Applications of Mamatwan Manganese Ore

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SYNOPSIS

The location and reserves of the Hotazel, Wessels, and Mamatwan types of South African manganese ores are discussed, together with their chemical analyses and smelting characteristics. Mamatwan ore is singled out for further consideration, and it is shown to be unsuitable for the production of high-carbon ferromanganese in the electric furnace. Owing to the enormous reserves of this ore, two alternatives exist for the economic recovery of manganese, viz, either the ore must be processed to a form suitable for electric-furnace feed, or a different smelting process must be introduced.

In terms of the former, a record of a test run with sinter made from Mamatwan ore is given, and it is shown that this sinter is inferior to raw ore as a primary feed to electric furnaces.

Attention is then given to the blast furnace, and it is pointed out that, under South African conditions, Mamatwan ore is eminently suited to this process. It is shown further that some major criticisms of the blast furnace can be refuted by the implementation of specific modifications to the process.

In conclusion it is suggested that South African reserves of anthracite and Mamatwan ore must spur investigation into the use of very low-shaft furnaces using highly basic slags and oxygen-enriched blasts.

LOCATION AND RESERVES

The vast bulk of South Africa's manganese-ore deposits is situated in the Kuruman—Postmasburg area of the northwest Cape centred on the town with the apt name of Hotazel. The relationship of this region to the rest of the country is illustrated in Figure 1, which shows export ports for these ores as well as inland centres of major consumption.

Figure 2 illustrates the area around Hotazel, and the location of the different types of ore deposits can clearly be seen from Wessels and Blackrock in the north, Hotazel in the centre, and Mamatwan and Adams in the south. Both Hotazel and Mamatwan are open-cast mines, while Wessels, which was opened in April 1973, is an underground mine because of the depth of the orebody.

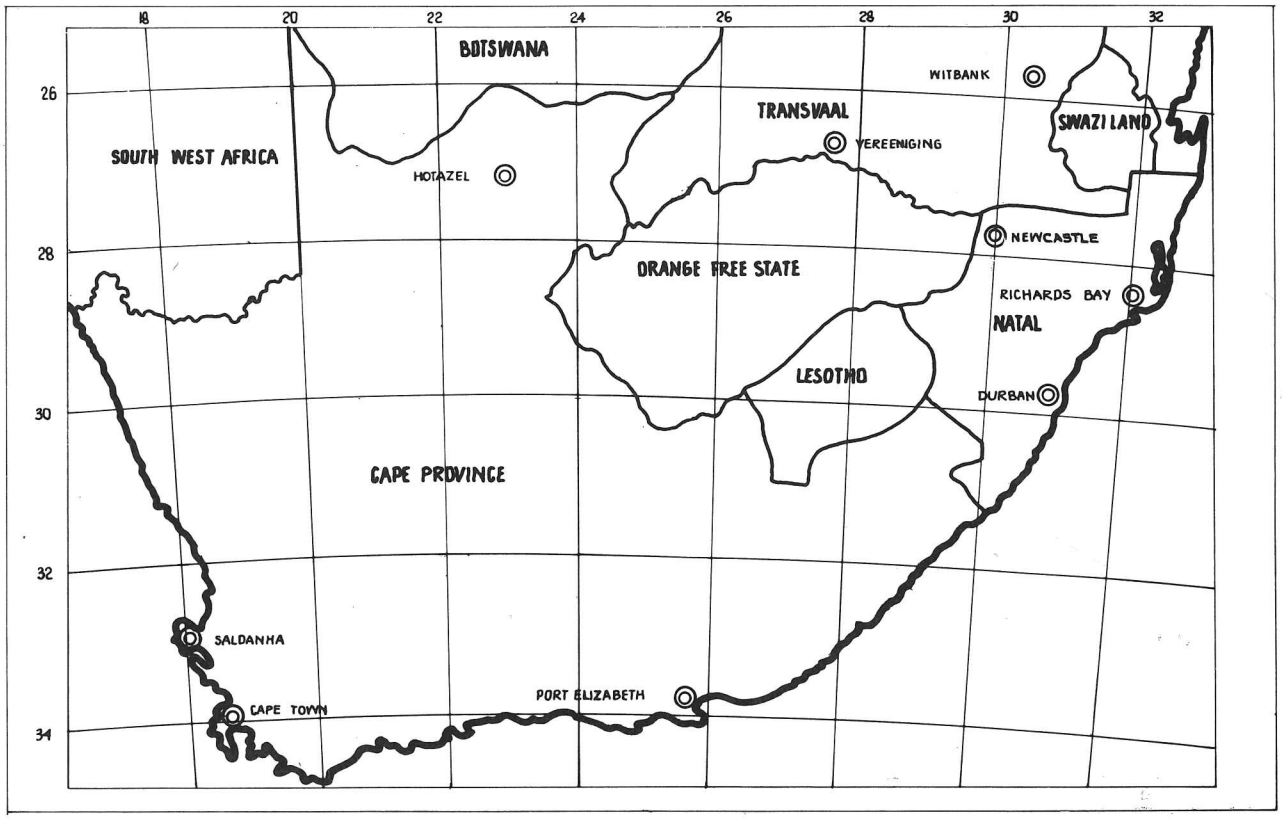

Figure 1
The Hotazel area in relation to the rest of South Africa

*Transalloys Limited, South Africa.
†Amcor Management Services (Pty) Ltd, South Africa.

The reserves of the three types of ores are estimated to be as follows:

Hotazel	3 million tonnes
Wessels	50 million tonnes
Mamatwan	50 million tonnes proven
	200 million tonnes probable
	More than 400 million tonnes possible.

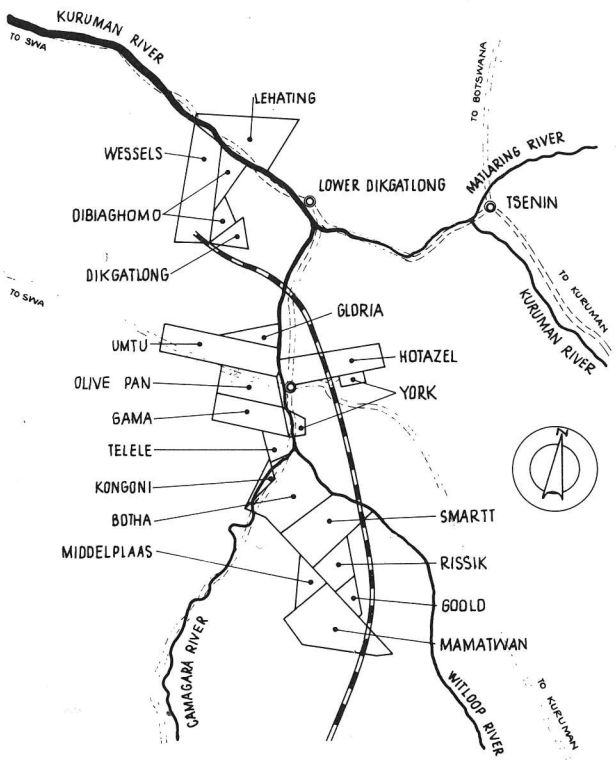

Figure 2
The area around Hotazel
27° latitude 23° longitude
Shade temperatures winter 0° to 25°C
Altitude 1170 metres
Rainfall (annual average) 200 mm

ANALYSES AND COMPOSITION

The ores under discussion have been designated the 'Jaspilite'[1] type in contrast to the three other main types of manganese ore found throughout the world. Typical analyses of the South African ores are shown in Table 1, together with analyses of ores representative of the other classified types.

