The Production of Manganese Alloys by the Sintering Process

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SYNOPSIS

One of the most important metallurgical problems to be solved in the production of ferro-alloys is the efficient use of ore fines. In this paper, the smelting of manganese ferro-alloys in electric furnaces by a sintering process will be discussed. The distinguishing feature of our sintering process is that it permits a positive, cost-conscious purchasing policy. The process involves the sintering of fine ores at a ferro-alloy plant and the use of this sinter, along with sized ore, as the raw material in the production of ferro-alloys.

The production of manganese ferro-alloys at the ferro-alloy plant of Nippon Denko Co., Ltd, Tokushima, is described. A description of the equipment and its operational characteristics, stating the advantages of the sintering process, is included.

INTRODUCTION

About 1955, for a variety of reasons, we were compelled to use manganese fine ores and finer-sized coke breeze as a substantial part of the mix in our ferromanganese plant at Kanazawa. This caused highly unstable furnace-operating conditions characterized by frequent abrupt blows and eruptions.

Thus, research was begun on the sintering of ore fines to avoid such problems. In 1961, A Dwight—Lloyd sintering machine was installed adjacent to the furnace, and the sintered ore thus obtained was used as the principal material in the production, through processing in electric furnaces, of ferromanganese and silicomanganese. This process resulted in an appreciable increase in electric-power input and a remarkable stability in furnace operation. The performance met our expectations, and the reduction in production costs was satisfactory.

The recent trend in ferro-alloy production has been the adoption of very large closed furnaces, which use uniformly sized ore and agglomerated screened-out fines.

It is our conviction that the sintering process is the most reliable and profitable method for the production of manganese ferro-alloys in large closed furnaces, because it results in stable operation and the economical use of fine-ore resources. Acting on its conviction, Nippon Denko, in 1969, established its large-scale coastal ferro-alloy plant at Tokushima (Figures 1 and 2). At the present

