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P R E P R I N T

RECENT DEVELOPMENTS IN PYROMETALLURGICAL PLASMA TECHNOLOGY

by

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ABSTRACT

This paper reviews the recent commercial advances that have been achieved in the application of plasma technology to pyrometallurgy. The most notable achievements are in remelting applications. The advantages and limitations of various commercial remelting plasma reactor systems are discussed. The potential for the application of plasma technology to smelting is briefly reviewed in general.

INTRODUCTION

Very recently great strides have been made towards commercial reality for plasma technology as regards pyrometallurgical applications of remelting and smelting. However, it is the potential that arc-plasma furnaces have demonstrated as melting furnaces that has brought about this development. Although their progress as smelting furnaces cannot be overlooked, an appraisal of the technology advances of plasma furnaces must focus on their applications as melting furnaces. Significant commercial advances have been made in the remelting of metal units in a variety of plasma-arc furnaces. Most notable are the remelting of ferro-alloy fines, scrap-iron and steel units, and refractory metals or high alloyed steels requiring protective atmospheres.

Remelting of ferro-alloy fines

Ferro-alloys (such as ferrochromium, ferromanganese, and ferrosilicon) are normally marketed in definite size ranges which favour relatively coarse material that will sink through a layer of slag and dissolve in the open bath of liquid slag and metal when added as alloying additions. Furthermore, such ferro-alloy additions are usually made at a late stage of the steel-refining process and must rapidly penetrate the slag. Ferro-alloys consist largely of intermetallic compounds that are normally very brittle. The methods used in the casting, handling, and crushing of these alloys to meet the requirements of custommers, results in a considerable amount of metal fines (i.e. metal less than 6mm in diameter) being produced. In favourable market conditions these metal fines are sold at prices well below that of the lumpy material (approximately 25 to 100mm in diamater). In depressed market conditions, such as those presently prevailing, these fines cannot normally be sold and represent a serious loss of revenue, as approximately 10 per cent of a submerged-arc furnace's ferro-alloy output reports as fines.

Because of their brittleness, agglomeration of the metal fines is not undertaken. Recycling of even a moderate amount of these metal fines to the submerged-arc smelting furnace for remelting is unfortunately detrimental to the process, because their high electrical conductivity lowers the electrical resistivity of the burden. As the submerged-arc furnace relies on a resistive burden for operation at high power, the recycled metal fines reduce the input power, and thus adversely affect the productivity of the submerged-arc furnace.

Remelting of metal fines has, in the past, met with only moderate success. The physical characteristics of these metal fines, such as poor susceptibility, the presence of entrained slag, high bulk density, and high electrical conductivity has tended to limit the application of the more conventional remelting techniques. The remelting of ferromanganese in an induction furnace is practised on a small scale[1]. The poor susceptibility characteristics of the fines dictate that a large molten heel of alloy must be maintained in the furnace. The presence of entrained slag and partially reduced materials further restricts the usefulness of the induction furnace as a viable technology for the remelting of ferro-alloy fines. The high bulk density of these ferro-alloy fines, as compared to typical scrap charges (roughly 3,5 t/m^3 for FeCr and FeMn less than 3mm compared with 1,5 t/m^3 for typical scrap charges) precludes their remelting in conventional open-arc furnaces. The primary reason for this is arc-flame damage to refractories in the side wall under open-bath conditions. Compensations must therefore be applied to the design of the furnace, the material-charging techniques, and melting procedures. However, the use of a d.c. transferred-plasma-arc appears to be very favourable for control of the energy transfer to the bath without damage to the refractories.

The Council for Mineral Technology (Mintek) maintained a World-wide watching brief on plasma developments[2] and identified the exciting possibilities that plasma-arc remelting of ferro-alloy fines presented when viewed in the South African context. The direct-current transferred-arc approach was chosen as the most suitable plasma-furnace configuration for in-house investigation of the various process-metallurgy options offered by this new generation of furnaces. This approach was chosen for the following reasons[3]:

(a) the use of an open bath of liquid slag and metal (the anode) permits greater control of the process metallurgy than with a choke-fed furnace,

(b) the electrical-supply characteristics and geometric arrangement of the transferred-arc furnace are similar to the conventional submerged-arc furnace and the change to direct current is relatively straightforward,

(c) scale-up to industrial operation is now feasible when a graphite electrode is used, and

(d) transferred-arc devices have low cooling-water losses (usually less than 10 per cent).

