DEVELOPMENTS IN THE DESIGN AND CONSTRUCTION OF DC ARC SMELTING FURNACES

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ABSTRACT

The aspect of sustainability of ferroalloy processes has long been a serious matter for consideration in many of the world's industrialized countries. A number of countries can be named where ferroalloy plants that were once flourishing, have all but disappeared. One of the most important factors playing a role in this type of occurrence is the cost and availability of quality raw materials.

Given that all natural resources will be depleted with time, users are compelled to develop new processes that are sustainable in the changing environment. The DC Arc Smelting Furnace is one such process that has proved itself, and has gained increasing popularity over the past two decades. This process, amongst other benefits, directly addresses the use of more readily available and more affordable raw materials in ferroalloy production.

Since early in the new millennium, GLPS has been involved in various studies for different clients with regards to furnaces for the production of ferroalloys. Two of these recent studies have culminated in the design, construction and commissioning of DC arc furnaces for the production of ferrochrome. One of these furnaces is a 10 MW unit at Mogale Alloys, and the other a 60 MW unit at the Middelburg Plant of Samancor Chrome. This paper discusses the approach taken in the design and construction of these two furnaces, which, although varying significantly in size and capacity, are very similar in many other aspects of their design.

1 INTRODUCTION

During INFACON 7 held in Trondheim in 1995, a presentation was made on the production of ferrochrome in a 30MW (40MVA) DC arc furnace[1]. This furnace has been a low cost producer of ferrochrome for more than 20 years.

During the 15 years prior to the present INFACON, three more DC arc furnaces were designed and built for the production of ferrochrome in South Africa. The smallest of these is a 10MW unit, which was commissioned at Mogale Alloys during August 2009. The largest of these was commissioned during May 2009, and is successfully being operated at a level of 60MW by Samancor Chrome. All three furnaces mentioned were designed and built on a Brownfield basis by GLPS in close co-operation with project teams from the various clients. To date, DC arc smelting furnaces up to a capacity of 70MW have been designed.

This paper will touch on the motivation for selecting DC arc furnace technology, and also on the project approach used. It will concentrate, however, mainly on engineering aspects such the design of the DC arc furnaces themselves, and the various types of auxiliary equipment utilized for these furnaces.

2 TECHNOLOGY SELECTION

In selecting the most suitable process technology for a commercial venture, two considerations usually take precedence:

- The selected process technology must be sustainable for the duration of the investment, taking into account all factors such as environmental considerations and the availability of resources.

- Both the process as well as the engineering technology must provide the user with a significant competitive cost advantage in the field of application.

Presentations at earlier Infacons have referred to the benefits of DC arc furnaces in ferro alloy production[2]. The following strategic aspects are pertinent to the selection of a DC arc furnace for the production of ferrochrome (and for certain other ferroalloys as well):

2.1 Raw Material Requirements

It is a known fact that sources of high grade raw materials worldwide are being depleted at a rapidly increasing rate. This is particularly true for lumpy chromite ore. The DC arc furnace is ideally suited for the efficient direct processing of chemically high grade fine ores, as well as of chemically low grade fine ores such as UG2 tailings from the platinum operations.

A further major benefit in terms of reductant requirements is that the DC arc furnace does not require the use of very expensive and increasingly scarce coke. Coal and anthracite are normally used as reductants. Both the reductant as well as the flux requirements can be made up from material sized below 20mm, which is often not ideal for other operations, and therefore more readily available.

2.2 Environmental Considerations

Due to the very high reducing conditions attained above the open bath of a DC arc ferrochrome furnace, the fines captured in the furnace off-gas system contain no hexavalent chrome, which facilitates disposal of this waste product. Furthermore, due to its ability to process fine materials, the DC arc operation lends itself to the processing of environmentally unacceptable fine wastes such as baghouse dusts from other furnace operations, recovering the contained metals and producing a relatively benign slag with a very low content of heavy metals.

2.3 Operating Cost

It is common knowledge in the ferroalloy industry that the DC arc furnaces currently in production, have for a number of years now consistently shown themselves to be low cost producers, even when compared to conventional submerged arc furnaces situated considerably closer to their main sources of ore.