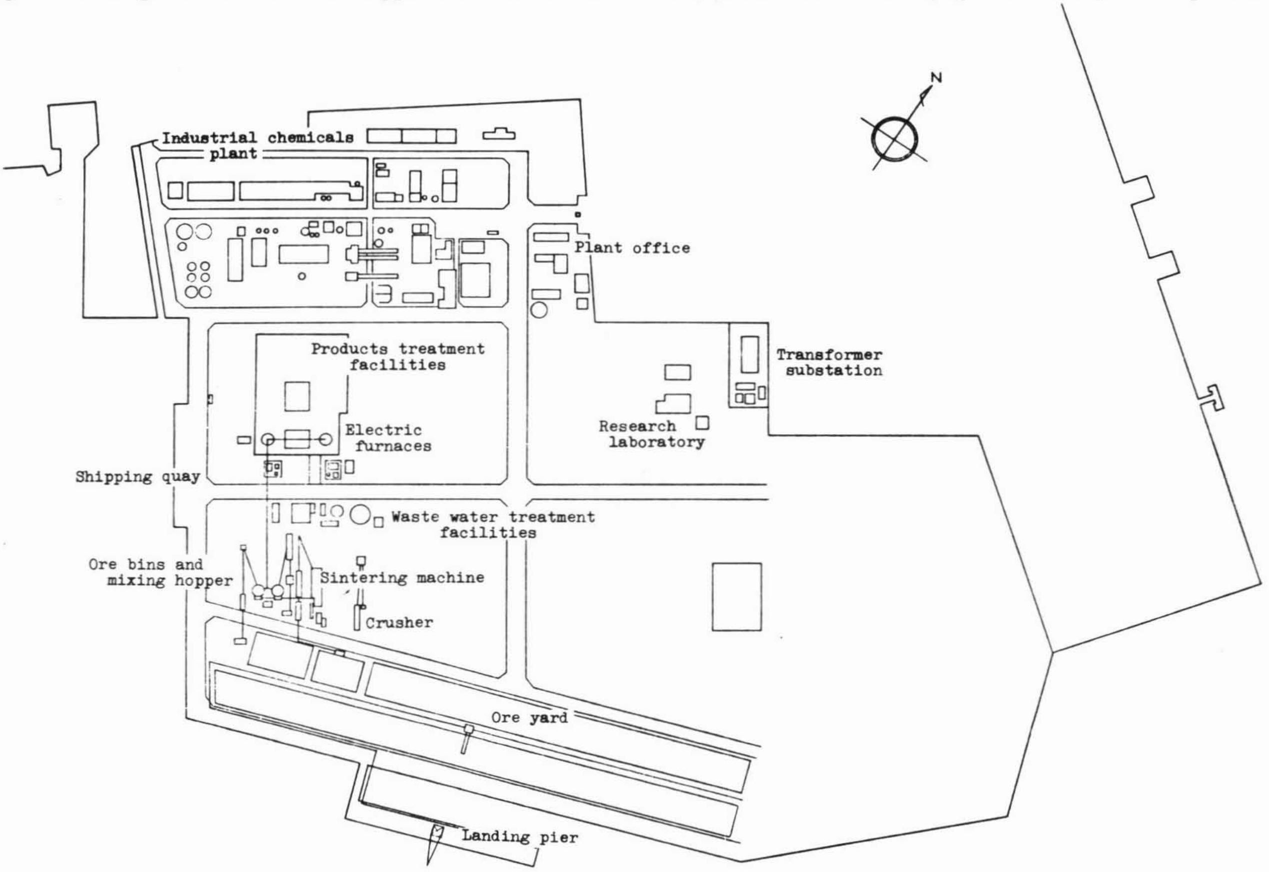

Figure 1
Layout of Tokushima Works, Nippon Denko Co., Ltd

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11 050 mm. The electrodes are 1700 mm in diameter, with a spacing of 4420 mm. The furnace is equipped with four tapholes for metal and four tapholes for slag, but only one for metal and one for slag are normally used.

One of the unique features of this furnace is its 'packed towers'. These are located between the overhead mix bins and the furnace cover, in which the wet mix comes into contact with the rising furnace gas. The packed towers are employed for drying the mix and for removing coarser dust particles in the furnace gas. This collected dust is recycled direct into the furnace, thereby improving the total manganese recovery.

A 15 000 kVA capacitor bank is connected with the tertiary winding of the transformer.

Furnace gas from the packed towers is cleaned successively by low-pressure Venturi scrubbers and a Theisen washer, and then burnt off at the flare stack. A bag filter at the tapping bay traps the manganese fume generated during the tapping operation. The design data for this furnace are given in Table 1.

The furnace used for silicomanganese production was put into operation in May 1971, and had the same design criteria as those for the ferromanganese furnace, except for some changes in dimensions. Its design data are also given in Table 1.

Table 1

Furnace design data

	No. 1 furnace high-carbon FeMn	No. 2 furnace SiMn
Shell diameter, mm	13 310	13 686
Shell depth, mm	6 430	7 530
Top of shell to hearth, mm	4 300	5 500
Hearth diameter, mm	11 050	11 420
Electrode diameter, mm	1 700	1 700
Electrode spacing face to face, mm	2 720	2 890
Transformer capacity, kVA	36 400	40 500
Capacitor, kVA	15 000	15 000x2
Primary voltage, V	33 000	33 000
Secondary voltage, V	246 - 198 Delta connected 198 - 166V Y- connected	267 - 190 Delta connected 190 - 155V Y- connected
Tap changer	On-load 21 taps	On-load 33 taps
Number of metal tapholes	4	3
Number of slag tapholes	4	3
Hearth thickness:		
Carbon paste stamp, mm	400	400
Carbon block, mm	1 200	1 200
Brick, mm	476	476

FURNACE OPERATION

The ferromanganese furnace at Tokushima has been producing high-carbon ferromanganese that meets Japanese Industrial Standard (JIS) FMn—1, with the following specifications: Mn 73 to 78 per cent, Si 1,2 per cent max., C 7,3 per cent max., P 0,40 per cent max., and S 0,02 per cent max. The typical analysis of the metal is Mn 74,5 per cent and Si 0,1 per cent.

Operational data and the heat balance are shown in Tables 2 and 3 respectively. The metal is cast direct into the moulds (70 mm long by 70 mm deep by 1420 mm wide) of a casting machine and is then crushed and screened. Undersized metal, which cannot be marketed, is fed back into the furnace.

The furnace is tapped every 4 hours, producing 50 tonnes per tap. The settling rate of the furnace burden seems to be uniform over the whole surface of the burden, except for the central region, where its rate is somewhat high if judged from the indication of the surface-level indicators. Consequently, it appears that the smelting zone in the furnace crucible is expanded sufficiently.

