Electric Smelting Furnaces in Southern Africa

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SYNOPSIS

Part I is intended to present a picture of the number and size of installations of electric smelting furnaces in Southern Africa at April 1974, with details of the individual furnace ratings and other characteristics.

The number of furnaces thus embraced comes to 61, with a total electrical rating of nearly one million kVA (excluding Rhodesia).

Part II of the paper covers some of the more interesting engineering features and design parameters relating to these furnaces and predicts some possible future trends.

The paper deals only with smelters operated from alternating-current electric power supplies and thus excludes aluminium smelters, which require direct-current supply. Otherwise the paper covers all types of electric smelters in Southern Africa, some producing ferro-alloys, others pig iron, others non-ferrous mattes, and others various 'chemicals' (non-metals). In this context, smelting, as distinct from melting, is defined as a furnace operation, carried out at high temperatures, whereby the charge materials react together chemically and emerge as entirely different materials. Melting simply changes the state of materials from solid to molten, their chemical nature remaining substantially the same.

PART I

Electric smelting furnaces have been installed in Southern Africa over a period of more than 40 years, but recently there has been a remarkable increase in the number and size of individual units built here for the production of ferro-alloys. The simplest explanation is that, while there are enormous reserves of ores in Southern Africa of the kind required for the manufacture of ferro-alloys and related products (such as calcium carbide), there are also plentiful supplies of extremely cheap coal suitable for generating electrical energy at a price that rises only slowly in comparison with many other commodities. In addition, water and labour are readily available in certain areas, and there are ample quantities of coking coal for use as the reducing agent in electric smelters and for the manufacture of high-quality electrode paste, which is necessary for the satisfactory operation of the self-baking (Söderberg) electrodes used in most electric smelters.

The tables giving particulars of the electric-smelter installations in Southern Africa have been subdivided as follows:

Table 1 — Ferro-alloy furnaces at Kookfontein, Tvl.
Table 2 — Ferro-alloy furnaces at Witbank, Tvl.
Table 3 — Ferro-alloy furnaces elsewhere in South Africa.
Table 4 — 'Matte' furnaces in Southern Africa.
Table 5 — Pig-iron and other furnaces in South Africa.

Table 1
Ferro-alloy furnaces at Kookfontein, Transvaal

Ref. code	Year	Main product	Rating MVA	Supply kV	Shell diameter m	Shell height m	Furnace type	Electrodes	Remarks
VA 1	1954	H.C. FeMn	10	11	8,34	4,25	Fixed, closed	3 SB 1090 mm	
VA 2	1951	H.C. FeMn	13,2	11	9,52	3,40	Fixed, closed	3 SB 1270 mm	Furnaces rebuilt (VA 2, VA 3)
VA 3	1951	H.C. FeMn	13,2	11	9,52	3,40	Fixed, closed	3 SB 1270 mm	
VA 4	1942	Si FeMn	4,6	6,6	6,71	4,10	Fixed, open	3 SB 781 mm	
VA 5	1942	Si FeMn	4,6	6,6	6,71	4,10	Fixed, open	3 SB 781 mm	
VA 6	1962	Si FeMn	7,8	11	B: 6,0 T: 7,3	3,96	Fixed, open	3 SB 890 mm	
VA 7	1957	H.C. FeMn	7,5	11	7,09	4,25	Fixed, open	3 SB 890 mm	
VA 8	1942	L.C. FeMn	1,2	6,6	2,13	1,82	Tilting, closed	3 GR 200 mm	Refining furnaces (VA 8, VA 9)
VA 9	1943	L.C. FeMn	1,2	6,6	2,13	1,82	Tilting, closed	3 GR 200 mm	
VA10	1972	FeSi (15% Si)	7,5	6,6	6,4	4,42	Fixed, open	3 SB 890 mm	
VA11	1973	H.C. FeMn	48,0	33	13,2	7,04	Fixed, closed	3 SB 1900 mm	
VA12	1974	H.C. FeMn	48,0	33	13,2	7,04	Fixed, closed	3 SB 1900 mm	

*H.C. = high-carbon
L.C. = low-carbon

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Table 2
Ferro-alloy furnaces at Witbank, Transvaal

Ref. code	Year	Main product	Rating MVA	Supply kV	Shell diameter m	Shell height m	Furnace type	Electrodes	Remarks
WF 1	1955	FeCr	8,0	21	6,4	3,5	Fixed, open	3 SB 890 mm	Ferro-Metals Ltd
WF 2	1955	FeCr	8,0	21	7,75	3,6	Fixed, open	3 SB 890 mm	Ferro-Metals Ltd
WF 3	1963	FeCr	15,0	21	9,45	4,5	Fixed, open	3 SB 1145 mm	Ferro-Metals Ltd
WF 4	1973	FeCr	48	33	12,0	5,67	Fixed, closed	3 SB 1700 mm	Ferro-Metals Ltd
WF 5	1972	FeSi	48	33	B:10,50 T: 9,64	3,95 1,70 5,65	Fixed, open	3 SB 1550 mm	Ferro-Metals Ltd (tapered shell)
WT 1	1964	SiMn	15	22	8,00	4,57	Rotating, open	3 SB 1143 mm	Trans-Alloys Ltd
WT 2	1964	SiMn	15	22	8,00	4,57	Rotating, open	3 SB 1143 mm	Trans-Alloys Ltd
WT 3	1964	M.C. FeMn	4	22	5,00	3,00	Tilting, open	3 SB 610 mm	Trans-Alloys Ltd
WT 4	1964	M.C. FeMn	4	22	5,00	3,00	Tilting, open	3 SB 610 mm	Trans-Alloys Ltd
WR 2	1965	FeSi	16	21,5	T: 8,09 B: 7,15	4,35	Rotating, open	3 SB 1143 mm	Rand Carbide Ltd (tapered shell)
WR 3	1972	FeSi	46,5	21,5	T:11,30 B:10,25	5,23	Rotating, open	3 SB 1550 mm	Rand Carbide Ltd (tapered shell)

