma-arc type. These pilot-plant furnaces range from 50 kVA to 3.2 MVA, and can be operated at power levels between 30 kW and 1.2 MW respectively. These facilities have supported the successful transfer of ferrochromium-smelting technology to industry, and are being used to develop processes for the smelting of ferromanganese and the production of magnesium metal. The decision to replace water-cooled devices with graphite cathodes appears to have been fully justified.

6. ACKNOWLEDGEMENT

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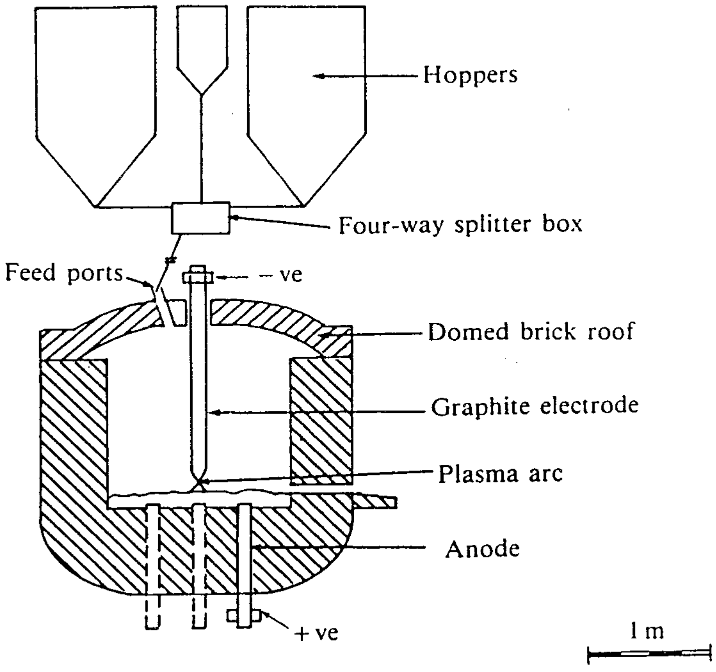
TABLE 1

Comparison of the original and new furnaces on the 3.2 MVA facility

Parameter	Original Furnace	New furnace	
		Air-cooled Shell	Water-Cooled shell
Shell diameter, m	2.5	1.5	1.8
Furnace height, m	2.4	2.5	2.5
Internal diameter, m	1.5	1.0	1.3
Internal height*, m	1.5	1.75	1.75
Height/diameter	1.0	1.75	1.35
Power flux at 1 MW, MW/m^2	0.5	1.27	0.75
Feed flux at 2 t/h, t/m^2h	1.13	2.54	1.51
Maximum tilt angle, degree	20	35	-
Typical working volumes, litre	500 to 600	300 to 400	400 to 500
Typical tapping volumes, litre	200	300	300
Envisaged converter charge, t	-	1 to 1.5	-