DC furnaces are cost competitive in spite of their main disadvantage, namely a relatively high specific energy consumption. Given the rapidly rising cost of electricity in South Africa, however, this aspect is cause for concern, and merits specific attention.

One last factor to be mentioned is the fact that due to the high operating temperatures and high reduction efficiency of a DC arc operation, high recoveries and an excellent metal from slag separation is obtained, and the resulting metallic content in DC arc ferrochrome slag is virtually zero. No metal from slag recovery operation is therefore required.

2.4 Capital Cost

An accurate comparison of capital cost between a DC arc and a conventional submerged arc furnace plant will obviously depend on a number of factors. The main item to be borne in mind, however, is the increasing scarcity of lumpy ore. This strongly implies that future submerged arc ferrochrome plants will have to include an agglomeration plant, such as a pelletizer. Based on the experience of GLPS, the relative capital costs of a brownfields DC arc plant, compared to a brownfields submerged arc plant, will be approximately as shown in Table 1, below.

Table 1: Comparative Capital Cost

<table>
<tr><th>Description</th><th colspan="2">Relative Cost</th></tr>
<tr><td>DC Arc Furnace</td><td colspan="2">100%</td></tr>
<tr><td>Submerged Arc Furnace</td><td>92%</td><td rowspan="2">136%</td></tr>
<tr><td>Pelletizing Plant</td><td>44%</td></tr>
</table>

3 PROJECT APPROACH

The following serves as a brief summary of the approach followed for recent successful DC arc furnace projects.

3.1 Plant Design

All design work for the relevant plant and equipment were done on with the latest 3-dimensional parametric design tools. An example of a plant layout drawing for a 70MW DC arc furnace plant is shown as Figure 1.

