A comparison of electric smelting on pilot and industrial scale

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SYNOPSIS

The paper compares operational parameters for the electric reduction smelting of pig iron and ferro-alloys in pilot and industrial furnaces. Data from two pilot furnaces of approximately 200 and 500 kW operating-load capacity, as well as from several production furnaces, are included. Examples are given for the smelting of pig iron, ferronickel, ferromanganese, ferrochromium, and ferrosilicon.

In most instances, the results from the pilot furnaces, such as the values for consumption and product analyses, corresponded fairly well with comparable data from the industrial furnaces. For ferrosilicon, the power consumption in the pilot furnace was higher than that in the industrial furnace.

SAMEVATTING

Die referaat vergelyk bedryfsparameters vir die elektriese reduksiesmelting van ru-yster en ferrolegerings in proef- en nywerheidsoondes. Data wat van twee proefoonde met 'n bedryfslasvermoë van ongeveer 200 en 500 kW en van verskeie produksie-oonde verkry is, word ingesluit. Daar word voorbeelde gegee vir die smelt van ru-yster, ferronikkel, ferromangaan, ferrochroom en ferrosilikon.

In die meeste gevalle stem die resultate wat vir die proefoonde verkry is, soos die verbruikswaardes en produkontledings, redelik goed ooreen met vergelykbare syfers vir die nywerheidsoonde. Vir ferrosilikon was die kragverbruik in die proefoond hoër as in die nywerheidsoond.

Introduction

Elkem-Spigerverket a/s is a main supplier of electric reduction furnaces on the international market, and also has a considerable ferro-alloy production in Norway. For both reasons, the company has a vital interest in electric reduction furnaces and their operation.

At their Research and Development Centre in Kristiansand, Norway, Elkem-Spigerverket a/s has a pilot plant with two electric smelting furnaces of approximately 200 and 500 kW. A rotary kiln for preheating and prereduction is directly connected with the 200 kW furnace. The pilot plant has equipment for the treatment of raw materials, such as crushing, screening, drying, and grinding, as well as equipment for pelletizing, briquetting, and sintering.

The pilot furnaces have been used extensively during the last 25 years for the test smelting of pig iron and ferro-alloys. The following have been some of the main purposes of the tests:

(1) to investigate the suitability of new raw materials for electric reduction smelting,
(2) to establish operating data, such as consumption figures and analyses of products,
(3) to supply data to be used for the dimensioning of industrial furnaces, and
(4) to undertake process-development work, such as in the preparation of raw materials, preheating, and prereduction.

The pilot smelting tests have almost always been conducted as continuous runs, 24 hours a day and 5 to 7 days a week. The total duration of each test has varied from 1 to 6 weeks, with a normal raw-material consumption of 50 to 300 tons. The scale of operation has been chosen as a compromise between the desire to operate on as large a scale as possible and the difficulty in procuring sufficiently large samples of raw materials.

A considerable amount of experience has been accumulated from these tests, and in several cases it is possible to make direct comparisons with the operation of industrial furnaces. Such comparisons of various metallurgical operating parameters are presented in this paper.

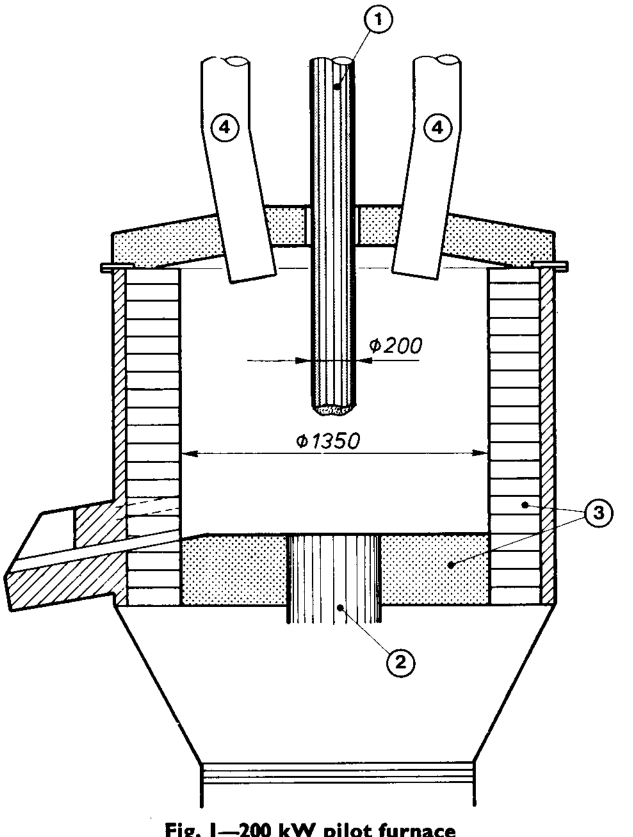

Fig. 1—200 kW pilot furnace
1 Graphite electrode
2 Bottom contact block
3 Magnesite lining
4 Feed pipes