* Distance from hearth to roof

The previous 1 MW furnace



The new 1 MW furnace

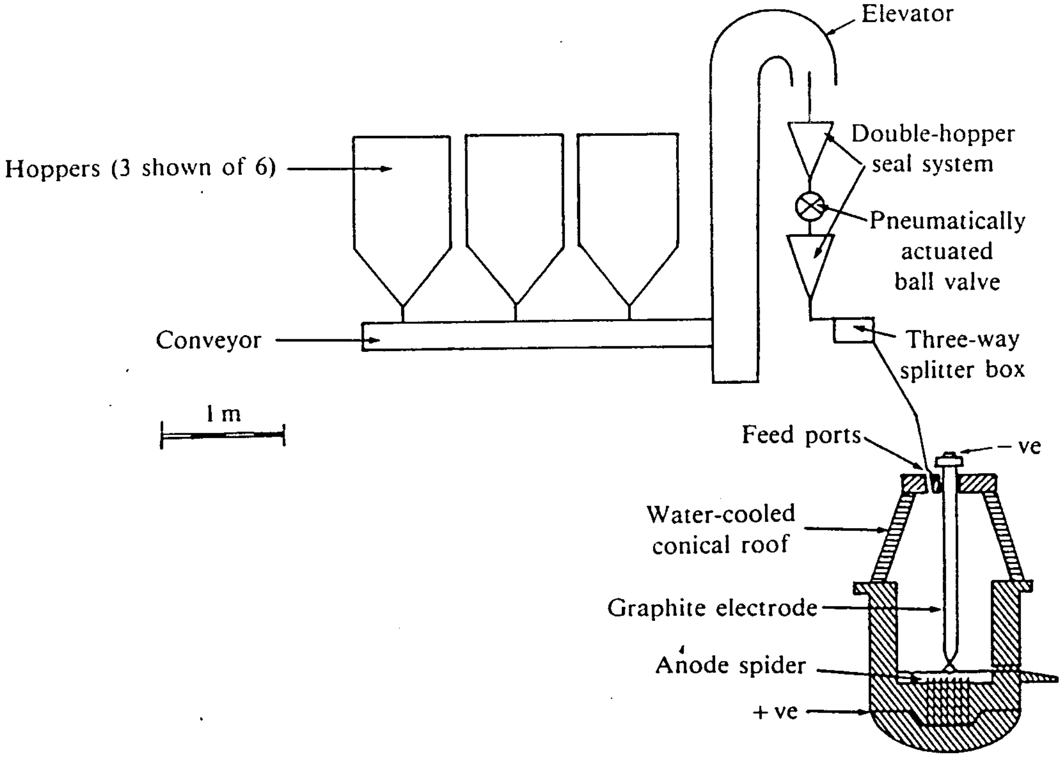


Fig. 1. The basic differences between the old and new furnace on the 3,2 MVA facility /10/.