It is to be regretted that, as far as is known, no detailed study has been made of the mineralogical composition of these South African ores, although a brief qualitative study has been made of Mamatwan ore[2]; unfortunately, the latter gives no quantitative information. Nevertheless, X-ray diffraction has shown that Mamatwan ore is composed chiefly of braunite with smaller amounts of manganite, hausmanite, and hematite. Its gangue material consists mostly of calcium carbonate and magnesium carbon ate, and it is interesting to note that no MnO_2 was found. The lack of this tetravalent oxide is apparently a characteristic of these ores.

Under the assumption that Hotazel and Wessels ores were derived from Mamatwan geologically in such a way that no new minerals were formed, the roughly calculated mineral composition based on Table 1 is given in Table 2.

ELECTRIC-FURNACE SMELTING CHARACTERISTICS

We in this country have very little experience in the smelting of foreign ores, so that any comparison of smelting characteristics is difficult. Nevertheless, it is the experience of our colleagues in Norway and Japan that the smelting of South African ores is accompanied by the following:

(i) a higher CO content in the off-gas,
(ii) possible deeper electrode penetration,
(iii) low P content in the final metal, and
(iv) increased kWh consumption per tonne.

The reason for this last item is so far a matter of conjecture, with lack of MnO_2, different mineralogical structure, and increased slag-to-metal ratios all being held accountable. To illustrate this phenomenon, Table 3 gives

Table 1
Comparative analyses of selected ores

Constituent	Hotazel*	Wessels*	Mamatwan*	Moanda†	Chiatura†	Grand Lahou†
MnO_2	35,6	39,9	32,7	77,55	46,02	66,94
MnO	37,4	28,7	24,1	3,82	24,72	4,78
Fe_2O_3	14,8	17,4	6,02	4,07	1,54	6,26
SiO_2	4,59	3,23	4,82	2,10	9,22	8,43
Al_2O_3	0,25	0,44	0,26	5,60	1,61	6,35
CaO	2,52	4,96	12,1	0,07	2,26	0,12
MgO	0,44	0,29	2,33	0,05	0,50	0,06
Na_2O	0,18	0,32	0,23	0,06	0,19	0,32
K_2O	0,14	0,10	0,36	0,61		1,36
P_2O_5	0,071	0,11	0,089	0,233	0,325	0,217
BaO	0,17	0,66	0,16	0,20	0,68	0,16
TiO_2	0,024	0,025	0,022	0,19	0,035	0,20
CO_2	1,36	2,13	13,6	0,05	4,16	0,17
Combined water	2,20	1,31	2,91	5,00	7,51	4,32
SO_3	0,059	0,11	0,035	0,055	0,021	0,047
Total	99,804	99,685	99,736	99,658	98,791	99,734
Mn	51,4	47,5	39,4	52,0	48,2	46,0
Fe	10,3	12,2	4,2	2,8	1,1	4,4
Mn/Fe ratio	4,99	3,89	9,38	18,57	43,82	10,45

*Source: South African Manganese Ltd. † Source: B.I.S.I.

Table 2

Approximate mineralogical composition of the ores

	Hotazel		Wessels		Mamatwan	
Braunite		46		33		48
Manganite		11		6		14
Hausmanite		21		32		—
Dolomite as:						
Calcite	4		9		22	
Magnesite	1	5	1	10	5	27
Hematite		15		17		6
Balance		2		2		5
		100		100		100

Table 3

Unit consumption with various mixtures

Ore mix		Mn in metal %	MnO in slag %	kWh per tonne
Hotazel, %	Mamatwan, %			
100	0	72	40	2800
80	20	76	40	2900
40	60	78	20	3150
0	100	80	20	3500

some typical unit consumption figures for various Hotazel—Mamatwan mixtures, although it must be remembered that these figures refer to old furnaces with high reactances.

As far as Wessels ore is concerned, at the time of writing no ore has yet been smelted, so that it is impossible to draw firm conclusions. However, judging from chemical analysis, we are led to believe that no large differences will be found between the characteristics of this ore and the Hotazel ore. This is illustrated by Figures 3 to 8, which are based on purely theoretical smelting-balance considerations. Here it is at once obvious that Mamatwan ore cannot be regarded as a suitable source of manganese for the production of high-grade 40 per cent MnO slag, whereas, for 20 per cent MnO slag, maximum production goes hand in hand with minimum amounts of this ore in the mix. Furthermore, it is a well-known fact that, owing to the CaO+MgO content, Mamatwan ore is certainly not suitable for the production of silico-