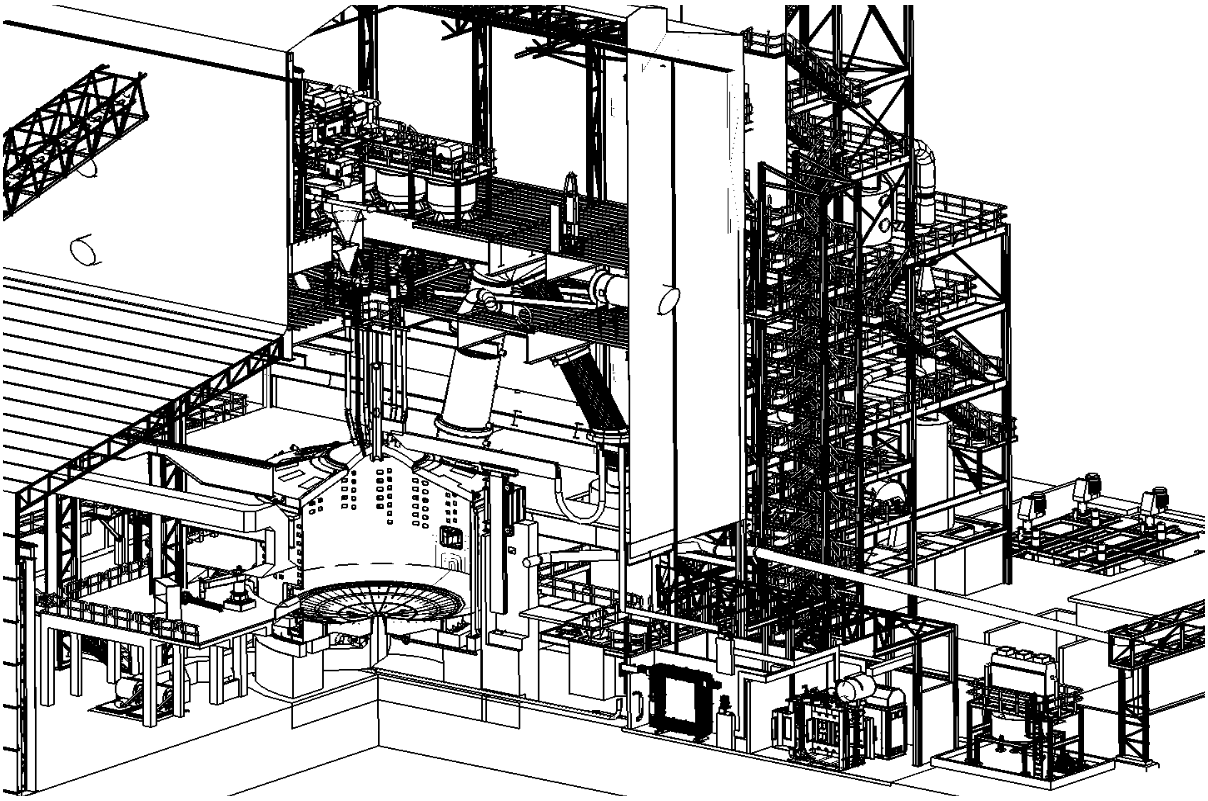

Figure 1: Section of 70MW DC Arc Furnace Plant

3.2 Project methodology

All projects were conducted on an EPCM (Engineering, Procurement and Construction Management) basis. From the beginning of the very first studies, personnel of all relevant disciplines of the Customer formed an integral part of the project teams.

Projects commenced with a pre-feasibility study, where baselines were established and costs were determined within 20%. A Design Base document was also drawn up for the project. The results of the pre-feasibility study would determine whether the project should continue, or be shelved. Once a decision had been taken to continue, a bankable feasibility study was conducted to determine capital cost to within a 10% accuracy. A detailed Project Execution Plan was then drawn up. This document served as the basis for obtaining Board approval for the execution of the construction phase.

The execution phase of the projects were managed and controlled by a Project Management Committee consisting of specialists in process, engineering and finances from both the Customer as well as the EPCM Contractor.

4 FURNACE ASPECTS

4.1 Electrode

Both 10MW and 60MW DC arc furnaces were each fitted with a single solid AGX grade graphite electrode. The sizing of the electrodes is summarized in Table 2.

Each graphite electrode is supported by a hydraulically operated mechanical arm, which can be raised and lowered as and when required. These arms also serve as current conductors to the electrodes. For maintenance purposes, the travel height of the electrode arms is such that each electrode can be raised to clear the furnace roof.

Table 2: Electrode configuration

Furnace		**Electrode**	
MW Rating	Max. Electr. kA	Dia. (mm)	Rating (kA)
10	32	400	43
60	90	600	92

4.2 Electrode Jointer

The joining of graphite electrodes on a DC arc furnace has in the past been one of the greatest contributors to furnace downtime. Electrode sections have to be added on at least once per day, with a minimum of 25 minutes furnace downtime resulting per operation.

A Piccardi automated electrode jointing system was installed on the 60 MW furnace as part of the project. An experienced team can now fit a new section onto a graphite electrode in a substantially reduced time frame, resulting in a significant increase in the average furnace availability. As the time of writing, a similar system had not yet been acquired for the 10 MW furnace.

4.3 Raw Materials Feed System

It is a requirement with DC arc furnace operations to balance raw materials feed rates with furnace power inputs. The feed into the furnace is therefore controlled from the hoppers on a loss-of-weight basis, in order to continuously monitor and adjust the furnace feed rate to the required levels. The control system is such that the weigh hoppers are never completely emptied of raw material, so that each feeder and partially filled hopper may serve as seal against the hot gases from the furnace

The raw materials feed system into the 60 MW DC arc furnace is shown in Figure 2.

For the 60MW furnace, raw materials in the correctly batched ratio are fed to six feed bins located above the furnace. From these feed bins the materials are fed into weigh hoppers via slide-gate valves, and from there through screw or vibratory tube feeders into the furnace feed pipes.

The 10 MW DC arc furnace is provided with a similar raw materials feed system, with the exception that only a single furnace feed bin is installed, feeding through two vibrating feeders into four feed ports to the furnace.