Silicomanganese of JIS SiMn—3 standard has been produced with the following specifications: Mn 60 to 65 per cent, Si 14 to 18 per cent, C 2,5 per cent max., P 0,30 per cent max., and S 0,03 per cent max. The typical analysis of the product is Mn 61,0 per cent, Si 14,5 per cent, and C 2,0 per cent.

The use of sinter that has been prepared specially for the manufacture of silicomanganese is limited to 45 per cent

Table 2

Operational data for the production of high-carbon ferromanganese and silicomanganese

	No. 1 furnace high-carbon FeMn	No. 2 furnace SiMn		No. 1 furnace high-carbon FeMn	No. 2 furnace SiMn
Production per month, t	9 198	5 641	Average power input, kW	25 741	27 980
Raw material per tonne			Secondary voltage, V	222 - 230	239-256
of metal:			Operating time, %	98,9	99,0
Manganese ore, kg	765	703	Power factor corrected, %	90,0	95,0
Sinter, kg	917	834	Recovery of Mn, %	81,7	80,8
Metal fine remelt, kg	144	124			
Coke, kg	344	418	Metal analysis:		
Limestone, kg	58	242	Mn, %	74,2	60,8
Ferromanganese slag,kg	—	795	Si, %	0,1	14,5
Quartzite, kg	—	177	C, %	6,8	2,0
Millscale, kg	—	92	Slag analysis:		
Electrode paste, kg	6	19	Mn, %	25,9	9,3
Slag per tonne of metal, kg	522	1 440	SiO_2, %	22,4	39,2
Power consumption per tonne			CaO, %	17,3	22,1
of metal, kWh	2 015	3 699	MgO, %	1,5	1,1

Table 3

Heat balance – high-carbon ferromanganese

		Calculation basis		Energy		
		Temp.(°C)	Quantity (kg)	x10^3 kcal	kWh	%
Heat input						
Power:				1732,9	2015,0	100,00
Heat output						
Sensible heat:	Alloy	1320-25	1000	295,7	343,8	17,06
	Slag	1380-25	522	185,3	215,5	10,69
	Exit gas	60-25	486,3Nm^3	5,6	6,5	0,32
	H_2O vapour in exit gas	60-25	31,1	0,5	0,6	0,3
	Mn vapour, tapping loss	1320-25	3,2	0,4	0,5	0,02
	Alloy loss, tapping loss	1320-25	27	8,0	9,3	0,46
	Dust	60-25	20	0,1	0,1	0,00
				(495,6)	(576,3)	(28,60)
Heat of vaporization:	H_2O		31,1	18,2	21,2	1,05
	Mn		3,2	3,1	3,6	0,18
Heat of formation:	Mn_3C	Mn	742	-16,2	-18,8	-0,93
	Fe_3C	Fe	187	6,0	7,0	0,35
	Slag		522	-60,0	-69,8	-3,46
				(-48,9)	(-56,9)	(-2,82)
Heat of reaction:	MnO_2 – MnO	MnO_2	380,9	141,4	164,4	8,16
	Mn_3O_4 – MnO	Mn_3O_4	467,2	112,2	130,5	6,48
	MnO – Mn	Mn	619,4	1036,1	1204,8	59,79
	Fe_2O_3 – Fe	Fe	164,9	289,0	336,0	16,67
	SiO_2 – Si	Si	1,0	7,5	8,7	0,43
	P_2O_5 – P	P	1,34	8,0	9,3	0,46
	H_2O – H_2	H_2O	19,5	74,0	86,0	4,27
	C + 1/2 0_2 – CO	CO	355,0Nm^3	-418,4	-486,5	-24,14
	C+O_2 – CO_2	CO_2	84,3Nm^3	353,9	-411,5	-20,42
	$CaCO_3$ – CaO	CaO	44,6	34,1	39,7	1,97
				(930,0)	(1081,4)	(53,67)
Heat Loss:	Cooling water	36-30	31 250	187,5	218,0	10,82
	Furnace body			58,8	68,4	3,40
	Transformer			28,1	32,7	1,62
	Others			81,8	95,1	4,72
				(356,2)	(414,2)	(20,55)
Total				1732,9	2015,0	100,00

of all the ore required because of the limited sintering-machine capacity. The furnace is tapped every 6 hours, producing 45 tonnes per tap.

