SiMn Production In A 150 kVA Pilot Scale Furnace

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ABSTRACT

Since 1986 11 student SiMn experiments have been carried out in a 150 kVA pilot scale furnace at the Department of Materials Technology and Electrochemistry, NTNU, Trondheim. These experiments have been reviewed and it is found that the cokebed area may be divided into an inner reduction zone and an outer melting zone. To obtain the proper product, it is essential to balance the melting in the melting zone and the reduction in the reduction zone. When HC slag is used in the process the boundary temperatures of the cokebed will be lower and it will be harder to obtain a high Si content in the metal. Quartz particles are found in the cokebed and this will have a great influence on the resistivity of the cokebed.

1 INTRODUCTION

Since 1986 11 student SiMn experiments have been carried out in a 150 kVA pilot scale furnace at the Department of Materials Technology and Electrochemistry, NTNU, Trondheim. This report will review these experiments and as a result find the best way of operating this furnace.

2 FURNACE

The experiments were carried out in a one phase 150 kVA furnace, with a top electrode, as shown in Figure 1. The other electrode was in the carbon bottom lining. The position of the graphite electrode and the voltage were set manually. The current and load for a specific charge mixture were then fixed.

3 PROCESS ZONES

The interior of the furnace may be divided into two main areas; first, a charge or prereduction zone, where the ore is still solid, and secondly, the cokebed where the ore and flux are melted. This is illustrated in Figure 2 where the results from the excavation of the furnace from experiment 240299 (Test E in Table 1) is shown. These two areas can again be divided into more specific zones as shown in the figure.

As the material enters the furnace the charge will be gradually heated. At the top of

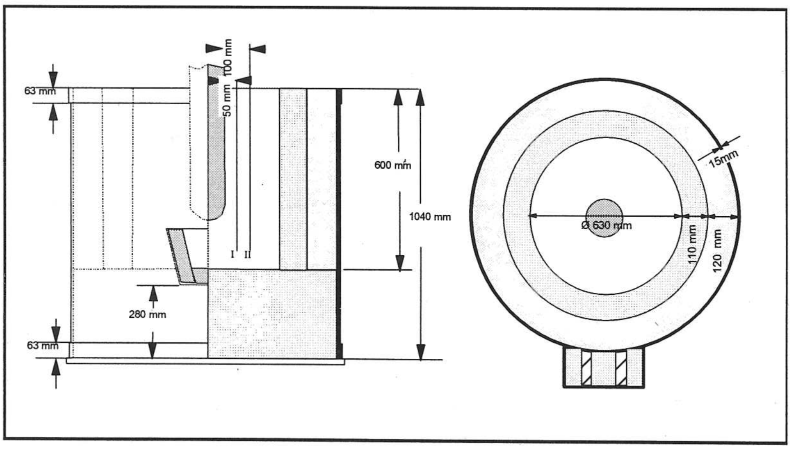

Figure 1. Pilot scale furnace

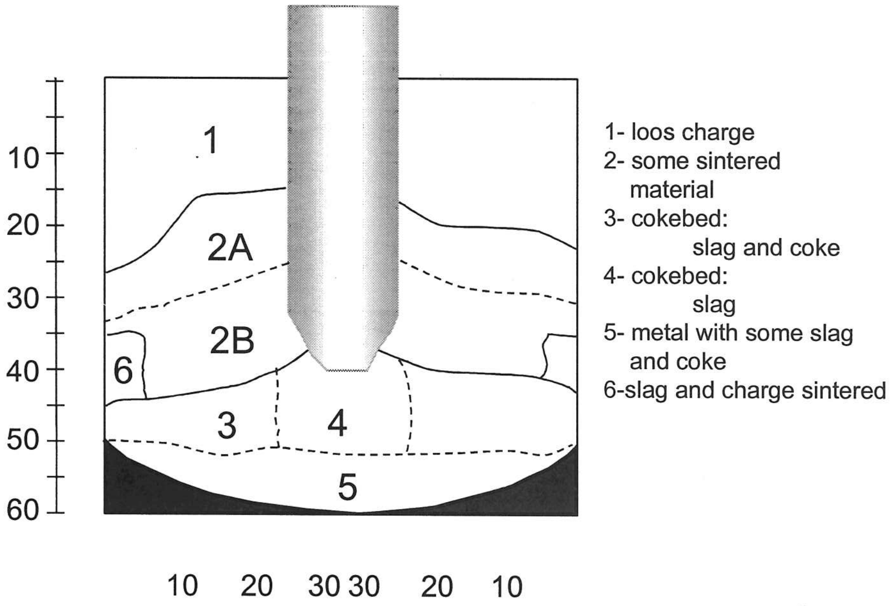

Figure 2. Typical furnace zones (Auganes, 1999b)