Mintek has had considerable success in the remelting of a variety of ferro-alloy fines (FeCr, FeMn, FeSi, and FeMnSi) in a 100 kVA experimental, as well as a 1.4 MVA semi-industrial, transferred-arc, molten-anode, furnace[4]. This work is currently being extended to 3.2 MVA-scale at Mintek. High-quality metal was produced in a lumpy form, and good recoveries were achieved. Furthermore, it was possible to effect a degree of refining or purification during remelt of some of the alloys investigated. The success of this testwork, the obvious economic incentives, and the relatively easy scale-up potential to full-scale industrial operation has resulted in the proposed installation in South Africa of at least two transferred-arc molten-anode plasma furnaces for the remelting of ferro-alloy metal fines. The decision to proceed with these industrial-scale plasma units was almost entirely motivated by the viability of the remelting of metal fines, although other options, such as smelting, are receiving considerable attention.

The plasma installation at Middelburg Steel and Alloys' plant in Krugersdorp was recently announced in the press[5]. This 20 MVA molten-bath-anode plasma furnace is expected to have a production capacity of 50 000 tons of ferrochromium per year. The furnace design is based on the ASEA-ELRED process and is illustrated in Figure 1[6]. The use of a single hollow-graphite electrode as the cathode alleviates the scale-up problems associated with the limits of the cathode torches as regards current-carrying capacity. Another important feature of the furnace is that the conducting hearth acts as the anode electrical connection. Anodes embedded in the hearth refractories require protection from the intense energy dissipated at the anodic-arc attachment. A necessary operating philosophy of these molten-anode furnaces is always to maintain a heel of metal above the anode to effect a degree of protection. The use of the conducting hearth tends to alleviate the problems associated with the protection of the integrity of the anodes. Furthermore, the conducting hearth is reported to ensure a symmetric current-flow distribution that creates an electromagnetic stirring action that is claimed as equivalent to that of an induction stirrer[7].

The design of the transferred-arc molten-anode plasma furnace chosen by a large ferromanganese producer for remelting applications is based on the Freital Steel System[8]. A 10.5 MVA single-cathode Freital furnace, designed for remelting ferromanganese fines, started up in March 1983. In contrast to the MSA furnace, water-cooled cathodes and anodes are employed. This furnace is somewhat different from the typical Freital furnace employed for remelting scrap-iron and steel units (Figure 2) as a single cathode is employed. The furnace is designed to remelt 50 000 tons of ferromanganese per annum and as the electrical energy requirement is 700 kWh/t, multiple cathodes are not necessary. The restrictions on current-carrying capacity of water-cooled cathodes necessitate the use of more than one cathode to effect scale-up. These cathodes must be introduced laterally as the plasma arcs would converge before attaching to the open bath of liquid slag and metal if they were placed in the furnace roof. This convergence would increase the problems associated with the protection of the integrity of the anodes.

Remelting of scrap-iron and steel units

The Freital furnace system was originally developed for the melting of steel and special steels, and is still being employed in that capacity. This development started in 1965 in the German Democratic Republic and the U.S.S.R. The Freital plasma furnaces have been in continuous operation for nearly ten years and have produced some 60 000 t/a of various grades of steel. The largest commercial furnace developed to date by Freital is rated at about 20 MW and employs three water-cooled cathodes[9]. The 40-ton scrap-melting furnace at Freital, East Germany, employes four water-cooled cathodes rated at 9 kA each. The installation of a 100-ton plasma furnace in the U.S.S.R. has been mentioned in the literature[7]. This furnace will employ six water-cooled cathodes rated at 10 kA each. However, the location of the cathodes around the furnace has been somewhat modified so that they all face in the same direction[10].