SINTERING PLANT AND ITS OPERATION

Adjacent to the furnaces is a sintering plant with a production capacity of 500 tonnes per day. Design data of the Dwight—Lloyd sintering machine are given in Table 4.

The moisture content of the mix to be charged into the pallets is 9 to 10 per cent. The addition of coke is 5,5 per cent for ferromanganese and 4,5 per cent for silicomanganese. The bed depth is about 300 mm. The sintering time is 9 to 13 minutes, depending upon the characteristics of the mix.

The optimum working conditions of the machine are maintained by control of the bulk density of the charged mix, the addition of coke, the degree of damper openings of the windboxes, and the fuel feed-rate. Operational data for the sintering machine are also given in Table 4.

Table 4

Design and operational data for the sintering machine

Effective grate area, m^2	14,6
Length of machine, m	19,3
Number of windbox	9
Pallet	1,0m x 0,6 m x 0,36 m x 73

	Sinter, high-carbon FeMn	Sinter, SiMn
Production per month, t	8452	4401
Operating time, h	350	228
Raw material per tonne of sinter, kg	1176	1160
Coke per tonne of sinter,kg	107	89
Fuel per tonne of sinter, litre	7	6
Sinter analysis:		
Mn, %	50,6	35,5
SiO_2, %	6,1	28,2
Productivity, t/m^2/h	1,62	1,32
Strength, %	81,0	76,0

INDIRECT REDUCTION

It was confirmed by our mineralogical study that the manganese in the sintered ore consists mainly of Mn_3O_4 and MnO. MnO_2 or Mn_2O_3 in the raw manganese ore is prereduced to Mn_3O_4 or MnO during the sintering operation. Consequently, if 100 per cent sinter is used for ferromanganese smelting, the exothermic heat of reaction cannot be used efficiently owing to the indirect reduction of the higher oxide of manganese to its lower oxide.

On the other hand, it is imperative for the improved operation of ferromanganese production with 100 per cent raw ores that the amount of this indirect reduction should be increased. This is done by extension of the region in which indirect reduction occurs — that is, the area of the furnace burden below 1000°C. The indirect reduction zone is expanded by an increase in the overall furnace burden. The increased furnace burden requires sizing and drying of the raw materials if blows, eruptions, and cave-ins in the furnace are to be avoided. The use of uniformly sized raw materials, however, increases the amount of screened-out fines that must be taken into account.

It is possible that some ores may give an appreciable amount of fines in the furnace during heating and prereduction. In that case, smooth and efficient furnace operation may be interrupted, expected savings may be lost, and furnace equipment may be damaged. In addition, the longer electrode length required by the deeper furnace burden increases the risk of electrode breakage, especially in larger furnaces.

In the development of our sintering process, we have worked continuously at solving the above problems and at obtaining highly stable and economical operation for the production of ferro-alloys.

ELIMINATION OF FURNACE BLOWS

The beneficial effect of the sintering process is basically due to the elimination of blows or eruptions of the furnace. This is due to the improved permeability of the burden and the decrease in the rate of evolution of furnace gas. This reduced evolution rate is accompanied by decreases in coke consumption and in the moisture content of the mix. A uniform, slow evolution of gas throughout the entire surface of the charge is also obtained in the sintering process.

Figure 4 shows the permeability of various furnace burdens measured at room temperature. The gas flow-rate per unit area of ferromanganese furnace when 55 per cent sinter is used is about 1,1 $Nm^3/min/m^2$, and that when raw ores are used is about 1,1 to 1,5 $Nm^2/min/m^2$. This means that, even in a conventional ferromanganese operation using raw ores containing fines, furnace blows will generally be eliminated in the initial stages until the crust or hanging of the charge occurs. As is also shown by the results, the burden of 100 per cent uniformly sized raw ores does not show any discernible difference when compared with a burden of 50 per cent sinter. However, such similarity in the permeability behaviour of the two burdens is not always expected in actual furnace operation. Occasionally, the smelting of a burden of 100 per cent uniformly sized raw ores is hindered by the occurrence of a large amount of fines due to ore-bursts during the heating and prereduction in the furnace. As opposed to this, the bursting of sintered ore during heating has never been observed in our heating tests and investigations of furnace crucibles.