the furnace no visual change as for example sintering or melting can be seen (1. charge zone). As the temperature increases the charge will start the formation of melt (zone 2A and 2B) both due to low temperature melting phases and due to condensed materials, as will be discussed later in this work. As the charge is getting close to the cokebed, the temperature will increase rapidly, and, except the coke, the charge will melt. In the cokebed (zone 3 and 4) the melted slag will coexist with solid coke. Previously, the cokebed has been defined as the area where the current is running, which means that in some cases the cokebed can be without coke particles. This is partly the case in this experiment where zone 4 was depleted in coke.

The cokebed may be divided into two zones. First an inner zone (zone 4), the reduction zone, where the temperature is higher and the reduction is high. This zone is surrounded by a melting zone (zone 3) where the charge will melt and be somewhat reduced. This is shown in Figure 3 where the metal is high in Si and the slag is low in MnO in the inner part of the cokebed. The tapped slag and metal will be a mixture of the products from the reduction and smelting zone. The metal in the inner zone will therefore be higher in Si compared to the tapped metal, which contained 18% Si in the last tap. The same phenomenon, that is the separation of a reduction and melting zone, has also been observed in the FeMn pilot scale experiments (Tangstad, 1996). The quality of the obtained product is determined by how these two zones are balanced, and the characteristics for each of them.

4 FURNACE OPERATION

4.1 Raw material

In the pilot scale experiments it was difficult to obtain 18%Si in the metal. By looking at the operational data (Table 1) one may clarify the reason for this. Regardless of other operational data, the only two experiments that obtained 18%Si in the metal were experiments A and E. These were the only two experiments without HC slag as a raw material. HC slag is slag from the high carbon ferromanganese production. HC slag has a lower melting temperature (about 1250°C) compared to the ores. When the BHP ore melts at around 1350°C (Tangstad, 1996) it will contain a mixture of liquid and solid phase, where the solid phase is MnO. The slag will therefore have a high viscosity and it will not flow freely. The ore will therefore continue to be heated until the reduction has proceeded and the melted ore will flow into the cokebed. The temperature, where the melted ore flows freely, may be as high as 1450°C for the ore. When no HC slag is present in the mix, the surface temperature of the cokebed will therefore be higher. The temperature in the cokebed will also be higher and the %Si in the metal will be high.

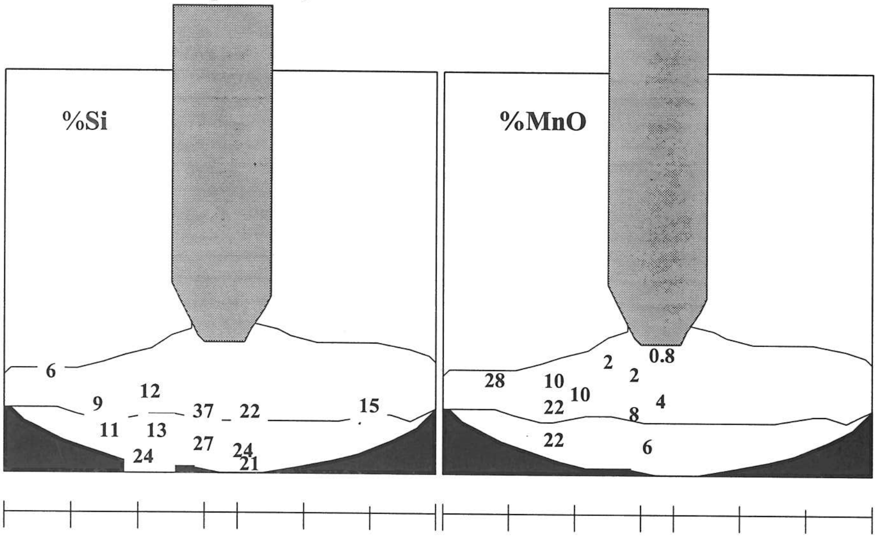

Figure 3. %Si in metal and %MnO in slag from experiment 240299. Tapped metal contained 18%Si.

