THE POTENTIAL OF PLASMA-ARC TECHNOLOGY FOR THE PRODUCTION OF FERROALLOYS

(Speaker)

NICHOLAS A. BARCZA

Assistant Director, Pyrometallurgy & Physical Metallurgy Division

Council for Mineral Technology (MINTEK)

(Speaker)

ALISTAIR B. STEWART

Assistant Director, Measurement & Control Division

Council for Mineral Technology (MINTEK)

ABSTRACT

The inherent disadvantages associated with the operation of the conventional submerged-arc furnace for the production of ferro-alloys has led to an intensive evaluation of plasma technology by many organizations, such as Mintek in South Africa. Small-scale and pilot-plant tests for the study of the applications of 'thermal plasma' to a number of pyrometallurgical processes, including the production of ferro-alloys, have been carried out in several countries in recent years. Many different plasma systems have been developed but two distinct categories are evident, namely transferred- and non-transferred-arc plasmas.

The transferred-arc type of system has usually been configured in an open-arc-furnace mode whereas the non-transferred-arc type of system has been applied to the tuyere of a shaft furnace. Water-cooled non-consumable, and graphite consumable, electrodes are used in the devices from which plasma arcs with power levels of up to 10 MW and greater are generated. Power systems that supply alternating current, or that use diode-bridge or thyristor-based rectification to supply direct current, are used to provide energy for the plasma devices.

In its philosophy regarding plasma, Mintek aims at bridging the gap between important small-scale fundamental research into plasma and actual industrial pyrometallurgical applications. A flexible multi-purpose pilot-plant facility, comprising several plasma units, is being built for the study, among other processes, of the technology of ferro-alloy production with a variety of plasma-arc systems. The transferred-arc approach is receiving priority following the successful smelting of high-carbon ferrochromium. The realization of full-scale operation is the present object of the South African ferro-alloy industry and Mintek is co-operating with several producers for the achievement of this goal.

INTRODUCTION

Many myths have arisen around the term plasma, primarily as a result of the various types of plasma and their very different applications. As an introduction to this paper, a suitable definition of 'thermal plasma', in the context of its potential pyrometallurgical applications, is necessary. A 'thermal plasma' is essentially a gas phase with an energy content sufficiently high that the ionization of a substantial proportion of the matter present is realized, and therefore permits the favourable conduction of electrical energy.

The fundamental factors that make 'thermal plasma' a potentially invaluable tool for use in the field of pyrometallurgy, and in particular for the production of ferro-alloys, are as follows: the very high energy concentration for controlled heating purposes, the 'chemically pure' high-temperature capabilities for the processing of refractory oxides, the treatment of which is difficult, and the unique electrical characteristics that offer flexibility for the processing of a wide range of substances. Although the actual temperatures within the plasma zone itself are generally very high (10 to 20 x 10^3K) this does not imply that the process would be at a temperature above the desired level.

'Thermal-plasma systems' can be divided into two categories, namely: (1) transferred-arc plasmas, and (2) non-transferred-arc plasmas. Simplified examples of the two categories are shown schematically in Fig. 1[1,2].

A transferred-arc plasma system is normally operated from a direct-current electrical-power supply. The electrode is generally the negative connection, i.e., the cathode, and the bath to which the arc is transferred is the anode or positive connection. The salient feature of this transferred-arc arrangement is the integral part that the electrical path of the plasma arc forms with the furnace, i.e., the anode is externally located from the plasma gun in, for example, the hearth of the furnace.

A non-transferred-arc plasma can operate from an alternating, or a direct-current, electrical-power-supply system. The two electrodes that carry the current are normally closely spaced and are often externally located from the vessel in which the materials are processed. The important feature of this non-transferred-arc configuration is the quite separate route that the electrical path takes from the vessel or furnace in which the process takes place.

A non-transferred-arc heater device is shown in Fig. 2[3]. The high temperature plasma 'tail flame' can be contained effectively in the equivalent of the raceway of a blast furnace by the use of a coke-filled shaft, as proposed by Santén[4].

The examples in Figs. 1 and 2 refer to the use of water-cooled, so-called non-consumable electrode-plasma systems, but the possibility of avoiding these water-cooled systems by the use of consumable graphite electrodes has been considered[5,6,7]. In addition, hybrids of one form or another have also been developed.

The aim of this paper is a brief review of work done in the study of the role of plasma in those fields of pyrometallurgy that bear some resemblance to, or in fact are directly aimed at, specific ferro-alloy processes.

A number of articles covering reviews of the applications of thermal plasma to pyrometallurgy have been featured in publications in the past few years[8,9,10,11]. Some of these articles have dealt with aspects of the processing of selected ferro-alloys, but the overall potential for the production of ferro-alloys by the use of plasma technology has not been covered.

DISADVANTAGES OF THE SUBMERGED-ARC FURNACE

The submerged-arc smelting furnace that has been the tried and tested processing equipment for ferro-alloys for over three-quarters of a century has some distinct disadvantages[12], of which some examples are as follows.