*M.C. = medium-carbon

Table 3
Ferro-alloy furnaces at miscellaneous places in South Africa

Ref. code	Year	Main product	Rating MVA	Supply kV	Shell diameter m	Shell height m	Furnace type	Electrodes	Location
FM 1	W/R	L.C. FeCr	12	33	NA	NA	T/O	3 SB	Machadodorp, Tvl
FM 2	1971	FeSiCr	24	33	NA	NA	R/O	3 SB	Machadodorp, Tvl
FM 3	1971	FeSiCr	24	33	NA	NA	R/O	3 SB	Machadodorp, Tvl
FM 4	1972	L.C. FeCr	12	33	NA	NA	T/O	3 SB	Machadodorp, Tvl
FC 1	1959	H.C. FeMn & FeSiMn	9,0	33	NA	NA	R/O	3 SB	Cato Ridge, Natal
FC 2	1959		9,0	33	NA	NA	R/C	3 SB	Cato Ridge, Natal
FC 3	1964	H.C. FeMn	9,6	33	NA	NA	R/C	3 SB	Cato Ridge, Natal
FC 4	1964		9,6	33	NA	.NA	R/C	3 SB	Cato Ridge, Natal
MR 1	1964	High-Cr_2O_3 slag	7,5	22	5,18	3,50	T/C	3 GR 305 mm	Middelburg, Tvl
MR 2	1964	FeCrSi	7,5	22	6,78	3,81	F/O	3 SB 914 mm	Middelburg, Tvl
MR 3	1964	Charge Cr	7,5	22	6,78	3,81	F/O	3 SB 914 mm	Middelburg, Tvl
MR 4	1965	Charge Cr	7,5	22	6,78	3,81	F/O	3 SB 914 mm	Middelburg, Tvl
MR 5	1967	Charge Cr	7,5	22	6,78	3,81	F/O	3 SB 914 mm	Middelburg, Tvl
MR 6	1970	Charge Cr	5,0	22	5,48	3,20	F/O	3 SB 760 mm	Middelburg, Tvl
KP 1	1964	High-Cr_2O_3 slag	9,0	11	5,94	2,97	T/O	3 SB 813 mm	Krugersdorp, Tvl
KP 2	1966	FeCrSi	16,0	11	8,53	4,16	F/O	3 SB 1080 mm	Krugersdorp, Tvl
KP 3	1970	FeCrSi	9,0	11	7,31	3,65	F/O	3 SB 1080 mm	Krugersdorp, Tvl

L.C. = low-carbon NA = Not available R/O = Rotating, open T/C = Tilting, closed
H.C. = high-carbon T/O = Tilting, open F/O = Fixed, open R/C = Rotating, closed
W/R = when required

Table 4

Matte furnaces in Southern Africa

Ref. code	Year	Main product	Rating MVA	Supply kV	Shell dimensions m	Shell height m	Furnace type	Electrodes	Location
RP 1	1969	see note (a)	$19\frac{1}{2}$	6,6	27,34 × 8	6,00	see note (b)	6 SB in line 1245 mm dia.	Rustenburg, Tvl
RP 2	1971	see note (a)	$19\frac{1}{2}$	6,6	27,34 × 8	6,00	see note (b)		
RP 3	1974	see note (a)	$19\frac{1}{2}$	6,6	27,34 × 8	6,00	see note (b)		
RI 1	1969	see note (a)	$7\frac{1}{2}$	6,6	20,42 × 5,95	3,81	see note (b)	6 SB in line 890 mm dia.	Bafokeng, near Rustenburg
RI 2	1972	see note (a)	$7\frac{1}{2}$	6,6	20,42 × 5,95	3,81	see note (b)		
RI 3	1973	see note (a)	$7\frac{1}{2}$	6,6	20,42 × 7,16	3,91	see note (b)		
RI 4	1974	see note (a)	15	6,6	25,91 × 8,69	3,89	see note (b)	6 SB in line 1143 mm dia.	Bafokeng
ZM 1	1972	copper matte	36	66	31,4 × 10,4	5,658	see note (b)	6 SB in line 1,5 m dia.	Mufulira, Zambia
BB 1	1973	Cu-Ni-Co matte	9	11	9,14 m dia.	6,10	see note (c)	3 SB 890 mm	Selebi-Pikwe, Botswana
BB 2	1973		9	11	9,14 m dia.	6,10	see note (c)		
RW 1	1971	see note (a)	$7\frac{1}{2}$	6,6	20,42 × 5,95	3,81	Rectangular, closed roof	6 SB in line 890 mm dia.	Marikana, nr Rustenburg

(a) Cu-Ni matte with platinum-group metals content.
(b) Rectangular, closed roof, cold charge.
(c) Circular, fixed closed roof for refining molten slag from Outokumpu Flash Smelter.