According to the heat balance, less HC slag will be beneficial to the operation. It will give lower energy consumption and a higher temperature in the reduction zone due to lower slag/metal ratio. It has, however, been the experience in operating industrial furnaces, that lowering the HC slag amount will be detrimental to the operation. It is, however, not established if the transition period is detrimental or the lower amount of HC slag itself. Assuming a stochiometric amount of coke, i.e. no change in the coke accumulation, the cokebed will be smaller when going from a HC slag operation to an ore operation. This is because of the higher melting temperature of the ore. This may lead to problems in the transition period, as there may be areas with solidified slag close to the cokebed area.

The experienced difficulties may also be caused by entering a difficult HC slag/ore area. It is possible that one must either have a high ore/slag ratio, or a low ore/slag ratio. An intermediate ratio may create a difficult operation. As previously stated, a HC slag operation will have a larger cokebed compared to the ore operation. An intermediate situation may lead to a half-smelted area in-between the cokebed and the charge zone. This could of course lead to trouble with the flow of materials down to the cokebed.

4.2 Electrode operation

To obtain the desired product, it is essential to balance the melting in the melting zone and the reduction in the reduction zone. Let us first look at the reduction zone. The energy input into the reduction zone must be high enough for the reduction to occur. At the same time, the production rate from this zone has to be high, which means that the reduction zone must occupy some volume. If, for example, the distance between the electrode tip and bottom electrode is 8 cm where 4 cm are filled with metal the volume ratio between the melting zone and the reduction zone may be 100 to 1. In this particular furnace the distance between the electrode and the bottom should probably be at least 15cm. It is important that the specific resistance is low. If this is the case one can have a relatively high electrode position and still obtain a high current, and also a high load. According to this theory experiment B would be close to optimal. So

Table 1. Operational data

	A	B	C	D*	E	F
Charge						
Mamatwan	33,7					
Temco sinter	22,5					
Comilog		31,4	20,2			
BHP			11,3		32,3	
Asman				31,6	21,5	41,3
HC slag		31,4	31,5	31,6		17,7
Quarts	22,5	13,4	16,1	17,9	19,4	23,1
Coke	16,9	17,6	16,8	13,1	19,4	12,9
Limestone	4,5	6,3	0,8		2,2	
Dolomite			3,4	5,9	5,4	5,1
Analyses						
%Si in metal	18,9	15,7	16,3	14,8	18,1	14,7
%SiO_2	41,3	41,1	43	43,6	44,6	46,8
%MnO	21,9	5,9	14,5	17,7	18,5	23,1
Electrical parameters						
Current (kA)	2,5		3,5	3,4	4,5	2,1
Voltage	42	30	28	31	32	39,9
Resistance (ohm)	16,8		8	11,4	7,1	26,2
Load (kW)	100	125	100	104,1	150	82
Elec. position (cm)**						
max	10	13	8	avrg. 5	5	8
min	4	4,5	1		-5	-3
elec. consumption (cm)			16,4	9	25	15

*Best of 5 experiments

** Reference: start position of electrode

why does this experiment not provide a metal with higher % Si? The slag contains only 5.9% MnO, which shows that the melting has been very low in this experiment. But the SiO_2 content is as low as 41%. In other experiments the SiO_2 content in the reaction zone is between 50 and 60%, although the tapped slag contains about 45% SiO_2 and 20%MnO. This means that in this particular experiment the SiO_2 content in the reduction zone was probably not much more than 41%, and due to this the Si content in the metal will be low (15.7%).

In the pilot scale experiments we see that the MnO content is very high except for experiment B which has already been discussed. This high MnO content shows that even if the reduction is high in the reduction zone, the slag and metal from this zone will mix with the low Si metal and high MnO slag from the melting zone. The production in the melting zone has not been in balance with the production in the reduction zone and the Si content in the final product was therefore low. To minimise the amount of MnO in the slag, the melting must be minimised. This could be obtained by physically minimising the melting zone either by using a larger electrode or by decreasing the furnace diameter.

Table 2. Typical analyses of raw materials (wt%).