1. The feed materials must be carefully sized, and very often agglomerated, for the achievement of adequate metallurgical results.

2. The electrical characteristics of the burden, the slag, and, in particular, the nature of the carbonaceous reducing agent, often impose constraints on the optimum process efficiency.

3. The fact that a method of direct regulation of the rate of descent of material into the high-temperature reaction zone of the furnace is not possible limits the degree to which the temperature, and hence the chemistry of the process, can be controlled.

4. The size, and thus capital cost, of a submerged-arc furnace, is much greater than is dictated by the reaction zone alone because of the large volume of burden that is unreacted, or merely partly reacted.

5. Long time constants are a feature of the submerged-arc process. The feed-forward and feed-back control is difficult and this causes the familiar response characteristics, of overshoot and undershoot, of the operation[13].

6. Problems often arise with the self-baking Soderberg electrodes because wear and breakages impede the maintenance of a constant length. Long stoppages cannot easily be tolerated, especially in larger furnaces where the diameter of the electrodes is large.

Despite these disadvantages many recent developments have been made in the field of ferro-alloy production in submerged-arc furnaces[13]. They include increase in physical size and power rating, progress in agglomeration, preheating, and prereduction techniques, computer-aided control and optimization, and improved understanding of the metallurgical reaction zones in such large ferro-alloy furnaces.

POTENTIAL ADVANTAGES OF PLASMA-ARC TECHNOLOGY

Plasma-arc technology offers several potential, or successfully demonstrated, improvements in the processing of ferro-alloys, including the following.

1. The configuration of certain plasma systems so that the more abundant, relatively cheap, fine feed materials, can be treated direct, i.e., without costly agglomeration, is a noteworthy advantage. Preheating and prereduction of unagglomerated fines can thus be considered, for example, in rotary kilns or fluidized beds prior to being fed to the plasma furnace as a means of energy

conservation. The use of lumpy and agglomerated material is also not precluded.

2. The use of a wider range of potentially less costly carbonaceous reducing agents than is the case in conventional furnaces is feasible in several of the known plasma systems.

3. Direct feed-forward control as regards the feed rate and input of electrical energy can be realized by the use of well-established principles of thermodynamics and energy balances for the maintenance of steady-state conditions at a selected optimum process temperature.

4. Water-cooled plasma guns or electrodes can be used on a reasonably large scale, and this could result in considerable savings in costly graphite electrodes.

THERMAL PLASMA : NON-TRANSFERRED-ARC SYSTEMS

SKF Steel & Engineering AB, Sweden

In the early 1970s SKF Steel's research into metallurgical reduction concentrated on plasma technology. Two processes were developed, one for the production of sponge iron (PLASMARED), and the other for the production of pig iron (PLASMASMELT)[4].

The PLASMASMELT process, shown in Fig. 3, is based on two stages; a prereduction stage, consisting of two fluidized-bed reactors, and a smelt-reduction stage that produces the gas that is used in the fluidized beds.

The smelting stage consists of a refractory-lined low-shaft furnace. Coke is fed into the top of the furnace and fine prereduced iron ore, coal fines, and fluxes are fed in just above the hearth region. The energy for the reduction is provided by an arc heater of the non-transferred type. The arc heater is located in the base of the shaft furnace. The fine feed materials are injected pneumatically into the plasma-arc tail flame, through tubes mounted in the shaft-furnace wall around the arc heater. The electrical power supply for the arc heater consists of an off-load tap-changing transformer with air-cored reactors for short-circuit limiting. Initially, alternating current was used but it was found that electrodes lasted longer when diode rectification was incorporated in the power supply and the output was thereby converted to direct current.

The pilot-plant tests carried out by SKF at Hofors for the PILOT-SMELT process, were done with one 1,5 MW torch supplied by Westinghouse. Westinghouse have already developed a 3.5 MW torch, and are now developing a 10 MW torch, both capable of operation with a thyristor-based power supply[3]. SKF have recently indicated that they have developed their own PLASMASWEDE plasma generator[16]. Scale-up of the process to 60 MW and more is probably quite feasible with multiple-arc heater devices.

Quite reliable operation of arc heaters is claimed in industrial environments with electrode life of more than 100 hours. Electrode replacement is routine and they are reasonably inexpensive. A major apparent disadvantage of the process is the difficulty in operating arc heaters at energy efficiencies above about 75 per cent. However, the shaft furnace is probably thermally more efficient than the open bath-type furnace that is normally used in processes where the transferred-arc mode is applied.

SKF have patented the production of ferromanganese in the PLASMASMELT type process[14]. Fine manganese oxide ore is injected, together with powdered coal and fluxes, into the reaction zone of the coke-filled shaft furnace. A range of ferromanganese alloys, including those with silicon contents greater than 5 per cent (achieved with fine quartz, e.g., silicomanganese), can be produced. A typical slag-to-metal ratio is 0.5 and the energy consumption is 3000 kWh/t of metal for high-carbon ferromanganese, and 4500 kWh/t for silicomanganese with 18 per cent silicon[14].