Although references to numerous other d.c. transferred-arc molten-anode plasma furnaces can be found, their development as steel-scrap remelting furnaces is dwarfed in the light of the advances made by Freital, and they will not be reviewed here. However, mention will be made of the a.c. transferred-arc plasma furnace developed by the Krupp Research Institute as an alternative to these d.c. transferred-arc plasma-remelting furnaces[11]. Figure 3 illustrates schematically the three-phase a.c. plasma furnace employed by Krupp. Although similar in design to a conventional open-arc furnace, the use of water-cooled cathodes achieves a saving of costs that would be incurred through graphite-electrode consumption. Furthermore, improved arc stability is achieved by the introduction of the plasma gas into the arc. Besides reduction of noise and flicker, considerable cost savings are achieved, as this stable arc obviates the need for fast-acting control of electrode movements to maintain the arc. The use of alternating current, as opposed to the direct current employed in the Freital system, eliminates the need for an electrical connection in the furnace hearth. Anode-integrity problems are thus not encountered. At each third of the cycle, the current flows from one cathode down to the bath, and back through the two remaining water-cooled torches (now the anodes). The neutral point is in the molten bath. In effect, the intense energy dissipation at the bath of liquid slag and metal is somewhat 'softened' by operation in this a.c. mode. However, because of the furnace's geometrical arrangement (a pointed water-cooled torch and a flat molten-bath surface) the plasma-arc energy is still directed onto the bath. This, in effect, protects the integrity of the water-cooled torches when they are the furnace-anode connections. Furthermore, scrap charges of densities lower than those required by a d.c. melting procedure (2 to 3 tons/m^3) can be employed in consequence of the 'softened' energy dissipation and vertical positioning of the torches. The scrap is melted down very rapidly below the torches and deep craters are formed. The torches are then slightly inclined to achieve melting between the craters to form a common central crater with a molten heel at the bottom. At this stage the scrap between the crater and the furnace wall is melted by the use of long arcs. When the furnace walls are exposed the arc lengths are reduced to minimize the thermal losses to the walls. A 10 MW furnace is planned for commissioning in the second half of 1984 at the Geisweid works of Krupp. Because of the current-carrying limitations of water-cooled torches, scale-up will be effected by the employment of a number of torches rated at 6 kA.

The remelting of refractory metals or high-alloyed steels requiring protective atmospheres

Daido Steel was one of the pioneers in the commercial development of plasma melting furnaces. The original Daido concept of combining plasma heating with induction heating (PIF) has met with considerable commercial success. The plasma torch supplements the energy from the induction coil and the argon atmosphere provides protection of the melt surface as is shown in Figure 4. The stirring action achieved by the induction coils efficiently distributes the intense energy dissipated at the anodic-arc attachment and problems of anode integrity are reduced. Furthermore, slag-metal contact is enhanced by the stirring and promotes the refining capabilities of this melting furnace. Daido currently operate four small PIF furnaces (of 0.5 and 2 ton). The relatively small scale of operation dictates the remelting of high-value products (e.g. aluminium, titanium, zirconium, and special steels with heat-resistant or electrical-conductive properties). The employment of a protective atmosphere, as opposed to a vacuum, reduces vaporization of elements such as manganese and chromium while the molten pool is effectively degassed. Contamination from graphite electrodes is avoided, giving a carbon-free environment. Deoxidation to values of oxygen less than 20 p.p.m. is achieved, as shown in Figure 5. Stainless steel with extremely low carbon contents (0.006 per cent) can be obtained[12].

More recently Daido have developed a plasma progressive-casting furnace (PPFC) that is conceptually similar to the well publicized transferred-arc plasma arrangement (known as PAR) patented by the Electric Welding Institute (U.S.S.R.)[12-16]. The PAR furnace illustrated in Figure 6 employs a consumable electrode, with controlled ingot-solidification and withdrawal techniques. The Daido PPCF is somewhat different to the PAR furnace in that an electrode is not remelted but scrap is charged continuously into the water-cooled mould (Figure 7). Up to six cathode torches rated at 5 kA are employed in Daido's 0.5 MW PPCF. A progressively produced solidified ingot is withdrawn from the crucible throughout the operation. Although the vacuum-arc furnace (VAF), the electroslag furnace (ESRF), and the electro-beam furnace (EBF), can be used for the same purpose, Daido claim that the PPCF has several distinct advantages such as its greater flexibility, and its ability to readily melt relatively high-vapour-pressure and reactive metals, and any shape of raw material. High melting-point inclusions can be separated, and heating and melting is uniform since the furnace is oscillated, and a number of plasma torches are used simultaneously.