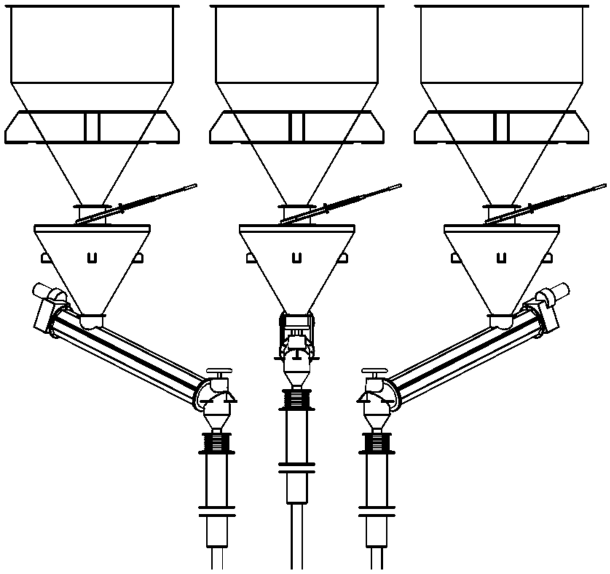

Figure 2: 60 MW Furnace Raw Materials Feed System

4.4 Furnace Proper

The general arrangement of both the 60 MW as well as of the 10 MW DC arc furnaces is shown in Figure 3. The size of the two furnaces relative to each other can clearly be envisaged from the drawings, where the shell diameter of the larger furnace is 12 metres, and that of the smaller furnace, 5 metres.

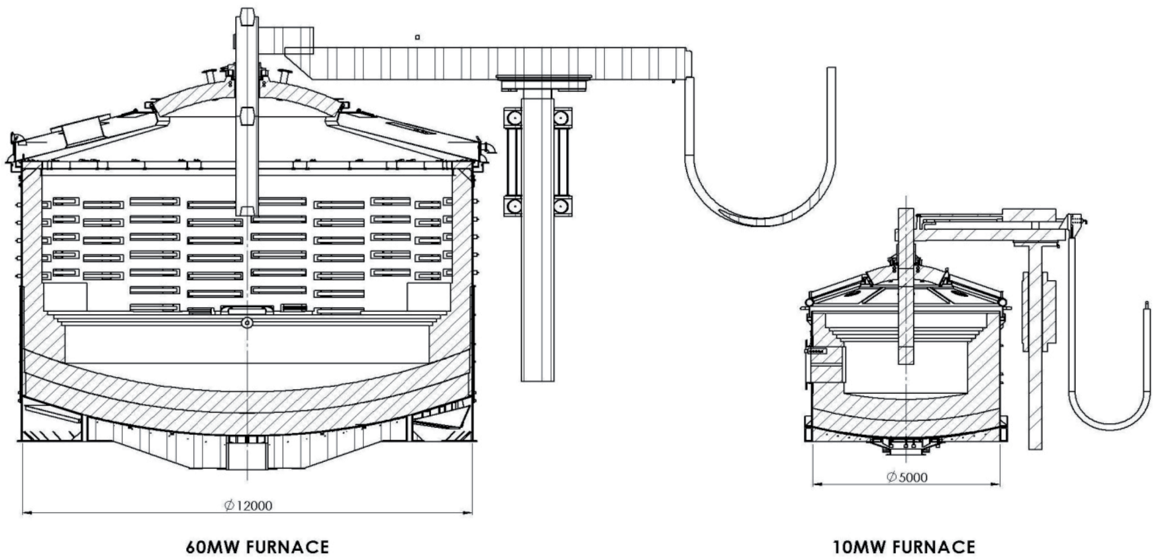

Figure 3: 60 MW DC Furnace & 10 MW DC Furnace

The position of the arm carrying the single graphite electrode can also be seen for each of the furnaces. In each of the furnaces under discussion the graphite forms the cathode, being at a negative polarity. The anode in the system is formed by the conductive hearth of the furnace. This hearth is made up of special refractory bricks provided in part with a conductive metal cladding.

The larger (60 MW) furnace is provided with two tap holes, and a refractory freeze lining on the side walls. The side wall lining is provided with a cooling system consisting of 120 copper plate coolers, each with a mass of between 380 kg and 600 kg, and each one fitted with a monel cooling coil for the flow of cooling water. The copper plate coolers were fabricated according to extremely stringent quality assurance standards. In addition to the abovementioned copper coolers, each taphole lintel is also provided with a copper cooling block.