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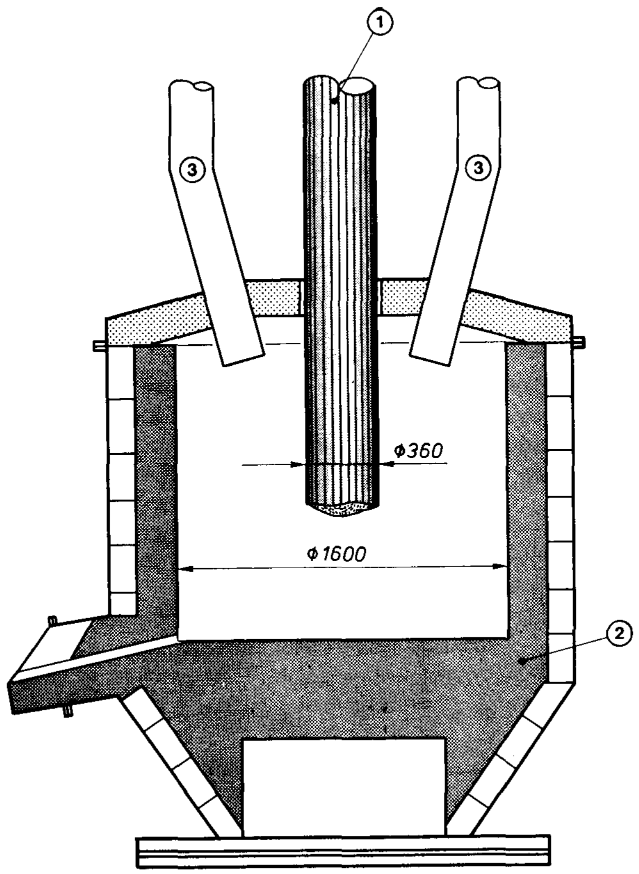

Fig. 2—500 kW pilot furnace
1 Graphite electrode 3 Feed pipes
2 Carbon lining

Furnaces

Pilot furnaces

Simplified sketches of the furnaces are given in Figs. 1 and 2. The combination of the 200 kW furnace and the rotary kiln is shown in Fig. 3. The rotary kiln is a countercurrent kiln heated by light fuel oil. The furnaces are single phase, with one 1500 kV.A transformer. The nominal secondary voltage ranges are 40 to 90 V and 80 to 180 V, each range with 32 steps.

The connections for the instruments measuring the secondary voltage and the kW/kW.h values are close to the furnaces to avoid fairly large losses in the secondary current leads.

Each furnace has one electrode and bottom contact. The bottom contact has been formed, either as a solid-metal block mould *in situ*, or as a solid rammed-carbon bottom. The two types are illustrated in Figs. 1 and 2 respectively. Each type can be used on either of the furnaces.

Typical refractory linings are also illustrated in Figs. 1 and 2. The refractory materials used depend on the type of process to be carried out, but in most cases carbon or magnesite is utilized.

For practical reasons (small diameter and periodical operation), graphite electrodes are used. The normal electrode sizes are indicated in the diagrams.

The furnaces can be operated either open or covered with a roof. On preheated or prereduced charges, they are always covered.

Proper equipment is available for the tapping and handling of metal and slag.

Industrial Furnaces

The industrial furnaces from which data have been collected are all three-phase, three-electrode, circular Elkem furnaces with Søderberg electrodes. Except for the silicon alloy furnaces, they are all covered. A simplified sketch of such a furnace is given in Fig. 4.

Comparisons

Brief examples are given of the smelting of pig iron, ferronickel, ferromanganese, ferrochromium, and ferrosilicon, on pilot and industrial scale. Efforts were made to find examples in which the same type of raw materials had been used on pilot and industrial scale. Where this was not possible, examples of the use of similar materials are given.