Conclusion

Although our present fundamental understanding of many of the phenomena in the generation and behaviour of thermal plasmas is still poor, thermal plasmas have been commercially applied in arc-gas heaters over the last two decades and are now being ingeniously applied to the development of a new generation of pyrometallurgical furnace systems. As a result, large-scale plasma furnaces have emerged that are proving themselves as viable commercial remelting furnaces. Although the progress made with these furnaces for smelting cannot be overlooked, it is dwarfed in comparison with the progress made for melting. Their application as smelting furnaces is hampered by a lack of fundamental understanding of the extent to which the thermodynamic and kinetic aspects of smelting process chemistry can be influenced by the plasma to optimize the overall process efficiency. Nevertheless, the potential for the improvement of pyrometallurgical operations through the application of plasma technology is immense and exciting and will, no doubt, lead to the continued commercial advances of these furnaces for both smelting and remelting applications.

Acknowledgement

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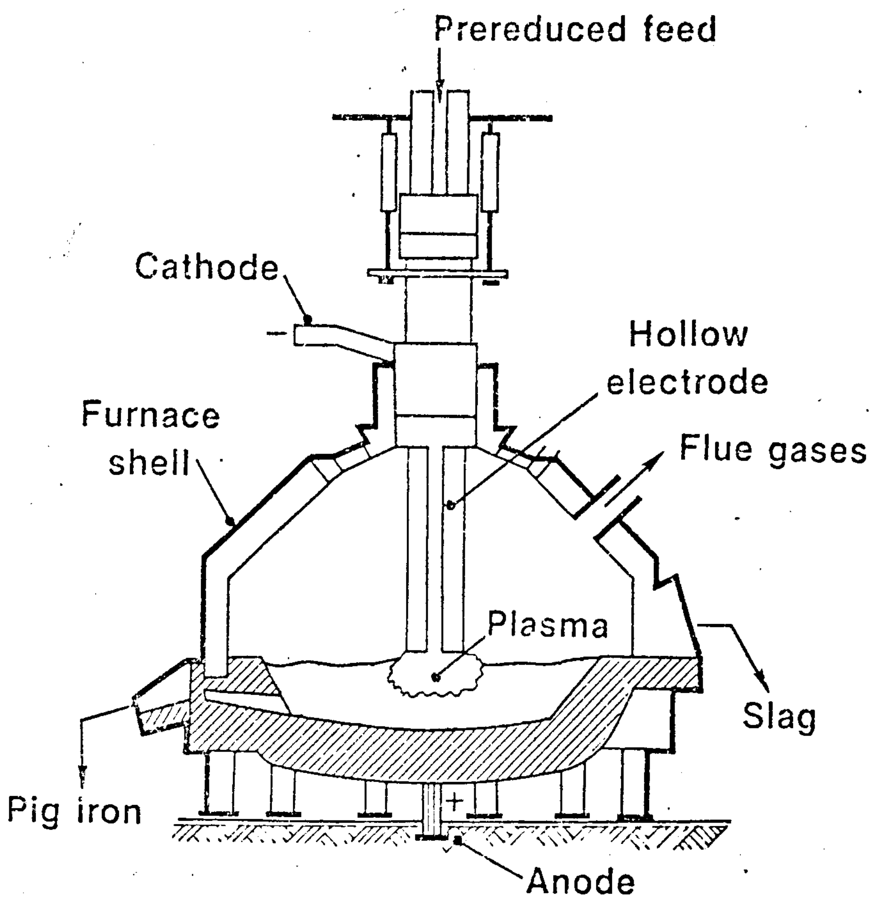

FIGURE 1. Schematic representation of the d.c. transferred-arc ELRED plasma furnace