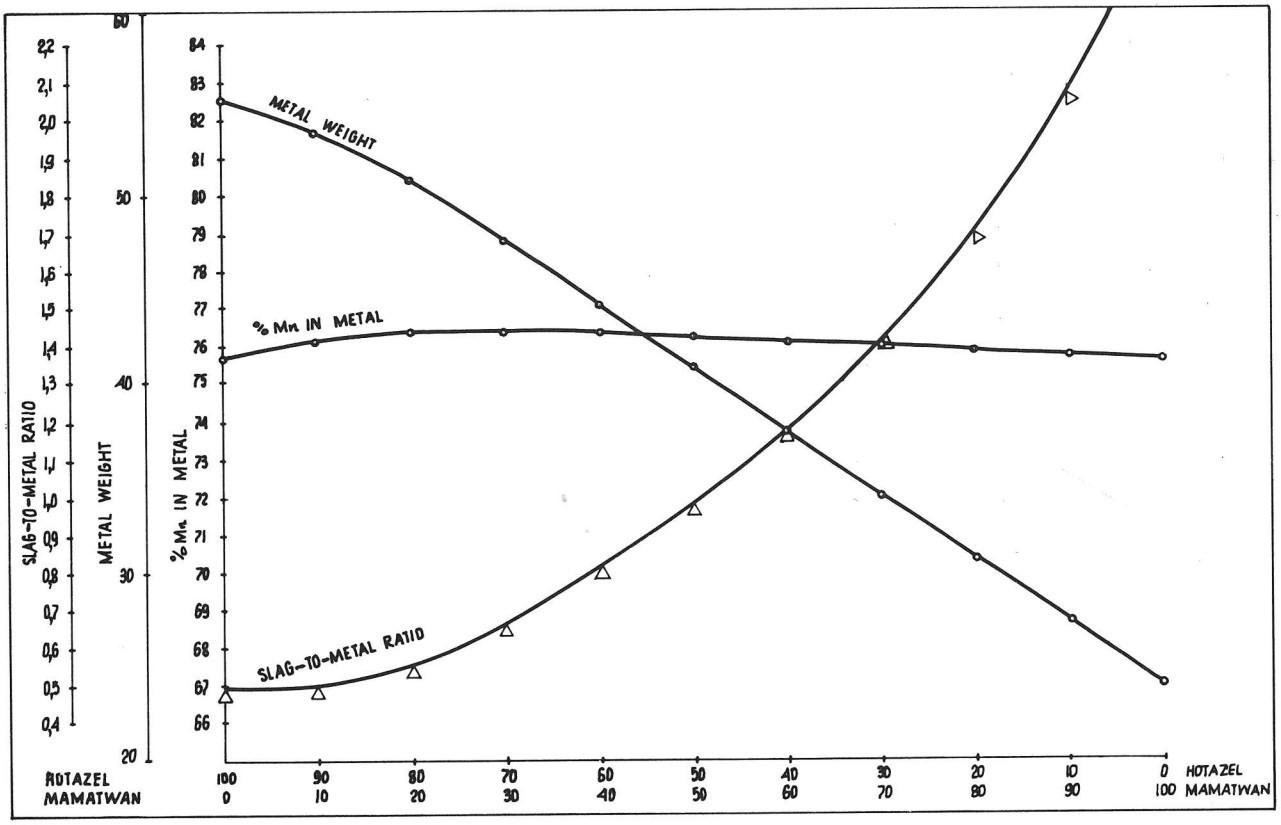

Figure 3

Smelting characteristics of Hotazel–Mamatwan mixtures – high-grade 40 per cent MnO slag

manganese, and, although it is suitable as a refining agent for the production of low- and medium-carbon ferromanganese, this application consumes comparatively small amounts of ore.

As a result of these considerations and the fact that there are such enormous deposits of Mamatwan ore, it has become necessary to obtain the answers to the following questions. Is it not possible to process Mamatwan ore to a form that is suitable as a feed to submerged-arc furnaces for the production of high-carbon ferromanganese? Failing this, is there not a process in which this ore can be utilized in its raw state?

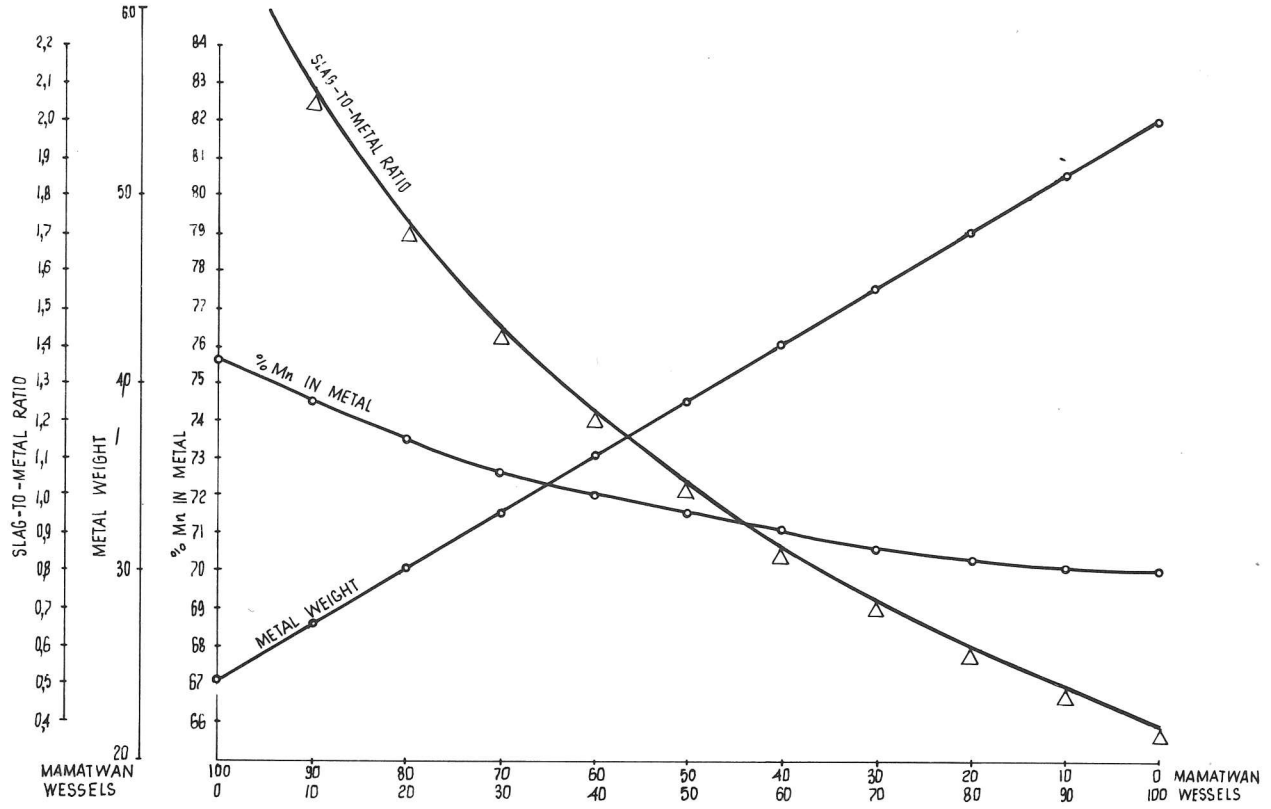

Figure 4

Smelting characteristics of Mamatwan–Wessels mixtures – high-grade 40 per cent MnO slag