Thus ferromanganese alloys can be produced by the SKF process on a pilot-plant scale, and the potential for scale-up looks promising.

SKF have also patented the production of chromium-iron alloys and stainless steel by the PLASMASMELT type process[15]. The content of chromium in these alloys is lower than that in high-carbon ferrochromium, but lower processing temperatures can therefore be used. A typical analysis of a chromium-iron alloy produced in the SKF shaft furnace is 19.6 per cent chromium, 0.32 per cent manganese, 1.2 per cent silicon, 4.8 per cent carbon, and the balance iron. This alloy can be refined in the conventional argon-oxygen decarburization process (AOD). The energy balance is claimed to be 25 per cent more favourable than that of the route for the production of stainless steel in which high-carbon ferrochromium is used.

The production of ferrochromium is also possible in a modified version of the SKF PLASMASMELT process. This PLASMACHROME process is discussed briefly in a recent SKF Bulletin[16].

Centre de Recherches Métallurgiques (CRM), Belgium

Unlike the direct-heating approach used by SKF, CRM have used the Westinghouse plasma-arc-heater system for the preheating of the blast prior to the tuyere of a small-scale commercial blast furnace[17]. The motivation for the use of this method for the preheating of the blast to a 'super hot' (2000°C) condition is based on the need for the replacement with alternative sources of energy of part of the metallurgical coke used in the blast furnace. The production of a 'super-hot' reducing gas can only be achieved by the use of such plasma-arc heating technology. Fig. 4 shows the incorporation of the arc heater into the blow-pipe and tuyere system of a conventional blast furnace. The blast furnace used for test purposes is located at the Cockerill-Sambre Company in Belgium and the findings can be summarized as follows[18].

1. The operation of the arc-heater system did not cause any major

problems of safety, i.e., electrical, and refractory wear was normal.

2. Electrode life within the arc heater was very short during the early stages but with experience life expectancy of the cathode was approximately 200 hours, and that of the anode was up to 800 hours.

3. The coke rate was decreased substantially from approximately 700 to 100 kg per ton of hot pig iron. Theoretically 80 kg per ton of metal is feasible.

The plasma system and the associated concept of the blast furnace appear to have merit for the production of pig iron in countries with expensive coke and relatively cheap electrical power[19]. The production of ferro-alloys by this indirect method of preheating the blast, rather than by the heating of the interior of the shaft directly, as proposed by SKF, has not been investigated but is a possibility.

THERMAL PLASMA : TRANSFERRED-ARC SYSTEMS

There are numerous examples of transferred-arc plasma systems but only those with some potential for the production of ferro-alloys are considered here. The Linde Division of Union Carbide introduced the first industrial prototype of a transferred-arc plasma system[20]. A discussion follows of the transition from conventional submerged-arc furnaces, through furnaces with hollow electrodes, to furnaces with water-cooled plasma torches.

Consumable Electrode Systems: Demag

For the production of calcium carbide Union Carbide developed a method for the feeding of fine lime down a hollow Soderberg electrode. A method is described in a recent Demag patent[6] for the smelting of high-carbon ferrochromium in an electric reduction furnace, into which fine feed materials are fed via a hollow electrode. The feed can consist of prereduced ore fines. Selected ore is also charged similarly to the normal submerged-arc furnace, for the refinement of the carbon in the metal. This also controls the liquidus temperature of the slag at a relatively high value to aid refinement of the carbon by the metallic oxides of iron and chromium. The carbon content of the ferrochromium that is produced in this manner is lower than that produced in the conventional submerged-arc furnace, namely 4 to 6.5 per cent instead of approximately 7 per cent. This system cannot be termed a classical transferred-arc system because the power supply is alternating current, and the bath of the furnace is shrouded with burden.

Consumable-electrode Systems: ASEA, Sweden

ASEA, together with Stora Kopperberg, have developed the Elred process for production of pig iron[5]. As with the PLASMASMELT process a two-stage prereduction in a fluidized bed, followed by a stage of smelting reduction is proposed. However, for the Elred process a circulating fluidized bed is used, and the smelting furnace is radically different from the shaft-furnace concept used in PLASMASMELT, but bears some similarity to the Demag system. The conventional, circular, steel-melting-type furnace with three electrodes, has been replaced by a furnace with a single, central, hollow-graphite electrode operating on direct current, unlike the Demag system previously discussed[6]. The hearth of the furnace is made conductive and forms the anode connection for the direct-current plasma arc, that operates in the transferred-arc mode. The hot, prereduced fines of feed material are fed directly into the plasma through the hollow graphite electrode. Fig. 5 illustrates the furnace used for the Elred process.

