THE DESIGN AND OPERATION OF TRANSFERRED-ARC PLASMA SYSTEMS FOR PYROMETALLURGICAL APPLICATIONS

١) ABSTRACT

The current object of plasma Arc furnace is to assist the metallurgical industry with the evaluation of thermal plasma technology. Research into the identification of the design criteria that affect the scale-up and operation of plasma units is being carried out. A ١٠٠ KVA D.C transferred-arc facility was built by my own efforts for electrochemical projects and melting of Ferro-alloys. Lack of knowledge of the mechanisms of stray arcing and energy transfer emerged as the major obstacles to the establishment of optimum design criteria.

٢) INTRODUCTION

it is considered that when compared with the submerged-arc furnace used for the production of ferroalloys) that plasma systems exhibit the following general advantages.

(a) The direct use of fine feed materials is possible.

(b) Independent control of feed rate and power can be achieved.

(c) The electrical conductivity of the materials does not limit input of power.

(d) Cost savings on electrodes can be realized.

(e) Higher power densities, and thus smaller reaction vessels, are probable.

A direct current (D.C.) transferred-plasma-arc approach was chosen instead of a non-transferred system for the following reasons:

i. 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.
ii. Transferred-arc furnace is similar to the conventional submerged-arc furnace and the change to D.C. is relatively straight forward.
iii. Detected-up the industrial operation, when a graphite electrode is used, is not possible.
iv. Transferred-arc devices have low cooling-water losses (usually less than ١٠ per cent).
v. The aim of this paper is briefly to discuss the operation of the ١٠٠ KVA facilities and to examine the potential difficulties associated with scale-up of the transferred-arc system to a commercially viable size, e.g., ٣٠ MW.

DESCRIPTION OF THE ١٠٠ KVA FURNACE

The equipment has evolved to a stage where continuous steady-state operation can be attained for several days. Therefore test work can now be carried out primarily to investigate the process chemistry with only minor attention being required for the operation of the equipment. A diagram of the furnace is shown in Figure ١ and the equipment is described in the following six sections.

i. Furnace Shell

A cylindrical steel shell, ٦٢٠ mm in diameter, was lined with a cast able Magnesia refractory to leave an inner volume of ٥٧ liters; the tap holding positioned ١٠٠ mm above the hearth.

ii. **Anodes**

Three stainless-steel rods (type ٣١٦), ٤٠ mm in diameter, were embedded in the hearth ١٢٠° apart, to carry the current from the bath to air-cooled copper clamps. A permanent metal bath within the furnace completed the anode connections. Temperatures were measured centrally in each anode ١٥ mm inside the furnace shell by axially located thermocouples (type K).

iii. Cathode

A hollow graphite electrode ٥٠ mm in diameter, with a ١٠ mm bore, was used as the cathode, connected via a water-cooled clamp to the power supply and support frame. The electrode was suspended vertically in the centre of the furnace with sufficient hydraulically controlled movement to reach the anode for arc ignition. Provision was made for mixtures of argon and nitrogen to be passed down the centre bore at ٥ to ٥٠ £/min to supply the plasma stabilizing gas. An arc of between ٥٠ and ١٥٠ mm in length was usually employed, and over this range the arc column was typically ٢٠ to ٣٠ mm in diameter, stable, and vertical. The graphite electrode passed through a seal mounted on the furnace roof.

iv. Roof and Electrode Seal

The roof consisted of a steel shell lined with carbon and backed with magnesia cast able. Three ports were located in the roof, one centrally for the cathode, the other two peripherally to provide a feed and an off-gas port. Each port was lined with an alumina tube to protect the carbon from erosion. A water-cooled electrode seal provided a means of electrically isolating the cathode from the remainder of the furnace which was earthed for safety reasons. The seal was maintained by using two different types of refractory rings and a nitrogen gas purge.

v. Feed System

Two types of feed system were employed, a vibratory, and a screw-type feeder, which were sealed from the atmosphere right up to the furnace. The feed material in the hopper constituted the inlet gas seal, and this enabled the furnace to run under slightly positive pressure conditions. The feed materials were in the size range ٠.٢ to ٦.٠ mm and fed at various rates (٥ to ٧٠ kg/h) under gravity through the single feed port direct into the bath. No attempt was made to entrain the feed particles in the plasma-arc column.

vi. Power Supply

A ١٠٤ KVA three-phase transformer provided with an on-load tap-changer (٤٣to ١٧٣ V) supplied power to three single-phase line reactors. A variable reactance can be selected and was usually ٠.٠٤ a in the range ٠.٠١ to ٠.٦٤ a. A diode bridge arrangement provided full wave rectification Typical operating values were ٩٠ V, ٨٠٠ A, and ٧٢KW measured across the cathode-anode bus bars.