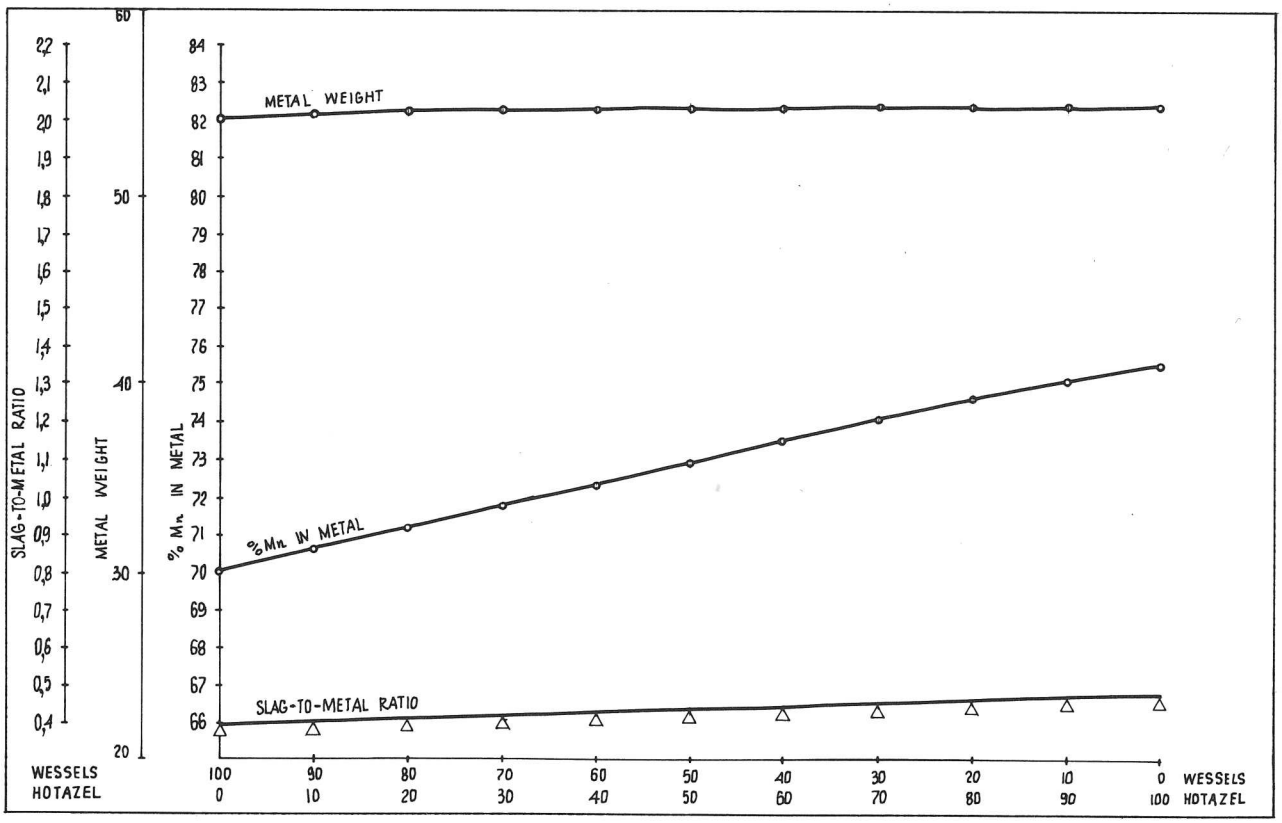

Figure 5

Smelting characteristics of Wessels–Hotazel mixtures – high-grade 40 per cent MnO slag

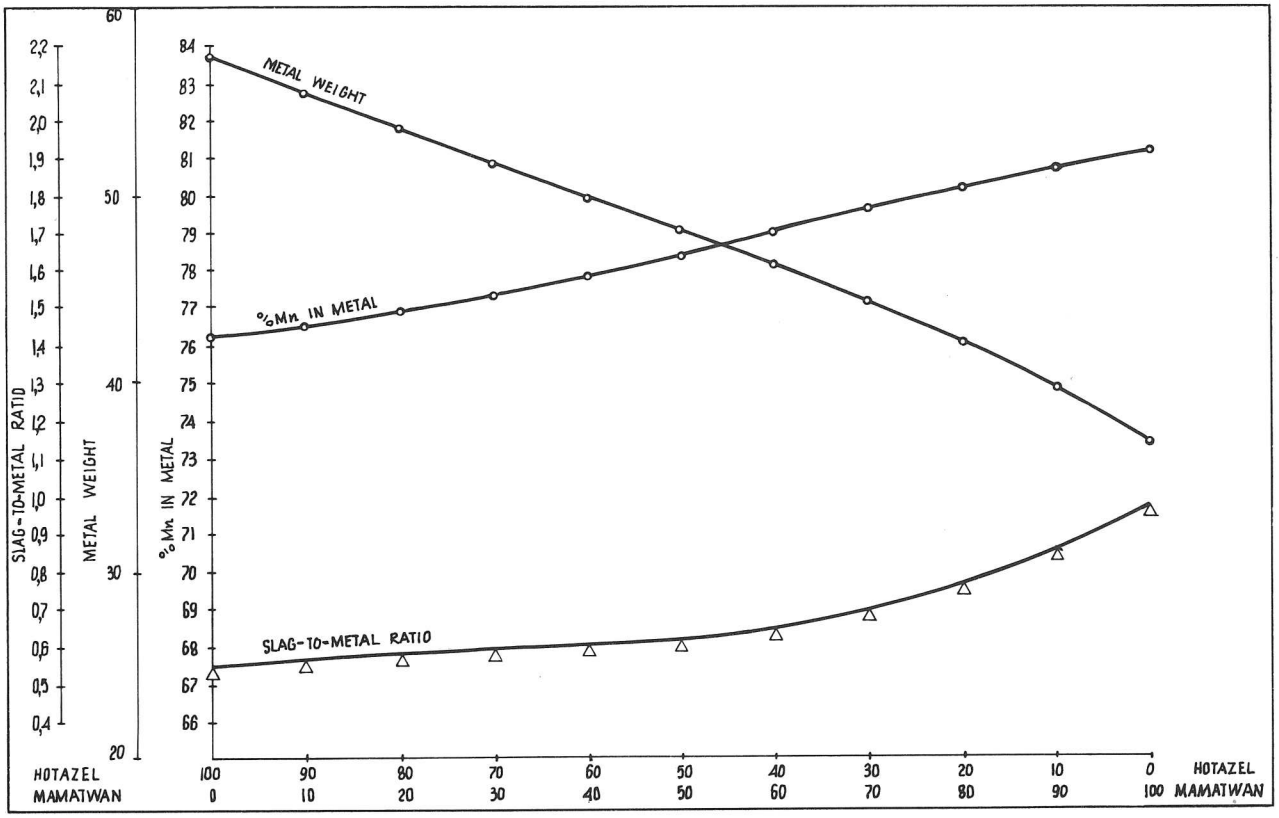

Figure 6
Smelting characteristics of Hotazel–Mamatwan mixtures – low-grade 20 per cent MnO slag

