Practical Aspects of DC Furnace Design

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ABSTRACT

This paper describes some of the practical aspects of the design of DC furnace's for smelting applications. DC furnaces have become accepted as a viable technology for a growing number of smelting applications viz.

- chromite
- ilmenite
- spent catalyst
- alloy steel dust and residues.

The development and acceptance of the technology at an industrial scale has been tempered by problems with harmonic generation in the electricity supply network, limits on electrode size and therefore current carrying capacity, roof damage due to stray arcing, excessive refractory wear and anode life. Recent developments in a number of these areas has led to many of these problems being minimised or overcome.

1. INTRODUCTION

The utilisation of DC Plasma Arc technology as a metallurgical processing tool has expanded over the last several years. This growth has been for a number of reasons, principal amongst which are:

- the relative ease of operation
- the ability to process fine and cheaper raw materials without pre-treatment
- improved control over process chemistry
- improved power utilisation
- lower electrode consumption

This technology has been successfully applied to:

- the smelting of fine chromite ores
- processing of titania bearing sands
- recycling of spent oil refinery catalyst
- the treatment of dusts and residues
- the production of antimony
- the reduction of copper/nickel slags

DC furnaces have experienced problems in several areas:-

- power rectification equipment causing harmonics in the electricity supply grid necessitating the installation of expensive filtration equipment
- furnace components, specifically the roof and upper sidewalls which were subject to damage from stray arcing, and the anode and refractories.

In the past five years, Pyromet has designed and supplied DC furnaces that have incorporated advanced technology that largely overcomes the problems listed above. This paper describes the principal advances employed.

2. POWER RECTIFICATION EQUIPMENT

Although DC Arc technology was demonstrated over a hundred years ago, its increased growth can be attributed to the developments in the semiconductor industry during the seventies; in particular high power rectification equipment.

Thyristor control, because of its demonstrated reliability and availability, had until recently, been the standard for DC plasma furnace applications. However recently there has been a move towards utilising transistor controlled rectification equipment [1]. The two major developments that have driven this are:

- the development of large insulated gate bipolar transistors (IGBT)
- more stringent requirements for the minimisation of voltage and current harmonics in power supply networks. (See Table 1.)

The overall effect is that the higher cost of a rectifier incorporating an IGBT chopper system is offset by the cost of power factor correction, harmonic filters, tap changers and large reactors required for thyristor based system.

TABLE 1: COMPARISON OF IGBT AND THYRISTORS

PARAMETER	IGBT	THYRISTORS
Relative component cost	High	Low
Distortion of power supply	Low	High
Harmonic filtering required	No	Yes
Cost of transformers	Low	High
Cost of reactors	Low	High
Unit efficiency	Low	High
Power factor	High	Low

Pyromet has installed a 10 MW supply based on the IGBT system, and it has been operating successfully for over a year.

3. FURNACE DESIGN PARAMETERS

3.1 ROOF

It has been clearly identified [2] that water ingress into the furnace, particularly if the refractory lining is based on Magnesite, can cause premature failure of the lining and possibly mechanical damage due to explosions.

The main reasons for water leaks in the production of ferrochromium has been identified as stray arcing onto the roof structure. Stray arcing occurs when the control of the arc allows for the preferential path to the molten bath to be transferred to the roof. Most of the roof configurations have been based on water cooled sections protected by refractory bricks and castables. Water cooling is necessary because of the high heat load placed on the roof in the open arc process. The conductive nature of the furnace atmosphere and perhaps volatile metal/slag mixtures frozen on the upper sidewall and roof areas, usually results in arc impingement and refractory/mechanical damage in unprotected furnaces. Damage to water cooled sections results in water leaks into the furnace.

Two obvious routes to limit this damage are:

- design components to cause the minimum water ingress
- reduce or eliminate stray arcing

The first option has been achieved by utilising low pressure cooling systems, which if holed, results in minimal water ingress. This approach has been enhanced by designing and installing components which can be rapidly isolated and easily replaced. More details of this approach are presented in reference [2].

Pyromet's patented approach [3] is to reduce the chance of stray arcing occurring by the minimisation of the voltage gradient by the distribution and stabilisation of the electrode to roof gradient across multiple electrical insulation gaps adjacent to concentric metallic sections of the roof.

3.2 ANODE DESIGN

The plasma arc is transferred from the cathode (normally a graphite electrode) to the anode via a conduction path in the hearth. There are several commercially available anode arrangements [4], [5]. However it is Pyromet's experience that for a diverse range of smelting applications , the anode design must be approached on a case-by-case basis

Steel based anodes (pins or concentric rings) are suitable for steel plant dust smelting, whereas matte smelting requires a protective layer of conductive refractory or a conductive hearth.