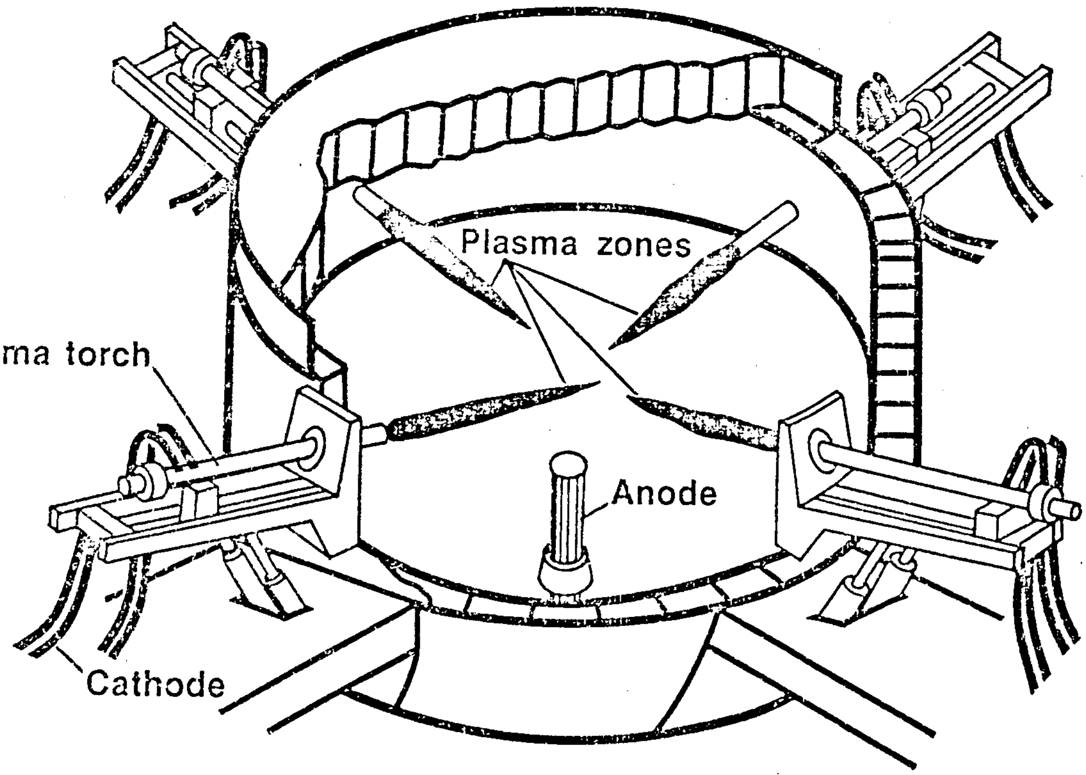

FIGURE 2. Schematic representation of the d.c. transferred-arc Freital Steel plasma furnace

