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THE PRODUCTION OF FERROCHROMIUM IN A 40 MVA DC PLASMA FURNACE

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ABSTRACT

This paper examines the design constraints and operational problems encountered on a 40 MVA DC Plasma Arc furnace. This unit replaced a 16 MVA DC Arc furnace which had successfully produced charge chrome since 1983.

The main body of the paper describes these problems and the actions taken to solve them. A section on taphole management shows the improvements made in refractory life. An account of control philosophy illustrates the advances made in power and feed control. The effect of operating parameters on metallurgy is discussed.

Although a number of constraints have restricted performance, sufficient information and experience have been gained to rectify them, resulting in the efficient production of ferrochromium from unagglomerated chromite fines on a commercially acceptable scale.

INTRODUCTION

In October 1991, Samancor Limited, a major ferro-alloy producer, acquired Middelburg Steel & Alloys (Pty) Limited which included the Middelburg and Krugersdorp ferrochromium works. Palmiet Ferrochrome operations (previously Krugersdorp Works), has one 40 MVA DC plasma furnace producing charge chrome and two 20 MVA submerged arc furnaces which presently produce silicomanganese.

The original 16 MVA DC Arc furnace, installed in December 1983, was based on the ASEA Elred Process. After only five years in production the confidence gained in operational flexibility, taken with the advantages that this route provided [1], led to the decision to uprate to a 40 MVA furnace. This furnace was commissioned in December 1988 and a description of the furnace installation has been given previously [1]. For clarity and continuity, however, reference to Fig. 1 will readily lead to an understanding of the two principles underlying the process, viz.:

(i) that it is a transferred-arc open bath process, and
(ii) that both the energy (electric power) and the reactants (chromite fines, reductant, fluxes) required for the high-temperature chemical reductions, enter the process via

a single hollow graphite electrode. Some of the advantages and drawbacks of this route are discussed in the body of the paper.

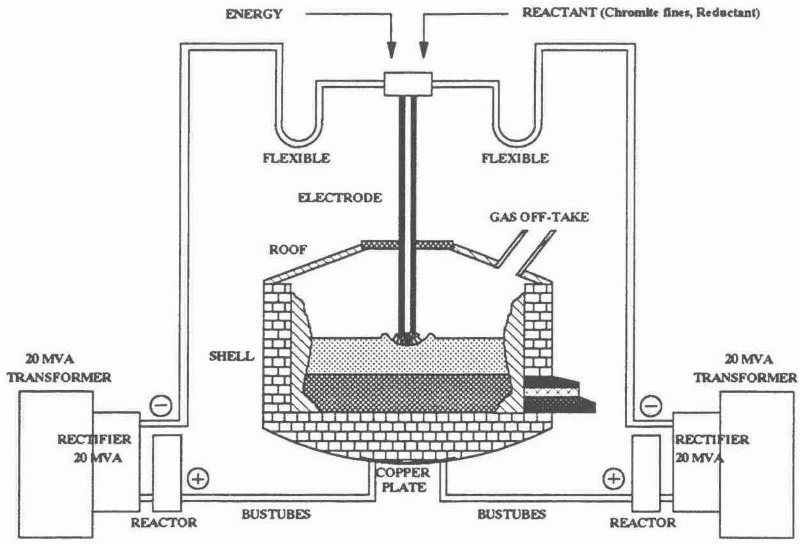

FIG. 1: Furnace Arrangement

As the operation progressed past the previous maximum load of 12 MW, several problems arose that had not been anticipated during the uprating design stage. These problems have been sufficiently resolved to allow the furnace to perform as an industrial unit comparable to conventional technology within the Samancor Group.

DESIGN REVIEW

Of the original dimensional criteria cited [1], three proved to have been adequately addressed. The remaining two did not consider fully the effect of running at higher loads and these will be discussed.

Table 1 illustrates some target parameters and the levels achieved on the 40 MVA unit up to 1994. The target parameters were expected to be achieved 18 to 21 months after start-up. It is apparent that the availability and mean running load are still lower than targeted, while the other targets have already been surpassed.

TABLE 1: Target parameters and level achieved by 1994

Parameter	Design target	Actual	
		1989	1994
Availability %	92,0	86,6	90,1
Load MW (ave)	27,0	17,7	26,1
Taphole life months	6	3	14
Chromium recovery %	85,0	82,2	90,1
Specific energy MWh/t	E	1,1E	0,95E

Operating experience identified areas which were overlooked at the design stage. These included problems with the following:
- arcing to the roof structure with subsequent water leaks
- gas cleaning plant
- electrical equipment
- feed transfer
- taphole management
- metallurgical control
- casting bay operation

Fig. 2 illustrates the shift in major causes of furnace downtime between 1989 and 1994. The major causes for reduced load, namely the gas cleaning plant, casting bay, and metallurgical problems, will be discussed in more detail.