At higher smelting temperatures of 1600-1800°C (FeCr and ilmenite smelting), problems have been encountered with the integrity of the ramming materials with steel based anodes and more reliable campaigns have been achieved with conductive hearths.

Above 2000°C (alumina catalyst smelting), the degree of superheat in the reduced metal alloy becomes a problem. The amount of superheat can be up to 700°C and such alloys are extremely penetrative. To contain such alloys it has been found necessary to construct the hearth and anode from close tolerance carbon blocks which virtually form a monolithic hearth in service. This necessitates substantial water cooling in the hearth region to maintain the structural and dimensional integrity of the furnace shell.

The key to good anode/hearth design is a thorough analysis of the heat distribution and flow and the stress pattern using finite element analysis. Pyromet have found the 3D Algor package to be invaluable in this respect.

3.3 REFRACTORY PROTECTION

The furnace refractory lining that is selected obviously must be compatible with the process requirements. The degree to which the furnace is then cooled with air or water depends on the operating temperature (and therefore the quantity of heat to be removed) and the power density (which determines the severity of stirring and the temperature at the refractory/melt interface). Many factors come into this discussion and again, the Algor programme facilitates the decision making process. For the purpose of this paper it is sufficient to point out the more recent cooling systems that have been successfully implemented.

Figure 1 shows the cross-section of a typical dc furnace designed to operate above 1800 °C at a relatively high power density of 790 kW/m².

The roof panels and upper sidewalls are cooled by high pressure water passages fixed to the inside of the panels and encased with castable.

The crucible has a hot face lining of magnesite brick with a high thermal conductivity. The outer lining consists of water cooled copper panels lined with castable. Copper fingers protrude into the refractory but the water cooling passages are drilled into the base panel and are external to the furnace. This configuration ensures that no water will be forced into the furnace if the copper fingers are damaged.

External water channels are welded to the outside of the shell in the lower hearth region and underneath the hearth. This helps to remove the heat generated by the passage of current through the hearth to the anode.

An alternative design to the copper fingers has been installed in a slag cleaning furnace and this is shown isometrically in Figure 2.

4. CONTROL ASPECTS

4.1 FEED

One of the most important factors in DC Plasma Arc processing is controlling the feed to power ratio according to the conditions in the crucible. Feed control also has a major affect on the control of voltage, current and power.

Higher feedrates than required result in arc instability, and the raw materials do not assimilate into the molten pool. This can cause preferential arcing, reduce process temperatures and can be a source of tapping difficulties. Lower feedrates than required can result in excessive process temperatures, driving side reactions which alter process dynamics and the danger of excessive refractory attack resulting in breakout.

The facility to vary the quantity of material fed down the centre of the hollow electrode or through roof ports offers the operator an extra element of control.

The active crucible can be represented by concentric temperature rings radiating from the centre to the face of the protective banks/refractory layer. Controlling the position of entry and the feed rate allows the operator to establish the dimensions of the molten bath and the temperature and process chemistry within the active crucible.

Feedrate control can be achieved by a combination of measurement of the instantaneous feed as well as the integrated loss in weight from a feed bin. The feedrate is then balanced with the furnace power to produce the required feed to power ratio.

4.2 ELECTRODE CONTROL

The control of the positioning of the electrode impacts on voltage, current and power. By providing a constant current output from the rectification system according to a power setpoint, and by controlling the electrode position according to a resistance setpoint, the voltage is indirectly controlled.

The speed of movement of the electrode is then, the only factor which is required to give a consistent furnace power control. The movement of the electrode is achieved by hydraulics.

5. CONCLUSIONS

Recent advances in power rectification equipment and techniques for minimising stray arcing have allowed Pyromet engineers to virtually eliminate many of the problems that have been experienced by operators of d c smelting furnaces. Coupled with innovative technology, this has resulted in the dc furnace now being considered as a viable alternative for an increasing range of smelting applications.

6. ACKNOWLEDGEMENTS

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7. BIBLIOGRAPHY

1. N. M. O'Brien and A. R. Jamieson, Application of DC Furnaces to Base Metal Smelting (Paper presented at the SAIMM Colloquium: Trends in Base Metal Smelting and Refining, Randburg, April 1997).