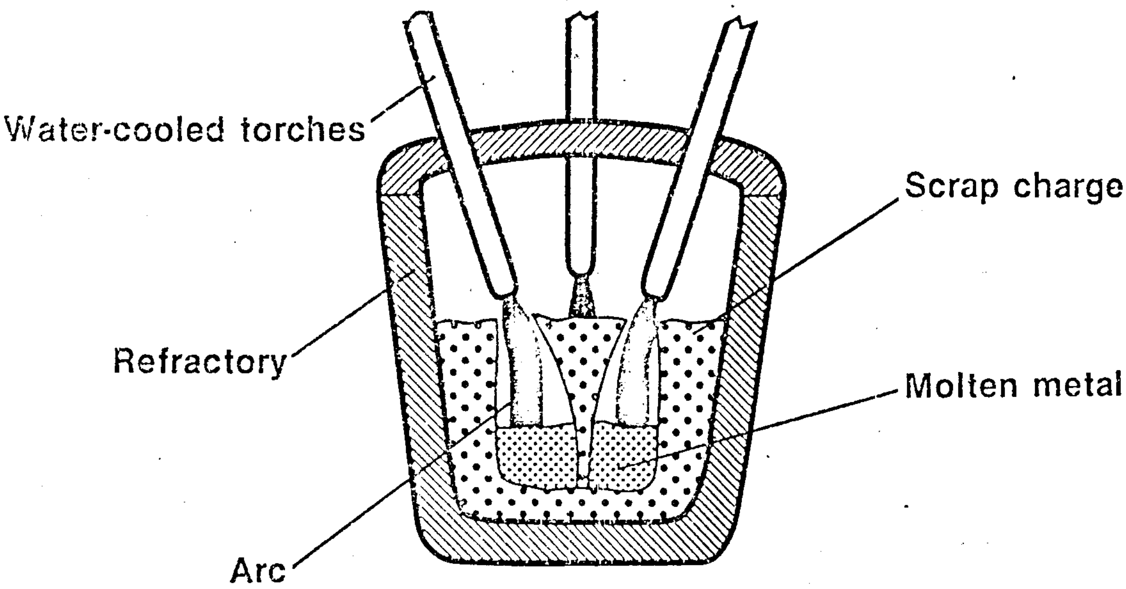

FIGURE 3. Schematic representation of the 3-phase a.c. transferred-arc Krupp plasma furnace

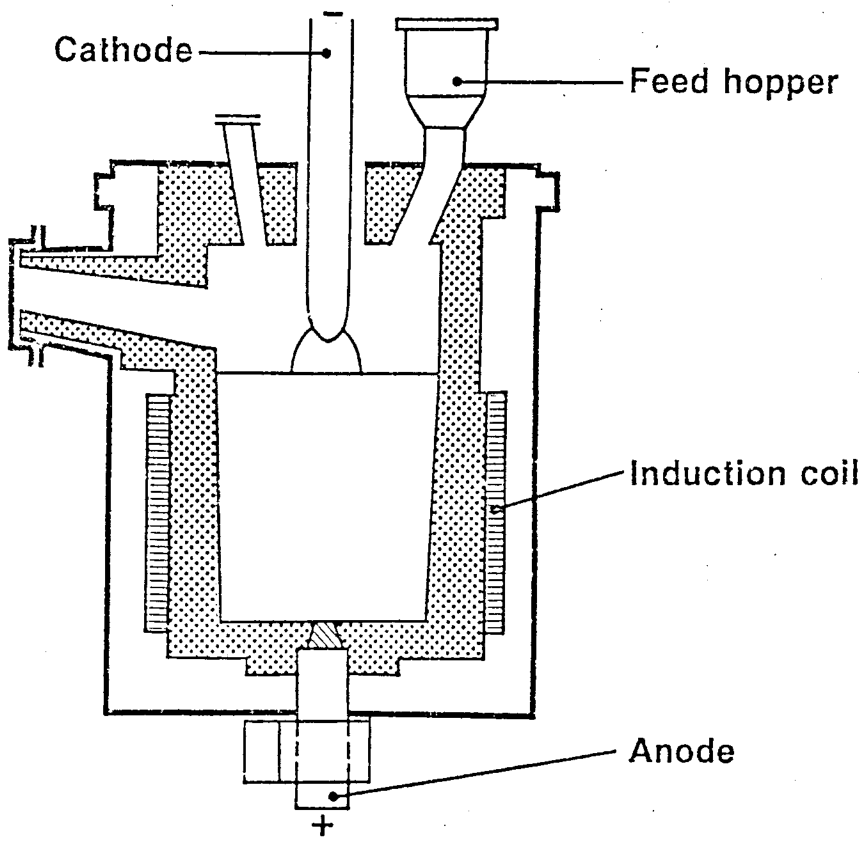

FIGURE 4. Schematic representation of the Daido d.c. transferred-arc plasma furnace combined with an induction-heating furnace (PIF)