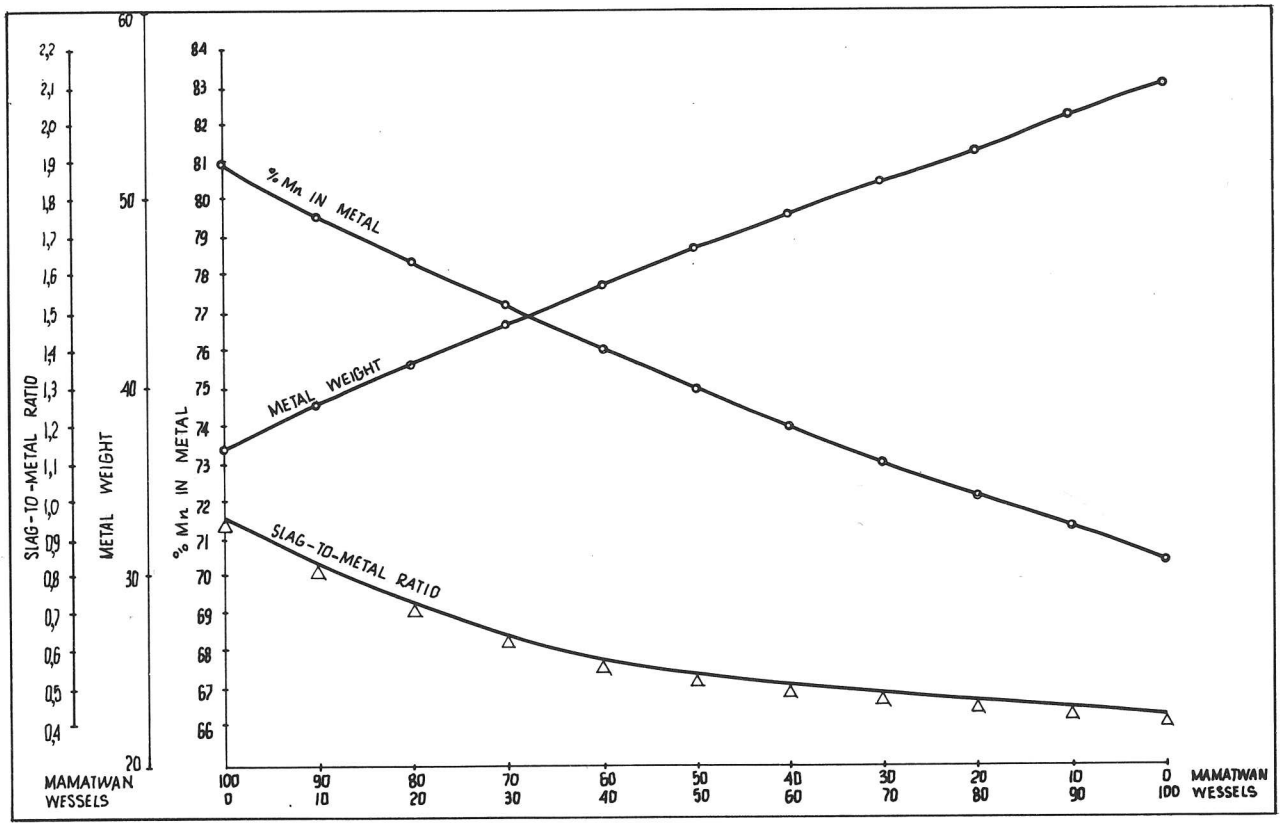

Figure 7
Smelting characteristics of Mamatwan–Wessels mixtures – low-grade 20 per cent MnO slag

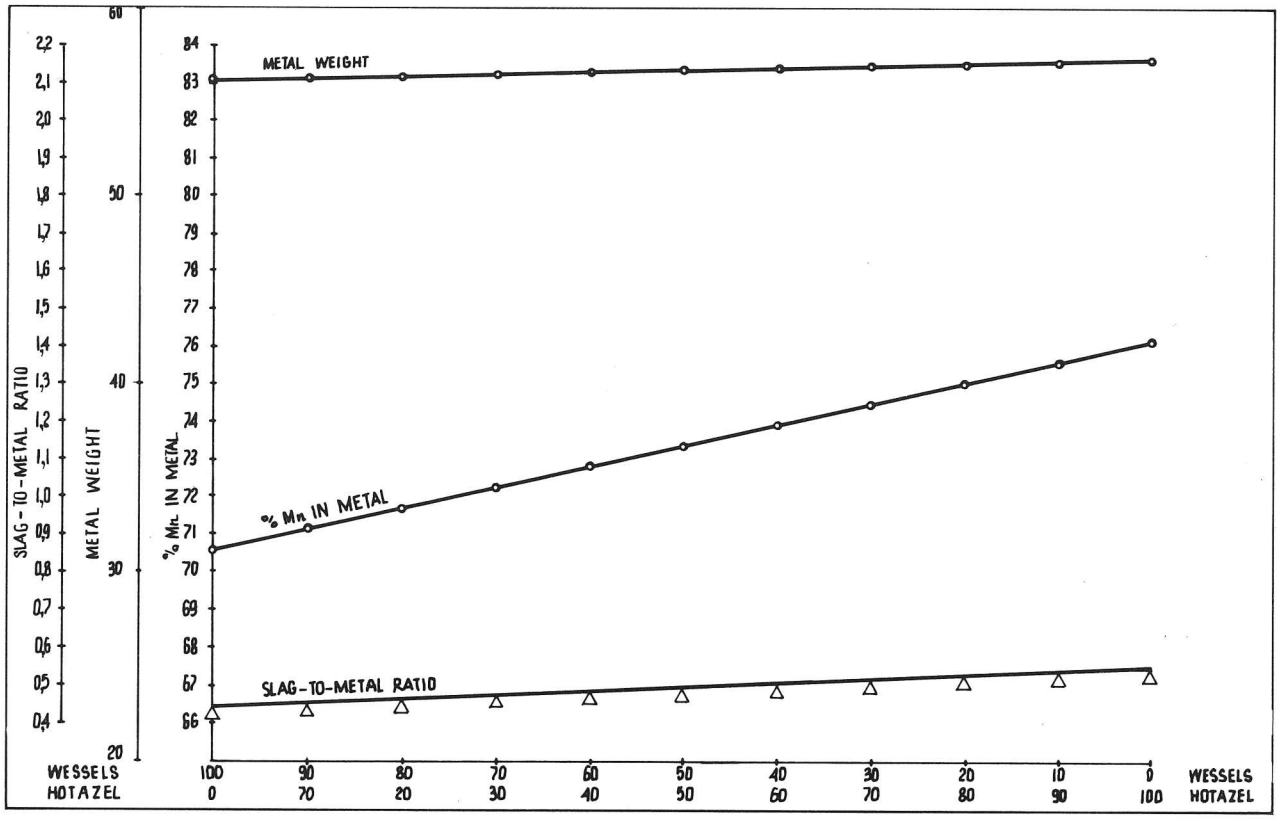

Figure 8

Smelting characteristics of Wessels–Hotazel mixtures – low-grade 20 per cent MnO slag

USE OF SINTERED ORE

Although little attention has yet been paid to pelletizing or to possible hydrometallurgical enrichment of the ore, we have conducted a brief test using sintered Mamatwan ore as primary feed to a furnace producing high-carbon ferromanganese with a low-grade slag. This experiment was conducted in spite of Australian reports to the contrary[3] and rumours from Japan that the use of sintered ore resulted in no improvement in furnace production. The object of the exercise was to get rid of unwanted fines arising from the mining operations and to see whether the increased gas permeability of the furnace bed did lead to increased production.

Accordingly, a quantity of fine ore less than 25mm in size was sintered on the No. 1 sintering plant of the Iscor Vanderbijl Works and then dispatched by rail to the plant of Metalloys Ltd at Meyerton, Transvaal. Analyses of the ore and the resulting sinter are given in Table 4, together with some comparative figures. On arrival at the Meyerton Works, the sinter was found to be only slightly comminuted, although it must be added that the rail distance between plants is only of the order of 20 km. Subsequent handling proved that the sinter did not possess the necessary strength, since the largest particle size at the furnace was approximately 25mm, compared with 75mm on arrival. This physical breakdown caused considerable trouble with the raw-material weighing equipment during the initial stages of the test because of an excessive amount of fines, and led to an undercoaled burden with enormous slag volumes.