The change-over from operation with alternating current to direct current has a significant effect on energy distribution and arc stability in the furnace. With direct current there is no commutation of the current each cycle and with sufficient current and a protective, stable, atmosphere, long stable arcs can be maintained without much arc stabilization (e.g. introduction of arc-supporting gases, constriction of the cathode jet, or other mechanisms of arc stabilization). In addition, much more energy is dissipated in the anode than in the cathode, so that the choice of the furnace bath as the anode ensures that the maximum amount of energy goes into the bath where it is required[21].

Another factor in the Elred furnace is the design of conducting hearth that ensures that the current flowing down the electrode spreads out symmetrically in the bath and flows down into the hearth[22]. This causes an electromagnetic stirring action which is claimed as equivalent to an induction stirrer. The symmetrical flow of current also results in the arc being perpendicular to the bath without any lateral direction imparted to it as in conventional open-arc furnaces using alternating current. This significantly reduces the problems of arc flare and 'hot spots' associated with open-arc furnaces. In addition, a foaming slag results from the carbon monoxide produced in the reduction reaction (the carbon boil), and this shields the refractories from the arc[5].

The testwork for the Elred smelting stage was done on a furnace of 30-ton capacity with a power input of 8 to 9 MW. Scale-up is not a problem because graphite electrodes capable of carrying 100 kA are already readily available and at the operating voltage of 300 to 400 V a 40 MW-furnace is quite feasible.

The processing of ferro-alloys has not been attempted in this type of furnace but presumably there is scope for such options as has been shown to be the case for the Demag system.

Non-consumable Electrodes: The Freital Steel System

Study of plasma-arc melting of steel started in 1965 in the German Democratic Republic (GDR) and in the Soviet Union (USSR). Further studies made on a small-scale pilot plant (3 tons) showed that the combination of the powerful, highly concentrated energy of the plasma together with the controlled atmosphere in the melting vessel gave fundamentally new conditions for the carrying out of these melting processes[23]. Scale-up to 3.5 to 4.0 MW per plasma gun (plasmatron) had been realized by 1973 at Freital Steel near Dresden in the GDR. The guns used were of the water-cooled, non-consumable, transferred-arc type with a tungsten cathode. The largest commercial furnace developed to date by Freital is rated at 19.8 MW and employs three plasmatrons[9]. A typical power supply from a thyristor based direct current system has an open circuit voltage of 660 V and a current of 9 kA. The normal operating voltage is between 300 and 450 V, dependent on the arc-stabilizing gas used (argon or nitrogen). In the 35-ton plasma steel furnace at Freital four plasmatrons are used, mounted around the side of the furnace, each torch feeding into the furnace from the side at an angle of about 30° from the horizontal. Control of the arc length is achieved by axial movement of the torches which for maintenance can be completely retracted from the furnace. Cathode life is longer than 100 hours and replacement can be achieved with minimum down-time.

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 technology is marketed in the Western World by Voest Alpine.

The plasma system is apparently deemed suitable for the production of ferro-alloys since reference was made in a recent publication[8] to the installation in the USSR of a 100-ton plasma furnace, based on the Freital system, for the smelting of ferro-alloys. Six plasma torches, mounted on the side walls, and supplied from a thyristor power source, are to be used. The current rating of the plasma torches is claimed to be 10 kA with a maximum operating voltage of 660 V. Fig. 6 shows the Freital System although some modifications are contained in a recent German patent, in which the location of the plasmatrons has been altered to face more or less in one direction[24].

Non-consumable Electrodes: The Daido Steel System

This transferred-arc plasma system is unusual in that a plasma-arc and an induction furnace are used in combination[25]. The plasma torch supplements the energy from the induction coil and the argon atmosphere provides protection of the melt surface as shown in Fig. 7. The power ratings of the plasma and induction systems are about equal and total about 1 MW. Since 1973 commercial use has been made of the Daido Steel's plasma-induction furnace for the processing of a variety of special alloys, e.g., stainless steel. Recovery values of alloys are very high and the quality produced is equivalent to that made of alloys in a vacuum-induction furnace. The scope for the smelting of ferro-alloys in the Daido system does not seem very great but the re-processing of metal fines, especially those of stainless steel, would be readily achieved[26]. The relatively small scale of operation would be the major detraction as far as the production of ferro-alloys is concerned.

Tetronics Research and Development Limited (TRD), in Great Britain

TRD has been carrying out research and development in the plasma field since the early 1970s. During this period it was believed by Tylko, who invented what was called the expanded precessive plasma device (EPP), that the full advantages of a plasma arc could truly be realized if the required chemical reactions were performed in the very hot plasma column. Only in this way could the very fast reaction rates be achieved. Various attempts were thus made to 'expand' the plasma zone for increase of the area in space through which the reactant particles could interact and thus achieve 'in flight' reactions[27].

The TRD torch is a water-cooled, tungsten-cathode, device with gas stabilization of the arc (argon) and direct current operation from a thyristor-controlled supply. A transferred-arc is set up between the cathode, and an anode ring, as shown in Fig. 8. Mechanical precession of the torch is used for rotation of the arc around the anode ring at high speeds. An 'expanded' plasma region is thus formed through which particular material is passed, and the 'in flight' reactions occur.