Table 5

Pig-iron and miscellaneous furnaces in South Africa

Ref. code	Year	Main product	Rating MVA	Supply kV	Shell diameter m	Shell height m	Furnace type	Electrodes	Location
WH 1	1968	see note (a)	33	33	14	5	see note (b)	3 SB 1,6 m dia.	Witbank, Tvl
WH 2	1968	see note (a)	33	33	14	5	see note (b)	3 SB 1,6 m dia.	Witbank, Tvl
WH 3	1968	see note (a)	33	33	14	5	see note (b)	3 SB 1,6 m dia.	Witbank, Tvl
WH 4	1968	see note (a)	33	33	14	5	see note (b)	3 SB 1,6 m dia.	Witbank, Tvl
WR 1	1950	Calcium carbide	25	21,5	T: 7,98 B: 6,36	4,60	Fixed open	3 SB 1219 mm	Witbank, Tvl
NH 1	1965	Calcium carbide	19,0	11	T: 7,5 B: 5,5	3,9	Fixed, open	3 SB 960 mm	Ballengeich, nr Newcastle, Natal
VA 8	1968	'Calmafos'	7,5	11	7,84	3,35	Fixed, closed	3 Gr 355 mm	Kookfontein, Tvl
VA 9	1967	Phosphorus	15	11	B: 8,12 T: 6,14	5,74	Fixed, closed	3 Gr 762 mm	Kookfontein, Tvl
VI 1	1965	Metallic tin (high purity)	0,35	3,3	2,44	2,20	Fixed, open	3 Gr 200 mm	Vanderbijlpark, Transvaal
VA12	1949	Experi-mental	3,6	6,6	3,50	2,43	Fixed, open	3 Gr 400 mm	Kookfontein, Tvl

(a) Pig-iron from vanadium-bearing magnetite after prereduction in rotary kilns.
(b) Fixed, closed roof, hot charge.

All the ferro-alloy furnaces are circular and have three electrodes arranged in an equilateral triangle.

All the matte smelters charged with cold material feed are rectangular and have six electrodes in line along the centre line of the furnace, and are in the Rustenburg area, Transvaal. A detailed description of the largest of these Rustenburg furnaces has been presented by Mostert and Roberts[1].

Thus there are two main types of electric smelters in Southern Africa. The technical part of this paper covers the more important differences between the two types.

NOTES ON TABLES 1 TO 5

Before discussion of the technical features relating to some of the smelting furnaces in the tables, it may be useful to summarize some of the information, as follows.

Table 6
Summary of Tables 1 to 5

	No. of furnaces	Total rating MVA
From Table 1 – Ferro-alloy furnaces at Kookfontein, Transvaal	12	167,0
From Table 2 – Ferro-alloy furnaces at Witbank, Transvaal	11	227,4
From Table 3 – Ferro-alloy furnaces at miscellaneous places in South Africa	17	185,7
Totals of S.A. ferro-alloy furnaces	40	580,1
From Table 4 – Matte furnaces in Southern Africa	11	157,5
From Table 5 – Pig-iron and miscellaneous furnaces in Southern Africa	10	202,4
Totals (at April 1974)	61	940,0

These figures are impressive by any standards and represent a very considerable capital outlay, both on the smelter plants themselves and on the electric generating and reticulation equipment necessary to supply the smelters, even if it is remembered that they operate at very high load factors – far higher than most other electrical loads. The geographical distribution of the furnaces is summarized in Table 7.

Table 7
Geographical distribution of furnaces in Southern Africa

	No. of furnaces	Total rating MVA
(a) Furnaces in Witbank, Middelburg, and the eastern Transvaal	26	499
(b) Furnaces in the 'South Johannesburg' area	16	193
(c) Furnaces in the 'West Johannesburg' area	3	34
(d) Furnaces in the Rustenburg area	8	103
(e) Furnaces in Natal	5	57
Totals for furnaces in S.A.	58	886
(f) Furnaces in Botswana	2	18
(g) Furnaces in Zambia	1	36
Totals of above	61	940
(h) Furnaces in Rhodesia	NA	NA

PART II

ELECTRODE SYSTEMS

These vary fairly widely, depending on the furnace application and the individual ideas of the furnace designer and builder. Broadly, the subject can be considered under various headings, as follows.

Type of Electrode

Most of the furnaces use self-baking (S.B.) electrodes, in which a carbonaceous paste is charged into a continuous steel cylinder, and this is lowered steadily into the furnace and consumed therein. The paste is baked into a hard, solid electrode during its downward movement.

This type of electrode is much cheaper than prebaked carbon or graphite electrodes, but the latter must be used in certain special cases such as the manufacture of elemental phosphorus and pure (iron-free) silicon and in small smelters requiring only small-diameter electrodes.