DISCUSSION OF THE OPERATION

The operation was aimed at the reaction of metal oxides in a liquid slag with a solid carbonaceous reducing agent in the bath of the furnace to

Yield a product metal.

i. Procedure

An initial arc was struck, and small amounts of a conductive metal were fed, which generated a molten pool under the cathode, followed by gradual heating (٦ to ٨ hours) at low power (٢٠ to ٣٠ kW) to bring the furnace up to a hearth temperature of about ١٦٥٠ A ١٠٠ mm 'heel' of metal was established during this time by the addition of further metal. The power input was varied to establish steady-state conditions as determined by the lining thermocouples (Figure ١). The power required to maintain these conditions, although determined in the absence of feed, was assumed to be constant under feed conditions also. Therefore a straight-line relationship between available power and feed rate was established from a calculation of the energy requirements of the desired reactions using standard thermodynamic data at ١٦٥٠°C. The furnace was then fed continuously using the feed rate — power relation¬ ship determined, but with monitoring of the process for fine adjustments throughout, i.e., lining thermocouples, dip samples, visual observation, and dip thermocouple (Q.I.T.) measurements. Ideally, the bath should remain fluid, and be covered with a thin layer of reacting feed material throughout the feeding period, after which the feed should b stopped, final measurements should be made, and the furnace tapped, although a further period of treatment could be carried out if necessary.

ii. Difficulties

The following problems encountered during the operation of the furnace resulted in significant improvements to the design.

i. Anode burn-through. A rapid (less than ٢ min) event leaving the refractory surrounding the anode almost intact. This resulted in three peripherally placed anodes replacing a central anode, but most
ii. Important was the maintenance of a ٥٠ to ١٠٠ mm metal heel at all times.
iii.

Stray arcing. Usually manifested by an increase in arc current without response to upward cathode movement. Apparently an additional current path consisting of cathode, carbon roof, steel shell, and anodes earth is established. An extremely irregular event which could occur at any time in the operation but most likely with long (high voltage) arcs, high furnace-roof temperatures, and the absence of feed. The use of a well-designed electrode seal and adequate purge gas greatly minimized the frequency of these events which seldom caused appreciable damage when eliminated rapidly (i.e., in less than ٢ min). The transformer was tapped down, the cathode was lowered, and occasionally the power was switched off briefly, to eliminate the stray arcing. Roof damage. Over heating and collapse of the roof refractory was solved by the use of a carbon lining. This was feasible because of the highly reductive conditions maintained in the furnace for the process chemistry.

iv. SCALE-UP

The success of this operation at ١٠٠ kVA scale for a number of Ferro-alloy processes, and at ٠.٥٥ MW for ferrochromium) led to a consideration of the scale-up requirements for commercial implementation. The furnace efficiencies achieved previously (٥٥ and ٨٢ per cent at ٧٠ kW and ٥٥٠ kW respectively) led to the assumption that a direct scale-up to ١٠ MW or greater would yield comparable efficiencies to submerged-arc practice, i.e., about ٩٢ per cent. The installation of a ٢٠ MVA industrial unit(٢) reflects confidence in the assumption. The testwork was conducted at similar power densities (٠.٥ MW/rrr) to those of current submerged-arc practiced), but the more constricted nature of a single d.c. plasma arc implies that much larger power densities are feasible. A examination of the scale-up problem in more detail is therefore of relevance. The two major areas of significance are the power supply and the furnace diameter which are discussed in the following sections for the specific case of ferrochromium at ٣٠ MW scale

v. Power Supply

i. The testwork done(l) defines the voltage range that can be used, e.g., ٤٠٠ to ٦٠٠ V which, in turn, fixes the current required, i.e., ٧٥ to ٥٠ kA. The choice of a single plasma device of this capability is limited at present to a graphite electrode in a similar arrangement to the ١٠٠ kVA furnace previously described. Water-cooled devices that would need to be employed in a multi-device configuration (which involves interactions between the arcs(٤)), are not considered here. However, a single water cooled device would place even fewer restrictions on the furnace geometry than a graphite electrode because of its smaller size and is effectively included in the discussion.

ii. The voltage range chosen implies an arc length and thus defines minimum bath-to-roof height. The influence of stray arcing suggests that the distance from the arc column to the walls and roof should be similar to the arc length to enhance a preferential electrical path via the bath.

iii. <u>Furnace Geometry</u>

The arc length, and the type of plasma device, define some areas of the furnace geometry but the choice of furnace internal diameter can, in principle, be selected within wide limits. The conventional method(٥) of scaling-up furnace diameters for submerged-arc practice is not applicable to a transferred-arc, single-electrode, open bath situation, largely because this method depends on burden and slag-resistance paths that are not significant in the plasma furnace. The relation between the internal diameter of the furnace and the power density (relative to the same diameter), at various power levels, is shown in Figure ٢. Conventional submerged-arc practice typically utilizes a power density of ٠.٥ MW/m٢ but preliminary observation of the ١٠٠ KVA furnace operating at greater than ١ MW/m٢ suggests that in an open-bath system much higher power densities could be utilized. The potential advantages of employing power densities of ١.٥ to ٢.٠ MW/m٢ are substantial as can be seen from Figure ٢, and imply a reduction in diameter from ٩ to ٥ m at ٣٠ MW. The limitations of employing such power densities are likely to be

(i) Chemical reaction rates, or

(ii) Energy transfer rates.

The chemical reaction rates were observed as extremely rapidH) and could be further improved with stirring, better distribution, and bath injection techniques. The effect of power densities upon the energy transfer rates, however, remains an unknown quantity because of a lack of knowledge of the energy-transfer mechanism from a plasma-arc column to the bath, roof, and side walls of a hot furnace.

CONCLUSIONS

The ١٠٠ kVA furnace demonstrated the advantages of transferred-arc plasma processing for ferro-alloys, particularly the metallurgical control, at similar power densities to those used in submerged-arc furnaces.

The scale-up of these plasma furnaces to ٣٠ MW at similar power densities, with adequate efficiencies, appears feasible, but it is evident that considerable scope exists for improving scale-up by the employment of higher power densities.

The attainment of these high power densities is at present limited by a lack of understanding of the mechanisms of stray arcing and energy transfer.