Tylko is now no longer with TRD, and is working on another expanded-plasma device, the sustained-shock-wave plasma device (SSP) at Minnesota University in the U.S.A. The achievement of 'in flight' reactions, particularly for the processing of ferro-alloys, by the use of the EPP proved difficult, and the furnace at TRD has been changed to an arrangement with the anode connection to the bath as shown in Fig. 8. Mechanical precession of the cathode is practised, but at lower speeds for distribution of the power of the plasma arc evenly within the hearth. Material for processing is fed through the roof of the furnace and partially shields the roof and upper refractories from radiation. Some degree of preheating will occur during the 'in-flight' passage of material but the main reactions occur in the bath. As with the Elred process, this arrangement takes advantage of the higher energy dissipation of the anode relative to the cathode. With a tungsten cathode the energy dissipation at the cathode is low (2 to 3 per cent) and with a well insulated furnace, this system has the potential for the achievement of very high energy efficiencies.

The TRD plasma-arc system has proved suitable for the production of ferrochromium on the 1.4 MVA pilot-plant scale[12]. With the use of Transvaal chromite, coal, coke, and suitable fluxing additions, on-grade high-carbon ferrochromium was produced with very high chromium recoveries (up to 98 per cent). The benefits that were demonstrated during the trials include the following. Fines can be treated directly without agglomeration. There is flexibility with regard to the choice of the carbonaceous reducing agent. The independent control of raw-materials feed and power input yields high controllability of the process, especially of temperature, and cost of maintenance of the water-cooled gun is low[28].

Only limited tests for the production of high-carbon ferromanganese have so far been carried out on the TRD transferred-arc facility[29]. The full evaluation of the production of high-carbon ferromanganese by this method is still being studied. It seems unlikely, however, that alloys with reasonably high contents of silicon could be produced without excessive losses of silicon monoxide.

The TRD plasma system should be capable of being scaled to a size economically and industrially viable, but further developmental work would be required before this goal could be realized.

Hybrid Systems: Consumable Electrodes

The Toronto System

The University of Toronto, Canada, has been working on a small 100-kW-scale system that uses three consumable hollow graphite electrodes[7]. These electrodes are inclined and an arc is struck between the tips. The electrical supply is merely a conventional three-phase alternating-current system and the electrode position is regulated to a set point for the chosen current. The arc region between the electrodes can be extended by the influence of a plasma-stabilizing gas, e.g., argon, hence the terminology 'extended-arc furnace' (EAF). The EAF has been used for smelting of iron ores, chromium ores, and high-grade manganese slag, as well as for the melting of metal fines. The potential for the production of ferro-alloys has been studied at Mintek and is commented on later.

Hybrid Systems: Non-consumable Electrodes

Bethlehem Steel

Bethlehem Steel has been involved for some time in the use of plasma, the work being based on the falling-film plasma reactor developed by McRae, shown in Fig. 9[30], in which an arc is set up between a tungsten cathode and water-cooled copper cylinder as the anode. The arc is stabilized by a gas (argon or nitrogen) that is introduced as a rotating jet. The solid reactant particles are injected into the stabilizing gas pneumatically and are centrifuged onto the anode inner walls, and form a film that melts. The melt flows down the walls, thus protecting the anode of the falling-film reactor, and achieving a long residence time of material in the reactor. The net result is good heat transfer, high conversion rates, and high energy utilization. The thermal efficiency is claimed as greater than 80 per cent. Another feature of the torch is that arc length varies up and down the anode column, dependent on the voltage and other factors, and it is not necessary to provide a sophisticated thyristor-based power supply to maintain arc stability. A simple direct-current welding transformer was used in the pilot plant tests.

This system has been used up to a scale of 1 MW for the production of iron and steel alloys, ferro-vanadium, molybdenum, and ferro-chromium.

The production of ferrochromium, and probably of ferromanganese alloys, is thus feasible with this plasma system, but scale-up limitations may handicap this approach to production of the ferro-alloys.

The Sustained Shock-wave Plasma System in Minnesota, U.S.A.

The sustained shock-wave plasma system (SSP) has been discussed in several recent publications[31,32,33,34]. The primary aim of the SSP system is the expansion of the volume of the plasma for the improvement of its capability, by the entrainment of a larger population of solid particles of feed than would otherwise occur. In the case of the earlier TRD systems this expansion of the volume of the plasma was attempted by mechanical precession of the plasma torch. The SSP system does not make use of mechanical precession of the torch for attempted expansion of the plasma volume, but makes use of what has been called an anode rotor[33]. A sketch of the SSP system is shown in Fig. 10.