Figure 1a is a section of a typical S.B. electrode, showing the main components, and is self-explanatory.

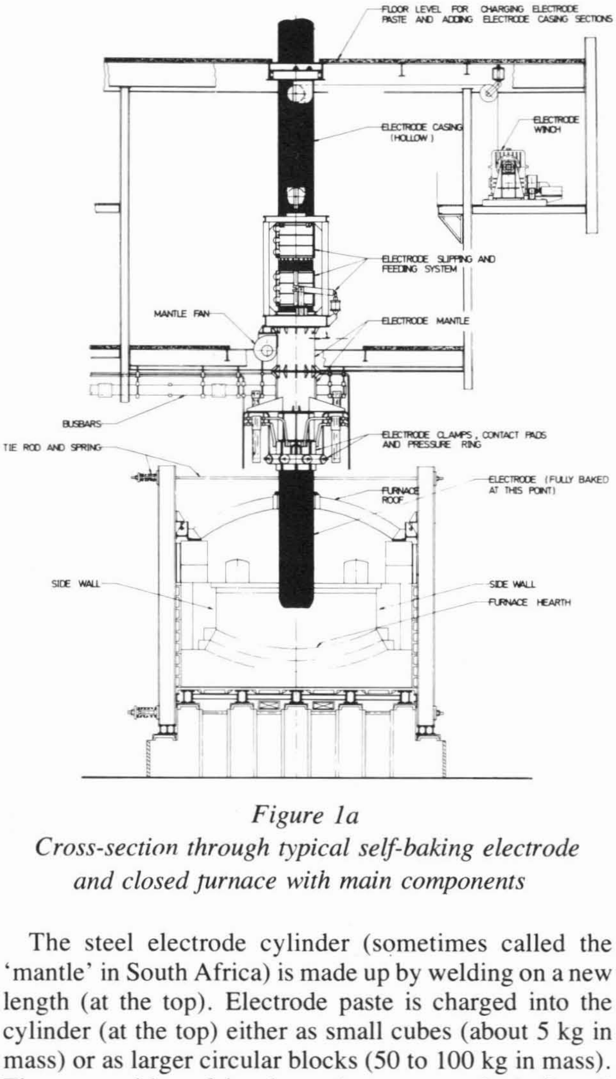

Figure 1a
Cross-section through typical self-baking electrode and closed furnace with main components

The steel electrode cylinder (sometimes called the 'mantle' in South Africa) is made up by welding on a new length (at the top). Electrode paste is charged into the cylinder (at the top) either as small cubes (about 5 kg in mass) or as larger circular blocks (50 to 100 kg in mass). The composition of the electrode paste must be 'tailored' to the furnace application and to the heat available for proper baking.

Successful (trouble-free) operation of S.B. electrodes depends upon very careful control of all the factors involved in the fabrication of the electrode in the furnace; but especially important are the welding technique and the proper alignment of cylinder lengths, a suitable type and size of paste, the exclusion of dust (and other foreign matter), and adequate quantity and temperature of air fed to the annular space between the electrode cylinder and the outer casing. All these requirements also presuppose that the design of the whole electrode system is correct, particularly in relation to the (cross-sectional) current density, the thickness of cylinder steel, the area and form of the heat-conducting fins, the type of current-conducting clamps (or shoes), the method(s) of clamping, the arrangement of the feeding or slipping mechanism, the smoothness of the electrode-movement system (hydraulic or electro-mechanical or some combination of these), and freedom from mechanical stresses due to unexpected distortion of seals and/or refractories.

Number of Electrodes, Configuration, and Electric Circuits

All the circular furnaces in Southern Africa now have three electrodes in equilateral triangular formation. Some of the early models had three electrodes in line, but this has gone out of fashion. All the rectangular furnaces have six electrodes along the centre line. This is a convenient arrangement both for electrical reasons and for charging raw materials in large quantities. Figures 1b, 2, and 3 show typical six-electrode furnaces.