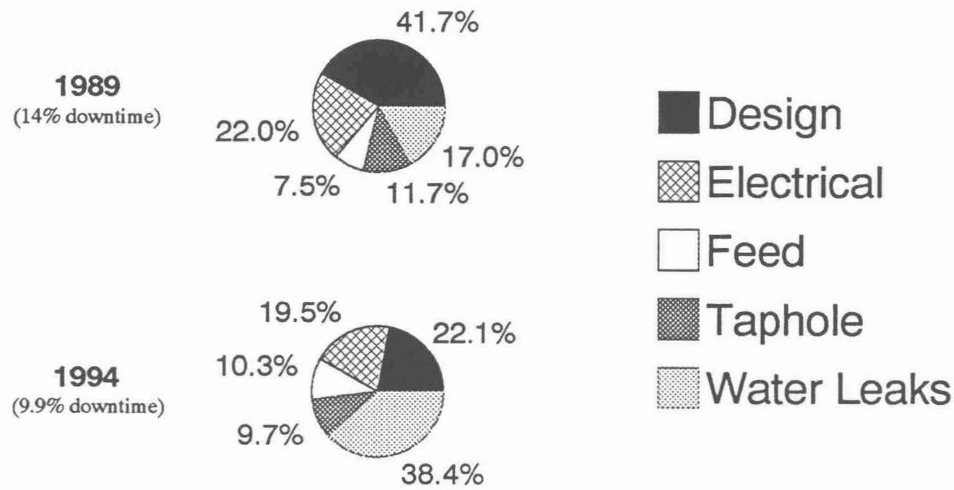

FIG. 2: Analysis of major causes of furnace downtime; 1989 compared to 1994

DISCUSSION OF PROBLEM AREAS

Roof structure water leaks

Water leaks from the furnace roof were one of the design criteria overlooked because none were experienced during the lifespan of the 16 MVA unit, which operated within a lower voltage regime (300 V to 520 V). Fig. 2 illustrates the resulting downtime on the 40 MVA unit.

Water leaks represent potentially the most dangerous threat to the life of the furnace. Most of the refractories used in the open-arc furnace are based on magnesite. Contact with water, and more critically, steam, results in hydration of the refractories and a complete breakdown of structural integrity, leading to the risk of slag and metal run-throughs.

The main source of water entering the furnace is from leaks caused by stray arcing onto the roof, the layout of which has been discussed previously [1]. Once water ingress is detected, repair work is undertaken. This involves major downtime as the furnace has to cool down before work can commence.

Stray arcing can be influenced by a number of factors including:
- arc resistance and stability
- bath configuration and conditions
- feed characteristics and input
- operating load
- anode insulation from furnace structure
- voltage peaks
- any combination of the above

The changes implemented to reduce the incidence of stray arcing and which allow the furnace to run at higher loads are:
- resistance and feed strategies to produce slag cover on the roof
- limit on the voltage level to control the occasional peak
- additional insulation
- on-line potential arc monitoring which automatically adjusts operating parameters according to an empirically derived curve
- re-design of the off-gas ducting, roof panels, water circuits, and the ring structure to reduce downtime

The first four actions were implemented to reduce the chance of arcing, while the fifth was carried out to lessen furnace downtime. The former actions resulted in reducing the random nature of the arc damage to the roof structure. Although arcing to other water-cooled roof components occurs, virtually no arcing is experienced on the roof panels. The success of these actions is illustrated in Fig. 3.