Some 'in-flight' reaction was achieved during the processing of both Minnesota taconite concentrate and low-grade chromite concentrate from Stillwater, Montana, U.S.A.[31,32]. A 40-kW laboratory-scale SSP reactor processed these materials. Fine taconite concentrate (over 75 per cent less than 44 µm) was used in these tests and an above stoichiometric quantity (200 per cent) of graphite was used as the reducing agent for the achievement of metallization levels of iron up to about 30 per cent.

The chromite feed was also fairly fine (75 per cent less than 300 µm). Reduction levels attained were 53 per cent for iron, and only 7 per cent for chromium. The reducing agent that was used was 200 per cent of the stoichiometric value.

From the results achieved so far on the SSP it would appear that neither the energy efficiency nor the reaction kinetics are very favourable. Scope for improvement is apparent, but time will tell whether or not this SSP system can be scaled up, and operated at power levels greater than 1 MW, so that valid pilot-plant tests can be conducted.

The SSP system's potential for the production of ferro-alloys cannot therefore be fully appraised at this relatively early stage.

PLASMA DEVELOPMENT AT THE COUNCIL FOR MINERAL TECHNOLOGY (MINTEK), IN SOUTH AFRICA

Mintek realized the potential of plasma technology for ferro-alloys some years ago[2] and more recently was involved, on behalf of Middelburg Steel and Alloys (MSA) in the ferrochromium trials at TRD[12].

The first experimental facility built at Mintek was a 100-kVA, three-phase, alternating-current, diffuse-plasma system, similar in design to that at Toronto. This system proved quite amenable to the melting, and the smelting, of various ferro-alloys, but, its future scale-up potential is limited by the operating problems that would probably occur with the inclined electrodes. The three-phase power supply for the diffuse-plasma furnace was easily converted to a direct-current power supply with a three-phase diode bridge, and numerous tests were carried out with transferred-arc, direct-current plasma torches at the 100-kVA level.

Recently it was decided that a larger pilot-plant facility should be built for the testing of the various plasma configurations. A flexible thyristor-based power supply was purchased, consisting of two thyristor converters, 6-pulse, 750 V, 1800 A, capable of operation in series, in parallel, or individually. This provides a wide range of operation of voltage and current for transferred-arc and non-transferred-arc torches, and also allows for the testing of dual-torch configurations.

A transferred-arc furnace with three hearth anodes and vertical raw-material feed, as in the TRD system, has been constructed. Extensive testwork is planned with this pilot-plant facility. The processing of the ferro-alloys will be studied over a period of some five years.

The installation of a furnace with a non-transferred-arc heater at Mintek is not contemplated in the immediate future, although developments, especially at SKF in Sweden, are being studied with great interest. The lower thermal efficiency and apparently more complicated operation of the arc heater, when compared with the transferred-arc-torch, influenced the adoption of the TRD-type-system at Mintek. The greater apparent flexibility in terms of process chemistry also favours the transferred-arc approach. Also, the transferred-arc-torch concept leads to furnace design and ancillary equipment that simulate the vast local installed capacity in terms of submerged-arc furnaces, enhancing the possibility of the transfer of technology, involving little retraining of staff, and, importantly, the possibility of the conversion of existing units to plasma units at relatively little cost.

Furthermore savings in capital costs of new transferred-arc plasma furnaces should be possible since the hearth dimensions are no longer subject to the previous constraints. Thus the size of a unit can be decreased to accommodate only those aspects of the design that are needed for the achievement of the process metallurgy. For example, unreacted burden can be avoided and the furnace could be tapped continuously.

DISCUSSION

Numerous factors have influenced the development of Mintek's philosophy regarding plasma. There was an initial lack of response from industry to a survey by Mintek on plasma. This was attributed to the wide rift that then existed between the fundamental bench-scale plasma developments and the potential industrial applications. Mintek thus aimed at bridging this gap by the establishment of a flexible pilot-plant facility in which both the more fundamental, and also the applied aspects, of plasma technology could be studied. A multi-disciplinary research-and-development organization such as Mintek seemed a suitable location for such a plasma facility. The basis for this philosophy was the realization that the many factors affecting scale-up of plasma units to full industrial size can only be effectively understood by the focusing of attention on both the fundamental and applied aspects of plasma. These include factors such as a study of the existing and modified process metallurgy, design and operation of torches, as well as of furnace and power-supply systems, and the overall monitoring and control of the process. Mintek enjoys close co-operation with industry and the philosophy evolved for plasma stems in large measure from this relationship.

In the establishment of the plasma pilot plant it was realized that a major requirement of a suitable system would be the testing of the amenability of various local ores to processing by plasma technology and the determination whether modified or improved processes could be devised both technically and economically. The tests carried out at Mintek have shown that a wide range of materials can be evaluated with relative ease as a result of the extra degree of freedom that the plasma systems offer, i.e., in terms of the independence of the feed rate of material, and power input. Furthermore, alternative specifications for alloys can be realized with such flexible process metallurgy.