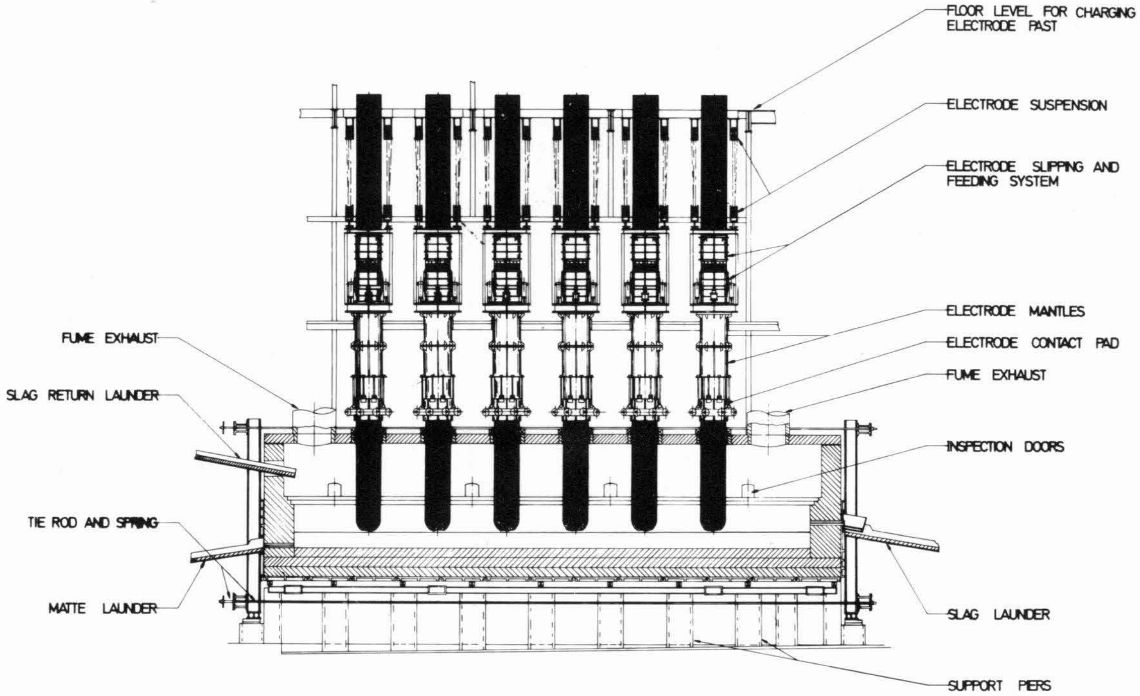

Figure 1b

Longitudinal section through typical rectangular six-electrode matte-smelting furnace

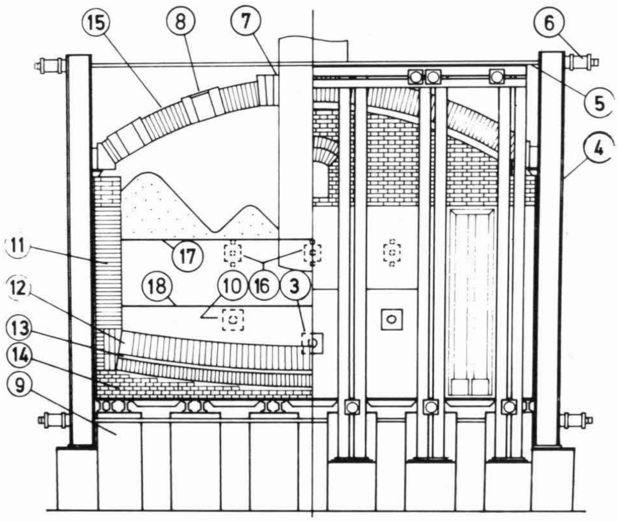

Figure 2

Section and end-elevation of typical rectangular matte-smelting furnace, showing tap-hole positions and charging ports

Electrically the two types are quite distinct.

In the three-electrode furnace, the heavy current conductors are arranged so that the secondary windings of that transformer are virtually connected in delta, but the actual delta joint is intentionally made only at the electrode clamp. All three electrodes must operate at the same nominal voltage but may in practice draw different currents from the electric supply, although this is undesirable.

In the six-electrode furnace, each adjacent pair of electrodes is fed from its own transformer and may thus be operated, if required, at voltages and currents very different from those in the other electrode pairs. This can be a very useful feature in a long rectangular matte smelter where molten-slag conditions may vary considerably over the length of the furnace. But the three pairs of electrodes in a six-electrode furnace are not, in fact, entirely independent electrically, since they are fed with vectorial voltages. This is shown in Figure 4, where "a" represents one method of phase connection and "b" another, giving rise to entirely different current flows in the so-called 'dead' areas – between electrodes 2 and 3 and between electrodes 4 and 5. This interesting phenomenon is being studied in South Africa with special reference to its effect on refractory-lining erosion.

Electrode Suspension and Movement

All the larger furnaces use a pair of hydraulic cylinders for each electrode-suspension system. Some smaller furnaces have been provided with winches, connected through a rope-and-pulley system. But the driving motors are fitted with electromagnetic (clapper-type) brakes, which can stop the electrode travel rather fiercely and occasionally cause electrode breakage.

There is a distinct preference for the hydraulic system because of its smooth action (naturally straight line) and simplicity of control. The hydraulic fluid is generally of the non-inflammable type.

Electrode Feeding or Slipping Mechanisms

As an electrode is consumed, it must be lowered into the charge to compensate for the loss and to maintain the required current in it. Obviously this lowering can be carried out by the normal suspension system, but only to a limited extent. Therefore the electrode must be 'slipped' or fed through the suspension system. This is accom-