In addition, crust formations or hangings of the charge occur very seldom during the sintering process because of the expansion of the smelting zone and the elimination of the abovementioned ore bursting. Consequently, cave-ins or irregular settling of the charge can be avoided, preventing the rapid evolution of a very large volume of furnace gas. With such burden behaviour, therefore, blows or eruptions occur very seldom.

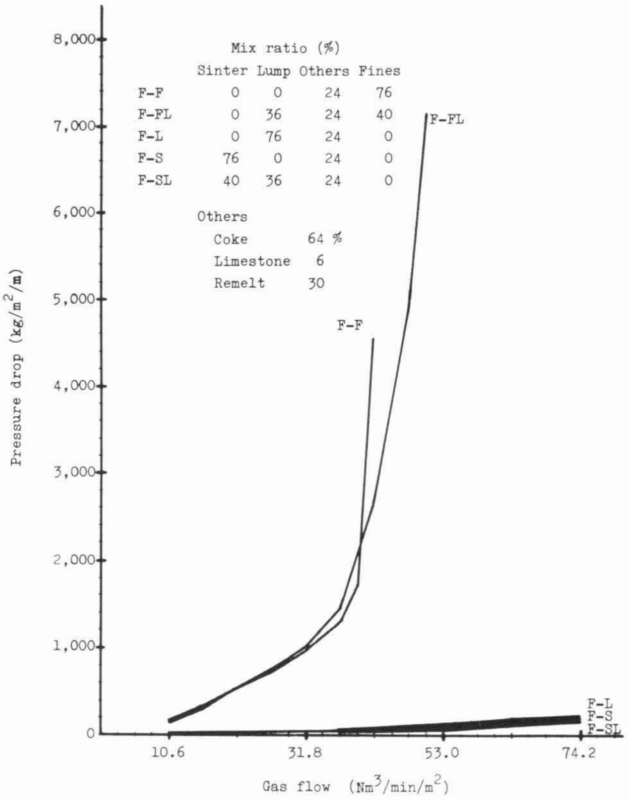

Figure 4
Relation between pressure drop and gas flow for several kinds of raw mix used in the production of high-carbon ferromanganese

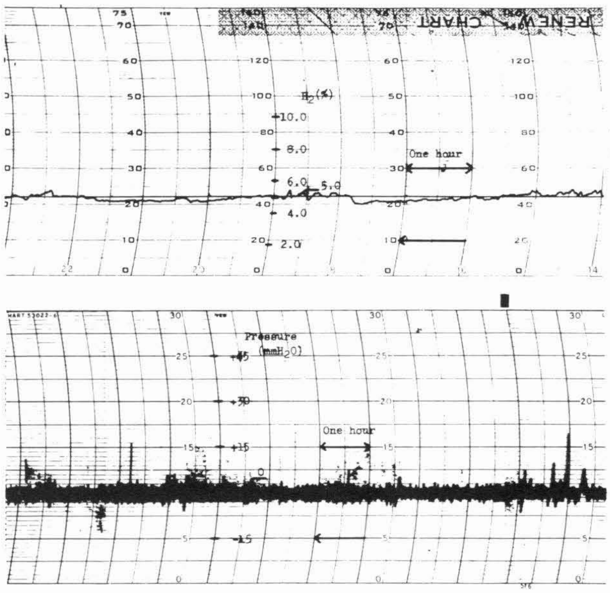

Figure 5
Charts showing H_2 content in the exit gas and pressure in the high-carbon ferromanganese furnace

Both the recording charts of gas pressure inside the furnace-cover and the hydrogen content in the gas (Figure 5) show highly stable operating conditions, confirming that blows or eruptions are insignificant in our ferromanganese furnace using 55 per cent sinter.

FURNACE LOAD, AND QUALITY OF THE PRODUCT

Owing to the elimination of furnace blows and crust formations, a smooth and uniform settling of the burden takes place, and stable operating conditions are attained. This has very beneficial effects on the quality of the final products. Fluctuations (2α) in the composition of our ferromanganese metal and slag are very small — metal: Mn 74,5± 0,4 per cent, Si 0,1± 0,01 per cent; slag: Mn 25,0±1,0 per cent.

The 55 per cent sinter operation allows the secondary voltage to be increased, and this voltage is greater than in conventional operation. This makes it possible to increase the operating load. In addition, a constant operating load is easily maintained in the uniform furnace conditions. The constancy of the furnace load is shown in Figures 6 and 7. One can expect great improvement in the production of a furnace using the sintering process, owing to increases both in furnace load and operating time.