Table 4

Chemical analyses of the ores and sinters

	Mamatwan		Imini*		Russian†	
	Ore	Sinter	Ore	Sinter	Ore	Sinter
MnO_2	32,9	22,1	75	21,7	34,09‡	28,18‡
MnO	20,3	39,4	2,5	55,4	28,25	38,45
Mn	36,5	44,5	49,5	56,6	43,42	47,59
Fe	4,9	6,4	1	1,35	2,33	2,47
Mn/Fe	7,4	6,9	49,5	41,9	18,6	19,3
SiO_2	7,5	9,0	9	10,7	15,62	10,58
Al_2O_3	0,6	1,1	1,1	1,4	2,98	1,64
CaO	11,2	13,0	1	1,2	9,12	16,02
MgO	3,2	3,7	N.R.	N.R.	1,62	0,55

*Source: DANCOISNE, P.L. Optimum manganese ore preparation. AIME Electric Furnace Conference, 1970

†Source: NARUSE, W., MIYAGAWA K., OKIGAWA, K. On the sintering test of manganese ore. *Tetsu To Hagane*, vol. 51, 1965. p. 608.

‡Calculated by difference.

The test was performed on the No. 2 furnace of the Metalloys plant, characteristics of which are set out in Table 5.

Table 5

Characteristics of No. 2 furnace, Metalloys plant

Capacity	13,2 MVA
Frequency	50Hz
Primary rated voltage	10 kV
Electrode diameter	1270 mm
Inter-electrode spacing	3700 mm
Electrode pitch-circle diameter	4250 mm
Shell diameter	9530 mm
Shell depth	3660 mm
Crucible diameter	7800 mm
Crucible depth	2135 mm

Initially the theoretical calculations were based on a slag with an MnO content of 25 per cent and on an ore mixture of 80 per cent sinter and 20 per cent Hotazel ore, since this blend formed part of the long-range planning regarding the commissioning of large furnaces at the plant. Two further points that led to the choice of this mix were that it was considered sufficiently high in sinter to be a typical reflection of what is generally accepted as a 'high-sinter burden' and at the same time to remain sufficiently close to the normal mixture so that direct comparisons could be drawn.

In practice, however, it was found that, to obtain a furnace load comparable with normal operation with ore, a slag with an MnO content of approximately 30 per cent had to be maintained. This change resulted in a heavy swing in favour of higher proportions of Hotazel ore, since, owing to the now excessive slag volume, the production as well as kWh per tonne and manganese recovery in the metal could be improved by reducing the amount of sinter used. Unfortunately, the test run was of too short a duration to attempt all sinter—ore combinations, although calculations did show that, even at the presumed optimum, this burden did not compare favourably with the normal ore mixture. A major contributing factor in this regard was that the planned amount of sinter that could be absorbed by the Works was reduced considerably, which would have led to a sharp increase in the cost of sintering. Because of the great comminution on handling, the possibility of railing or exporting the sinter to other plants could also not be considered.

Table 6

Operating characteristics

	Sinter burden	Ore burden
Raw material consumption per tonne		
Sinter	2265	–
Mamatwan	–	1350
Hotazel	568	900
Quartz	147	–
Dolomite	–	50
Coal	842	780
Metal production, t	67,5	71,5
Slag production, t	80,8	57,2
Slag-to-metal ratio	1,2	0,8
kWh per tonne	3400	3150
Metal analysis, %		
Mn	75,1	78,5
Si	0,43	0,15
Slag analysis, %		
MnO	31	22
FeO	0,4	0,5
CaO	25	30
MgO	6	8
Al_2O_3	5	7
SiO_2	31	31

A summary of the results of the test is given in Tables 6 and 7, and it is interesting to note that the differences between ore and sinter operation correspond fairly closely with reported Australian practice[3]. Electrical characteristics have also been included, although it must be realized that, because of some possible inaccuracies in the meters at the furnace, these figures are not absolute values. Rather, the tables should be regarded as relative and for comparative purposes only.

Table 7

Electrical characteristics

	Sinter burden	Ore burden
Primary voltage, kV	11,6	11,5
Primary amperage, A	680	680
MVA	13,6	13,5
Furnace load, MW	10,35	10,5
Reactive load, MVA	8,89	8,55
Power factor	0,76	0,78
Secondary voltage, V	160	161
Secondary amperage, kA	49,2	48,6
Furnace resistance, mΩ	1,43	1,48
Power density, W/cm²	262	266
Current density, A/cm²	3,73	3,69
Reactance per phase, mΩ	1,22	1,21
Mn in metal, %	75,1	78,5
Si in metal, %	0,43	0,15
MnO in slag, %	31	22

BLAST-FURNACE CONSUMPTION

On the basis of the above, it is clear that Mamatwan ore is unsuitable for the electric-furnace production of high-grade 40 per cent MnO slag, and, although it can be used for the production of 20 per cent MnO slag, the results do not compare favourably with overseas practice. On both counts, the blame has been laid on the high CaO+MgO content of this ore and to a lesser extent on the absence of MnO_2. However, when we turn our attention to the ore characteristics that are desirable for blast-furnace practice under South African conditions, we find that they are these very same properties.

In the first instance, with South African coke, these highly basic components render the burden self-fluxing, which, besides leading to a saving in the cost of flux, ensures that these components are spread evenly throughout the mix so that the troublesome condition of 'basicity segregation' does not arise. In parenthesis, it might be added that size segregation seldom occurs and, if it does, is more often than not associated with weak coke. The ore itself is dense and hard; so the channelling and slipping of the furnace are relatively rare.

In the second instance, ferromanganese blast furnaces are generally notorious for the high temperature of the top gas since the high porosity of the charge and the relative absence of indirect reduction allow the furnace gases to rise through the shaft with only a small amount of cooling.

Table 8
Comparative operating statistics

	Iscor, Newcastle No. 2	Workington* No. 4	Duquesne† No. 2	Works‡ B
Hearth diameter, m	4,88	4,8	6,25	
Working volume, m^3	418	498	819	
Blast volume, m^3/min	790	736	1215	
Blast temp., °C	900	1020	818	864
Blast pressure, atm	0,71	0,82	1,22	
Raw-material consumption, kg/t				
Ore	2200	2110		2319
Coke	1800	1450	1882	2080
Flux	—	200	742	936
Metal analysis, %				
Mn	78,6	78,2	77,6	73,3
Si	0,73	0,46	0,58	0,98
P	0,07	0,16	0,24	0,34
S	0,04		0,03	0,02
Slag analysis, %				
MnO	13,9		10,3	13,9
CaO	36,9		32,5	
MgO	8,6		10,8	
Al_2O_3	10,5		20,8	
SiO_2	30,2		23,1	
Metal production, ton/d	185	212	300	
Slag-to-metal ratio	0,85	0,50	0,94	1,06

*Source GREENHALGH, F. and HUNTER, W. Ferromanganese production at Workington. *J. Manganese*, June 1969.