Besides a brief reference to the furnaces, each example includes a few main characteristics of the charge materials and tapped products, together with a few main values for consumption. These values are given per ton of produced metal, except for ferronickel, where they are given per ton of dry ore. The values for electrode consumption are given as kilograms of graphite for the pilot furnaces and kilograms of electrode paste for the industrial ones. The values for the consumption of fixed carbon are based on the reductants in the charge only. The measurements of kilowatt-hours are from the secondary side of the transformer of the pilot furnaces, and from the primary side of the industrial furnaces. No correction factors were used on any of the values.

Tables I to IX use the following abbreviations:

P 1	200 kW pilot furnace
P 2	500 kW pilot furnace
IN 1-IN 20	Industrial production furnaces

Pig Iron

Tables I and II give examples of the smelting of three different types of raw materials. The following industrial furnaces are included:

IN 1-4	Four 3300 kV.A pig-iron furnaces
IN 5	One 33 000 kV.A pig-iron furnace
IN 6-9	Four 30 000 kV.A pig-iron furnaces

In example 1, the ore analyses are for the lime sinter only. In the industrial furnaces (IN 1-4), 91 per cent of

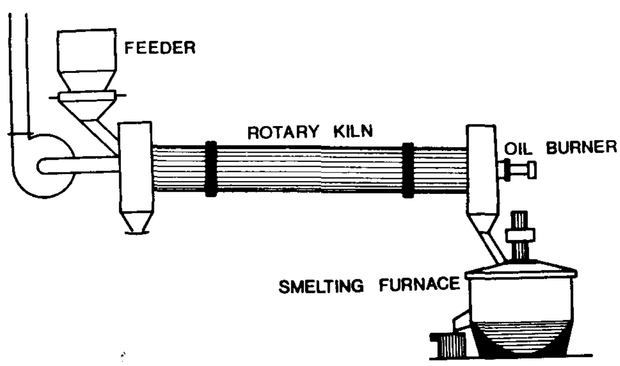

Fig. 3—200 kW pilot furnace and rotary kiln

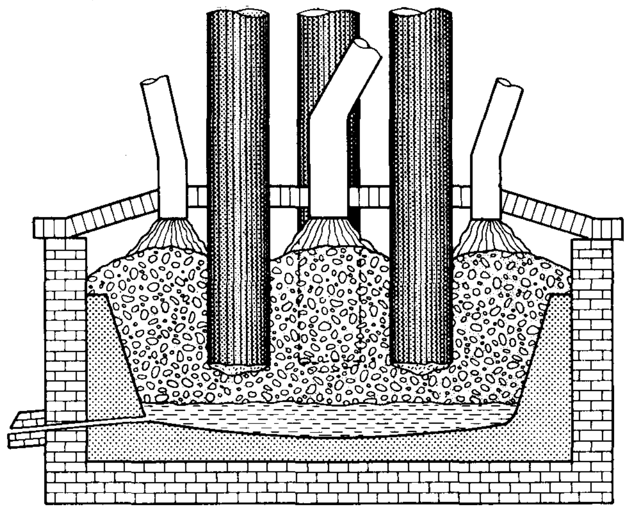

Fig. 4—Three-phase industrial furnace

the ore was lime sinter, while the remaining 9 per cent was pellets with the following analyses: 65 per cent Fe, 0,5 per cent CaO, 0,3 per cent MgO, 4,7 per cent SiO_2, and 1 per cent $Al_2O_3+TiO_2$. In the same furnaces, about 90 kg of limestone was used per ton of pig iron.

In example 3, the countercurrent pilot kiln, heated by light fuel oil, was used. The hot kiln discharge was transferred to the pilot furnace (P 2) by means of a container mounted on a waggon. In the industrial operation, cocurrent kilns heated by coal powder were used.

The operating parameters are shown in Table II.

The main reasons for the higher power consumption from the industrial operation in example 3, are a higher slag volume, as well as a higher slag basicity and a higher slag temperature, than in the pilot test.

Ferronickel

Various types of lateritic ores have been tested in the pilot plant by the rotary kiln–electric furnace process. The example detailed in Tables III and IV concerns the smelting of garnierite, which was tested in the 200 kW pilot furnace more than 20 years ago.

The data from the industrial operation are for the following furnaces:

IN 10-17 Eight 13 500 kV.A ferronickel furnaces.

The consumption of electric power was considerably better in the industrial operation than in the pilot tests.