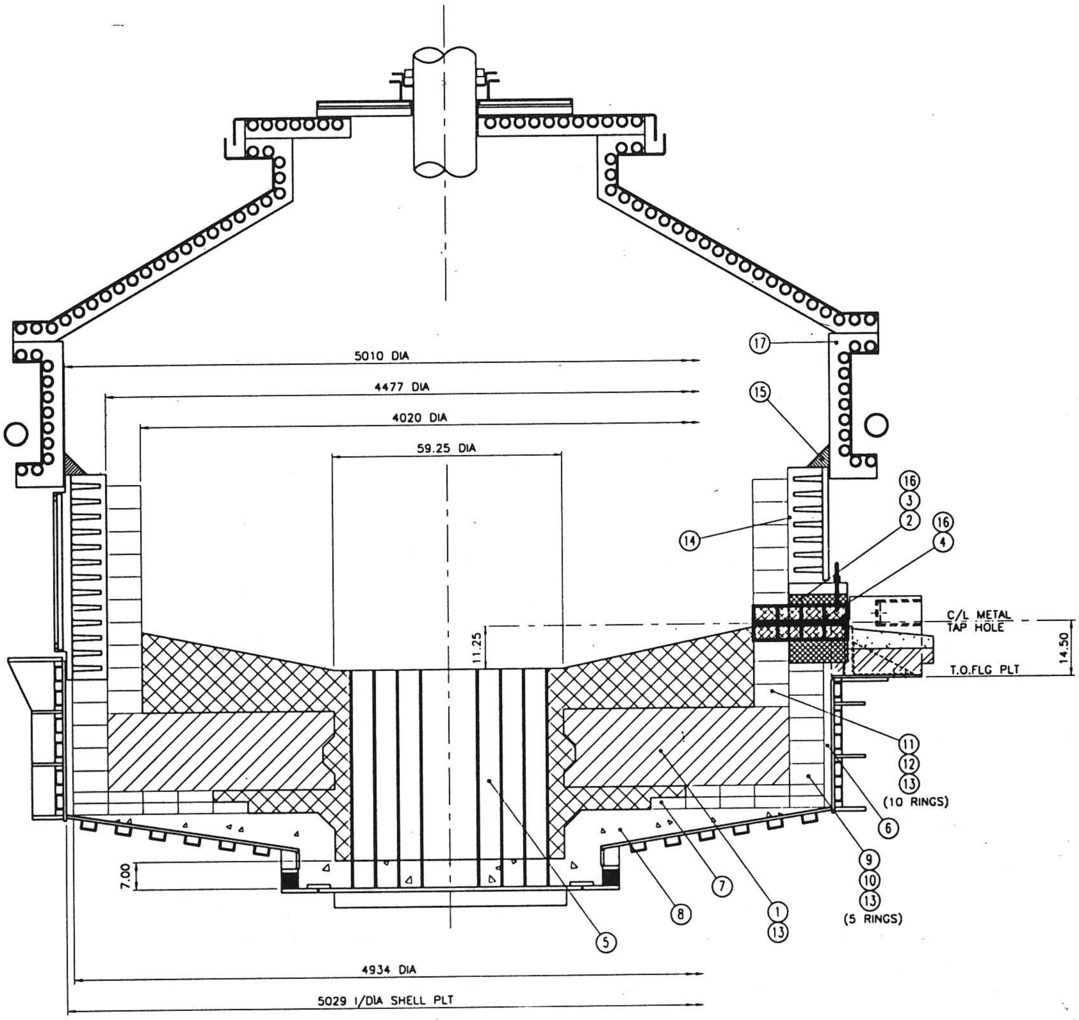
2. M. Ford and J. F. Oosthuizen, "The production of Ferrochromium in a 40 MVA DC Plasma Furnace," Proceedings of the seventh international Ferro Alloys Congress, Infacon 95, 263

3. A. R. Jamieson, "Methods of Reducing the Occurrence of Stray Arcing in DC Electric Arc Furnaces" (Provisional Patent Application No. 97/0482)