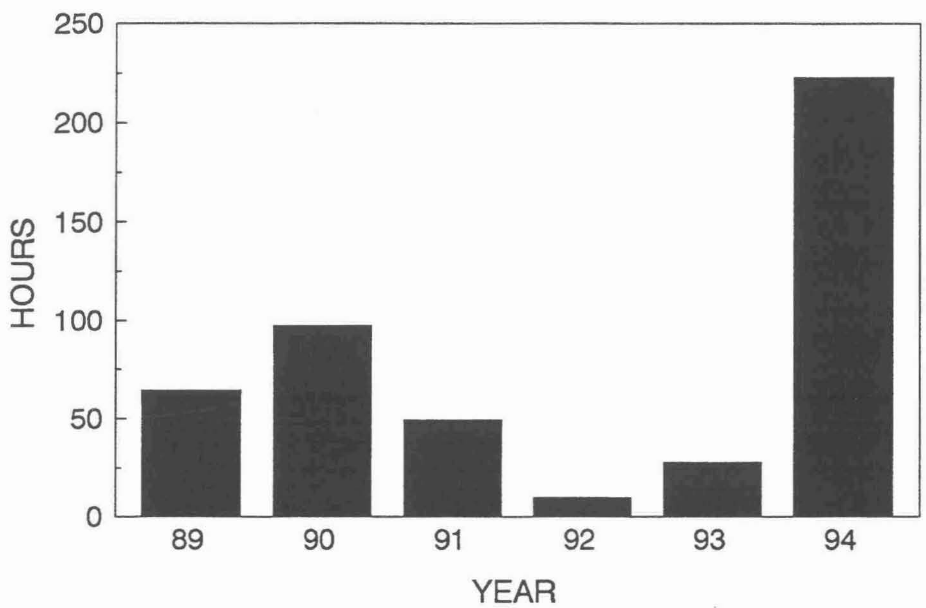

FIG. 3: Hours Lost to Water Leaks

Fig. 3 shows a marked decrease in the lost time between 1990 and 1992, taking into consideration that the peak load increased over the same period. The very marked increase in downtime from mid-1993 was due to the deliberate policy of operating the furnace near maximum load which led to a marked increase in arcing and necessitated further design changes and replacement of major water-cooled structures.

The design changes to some of the equipment have reduced repair time by approximately 15%, because of:
- improved accessibility
- more-easily repaired components
- quicker replacement when necessary

Further improvements will only be attempted during the next reline.

Gas cleaning plant

A high energy wet scrubbing gas plant was built to comply with air pollution requirements. The gas is cleaned by controlling the differential pressure across two venturis. The expelled solids are transferred to a rake thickener for separation and are discarded. All water used is cooled and recirculated. The gas stream, after on-line analysis, passes through a water seal to a stack. A recirculating damper, between the water seal and the second venturi, controls the furnace pressure.

The initial design could not maintain the required availability or allow operation at design load. The gas plant has caused 50% of all reduced load on the 40 MVA unit from start-up to 1993. Apart from the pollution problem, the furnace is forced to run at restricted load when the gas plant is non-operational. Some of the factors that reduced operating efficiency include:
- build-up of solids in the system
- inability of gas analysers to cope with water-saturated gas
- inadequate design of some components

Changing duct design, increasing the number and careful positioning of cleaning sprays, improving sump agitation, revamping the sampling and analysis of the gas, were some of the measures which have resulted in greater availability and high capacity of this unit.

Electrical equipment

Power to the 40 MVA furnace is supplied via two 20 MVA transformers. The power unit consists of two six pulse thyristor rectifiers. Three capacitor banks, two of which have been commissioned, were installed to filter out unwanted harmonics.

Under load, an unexpected harmonic was generated. The logic of the power control system resulted in an imbalance between the two rectifiers, which added to this problem. The harmonics generated caused numerous trips of the capacitor banks resulting in lengthy periods of downtime.

Computer analysis of the system identified the responsible harmonic and the filtering frequency of the capacitor banks was tuned to reduce its effect.

Power control, previously performed by a programmable logic controller, is now a function of the high speed controllers of the rectifiers. This reduces the response time, resulting in greater power stability and less harmonic generation.

The electrical system is not considered a constraint in reaching design loads. It is possible that, when running maximum load, harmonic generation may reappear but commissioning the third capacitor bank could resolve this.

<u>Taphole</u>

Taphole management is one of the most critical determinants of availability on the plasma furnace. In an open-arc furnace there is no burden for sealing or to provide any protection to the refractories in the taphole area. Taphole life is dependent on:

- bath conditions and metallurgy
- limiting use of oxygen lancing
- selection and configuration of refractories
- protective banks or freeze layers
- taphole sealing practice
- response to specific temperature change
- eliminating water ingress

Operating experience proved that the above factors are equally important and that by neglecting one or more, premature failure results. Initially the life expectancy of the taphole was three to six months. Not only is a repair lengthy, but burn-throughs are also dangerous and cause extensive structural damage.

The installation of a dedicated mudgun and drill combination, and the development of new sealing materials have improved taphole management.

Temperature monitoring in the area surrounding the taphole indicates the degree of taphole protection at any given time. Deviation from set standards will initiate responses such as operational adjustments, metallurgical changes or preferential feeding. Operating experience gained determines the response to temperature changes.

The initial taphole configuration lasted for six months before failure. The upper taphole area was water cooled by a copper lintel attached to the inner shell. Various combinations of refractory materials and designs were used with little or no improvement.

Water-cooled copper blocks were mounted on three faces of the tapping block. The risk and consequence of water ingress led to only the top cooling block being retained in future designs.