TABLE I

RAW MATERIALS IN THE SMELTING OF PIG IRON

Example no.	1		2		3	
Ore type	Lime sinter I		Lime sinter II		Lump ore	
Furnace	P 2	IN 1-4	P 1	IN 5	P 2	IN 6-9
Analyses of ore, %						
Fe	54,0	56,6	54,4		57	54
CaO	8,2	8,1	6,7		—	
MgO	3,2	1,7	2,5		1,1	1,8
SiO_2	8,8	7,9	6,6		1,1	1,0
Al_2O_3	1,7	2,0	4,6		3,5	4,0
TiO_2			1,8		12,5	14
V_2O_5			0,7		1,7	1,6
Reductant	Coke		Coke		Coal	
Fluxes	None	Limestone	Limestone		Dolomite Quartzite Limestone	
Furnace charge	Cold		Cold		Kiln preheated and prereduced	
Estimated temperature, °C					850	800
Prereduction, %					30	35

TABLE II

OPERATING PARAMETERS IN THE SMELTING OF PIG IRON

Example no.	Furnace	Power load kW	Consumption per ton of pig iron: kW.h	Fixed C kg	Electrode kg	Metal analyses: Si, %	C, %	Slag: kg per ton of pig iron	$B=\frac{CaO+MgO}{SiO_2}$	TiO_2 %
1	P 2	420	2075	308	6	1,2	4	420	1,23	
	IN 1–4	21400–21800	2050–1990	300	10–12	0,7	3,8	380	1,38	
2	P 1	180	2240	312	14	0,9	4	450	1,4	
	IN 5	25000	2150	310	30	0,8	4	450	1,4	
3	P 2	280	1340	345	9	0,1	3,2	735	1,25	34
	IN 6–9	24000	1550	440	10	0,25	3,5	800	1,55	32

This is most likely due to better preheating and calcination, probably combined with a partial prereduction of the ore in the rotary kilns.

Ferromanganese

The pilot smelting detailed in Tables V and VI was performed in the 500 kW furnace, while the data for the industrial operation are for the following furnace:

IN 18 18 000 kV.A ferromanganese furnace.

The ore mixtures were not exactly the same in both furnaces, and the following two were chosen to serve as examples.

Furnace	P 2	IN 18
Ore, % (dry basis)		
Hotazel	20	
South African low-grade		13,2
Amapa	36	45,5
Grand-Lahou	20	
Russian+Moanda		17
Ghana spat	24	24,3

The two ore mixtures are fairly similar in physical as well as chemical composition, South African low-grade ore being substituted in the industrial furnace for Hotazel ore, and Russian+Moanda for Grand-Lahou. Ghana spat is a carbonate ore with a carbon dioxide content of approximately 30 per cent.

Ferrochromium

The example detailed in Tables VII and VIII concerns the smelting of ferrochromium from pellets with a kiln-preheated charge. In the pilot plant, this smelting was performed in the 200 kW furnace. The later industrial operation involved the following furnace:

IN 19 24 000 kV.A ferrochromium furnace.

When the preheating line of the industrial plant is bypassed and the smelting is performed with a cold pelletized charge, the energy consumption amounts to between 3400 and 3500 kW.h/t, which means that the preheating reduces the energy consumption by 600 to 700 kW.h/t.

Ferrosilicon

The example is from the smelting of 75 per cent ferrosilicon in the 500 kW pilot furnace and the following industrial furnace:

IN 20 15 000 kV.A ferrosilicon furnace.

The raw materials per ton of produced metal were as follows:

Furnace	P 2	IN 20
Quartzite, kg (dry basis)	2182	1890
Coalite, kg (dry basis)	693	708
Longyear coal, kg (dry basis)	513	275
Mill scale, kg (dry basis)	306	254

The quartzite was a normal Norwegian type containing approximately 98 per cent SiO_2 and 0,7 per cent Al_2O_3.

The operating parameters are shown in Table IX.

The power consumption in the 500 kW pilot furnace was usually in the range 10 000 to 10 750 kW.h per ton of 75 per cent ferrosilicon. The SiO_2 recovery varied in the range 75 to 90 per cent. In industrial operation, the power consumption may vary between 8100 and 10 000 kW.h per ton of 75 per cent ferrosilicon, which is lower than obtained in the pilot furnace with comparable raw materials.