Mintek's fundamental research activities are primarily directed towards a better understanding of the efficiency of conversion from electrical to thermal energy. The effectiveness with which the thermal energy is utilized in the actual pyrometallurgical processing is also being studied. A detailed understanding of the influence of the characteristics of the power supply, (i.e., alternating or direct current), design and operation of plasma torches, (i.e., transferred- or non-transferred-arc), design of furnaces, (i.e., dimensions, open bath, or shaft type), feed input, location of the plasma torch, etc., is essential. Insufficient work has been carried out in these areas of research to date. Mintek's links with the more fundamental research into plasma are also being strengthened, thanks to the contact that members of staff have with some of the leading Universities in the U.S.A., Canada, and Japan. The Mintek-University of the Witwatersrand (Wits) Pyrometallurgy Research Group in the Department of Metallurgy at the University has made invaluable contributions to a better understanding of the characteristics of the slag and metal systems[13]. This background is necessary if the process metallurgy is to be optimized in the various plasma systems. Effectively, Mintek is endeavouring to develop the expertise, using a multi-disciplinary approach, for optimization of the overall process as regards mechanical, electrical, process-metallurgy, and control aspects.

The applied aspects being studied at Mintek cover the production of virtually all the ferro-alloys, iron and steel, and special alloys, as well as non-ferrous pyrometallurgy. Most of the attention, however, is being devoted to production of ferro-alloys at this stage. The direct collaboration with local industry is a further factor that will play a vital role in the successful transfer of technology.

CONCLUSION

It is hoped that, as a result of the research and development on plasma technology, Mintek will be in a position, in the not too distant future, to demonstrate to industry which plasma systems should achieve successful specific full-scale pyrometallurgical operations. In addition, assistance with the design and operation of plasma systems will be possible. Considerable pilot-plant work is necessary before this stage can be reached. The choice between, for example, the SKF non-transferred-arc heater system, configured in a low shaft furnace, and the transferred-arc, such as the water-cooled TRD torch, or the graphite-electrode Elred system, configured in the form of an open-arc furnace, is the type of decision that industry will have to make if, as seems probable, conventional technology becomes less economic, and perhaps obsolete. Mintek will not be able to devote equal effort to all the options, and thus the approach so far has been concentration initially on the open-bath transferred-arc furnace configuration, while a watching brief has been kept on other developments. Two good reasons for this choice are the better control afforded over the process metallurgy by this configuration, and the similarity to the geometry of conventional submerged-arc furnaces, and hence the relative ease with which existing plants can accommodate possible changes to new technology. There seems little doubt that before very long ferro-alloys will be produced in plasma-type furnaces, the only question is, in which type of plasma process?

ACKNOWLEDGEMENTS

This paper is published by permission of the Council for Mineral Technology (Mintek). Thanks are also due to the following colleagues at Mintek. Dr P.R. Jochens for valuable assistance with the philosophy developed for Mintek's approach to plasma-arc development and Messrs T.R. Curr, K.U. Maske, and J.F. Mooney for useful discussions. The helpful association with colleagues in the South African ferro-alloy industry is gratefully acknowledged as is the fruitful contact with Tetronics Research and Development Limited.

REFERENCES

1. SAYCE, I.G. Plasma processes in extractive metallurgy - Advances in extractive metallurgy and refining. London, *Trans. Instn. Min. Metall. Paper no.* 27, Oct., 1971. pp. 241-274.

2. HAMBLYN, S.M.L. Plasma technology and its application to extractive metallurgy. *Minerals Sci. Engng*, vol. 9, no. 3. Jul., 1977. pp. 151-176.

3. FEY, M.G., and MELILLI, W.J. The application of thermal plasma systems to economic scale ironmaking. Preprint 5th International Symposium on Plasma Chemistry. Edinburgh, Scotland. Aug., 1981. pp. 1-21.

4. SANTEN, S. Method of producing metal from metal oxides. *South African Pat.* 80/5045. Aug. 18, 1980. pp. 1-7.

5. BENGSTSSON, E., and WIDEL, B. The chemistry of the Elred Process. *Iron Steelmaker*, Oct., 1981. pp. 30-34.

6. RATH, G. Continuous smelting method for ferrochrome. *U.S. Patent.* 4,235,623, Nov. 25, 1980. pp. 1-3.

7. PICKLES, C.A., WANG, S.S., McLEAN, A., and ALCOCK, C.B. A new route to stainless steel reduction of chromite ore fines in an extended arc flash reactor. *Trans. Iron Steel Inst., Japan*, vol. 18, no. 6, 1978. pp. 369-382.

8. BHAT, G.K. Technical and commercial aspects of plasma heat applications in primary melting, secondary remelting and refining operations. *J. Vacuum. Sci. Technol., 18(3)*, April 1981. pp. 1293-1302.

9. CHANG, C.W., and SZEKELY, J. Plasma applications in metals processing. *J. Metals, N.Y.* Feb. 1982. pp. 57-63.

10. KUBANEK, G.R., GAUVIN, W.H., IRONS, G.A., and CHOI, H.K. The industrial applications of plasmas to metallurgical processes. Presented at the 4th International Symposium on Plasma Chemistry, Zurich, Switzerland. Aug., 1979. pp. 1-15.