4. D. Hurd and J. Kollar, "A Growing Technology in Electric Steelmaking," EPRI Centre for Materials Production, 1/91

5. A. R. Jamieson, "DC Arc Furnace Anode Structure" (Granted S. A. Patent No 95/8389)

FIGURE 1



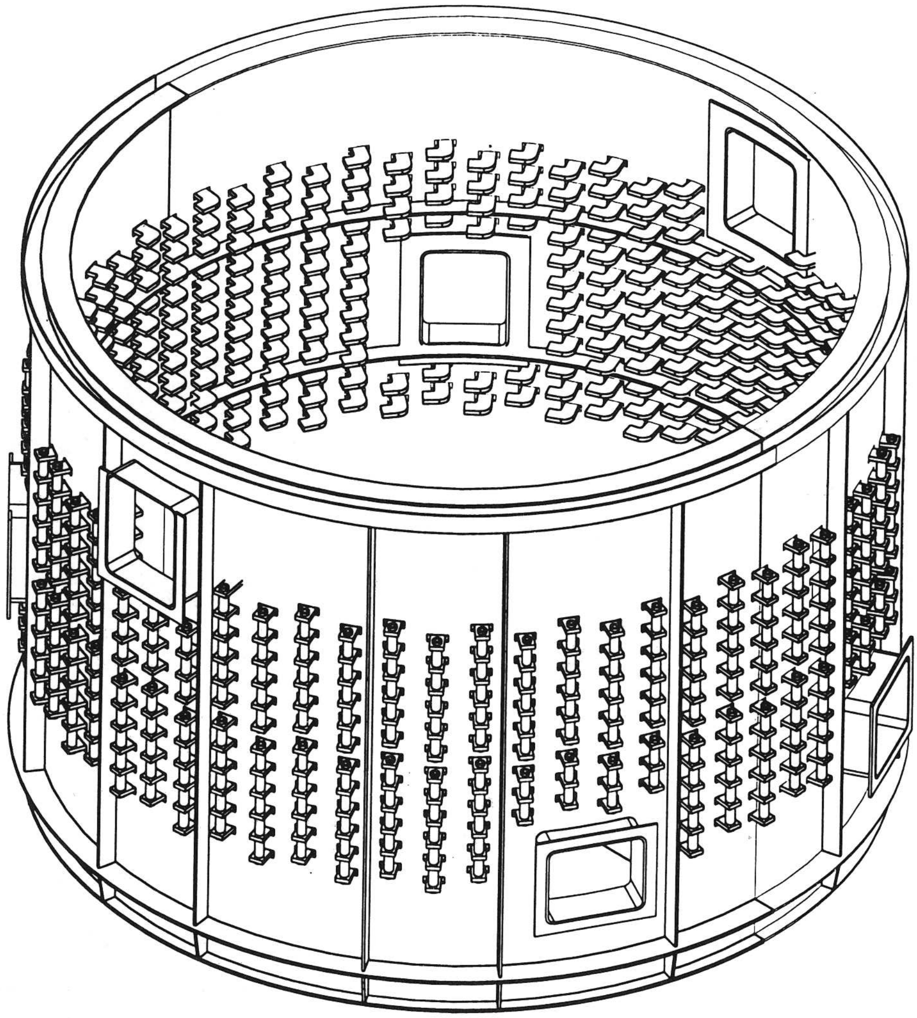
--- SECTION THROUGH METAL TAP HOLE ---

NOTE:-QUANTITIES ARE ACTUAL INSTALLED & DO NOT INCLUDE WASTAGE & BREAKAGE

ITEM	QTY	DESCRIPTION	MATERIAL	KG's	REMARKS
17	16,6m³	MAG-ALUMINA SPINEL	LCMAS	47300	
16	200kg	CARBON MORTAR	CC-3D	200	-
15	0,2m³	ALUMINA RAMMING	-	530	-
14	5,5m³	94% Al_2O_3 CASTABLE	HICAST 90	16280	-
13	40	25 kg BAGS Al_2O_3 MORTAR	95P	1000	-
12	540	99% Al_2O_3 BRICK	VR99	4400	-
11	1310	99% Al_2O_3 BRICK	VR99	10500	-
10	180	99% Al_2O_3 BRICK	VR99	1400	-
9	840	99% Al_2O_3 BRICK	VR99	6800	-
8	2,8m³	HR MgO RAMMING	-	8120	-
7	760	94% MgO BRICKS	-	6100	-
6	0,8m³	CARBON RAMMING G60T	G60T	1680	-
5	7,73m³	CARBON RAMMING CERRAM G90RTI	G90-RT	13300	-
4	4	CARBON TAPHOLES BLOCK	SCG-20	40	-
3	12	CARBON BRICKS	SCG-20	55	-
2	9	CARBON BRICKS	SCG-20	83	-
1	24	CARBON BLOCKS	BC-5	11200	

PYROMET

FIGURE 2



TYPICAL ISOMETRIC VIEW ON A PYROMET FURNACE
SHOWING COOLING ELEMENTS IN POSITION

PYROMET