Conclusion

In most cases the results from the pilot furnaces, such as the values for consumption and product analyses, correspond fairly well with comparable data from

TABLE III

RAW MATERIALS IN THE SMELTING OF FERRONICKEL

Ore	Garnierite	
Furnace	P 1	IN 10–17
Analyses of ore, %		
Ni	2,7	2,5
SiO_2	40,4	40
MgO	22	25
CaO	Trace	
Fe_2O_3	15,9	12–20
Loss on ignition	12,2	10–12
Reductant	Coke	Anthracite
Fluxes	Limestone (60 kg per ton of dry ore)	None
Furnace charge	Kiln preheated/calcined	
Estimated temperature, °C	800	850–900
Remark	Countercurrent kilns heated by fuel oil	

TABLE V

RAW MATERIALS IN THE SMELTING OF FERROMANGANESE

Ore	Mixtures as shown in text	
Furnace	P 2	IN 18
Average analyses of ore, %		
Mn	43,9	43,2
Fe	6	5,9
SiO_2	6,9	5,6
CaO	1,9	1,8
MgO	1,2	1,6
$Al_2O_3+TiO_2$	3,9	4,1
Reductant	Coke	
Fluxes	Dolomite	
Furnace charge	Cold	

TABLE IV

OPERATING PARAMETERS IN THE SMELTING OF FERRONICKEL

Furnace	Power load kW	Consumption per ton of dry ore				Analyses of crude metal			Slag		
		kW.h	Coke (dry basis) kg	Anthracite kg	Electrode kg	Ni, %	Si, %	C, %	kg per ton of dry ore	Ni, %	MgO/SiO_2
P 1	145	630	33		2,3	25,5	3,5	2,2	700	0,08	0,65
IN 10–17	11000	About 550		50	1,5	20–25	2–3	1,7–2,2	750	0,08	0,64

TABLE VI

OPERATING PARAMETERS IN THE SMELTING OF FERROMANGANESE

Furnace	Power load kW	Consumption per ton of pig iron			Metal analyses		Slag			Furnace gas vol. % CO_2
		kW.h	Fixed C kg	Electrode kg	Mn, %	C, %	kg per ton of metal	$B=\frac{CaO+MgO}{SiO_2}$	MnO, %	
P 2	350	2767	380	7	76	6,7	644	0,53	39	37
IN 18	11700	2827	370	9	79,1	6,8	661	0,94	35,3	38,7

industrial furnaces. However, for ferrosilicon, the power consumption in the pilot furnace is higher than that obtained industrially.

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TABLE VII

RAW MATERIALS IN THE SMELTING OF FERROCHROMIUM

Ore	Heat-hardened pellets	
Furnace	P 1	IN 19
Analyses of pellets, %		
Cr	29,2	28,3
Fe	20,4	17,8
SiO_2	1,8	6,4
Al_2O_3	13,8	12,2
MgO	9,4	11,4
CaO	0,7	0,4
TiO_2	—	0,5
Reductant	Coke	
Fluxes	Quartzite Limestone	Dolomite
Furnace charge	Kiln preheated	
Estimated temperature, °C	1000–1100	1000–1200

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TABLE VIII

OPERATING PARAMETERS IN THE SMELTING OF FERROCHROMIUM

Furnace	Power load kW	Consumption per ton of metal			Metal analyses			Slag			
		kW.h	Fixed C kg	Electrode kg	Cr, %	C, %	Si, %	kg per ton of metal	Cr, %	$\frac{CaO+MgO}{SiO_2}$	Al_2O_3 %
P 1	210	2950	470	12	50,3	6,8	3,6	1100	4,2	1,35	27
IN 19	19000–20000	2700–2900	435	—	52,5	7,3	2,5	1200	5	1,15	25

TABLE IX

OPERATING PARAMETERS IN THE SMELTING OF FERROSILICON

Furnace	Power load kW	Consumption per ton of metal			kW.h per ton of quartzite	Fixed C rate %	Metal analyses		Recovery of SiO_2 %
		kW.h	Fixed C kg	Electrode kg			Si, %	Al, %	
P 2	567	10 670	849	58	4890	99,4	76,1	0,8	75
IN 20	11 000	8 845	729	62	4680	98,5	76,0	1,4	88

$$\text{Fixed C rate} = \frac{\text{moles of fixed C from reductants}}{2 \cdot \text{moles of } SiO_2 \text{ from quartzite}} \cdot 100\%$$