The present taphole consists of carbon blocks enclosed in brickwork of a similar quality to the working hearth, and this layout has increased taphole life (as shown in Table 1).

<u>Other design limitations</u>

The angle of the off-gas ducting resulted in excessive erosion of the steel, which only became evident at increased loads. Changing the material specification and gas direction should resolve this. At the higher loads, cooling of the ducting could initially not be achieved with the installed capacity. Loads were restricted to accommodate this. Increasing cooling capacity by 50% allowed the furnace to operate at its intended level.

Post-taphole material handling was time consuming and a constraint in achieving higher loads. Changes to the skimmer configuration and slag and metal handling methods reduced turnaround time considerably.

SUCCESS OF SCALE-UP

Fig. 4 illustrates trends on the 16 MVA (1984 - 1988) and 40 MVA (1989 - 1994) furnaces in terms of availability and power input. The best availability to date, shown in this figure, is just over 90%. However, the plasma furnace utilises a jointed electrode arrangement, and the connecting of sections allows a maximum achievable availability of 97%.

Although the pattern of increasing availability and load on the 16 MVA unit continued on the 40 MVA unit, base line availability was higher at higher loads, reflecting the improvements gained from uprating. However, the effect caused by certain limitations, which only became evident at higher loads, can be seen as availability soon reaches a plateau.

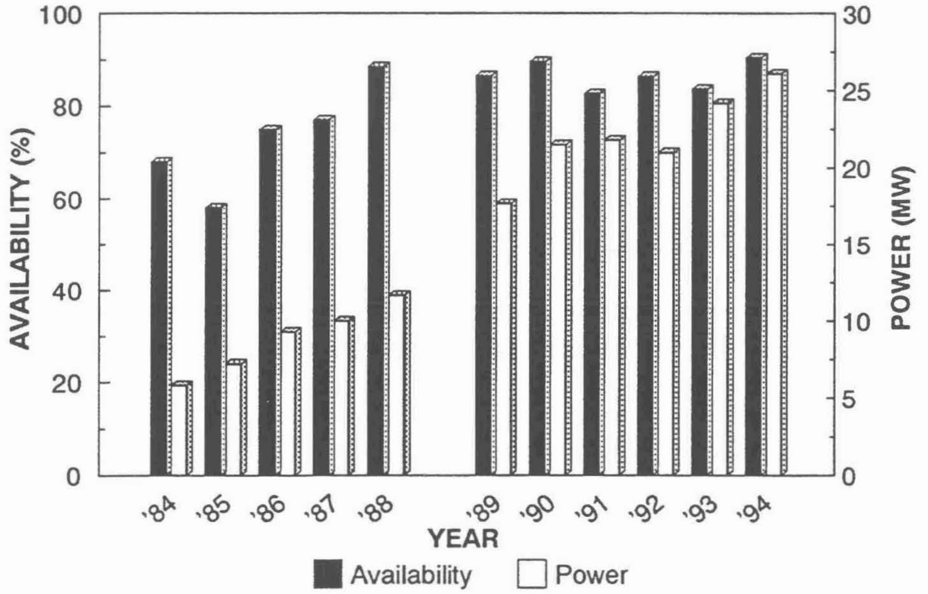

FIG. 4: Load and availability improvements: 1989 to 1994

The information and experience gained over the operating period will be used to rectify these restrictions and enable the furnace to run at or above the original designated targets. The success achieved in producing ferrochromium from unagglomerated chromite fine ore proves a plasma operation can compete very favourably with conventional submerged-arc furnace technology using lump ore.

Further planned improvements will give definite advantages to the plasma route. The costs of changes and improvements already effected to operate at or above the original targets were absorbed within operating costs, and further changes envisaged will cost only a fraction of the original uprating.

METALLURGICAL AND OPERATIONAL FEATURES

Control philosophy

Successful operation is dependent on maintaining the optimum power to feed ratio. The slow control response on the 16 MVA unit led to unstable power and feed input affecting overall operation stability. This has been resolved by the installation of high speed rectifier banks.

The supply of raw materials is controlled by an ASEA Pressductor programmable logic controller (PLC) system. The feed control is done by an ASEA Masterpiece PLC with software developed in-house.

Although the principle of control is similar to that used on the 16 MVA furnace, changes were made to improve the accuracy, including increasing the data sampling frequency.

The current system of sampling and then integrating the values results in a signal which controls the feedrate.

The interaction of two loops, one of which is controlled by the programmable high speed controller unit in the rectifier and the other reacting to arc stability, maintains the power input to the furnace at the required pre-set level.

Both power and feed control have developed to a level that will not be a constraint at higher loads.