The smaller (10 MW) furnace is fitted with a single taphole, and does not make use of copper plate coolers in its side walls.

4.5 Furnace Roof

The furnace roof is made up of two separate sections, namely a centre section and an outer section. The entire roof is electrically isolated from the furnace shell by means of a sand seal on which it rests. This sand seal also serves as a gas seal.

The furnace centre roof section is protected in part by a refractory brick lining, and in part by a cast refractory section in the centre. This section serves as an electrical insulation between the furnace graphite electrode and the remainder of the furnace roof.

The outer roof section is protected by a sacrificial gunited lining at startup, and provided with a sealed water spray cooling system on the outside. This system was installed for safety purposes, as the water in it is not under pressure, and therefore poses a minimal threat in the event of a leak occurring in the furnace roof. This spray cooling concept is commonly applied in the steel industry.

4.6 Furnace Power Supply

Large DC power supplies were developed for furnace applications in the steel industry and are available from a number of vendors. DC furnace power supplies have a proven reliability of even better than the furnace transformers on AC furnaces.

The typical configuration consists of an MV circuit breaker, rectifier transformer, SCR rectifier, DC isolator & earth switch and DC reactor. A typical electrical single line diagram is shown in Figure 4.

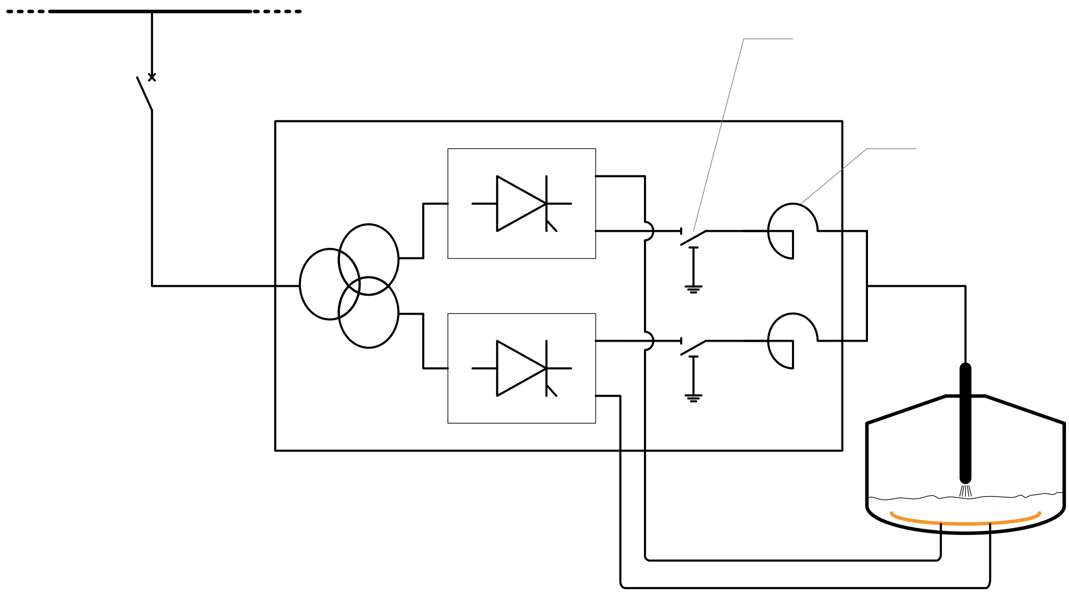

Figure 4: Single line diagram of furnace power supply

Important characteristics of typical DC Furnace Power supply are:

- Balanced three phase load
- High power utilization - Constant power input into furnace
- Ability to operate at reduced load
- Constant and stable arc

4.7 Magnetic Compensation

Experience has shown that in a DC arc furnace with a single power supply, arc deflection occurs due to induced transverse magnetic flux components. The result is an uneven, and sometimes catastrophic, wear in the furnace refractory lining.

Based on extensive magnetic flux readings taken on an existing DC arc furnace, a computerized model was compiled and a system developed and patented by GLPS to provide compensation for arc deflection. As shown in Figure 4, this system consists of compensating conductors coupled to a variable power supply to counteract the transverse magnetic flux caused by the furnace power supply. The compensating power supply is synchronized with the furnace power supply.