†Source: STAPELTON, J.M., *et al*, Ferromanganese production with oxygen enrichment. *J. Metals, N.Y.*, Jan.

‡Source: DURRER, R., and VOLKERT, E. Die Metallurgie der Ferrolegierungen. Berlin, Springer, 1971.

This effect can be compounded by use of an ore containing large amounts of free MnO_2, such as pyrolusite or psilomelane, when the highly exothermic reduction of this compound by carbon monoxide in the upper part of the stack will increase this temperature still further.

For many years, Mamatwan ore has been smelted successfully in what is now Iscor's No. 2 blast furnace at Newcastle in Natal. Figures relating to a typical operation are given in Table 8, together with comparative figures from overseas practice.

THE MANGANESE BLAST FURNACE

Charges have been levelled at the blast furnace, supposedly owing to its inferiority to the electric furnace in the smelting of manganese ores. The fact that priority has been accorded to the electric furnace has, to the best of our knowledge, resulted in very little research being done to improve the present position of blast-furnace practice. For example, as far as is known, a blast furnace designed solely for the production of ferromanganese has not yet been erected. Usually the units employed are 'hand me downs' from pig-iron practice that have become uneconomic.

In any event, these charges against the blast furnace generally include the following:

(i) coke rates as high as three times those for pig iron,
(ii) high volume and temperature of the top gas, with resultant cleaning problems and high manganese stack losses,
(iii) high silicon in the final metal and limited slag basicity, and
(iv) high capital investment.

Coke Rate

The well-known fact that reduction in a manganese furnace is by the 'direct' process as a result of the inhibiting effect of CO_2 gives rise to several associated effects. As already mentioned, the porosity of the charge leads to hot off-take gases and high losses of manganese by volatilization. To counteract this effect, the furnace is not driven at the high rates applicable to iron furnaces. In this manner, the production is even lower than the *pro rata* calculated amount per hearth area of pig-iron furnace, which reduces the return on investment still further.

Although capital investment is mentioned later, it behoves us to ask the question: Is coke really a necessity? Certainly in converted pig-iron furnaces it must be considered essential if the burden pressure in the stack is to be taken into account. On the other hand, the scarcity of good metallurgical coke cannot be ignored, and, especially in countries having limited reserves of good coking coal, such as South Africa, it stands to reason that the established iron furnaces are to be given priority.

Manganese furnaces must then be content to take second best, although, with higher coke rates and more critical heat demands insofar as the possible chilling of a furnace is concerned, it appears that the situation can resolve into a dilemma.

Form coke and anthracite have been mentioned as possible replacements for metallurgical coke, and, although little information is available on the former, some work has apparently been done or is being done on the feasibility of using the latter. In either event, both the enormous deposits of manganese ores suitable for blast-furnace reduction and the looming shortage of metallurgical coke in this country render it imperative that an economic substitute should be found speedily.

Top Gas

The volume of off-take gases from a manganese furnace is quoted [4] as being more than twice that of a comparable iron furnace, the difference lying in the increased coke rate. A further effect of this increased porosity of the bed is the higher temperature of these gases. Both these effects have a decidedly deleterious outcome on the gas-cleaning system, and it is only by employment of large installations costing large sums of money that some measure of success is achieved. Even so, large capital investment does not automatically guarantee success, and consideration must be given to the question of oxygen injection as a possible solution to some of these problems.

While it might be a moot point that the introduction of oxygen into the blast leads to a reduced volume of exit gases owing to the replacement of nitrogen, it is a well-known fact that it does lead to a reduced top temperature as a result of the redistribution of isothermals in the stack. Thus Stapleton *et al.*[5] have shown a reduction in excess of 20 per cent when using 26,5 per cent oxygen in the blast, and, although this figure refers to sensible heat of the top gas as well as cooling and radiation, it would apparently be safe to assume that top-gas evolution is reduced considerably with oxygen addition. In this context of gas cleaning, it would be most interesting to determine exactly just what the effect of oxygen on the top-gas volume is, since it might be possible so to reduce this volume and temperature that the efficiency of established gas-cleaning systems is increased considerably.

In addition, such a scheme is made more attractive still by the increase of production as well as the reduction of coke rate that accompanies oxygen enrichment. At an oxygen content of 26,5 per cent, Stapleton *et al.* claim figures of 29 and 11 per cent respectively, while Durrer and Volkert[6] mention a coke saving of 250 to 375 kg per tonne and a production increase of 15 to 20 per cent at an oxygen content of 30 per cent. It is worth noting that, in the last case, the calorific value of the off-gas increased by approximately 30 per cent.

High Silicon Content

In direct contrast to silicon contents below 0,2 per cent in electric-furnace metal, a generally accepted level in blast furnaces would seem to be of the order of 0,7 per cent. From experience gained on No. 2 furnace at Newcastle, this level of silicon is empirically established by the heat reserve of the furnace in such a way that, if for some reason the silicon does fall to dangerous levels, there is enough time in hand to enable short-term changes to carry the furnace through until the coke addition arrives at the tuyères.

However, silicon content is not only a function of hearth temperature but is also related to slag basicity in such a way that high basicity, besides resulting in a low MnO content in the slag, is generally correlated with low silicon in the metal. Of course, difficulties do arise in that an increase in basicity is limited by viscosity considerations. In this regard, Sully[4] has mentioned a process that has been developed in Germany and that makes use of previously unattainable basicities as high as 2,8 by varying the MgO content of the slag between 8 and 18 per cent. Furthermore, it has also been claimed that MgO and SiO_2 can be replaced by Al_2O_3 with advantageous results. This has been substantiated by Jon[7], who shows the relation between basicity, expressed as

$$\frac{CaO+MgO}{SiO_2},$$

and the Al_2O_3 content of the slag. Here it is pointed out that, at optimum and particularly low levels of MgO, basicities in excess of 3 are attainable at Al_2O_3 contents of approximately 30 per cent.

Sully quotes an example, using slag-forming constituents of the following analysis: CaO 36,90 per cent, SiO_2 19,58 per cent, Al_2O_3 21,50 per cent, MgO 9,20 per cent — 'The manganese content of the slag was reduced to the low value of only 3,9 per cent while the silicon content of the ferromanganese which contained 55 per cent Mn was only 0,27 per cent'.

Given the increased heat reserve afforded by oxygen injection and a higher basicity than this example, it would surely appear that silicon contents below 0,2 per cent in blast-furnace metal are a distinct possibility.

High Capital Investment

As mentioned earlier, to the best of our knowledge no blast furnace has yet been designed exclusively for the production of ferromanganese. Thus, to date, old pig-iron furnaces have been used with typically tall stacks. In our eyes, these serve no metallurgical function but only contribute to the capital invested insofar as costly structures must be erected to support such large edifices. In consequence, all ancillary equipment must be designed large enough to match increased pressures, stresses, and the like.