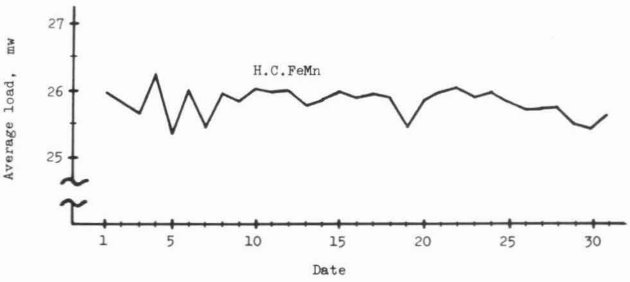

Figure 6
Average load in the production of high-carbon ferromanganese, May 1973

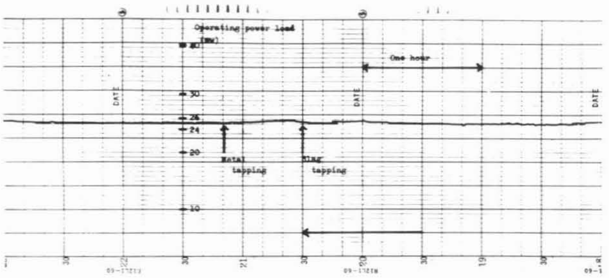

Figure 7
Chart showing operating power load in the high-carbon ferromanganese furnace

SMELTING AT LOWER TEMPERATURE

In our operation, the silicon content of the ferromanganese is very low (0,1 per cent). This low silicon content implies a restriction on the formation of silicon and is indicative of the direct reduction occurring in the lowered temperatures of the expanded smelting zone. It also demonstrates that local overheating never occurs with our process. These observations are also supported by the results of our temperature measurements. The metal-tapping temperature is 1320°C for ferromanganese when 55 per cent sinter is used and the slag basicity ($CaO+MgO/SiO_2$) is 0,8.

Smelting at lower temperatures has a positive effect on energy savings because of a decrease in the sensible heat of the metal and slag and in the amount of silicon to be formed. It also exerts a favourable influence on the electrical resistance of the furnace burden.

DECREASE IN DUST EMISSION

The amount of dust generated in our production process is about 30 kg per tonne of metal for our ferromanganese furnace. This is one-half to one-quarter that of other furnaces, which are generally reported to generate 60 to 120 kg per tonne of metal.

The heat that escapes through dust emission is small, but this heat loss becomes larger when furnace blows or eruptions occur. Manganese oxide or silicon dioxide in the dust presumably results from the vaporization of metallic manganese and silicon monoxide. If the furnace erupts and a mixture of approximately 30 kg of manganese vapour and 20 kg of silicon monoxide vapour is blown off from the surface of the charge at 1300°C, the heat loss is equivalent to about 140 kWh.

In the ferromanganese operation with 55 per cent sinter, there are no noticeable furnace blows, and the temperature of the gas liberated from the burden is below 200°C. This means that the heat loss in the form of manganese and silicon monoxide vapours is insignificant.

FURNACE DESIGN

The abovementioned reasons make it clear that hearth depth, electrode spacing, and secondary voltage range should be taken into account in the design of a furnace for the sintering process.

Since, with the sintering process, an increase in hearth depth would not be accompanied by a proportional increase in indirect reduction, the hearth depth has not been increased. Deep-burden operation is associated with an increased risk of electrode breakage. Our furnaces at Tokushima operate with 2700 to 3000 mm of electrode length below their holders. This length is over 500 mm shorter than that of most of the larger furnaces now being operated.

In the design of a furnace for the sintering process, the expansion of the smelting zone in the crucible is an important factor. This expansion prevents overheating in the smelting zone and consequently results in stable furnace operation. The electrode spacing should be designed so that the positive effects of the expansion of the smelting zone are not diminished. It will be somewhat larger than that of a conventional furnace. Such a furnace will permit increased furnace loads and electrical resistance, making it possible to capitalize fully on the advantages inherent in the sintering process.

CONCLUSION

The present situation of manganese-ore resources in the world compels ferro-alloy producers to use much more ore fines than they did in the past. Consequently, it is imperative that the screened-out fines should be agglomerated and utilized efficiently.