The system has proved to be effective in preventing arc deflection, and has been installed in both the 10 MW and 60 MW DC arc furnaces mentioned in the current report.

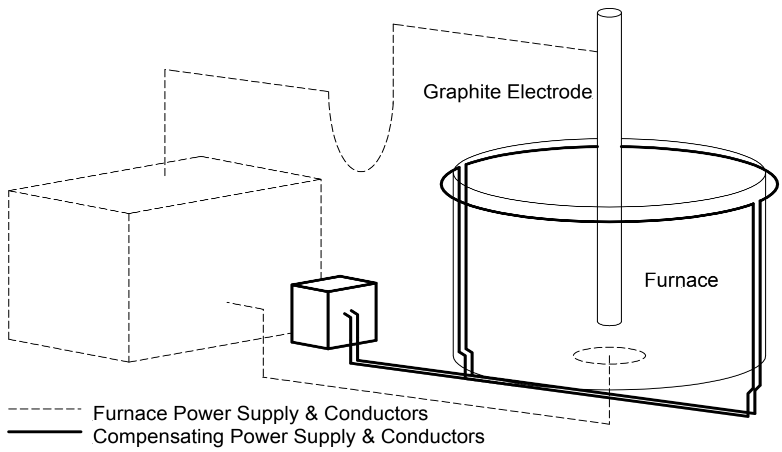

Figure 5: Arc Compensation System

4.8 Instrumentation and Control

The architecture of the automation system for the relevant DC arc furnaces takes the form of a distributed control layout, where extensive use is made of remote IO panels situated close to the process within the different functional areas of the plant. The remote IO panels are linked together on a Profibus fiber backbone constructed in a ring topology, which provides a high level of redundant communication capability in the event of a break in the fiber cable. It is on this fiber backbone that the motor control centers and furnace power supply controllers are also connected and communicate with the plant PLC.

The PLC is connected to a higher level plant Automation System which includes the engineering stations, manufacturing execution system (MES) and operator stations. The automation systems network manages the motor management controllers, plant instrumentation and all 3rd party control systems (furnace power supply controller) connected to the communication network. All this information is directed, managed and stored by the supervisory control and data acquisition software (SCADA). Refer to Figure 5 for an illustration on the automation system hierarchy.

The objective of the Automation systems for a furnace complex of this size is to enable control and feedback from all components of this plant, including emergency power backup systems. The automation system for the 60MW furnace complex needs to manage close on 1300 process objects.

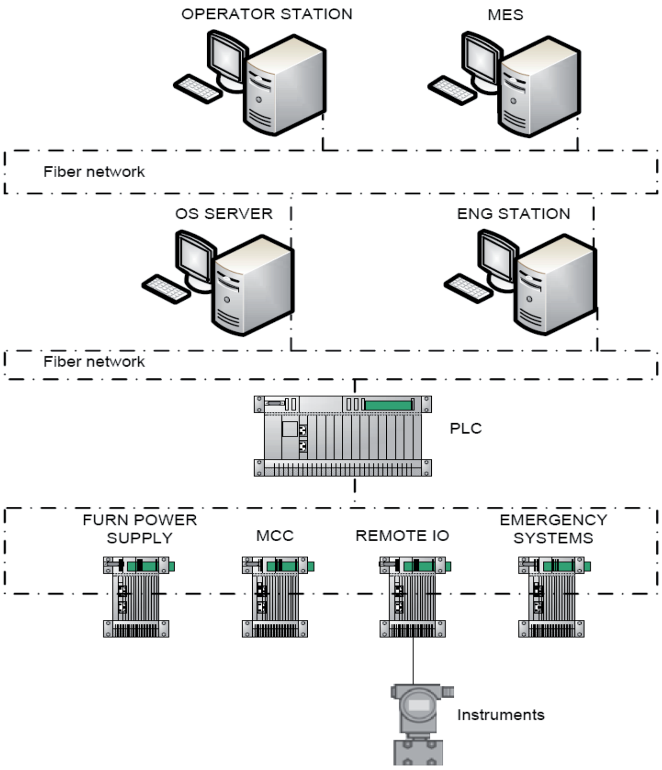

Figure 6: Automation Network Topology

For the implementation of the integrated automation system for the 60MW furnace complex a decision was made to group certain components of an integrated automation system together under a single technology & solution provider. Approaching the automation system solution implementation in this manner effectively ensured a very fast ramp up time for the 60MW smelter as there was seamless integration between the major components of this plant, such as the furnace power supply control, motor control, instrumentation and automation network.