In this context, and with reference to Mamatwan ore in particular, a number of factors must be taken into consideration. In the first place, the absence of indirect reduction precludes a large volume above the tuyères. In the second place, it has been shown that Mamatwan ore undergoes no chemical changes in a reducing atmosphere from 200 to 800°C, so again a certain part of the shaft can be dispensed with. In the third place, injection of oxygen into the blast so rearranges the isothermals within a furnace that the top of the furnace cools and presumably, the higher the oxygen content, the colder the top, so that the section over which no appreciable temperature gradient exists is surplus to our needs. In the fourth place, the possibility of the removal of a large section of the shaft to some extent dispenses with the onerous requirements of a blast-furnace fuel, and attention can be focused on form coke, anthracite, or perhaps even coal.

CONCLUSION

It is claimed by Durrer and Volkert that the world's reserves of high-grade manganese ore amount to approximately 500 million tonnes. Mamatwan-type ore, which so far has not been regarded as belonging to this classification, possibly totals the same amount. It has been shown that, compared with other ores, Mamatwan ore is not regarded as suitable for submerged-arc furnaces, but can be used effectively in blast furnaces, and, therefore, by introducing such a process, we stand to double the quoted ore-reserve tonnage.

Moreover, there are strong indications that point towards the feasibility of the process in low-shaft furnaces using oxygen-enriched blast and a cheap fuel such as form coke or anthracite. Extrapolating these pointers to the extreme, it would not seem improbable to imagine structures 10 metres in height being blown with virtually pure oxygen and producing metal at twice the present rate and for half the cost.

A strong incentive for further investigation exists in this country because we possess very large reserves of both Mamatwan-type ore and anthracite; but, in the final

analysis, do we possess the necessary entrepreneurial spirit to develop this process and bring it to economic viability?

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DISCUSSION

Mr A. Melvill.*

Mr Featherstone, in his discussion on the application of Mamatwan manganese ore, suggests that it is not suitable for the production of silicomanganese. In the context of world manganese ores and production of manganese alloys, he is correct. However, in South Africa, where the availability of high-grade ores is limited, the Mamatwan ore, with its low manganese content of approximately 39 per cent but high Mn/Fe ratio of nearly 9:1, assumes a different role when one considers the overseas alloys markets. This point is clearly illustrated by the Transalloys operation, which is dependent upon Mamatwan ore for its source of manganese units in the production of silicomanganese and medium-carbon ferromanganese.

The use of Mamatwan ore in a submerged-arc operation to produce silicomanganese does place limitations on the economics of the process, for example:

(a) the high CaO+MgO content of the ore limits the silicon content in the alloy,
(b) manganese losses are high owing to the large gangue content of the ore, which results in a high slag-to-alloy ratio, and
(c) power consumption is higher than normal for comparable slag-to-alloy ratios.

In the Transalloys operation, the proximity to the source of ore, and the ability to produce a high manganese content in the alloys, appear to make the delivered cost of the alloy to Europe or America competitive. It is doubtful whether a production operation located in these overseas markets could be economic if based only on Mamatwan ore, since the transportation cost per manganese unit would be very high from the mine to Europe or America.

Mr Featherstone (in writing):

Mamatwan ore is indeed used successfully in the production of silicomanganese at Transalloys, and I am in complete agreement with Mr Melvill insofar as the unique situation in this country does allow for this successful operation.

Mr W.H. Magruder●.

As you probably know, there is a Ghana carbonate ore similar to Mamatwan (30 to 32 per cent manganese). Sometime in the early 60s, a one to two months' test operation using the Ghana ore was carried out at our Marietta Plant, which involved the use of 100 per cent Ghana carbonate for silicomanganese production. This ore works fairly well because the carbonates decompose in the upper part of the furnace, which maintains a cold furnace top and allows the electrodes to run fairly deep. However, it is not a simple operation, and I am full of admiration for the work done at Transalloys.

Mr N.A. Barcza†:

One can note that the chemical composition of the various manganese ores shows that they contain manganese oxides in the MnO_2 and MnO oxidation states.

(1) How representative is this of the actual nature of the manganese oxide in the ore?
(2) To what extent will a typical Mamatwan ore, for example, undergo thermal deoxidation up to temperatures of, say, 1600°C (i.e., when there is no reducing agent added)?
(3) Has any experimental work been carried out on the direct reduction, with carbon, of South African or any other manganese ores? This would be with a view to producing a medium-carbon ferromanganese in, say, a rotary kiln at temperatures of about 1400°C.

Mr Featherstone (in writing):

(1) The generally accepted convention of reporting MnO_2 and MnO does not indicate that the manganese is present as these specific oxides. Owing to the difficulty involved in wet-chemical analysis of the range of oxides, a greater proportion of MnO_2 is representative of a larger amount of higher oxides.
(2) Let me refer to some testwork done several years ago. Mamatwan ore starts melting at about 1450°C and is completely molten at about 1550°C. Even at these temperatures, a significant amount of MnO_2 was reported, indicating that complete conversion to MnO had not occurred.
(3) During this test, we did, in fact, feed coal to the molten ore in an attempt to convert all the manganese to MnO, but we found that, after a certain level, the liquidus temperature rose so high that even at temperatures above 1600°C we were left with a pasty mass that was barely liquid. As a matter of interest, this material analysed at 2,5 per cent MnO_2.

Apart from this, we are not aware of any experimental work being done on direct reduction with carbon.

Mr Selmer-Olsen.

It is difficult to analyse accurately for MnO_2 and MnO separately. On the second question, it is not easy to go into all the details in the short time available, and I suggest that reference should be made to the paper I presented yesterday. As to the third question, we tried to reduce the higher oxides with carbon to the lower oxide states, but found that the liquidus temperature increased and the operation of the furnace became difficult.

Mr M. Sciarone.*

It is concluded, from a mass balance, that maximum production is related to a high metal production (or a low slag-to-metal ratio). The amount of slag produced affects the operating resistance. The experience at Kookfontein indicates that a reasonable slag-to-metal ratio is desirable. To obtain this condition, a considerable amount of Mamatwan ore is used successfully in our burden for high-carbon ferromanganese production.

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Mr Featherstone (in writing):

A mix with low slag-to-metal ratio was tried on the old furnaces at Kookfontein with some measure of success in the manufacture of 40 per cent MnO slag. The furnace resistance was increased, enabling a higher production level to be maintained. However, it is a well-known fact that, the harder a furnace is driven, the closer the tolerances that must be attained, particularly in raw-material control. As mentioned by Mr Selmer-Olsen in his paper, variation in ore analysis and inaccurate weighing rendered furnace control extremely difficult, and the plant reverted to a practice involving higher slag-to-metal ratios.

Mr Selmer-Olsen:

Inexperienced young metallurgists usually want to reduce the slag-to-metal ratio to obtain optimum production, but in actual fact it is necessary to obtain an optimum slag-to-metal ratio in order to maintain the correct furnace resistance. Mamatwan ore has proved useful in this respect.

Mr Featherstone (in writing):

I should like to take this opportunity of expressing my appreciation to Mr Selmer-Olsen for having presented this paper in my absence.