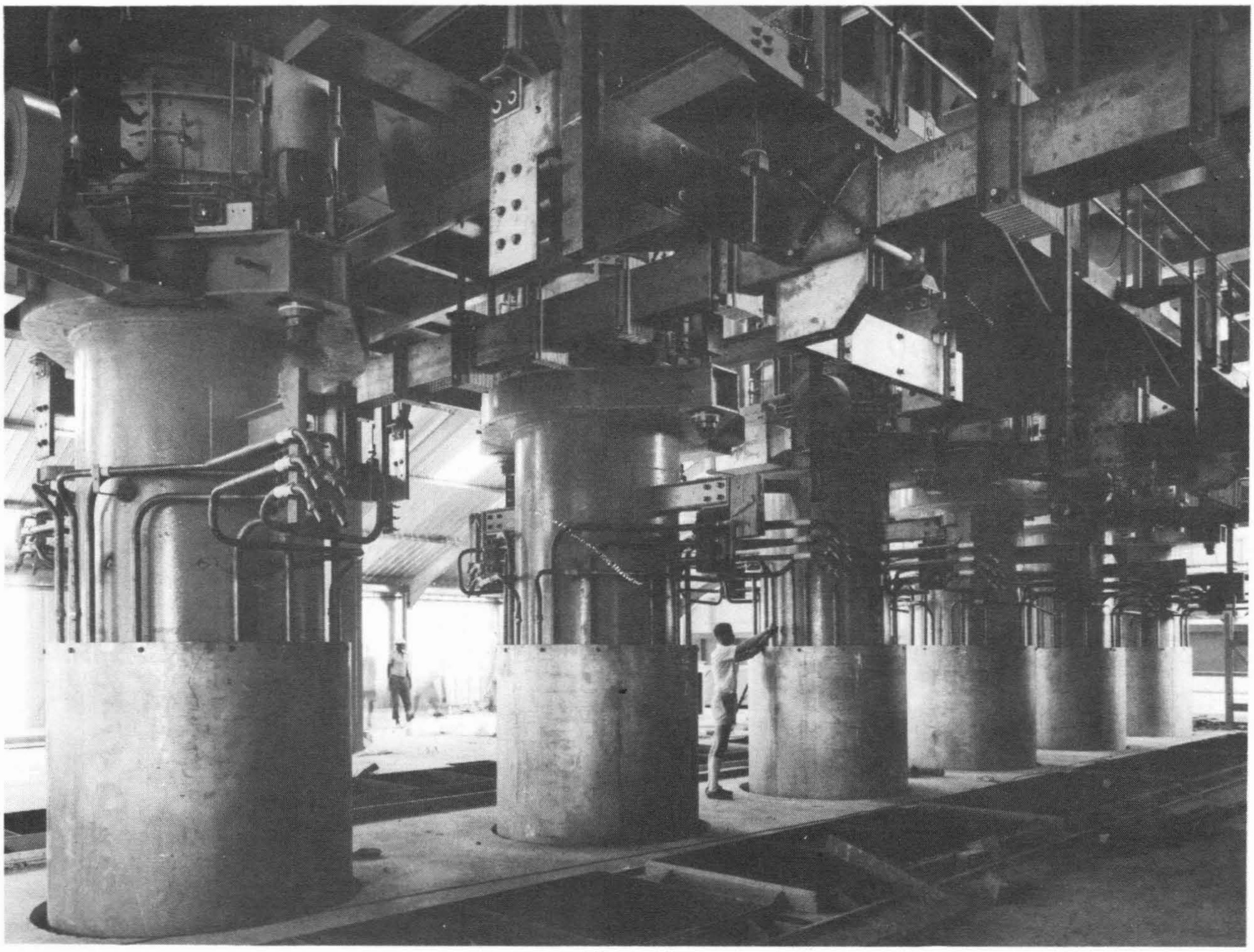

Figure 3
Photograph of six-in-line self-baking electrodes on a 19,5 MVA rectangular furnace in Rustenburg

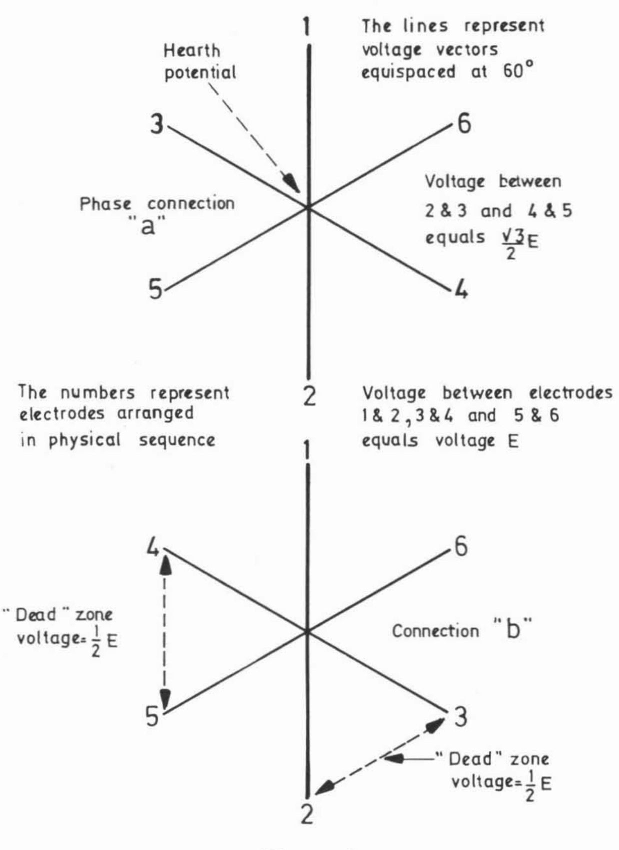

Figure 4
Three-phase vector diagrams for six-electrode furnace

plished by the use of two 'girdles' or devices that grip the electrode cylinder above the current-carrying clamps. Different manufacturers use different methods to control these girdles, but basically they are all arranged so that the distance between the upper and lower girdles can be changed by a small amount, generally 15 to 30 mm, this being the feeding stroke or the distance through which the electrode can be slipped down to compensate for wear at its lower end. On many furnaces, the girdle pressure on the electrode is exerted by compressed air, acting through flexible rubber sleeves arranged so that, as one girdle grips the electrode, the other is released. On some furnaces, the girdle pressure is obtained from springs, set carefully to carry the electrode weight by frictional forces.