Metallurgical and operational features

The furnace mix consists of dried fine chromite and fluxes, with bituminous coal and anthracite as reductants. Table 2 illustrates the conditions for producing two typical alloy compositions.

Tables 1 and 2 illustrate some of the advantages that this unit has over conventional routes, and these include:

- fine and cheaper raw materials can be used
- the furnace runs with a 100% unagglomerated fine chromite input
- expensive metallurgical coke is not required for the reductant source
- rapid response unit able to produce a range of alloy grades. The furnace can produce metal with silicon specification that is not achievable in submerged-arc furnaces smelting Transvaal chromite
- no electrical constraints as no burden present in the furnace. This allows freedom in selecting slag chemistry composition and imposes no restriction in electrical power input
- high chromium recovery and good sulphur control is achieved

These indicate a benefit in both operation and costs, and consistent results are obtained by monitoring and controlling the following parameters:

- feed rate
- resistance

- reductant level
- bath size
- metallurgy

TABLE 2: Alloy composition, slag composition and furnace feed ratio for low and medium silicon alloy

	Low silicon alloy		Medium silicon alloy	
	1989	1994	1989	1994
Alloy composition				
	%	%	%	%
Cr	52,9	53,6	52,0	53,1
Si	1,0	1,5	4,0	4,0
C	8,6	8,5	7,5	7,7
S	0,027	0,014	0,010	0,011
Slag composition				
SiO_2	30,2	23,3	28,0	26,1
MgO	21,5	23,2	23,0	22,5
CaO	17,7	14,8	14,0	14,3
Al_2O_3	30,6	38,6	35,0	37,2
Furnace feed ratio				
Chromite fines	100,0	100,0	100,0	100,0
Limestone	16,1	11,0	12,0	12,0
Quartz	7,9	6,0	12,0	10,0
Anthracite	30,1	31,0	33,0	33,0
Bituminous coal	-	6,0	-	6,0

If the feedrate is too high then material cannot be taken into the melt, causing instability of the arc. The bath becomes cold, reducing process temperature, and some material accumulates on the protective banks changing the bath size, leading to tapping difficulties. Low feedrate increases temperature, which drives unwanted side reactions and dissolves the protective banks, resulting in off-grade material and refractory attack. Adjustments to overcome feed imbalance lead to restricted load.

Resistance is generally used as an indicator of arc length, although low resistance does not necessarily mean a short arc. Under stable operation movement in arc length influences the process temperature. For example, decreasing arc length increases the silicon content of the metal, as there is more energy available to the process. Resistance variations result in current changes, which affect the degree of bath stirring, influencing the contact required for chemical reaction.

The ratio of coal and anthracite utilised is dependent on furnace conditions and process temperature. Carbon shortfall can cause increased electrode consumption and dissolution of the protective banks. It also results in high chromium oxides in the slag, insufficient silicon reduction, and poor desulphurisation. An over-carbon situation leads to a longer and less stable arc, moving the energy source away from the melt. This results in a drop in the silicon in the metal, as there is insufficient energy to drive the silica to silicon reaction.

The bath size plays a role in metallurgical control as it affects the process temperature. The changing of bath geometry from an open shallow bath to a closed deeper bath was originally controlled by varying the flux additions in the charge. This is now achieved by varying the amount of carbon available in the process.

Some of the metallurgical changes that occurred are shown in Table 2. In 1989 the production of a 1,5% maximum silicon alloy, while keeping the sulphur below 0,02%, was not always successful. Maintaining the highly reducing conditions to allow desulphurisation occasionally allowed the silicon to exceed specification. The mix change shows a slight reduction in quartz addition with an increase in reductant level. This keeps the bath closed, allowing sufficient process temperature to obtain the silicon level while maintaining a desulphurising environment. The shift to this slag regime resulted in lower slag to metal ratio and a corresponding decrease in specific energy consumption with an improved chromium recovery (as shown in Table 1).

The advances made were as a result of the above, plus the evolution of data acquisition which identified problems and manipulation techniques that solved them. The initial system was basic and measured a small number of parameters. The next stage allowed limited analysis to be done and the current system is able to generate much more data in easily accessible form to a wide range of users.

CONCLUSIONS

The authors have attempted to show that, even with some design constraints that restrict performance, the 40 MVA unit is able to successfully produce ferrochromium from unagglomerated chromite fines on a commercially acceptable scale. The advantages [1] offered by this technology have contributed to Samancor's competitive cost and strategic placement in the ferrochromium market. The furnace is running close to its designed targets and the information and experience gained should both improve efficiency and decrease costs further.

ACKNOWLEDGEMENTS

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