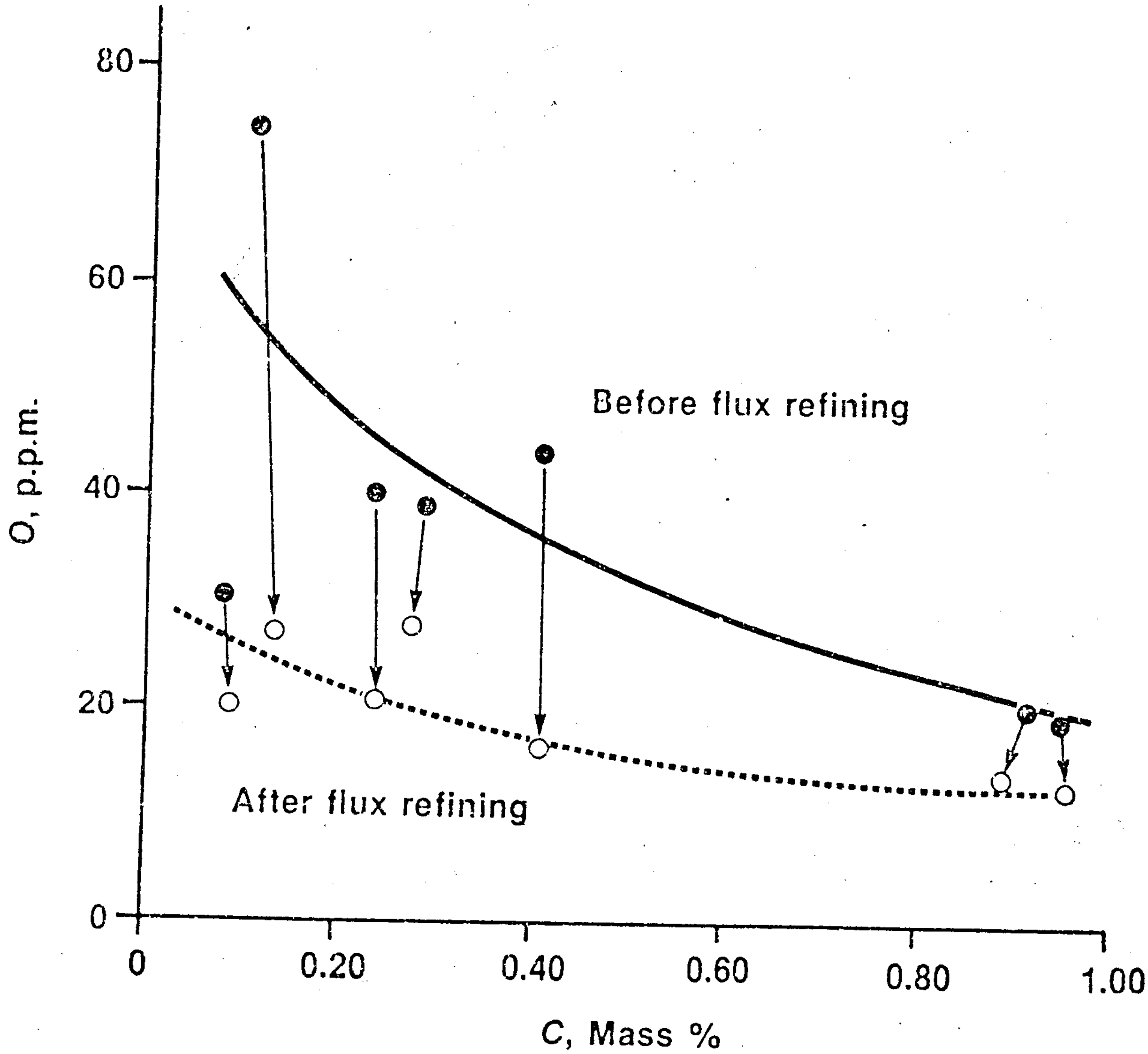

FIGURE 5. Deoxidation levels and carbon contents for the Daido PIF facility showing that remelting of stainless steels results in improved oxygen levels