11. RYKALIN, N.N., *et al.* Thermal plasma technology : Trends and engineering problems. Preprint, 9th International Congress, U.I.E., Cannes, 1980. pp. 1-23.

12. BARCZA, N.A., CURR, T.R., WINSHIP, W.D., and HEANLEY, C.P. The production of ferrochromium in a transferred-arc plasma furnace. Preprint 39th Electric Furnace Conference, Houston, Texas, Dec. 1981. pp. 1-27.

13. BARCZA, N.A., FEATHERSTONE, R.A., and FINN, C.W.P. Recent developments in the ferro-alloy field in South Africa. Twelfth CMMI Congress, Johannesburg, South Africa. May 1982. pp.215-224.

14. SANTÉN, S., and JOHANNSON, B. Method of producing molten metal consisting mainly of manganese and iron. *South African. Pat.* Application 81/1540. 5th March, 1981. Applicant - SKF Steel Engineering Aktiebolag. pp. 1-5.

15. SANTÉN, S., and EDSTRÖN, J.O. Method of manufacturing stainless steel. *South African Pat.* Application no. 80/7152A. 18th Nov., 1980. Applicant: SKF Steel Engineering Aktiebolag. pp. 1-14.

16. HERLITZ, H. SKF Steel secures first plasma plant order. *SKF Steel Eng. Bulletin.*, Jun., 1982. pp.1-8.

17. PONGHIS, N., VIDAL, R., and POOS, A. Operation of a blast furnace with super hot reducing gas. Presented - AIME Conference, Detroit. U.S.A. *AIME Ironmaking Proceedings*, vol. 38, 1979. pp. 224-229.

18. POOS, A. Plasma generators and their applications for the reduction and melting of iron. Preprint ISCOR Blast Furnace Symposium, Pretoria, South Africa. Jun., 1982. pp. 1-14.

19. FEY, M.G. Method and apparatus for electrically firing and iron blast furnace. *U.S. Pat.* 4,247,732. Jan., 27, 1981. pp. 1-8.

20. McCULLOUGH, R.J. Plasmarc Furnace, a new concept in melting metals. *J. Metals, N.Y.* Dec. 1962. pp. 907-911.

21. STENKVIST, S.E. Private Communication. 1982.

22. ASEA AB, Välteräs, Sweden. *German Pat.* Gleichstrom - Lichtbogenofen. 29 05 553 Kl: F27B - 3/08.

23. McCOMBE, C. Plasma-arc - a joint USSR/GDR Development in Electric Steelmaking, Steel Times Int., Sep., 1978. pp. 86-87.

24. ESSER, F., KLOPPER, D., and LACHNER, W. Metallurgischer Plasmaschmelzofen, *German Pat.* 29 51 120. 2 Jul., 1981.

25. ASADA, C., and ADACHI, T. Plasma induction melting. Neue Hütte, 1971, 16 (11) 657-660. BISI 20029. pp. 1-9.

26. SUGIURA, S., and FUJINE, M. Decarburization and denitrogenization of stainless steel by plasma jet. (KOON GAKKAISHI). *Journal of the Japanese High Temperature Society*, vol. 6, no. 4. 1980. pp. 155-162. (in Japanese).

27. TYLKO, J.K. *British Pats.* 1390351, 1390352, and 1390353. 7 Feb., 1972.

28. PAGE, D. Plasma - A new approach to ferro-alloy processing. *Metal Bull. Mon. (Supplement)*, April, 1980. pp. 47-49.

29. MONK, J.R. Applications of plasma to metallurgical processes. Proceedings, 5th International Symposium on Plasma Chemistry, Aug., 1981. Edinburgh, Scotland. pp. 162-166.

30. MacRAE, D.R. Plasma processing in extractive metallurgy : The falling-film plasma reactor. AIChE Symposium, series no. 186, vol. 75, 1979. pp. 25-30.

31. REID, K.J. Direct steelmaking based on solid plasma interactions. Proc. 53rd Annual Meeting, Minn. Section, AIME and 41st Annual Mining Symposium, 1980. pp. 6-1 to 6-25.

32. MOORE, J.J., REID, K.J., and TYLKO, J.K. In-flight plasma reduction of domestic chromite, *J. Metals, N.Y.* Aug., 1981. pp. 43-49.

33. TYLKO, J.K., MOORE, J.J., and REID, K.J. Extraction of metals in the new sustained shockwave plasma (SSP) reactor. Extraction Metallurgy 1981. Papers presented at the IMM Symposium, London. 21-23 Sept., 1981. pp. 234-256.

34. MASKE, K.U., and MOORE, J.J. The application of plasmas to high temperature reduction metallurgy. Draft for publication submitted to *High Temperature Technology*, Butterworth Scientific Ltd., Journals Division, P.O. Box 63, Guildford, Surrey GU2 5BH, England.