Electrode Contact Clamps (or 'Shoes' or 'Pads')

For self-baking electrodes, these take the form of heavy non-ferrous water-cooled castings surrounding the electrode, with inner faces machined to fit the steel electrode casing and thus provide good electrical contact for efficient current transfer. The pressure between clamp and electrode is obtained either by springs with hand tensioning or by hydraulic rams with remote control.

The latter arrangement is preferable on all large electrodes and essential on all open furnaces. The spring system is acceptable for closed furnaces, where the clamps are readily accessible and the furnace roof provides protection from the heat radiated by the charge below.

The current and the cooling water to the contact clamps are carried by special thickwalled high-conductivity copper tubes. The clamps are made either in high-conductivity copper or high-conductivity bronze (typically 85 per cent Cu). The latter has both manufacturing and maintenance (repair) advantages.

The number of clamps per electrode is usually 6 or 8.

Electrode Current Density

This normally refers to the average or apparent current carried by unit cross-section of the electrode between the clamps and the charge; but, in fact, there are two other correct densities, which are also of great importance. These are:

(1) The correct density per unit area of clamp, i.e., as the current enters the electrode. This can be called the *ingress* current density. It is especially critical in open furnaces, where the clamps are subjected to intense heat from below and large volumes of dust and grit of all kinds. Typical figures are between 1 and 3 A/cm^2.

(2) The current density per unit area of electrode as the current leaves it, i.e., the *egress* current density. This is particularly important in matte furnaces, where the electrodes are immersed in molten slag and it is desirable for the electrical energy to be released as resistive heat in the slag rather than in arcs at the electrode surface. Typical figures are between ½ and 2 A/cm^2.

In true submerged-arc furnaces, the egress-density figures are far higher at the end of the electrode where an arc is required to produce high local temperatures and where most of the power is located. Some interesting work has been carried out by the National Institute for Metallurgy to determine the vertical distribution of power in a submerged-arc furnace[2] under various conditions.

This brings us to the cross-sectional current density. Here it must be remembered that the current does not flow uniformly over the whole area, partly because of the skin effect and partly because proximity of the other electrodes distorts the current pattern. These effects increase as the electrode diameter and current values become larger, and they become extremely marked with electrodes beyond about 1½ metres in diameter. Thus the furnace designer limits the apparent density in these large electrodes to some 3 or 4 A/cm^2, whereas density figures of 6 to 10 are found in smaller furnaces. A correct choice of the maximum density requires considerable experience and technical knowledge of each furnace application.

Electrode Control or Furnace Power Regulation

Many furnaces operate with simple current control, i.e., each electrode is moved up or down as required to maintain constant current, and this is done automatically by current-sensitive apparatus. Preferably the speed of movement should be proportional to the out-of-balance current, and great ingenuity has been exercised to provide this feature, which prevents hunting and ensures smooth electrode movement without jerkiness.

Fortunately the currents in an electric smelter tend to change slowly in comparison with a conventional open-arc furnace melting steel or copper. Nevertheless, a well-designed automatic regulator is essential to ensure that the furnace can be operated continuously at its highest optimum power level so that the highest possible throughput of material and lowest cost of energy (per unit) can be maintained.

But, in all smelters, the resistivity of the charge can vary sometimes over wide limits[3]. Therefore, the electrode voltage must also be adjusted to take this into account. The choice of voltage is often left to the skill of the furnace operator, but with increasing sizes this is undesirable[4]. There is certainly great scope in this direction for a more comprehensive measurement of furnace conditions followed by more automatic control to ensure the most efficient use of the whole plant.

Considerable development work is being carried out on this fascinating subject at different places. Perhaps more progress would be made more speedily if furnace users and designers could be persuaded to attack the problems on a cooperative basis for the whole ferro-alloy industry. This is especially important as electric smelting furnaces become larger, because not only are the material-throughput figures higher, but inherent furnace power factors are lower, and every effort must be made to run these large furnaces at the highest possible power factor[5].

FURNACE DESIGN PARAMETERS

These have been evolved over many years, partly as a result of practical experience. Nevertheless, some interesting and well-known theoretical papers have been published[6,7], these dealing essentially with three-electrode furnaces.

A more recent paper[8] deals with six-electrode matte-smelting furnaces and, in effect, stresses the importance of correct electrode and furnace sizing (for each application) and correct choice of parameters such as ratios of hearth width and length to electrode diameter and pitch.

Considerations of refractory-lining life play an important role in these parameters, including the power applied per unit area of hearth.