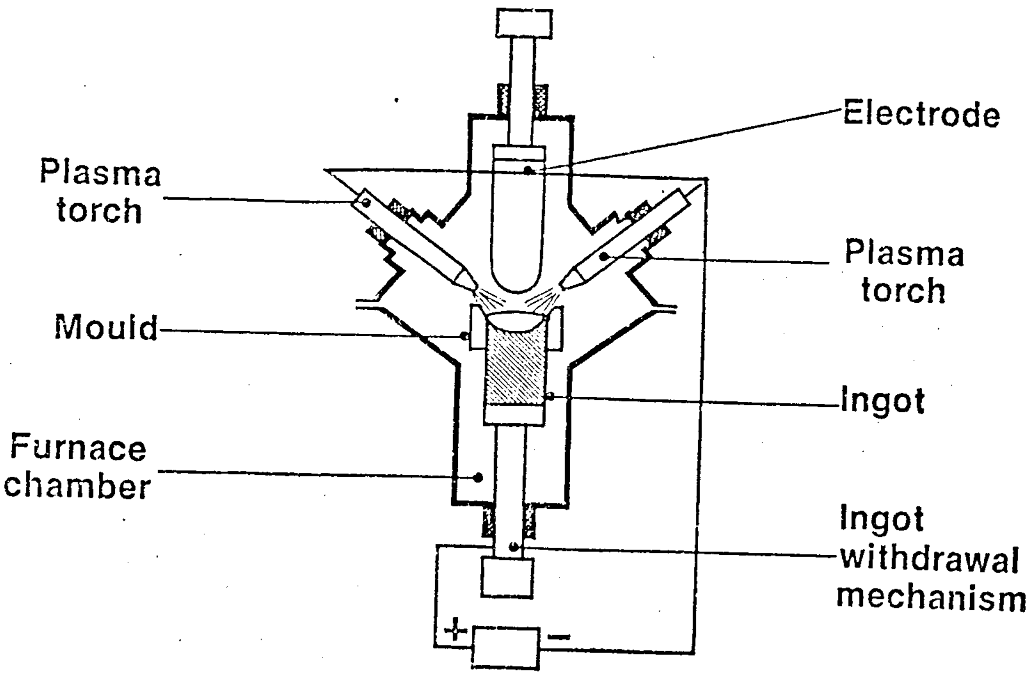

FIGURE 6. Schematic representation of the d.c. transferred-arc remelting plasma furnace (PAR)

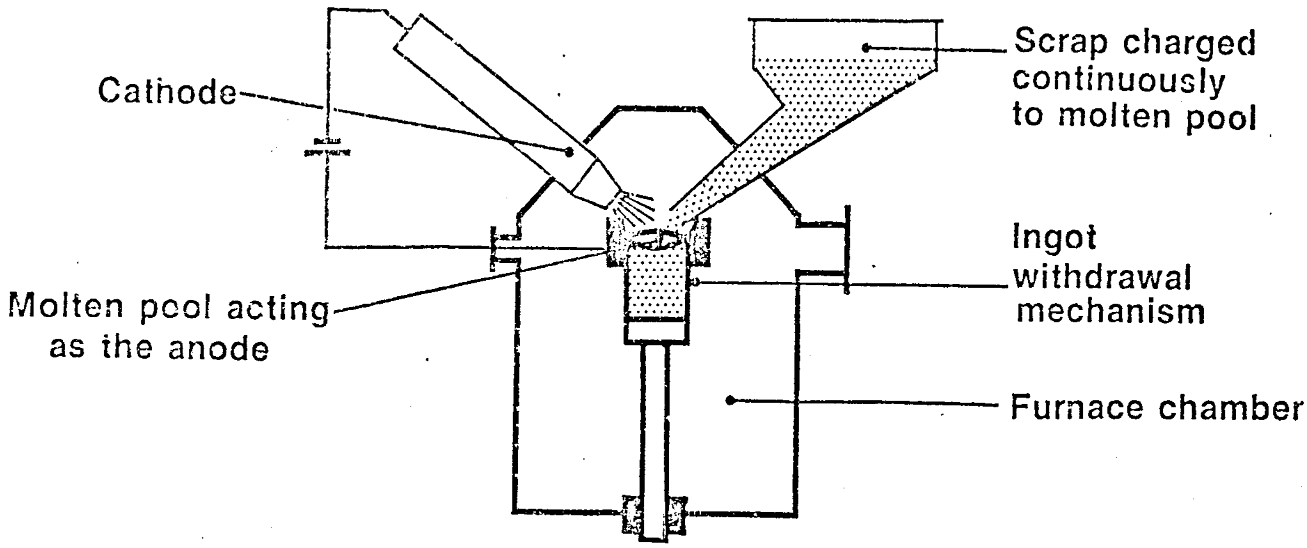

FIGURE 7. Schematic representation of the Daido d.c. transferred-arc plasma progressive casting furnace (PPCF)