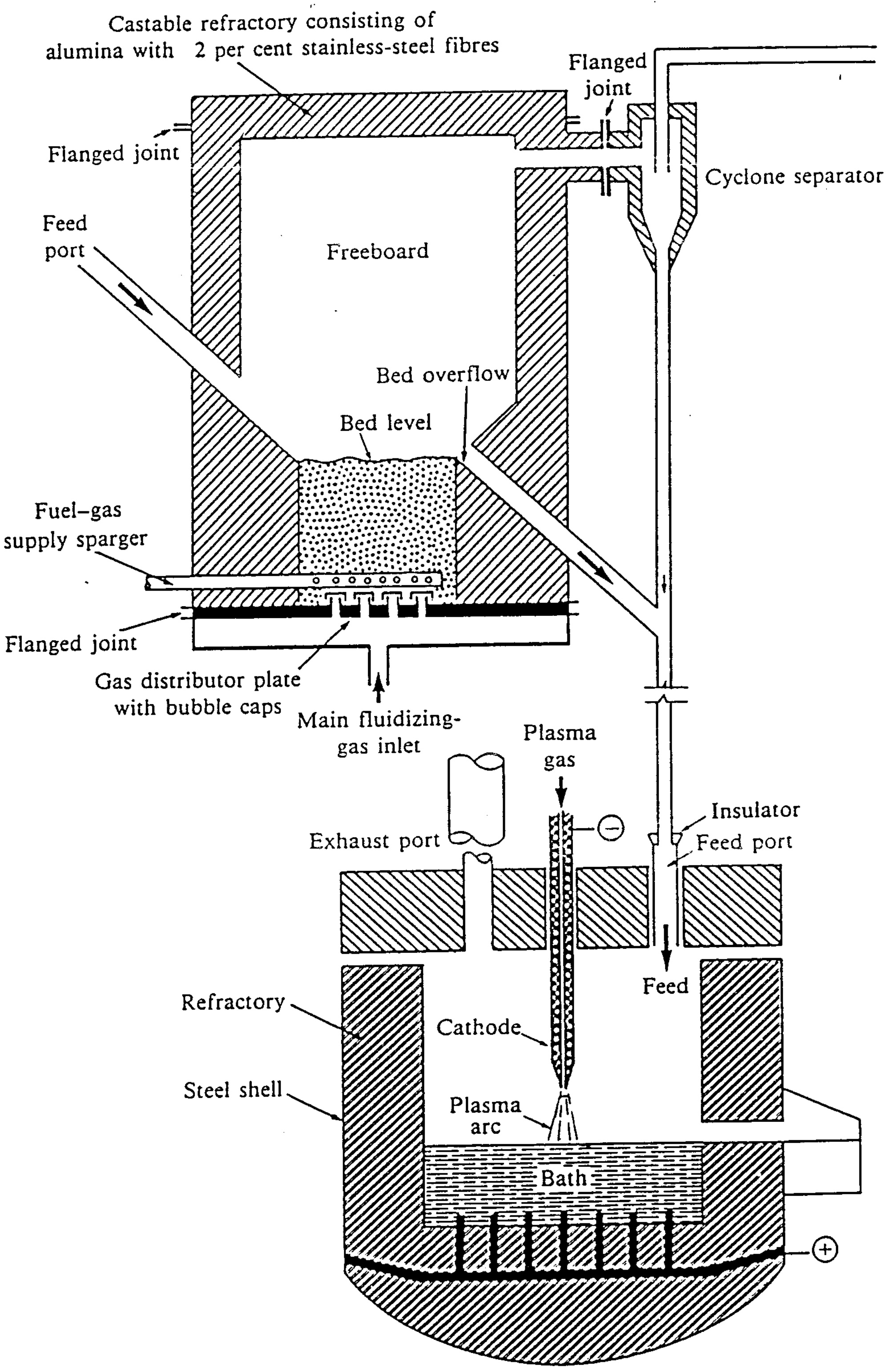


Fig. 2. The 200 kW facility, showing the fluidized-bed reactor and the plasma-arc furnace /5/.

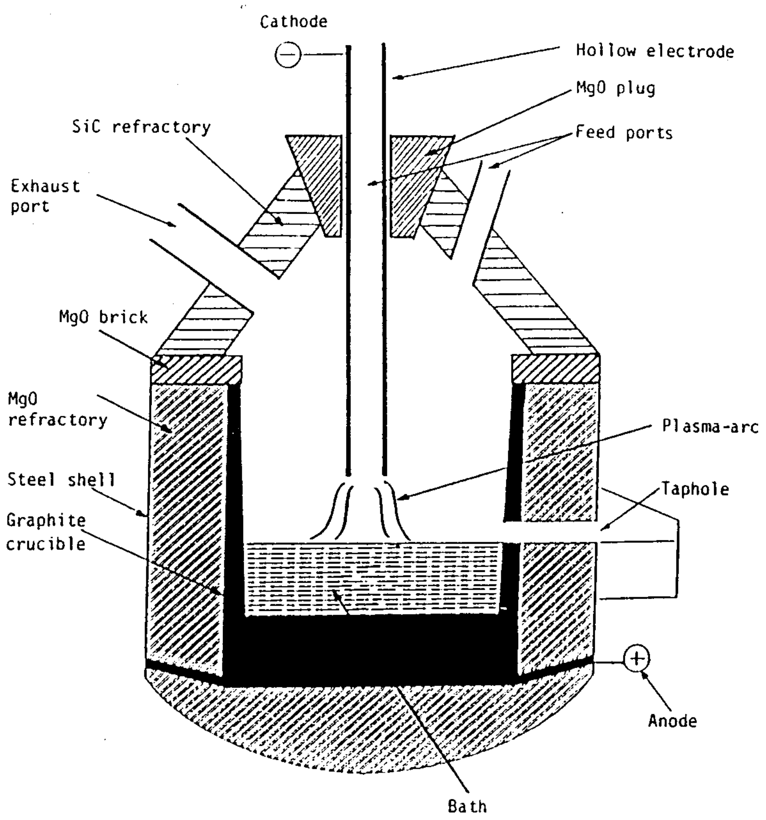


Fig. 3. The 200 kW facility, showing the new conical roof design.