	%Mn	%Fe	%Al2O3	(CaO+MgO) SiO2
Mamatwan	34.8	4.2	0.5	2.8
Temco sinter	54.2	7.0	4.3	0.2
BHP	51.5	2.8	3.2	0.1
Comilog	50.3	3.1	5.2	0.1
Asman	51.1	10.5	0.2	0.9
HC slag	27.1	0.1	15.0	0.8

4.3 Cokebed resistivity

Quartz particles was found in the cokebed zone. The specific resistance in these experiments is probably highly influenced by the amount of quartz. The experiments with the lowest resistance, experiment B and C, were also the experiments with the least amount of quartz added. The experiments with ore only, no HC slag, are then excluded from the comparison as they have a higher cokebed temperature and will therefore dissolve the quartz more easily due to a higher reduction rate.

Some of these observations may also be transferred to industrial furnaces. When we see that quartz particles will survive in the reduction zone in the pilot scale furnace, this may also be the case in industrial furnaces. The quartz particles increase the resistance and keep the electrodes deep. However, this may also have an erratic effect on the electrodes. When the electrodes are deep in the furnace the quartz may melt down, and the resistance decreases, and the electrodes goes up.

In one of the experiments the electrode was very deep in the furnace, resulting in a very small reduction zone and a large melting zone, as described above. Can this situation also occur in an industrial furnace? If there is a lot of quartz in the cokebed, and therefore a high resistivity, the same situation may occur.

4.4 *Microprobe investigation*

Excavated samples have been picked from two experiments and investigated in the microprobe.

1. Two samples from the interface between the prereduction zone and the cokebed in Experiment no. 3 from Auganes' master experiments (1999a) have been investigated. Here, the charge contained HC slag and Asman 48 ore in equal parts and the obtained Si content in the metal was 13.5%. In this experiment the electrode tip was extremely high up in the furnace and the temperatures in the cokebed had not been very high. This can be seen from the excavations described in the diploma thesis.
2. Samples from the cokebed and the prereduction zone in the Student experiment (spring 1999) was investigated. In this experiment no HC slag was used in the charge. The temperatures in the cokebed had apparently been very high judging from the excavation samples from the cokebed zone.

The investigation of these samples have been more thoroughly reported elsewhere (Tangstad 1999a, Tangstad 1999b) and here only a summary will be presented. This summary is however based on very few samples and the significance is low.

When a charge consists of both ore and HC slag, the HC slag will melt at a lower temperature compared to the manganese ore. When the HC slag melts is will be relatively fluid, while the high MnO slag, originating from the ore, will be very viscous when it is melted. In cokebed tests (Tangstad, 1999c) we see that a prereduced Comilog ore did not trickle down a coke bed even if the temperature in the melted ore is as high as 1550°C. This means that the HC slag will melt first and be more fluid. It will then dissolve any quartz particles in the neighbouring areas. Both the liquidus temperature and the viscosity will then go down. As quartz particles continue to dissolve, the viscosity will rise slightly. When the slag contains 50% SiO_2 the viscosity will still be below 10 Poise at 1330°C.

When the temperature is high enough the metal from the HC slag will be enriched in Si.

When the temperature in the cokebed is high, as it was in the student experiment, Mn- and SiO-gas from the cokebed would condensate at the particles in the prereduction zone and form low temperature melting phases. These gases would condensate to a high SiO_2 slag, which melts at a low temperature. Some of the condensate would also form metal with a high Si-content over 20% high up in the prereduction zone. These condensates were destroying the quartz particles. When the quartz was attacked by this SiO-Mn and some times K gas, which was oxidised at the grain boundaries, the quartz particle would crumble into pieces of less than 1 mm sizing.

When the coke particles in the cokebed was investigated it was found that the coke particles were penetrated with slag. The slag wetted the coke well, which is not what was found by Rait (1998).

5 CONCLUSION

11 pilot scale experiments have been performed in a 150kVA furnace over several years. While most of the tests only reported operational data, a couple of tests included excavation results. The conclusions from these tests were as follows:

- The cokebed area may be divided in an inner reduction zone and an outer melting zone. To obtain the proper product, it is essential to balance the melting in the melting zone and the reduction in the reduction zone.
- When HC slag is used in the process the boundary temperatures of the cokebed will be lower and it will be harder to obtain a high Si content in the metal.
- Quartz particles are found in the cokebed and this will have a great influence on the resistivity of the cokebed.

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