4.9 Tapping Configuration

The high temperature open bath operation of a DC arc furnace enables separate tapping of slag and metal, consistently giving a very clean tapped metal into the ingot moulds. It is therefore ideal to equip a DC arc furnace with two tapholes.

The 60 MW DC arc furnace under discussion was designed with two tap holes, positioned on opposite sides of the furnace. One tap hole serves for metal tapping, and the other for slag tapping, with the slag taphole at a higher level than the metal taphole. Each tap hole is provided with an efficient tapping drill and clay gun combination, as the metal tap hole is normally closed against the flow.

4.10 Furnace Cranes

The overhead cranes installed in the 60 MW DC furnace building merit specific mention in this report. Considerable attention was paid to this part of the layout, in order to make the replacement of a furnace centre roof, as well as other maintenance operations in this area, as user friendly as possible.

The DC furnace centre roof section has a mass of between 30 tons and 40 tons, and must be replaced periodically. Two 20 ton overhead cranes were provided, one on each side of the furnace roof, to handle this centre roof section. Due to the height restriction between building floor and building roof in the relevant area, an underslung type of overhead crane was specified for this purpose.

4.11 Off-Gas Cleaning

Two practical options were considered for the cleaning of the off gas for the DC furnaces under discussion, namely a wet Venturi Scrubbing system, and a Disintegrator Scrubber system.

The 10 MW DC furnace at Mogale Alloys was fitted with a wet Venturi Scrubbing system, as per the instructions of the Client.

The 60 MW DC furnace at Samancor Chrome was fitted with a Disintegrator Scrubber, for the following reasons:

- A disintegrator scrubber plant minimizes the explosion hazard caused by the presence of CO gas. In contrast to this, the hazard posed by a conventional scrubber plant in this regard is severe, as previous experience has proved. A conventional scrubber operates with a high negative pressure between venturies and fans, which increases the risk of air ingress and the resulting explosion damage. A disintegrator scrubber system operates with a very low negative pressure.
- The gas cleaning efficiency of a disintegrator scrubber is better than that of a conventional scrubbing system. Although the design specification for a typical disintegrator scrubber is 20 mg/Nm3, it in practice achieves particle levels as low as 10 mg/Nm3 in the cleaned off gas. In contrast to this, the vendor guarantee in a conventional venturi scrubber is only 30 mg/Nm^3, and based on previous experience it is doubtful whether better than this will be achieved.
- All indications are that the maintenance and operating costs for a disintegrator scrubber will be lower than for conventional venturi scrubber.

5 CONCLUSIONS

During the past two decades the DC arc smelting furnace has moved from a position where it was previously not considered as an expansion option by many potential users, to a position where it is very definitely a leading contender – if not the leading contender - in terms of technology and sustainability in the ferroalloys production. The fact that DC arc furnaces with ratings of between 10 MW and 60 MW are currently operating successfully, and units with ratings of up to 70 MW are currently in an advanced design stage, indicate that this is an applicable technology for all potential users, both large and small.

6 ACKNOWLEDGEMENTS

This paper is published by permission of both Samancor Chrome and Mogale Alloys. The contributions of various technical personnel of both these companies are acknowledged and greatly appreciated.

7 REFERENCES

[1] Ford, M. and Oosthuizen, J.F., “The Production of Ferrochromium in a 40 MVA DC Plasma Furnace”, INFACON 7 Proceedings, 1995, pp. 263-272.

[2] Slatter, D.D., “Technological Trends in Chromium Unit Production and Supply”, INFACON 7 Proceedings, 1995, pp. 249-262.