In conclusion, because of the sintering process, we have been able to pursue a cost-conscious purchasing policy based on an increased use of ore fines. Furthermore, our production per furnace unit has also been greatly improved, owing to increased furnace loads and stable operating conditions.

Our long experience with the sintering process has convinced us of its effectiveness in the production of manganese ferro-alloys. This is especially true at the present time, when larger and larger furnaces are being developed.

DISCUSSION

Mr R.F. Jennings:*

(1) Is the sinter used in Nippon Denko's ferromanganese furnaces screened? If so, at what size and at what stage before entering the furnace?

(2) Is the sinter cooled or used hot?

(3) Is the sinter mixed with the lump ores before being fed to the 'packed towers', or are the ores and sinter fed separately to these towers?

(4) Would the author consider the use of 100 per cent sinter in the furnace burden if he had the necessary capacity of sinter machine?

Mr Naruse:

(1) Yes, it is screened at 10 mm by the hot screen after the sinter breaker.

(2) It is cooled by the cooler after being screened.

(3) The sinter is mixed with the lump ores before being fed to the 'packed towers'.

(4) Yes, I would, of course.

Mr R. Archer†:

What is the chemical analysis of the sinter?

Mr Naruse:

The following is the chemical analysis of the sinter that was used during the period when the heat balance shown in Table 3 was calculated:

Mn 50,6 per cent, SiO_2 6,1 per cent, CaO 4,8 per cent, Al_2O_3 6,4 per cent, Fe 5,5 per cent, MgO 0,1 per cent.

Mr S. Selmer-Olsen:‡

Has Mr Naruse any experience in sintering chromium ore in his sintering plant? If so, why does everybody go for pelletizing, instead of sintering, of chromium ores?

Mr Naruse:

We are producing ferrochromium by the sintering process. We are fully satisfied with its performance results as in the case of ferromanganese. The operation is also characterized by an increase in productivity, and stable and trouble-free operation.

I read a paper on the results of the operation at the 81st Congress of the Iron and Steel Institute of Japan in 1971. And you can also read its outline in the Special Issue of *Metal Bulletin* in 1971. And now our Toyama Works is producing ferrochromium with 100 per cent sinter charge. Its results are also satisfactory.

As to your second question, I do not think that everybody goes for pelletizing instead of sintering. It is true that a remarkable reduction in power consumption can be expected for the prereduced-pellet process; but that process is so complicated and sophisticated that it requires very careful and delicate control. Furthermore, even if the power consumption by the furnace is reduced, additional energy consumption is required in the kiln operation. I think the sintering process can bring the most beneficial effects to ferrochromium production.

I would like to point out the reasons as follows.

(1) The furnace operation with the sintering process, compared with lumpy ore, makes it possible to reduce power consumption.

(2) It is possible to install a sintering machine for existing furnaces as well as for new furnaces, and to use the mixture of the raw ore and the sinter in a desired ratio.

(3) The operation of the sintering process, both sintering-machine operation and furnace operation, is so simple and stable that the furnace can be operated at the maximum load without any trouble.

(4) Moreover, the sintering process is characterized by reasonable installation cost, simple maintenance, and high productivity.

Mr Ricardo P. Guevara:*

In Section 1 of this Congress, three papers were read on processes utilizing raw-material fines that would otherwise be wasted in ferro-alloy production. These processes are sintering, pelletizing, and chromite fines reduction with ferrosilicon. In calcium carbide production, which is also a reduction process and very similar to ferro-alloy processes, raw-material fines have been successfully utilized by direct feeding into the furnace reaction zone through hollow electrodes, in systems developed by Union Carbide.

Nippon Carbide also sells the design of hollow-electrode fines feed, as do some Taiwanese companies.

Could the hollow-electrode system of fines feed be adapted to some ferro-alloy processes, for example, 50 per cent ferrosilicon?

Mr Naruse:

As you mentioned, some calcium carbide producers are successfully adopting the fines-feed system with hollow electrodes. I suppose, one of the reasons why ferro-alloy producers do not utilize this system is that they are afraid of the blocking of the charge materials inside the hollow electrodes because of the difference in smelting between the ferro-alloy and calcium carbide. Some ferro-alloy producers tried to use this system, but I have had no experience.

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*Simon Carves Ltd, Britain.

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