As a paper dealing with the electrical characteristics and parameters of submerged-arc furnaces has already been presented here (by Mr J. Westly), it is not proposed to deal with the subject more extensively in this paper.

FURNACE SHELL AND REFRACTORIES

As indicated in the introduction, there are two distinct types of electric smelters in Southern Africa – the three-electrode circular and the six-electrode rectangular.

An extremely important difference occurs in the refractory linings. In the circular furnace, all expansion of the lining must take place within the shell, which is of finite dimensions. Thus the upper electrode mechanisms can all be located accurately with respect to the shell, and a simple elegant mechanical design can result.

But the rectangular furnace is in effect a flexible box of bricks provided with spring-loaded walls to allow for movement of the bricks with temperature changes. During heating up, a 20/50 MVA rectangular furnace may expand (move) by as much as 20 to 30 cm. So the six electrodes (or most of them) must be capable of some horizontal movement to maintain them in proper alignment with the furnace roof ports. As each electrode system may weigh 20 to 40 tonnes, this poses a considerable problem in relation to the furnace-building structure.

CONCLUSION

The technical part of this paper has intentionally not covered such aspects as

power-factor correction,
fume exhaust and dust removal, and
refractory requirements.

These subjects are being dealt with adequately in other papers at this Congress.

Other aspects not covered, because of shortage of time and space, are:

furnace transformer designs and circuits, high-voltage switching,

low-voltage (heavy-current) conductors, fixed and flexible,

furnace-charging arrangements,

furnace tapping, and

furnace cooling-water systems.

These subjects are perhaps of interest mainly to the management and staff of electric-smelting-furnace operating companies. However, new literature and books dealing in some detail with all these matters are at present in course of preparation and publication.

ACKNOWLEDGEMENT

The author gratefully acknowledges the assistance received from various sources, notably from electric-smelting-furnace designers and manufacturers for some of the technical information and illustrations, and from furnace-operating companies for their help in compilation of the tables. Their permission to publish so much data about their plants is sincerely appreciated.

REFERENCES

1. MOSTERT, J.C., and ROBERTS, P.N. Electric smelting of nickel-copper concentrates containing platinum-group metals. *J.S. Afr. Inst. Min. Metall.*, vol. 73. 1973. p. 290.
2. URQUHART, R.C. The dissipation of electrical power in the burden of a submerged-arc furnace, Johannesburg. National Institute for Metallurgy. *Report no. 1521*, 1973.
3. DOWNING, J.H., and URBAN, L. Electrical conduction in submerged arc furnaces. Electric Furnace Conference AIME, vol. 23, 1965. p. 93.
4. PERSSON, J.A. The significance of electrode-to-hearth voltage in electric smelting furnaces. Electric Furnace Conference AIME, vol. 28. 1970. p. 174.
5. SCHANCHE, C.H., BUGGE, N.E., and BRAATEN, O. Today's trend towards larger electric smelting furnaces. *J. Metals*, vol. 19, no. 5, 1967. pp. 60-65.
6. ANDREAE, F.V. Design and control of ferro alloy furnaces. *Trans. Am. Inst. elect. Engrs*, vol. 75, 1950.
7. KELLY, W.M. Design and construction of the submerged arc furnace. *Carb. Graphite News*, vol 5, no. 1. April/May 1958.
8. PERSSON, J.A., and TREILLARD, D.G. Electrothermic smelting of copper and nickel sulphides and other metal bearing constituents. *J. Metals*, vol. 25, 1973. pp. 34-39.

DISCUSSION

Dr R.C. Urquhart:*

Please comment on the pros and cons of six-in-line furnaces, compared with three-electrode furnaces, for ferro-alloys.

Mr King:

For closed or semi-closed furnaces of very large dimensions for ferromanganese, silicon, and iron, the six-in-line arrangement is really worth consideration. I think one could make a saving of 20 to 25 per cent on electrode diameter, which, if you square it up, means a considerable saving in weight for each electrode. The total weight – which will have to be carried by the structure – for six smaller electrodes will, I think, be about the same as that for three larger electrodes. A big advantage is the great flexibility in voltage and in electrode power in each pair of electrodes, and I think there are charging advantages as well.

Mr M. Sciarone†:

Please comment on the usage of three single-phase transformers, compared with one three-phase transformer.

Mr King:

I always thought that, for anything except small furnaces, one should use three single-phase transformers. It is advantageous to keep one up your sleeve in case of one breaking down, in which case it will not take long to install the spare one. Secondly, this country is limited in the size of the transformers it can manufacture. It is possible here to build big single-phase transformers, but it might be impossible to build one big three-phase transformer. There are also advantages in the control of single-phase transformers, and, if one has capacitors, there are certain advantages that way. For six-in-line furnaces, one always has single-phase transformers.

Mr J.A.R. Putz:*

What are the shell diameter and height of the Machadadorp furnaces, and what are the electrode diameters?

Mr King:

This information is unfortunately not available.

Mr H. Tuovinen‡:

What life can be expected from various linings for high-carbon ferrochromium and charge chromium?

Mr King:

I think this question requires rather careful consideration, especially where availability in the country is concerned. The local material must be compared with the material imported from places where the materials are provided by nature in a better form.

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