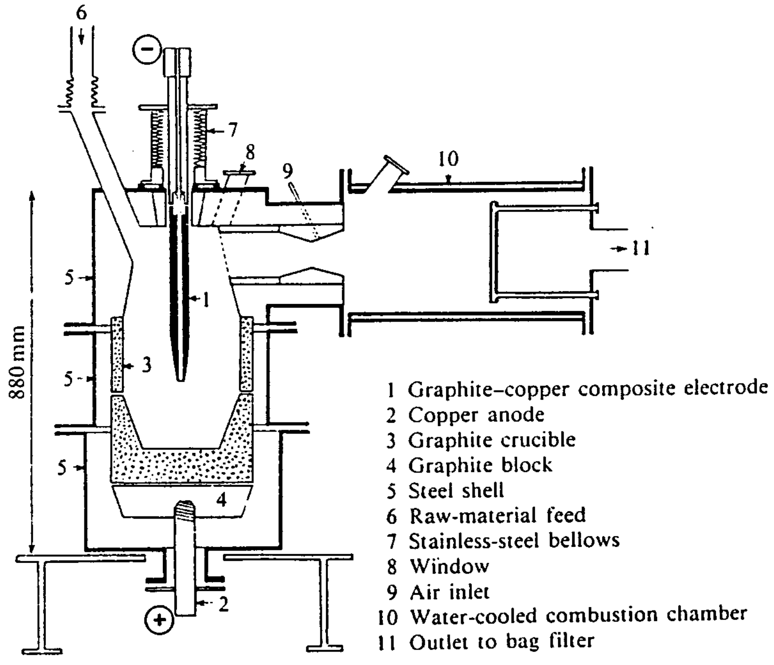
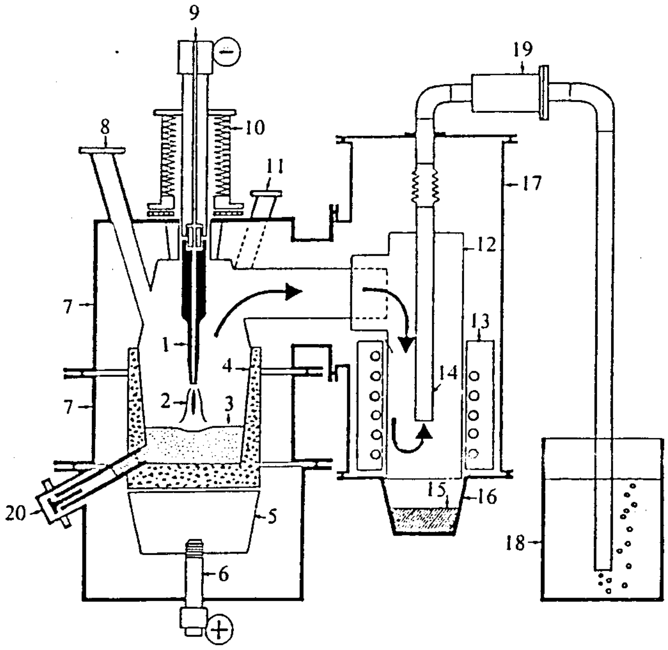
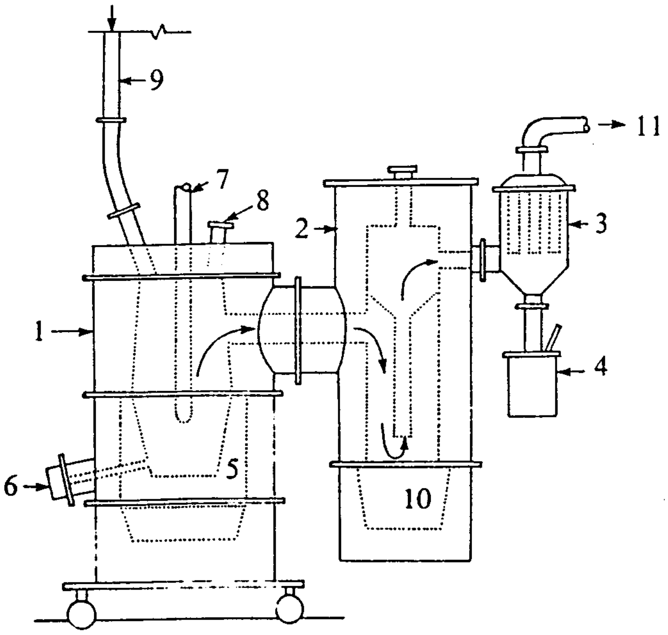


Fig. 4. The 50 kVA furnace and combustion chamber /6/.



1 Graphite–copper composite electrode
2 Plasma zone
3 Molten bath
4 Reaction crucible
5 Graphite block
6 Copper anode
7 Steel shell of furnace
8 Feed port
9 Supply of argon plasma gas
10 Steel bellows
11 Window
12 Inner cylinder of condenser
13 Kanthal wire heating element
14 Outlet pipe of condenser
15 Condensed magnesium
16 Condenser crucible
17 Outer shell of condenser
18 Tank for dilute hydrochloric acid
19 Filter
20 Taphole

Fig. 5. The 50 kVA furnace and condenser /6/.



1 Steel shell of furnace
2 Outer shell of condenser
3 Filter
4 Dust collector
5 Graphite crucible
6 Taphole
7 Electrode
8 Window
9 Feed port
10 Condenser crucible
11 Exhaust connected to acid tank

Fig. 6. A schematic drawing of the 100 kVA furnace with condenser /6/.

Fig. 7. A schematic arrangement of the feed system, furnace and power supply of the 40 MVA furnace for ferrochromium production /9/.