Production of HCFeMn Using High Proportions of Sinter in the Charge

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Abstract

The SEAS plant at Dunkirk, France, has a large capacity electric reduction furnace, whose operations require the use of a very homogeneous charge, and a continuous sintering machine. Due to these features, SEAS developed a technique for using higher proportions of sinter in charge operations, finally working with 100% of sinter in the charge, consisting 100% of sinter feed from the Azul mine at Carajás, Brazil.

The main results of this operation indicate the feasibility of working with high proportions of sinter and high alumina slag, ensuring stable operations with no blow-outs or eruptions. Specific consumption of coke and electrode paste was very low with dust emissions minimized, thus reducing manganese loss.

Operations based on 100% sinter were shown to be technically feasible to SEAS.

Introduction

Located at Dunkirk in northern France, the *Société Européenne d'Alliages pour la Sidérurgie* (SEAS) manganese alloy producer is owned by Companhia Vale do Rio Doce - CVRD, Brazil and SOLLAC (Usinor Sacillor), France. It started up operations in December 1991.

This plant is located in a region housing a wide variety of industries, with adequate infrastructure, close to a port that can moor carriers with a draught of up to 14.20 meters. All alloy production is handled by a single 102 MVA electric furnace using lump ore or sinter from a sintering machine with a burning area of 43 m^2 and an annual production capacity of 450,000 tons of manganese sinter.

This plant was specially designed to work with different ore blends. However, the metallic charge basis at SEAS has historically come from lump ore and sinter produced with sinter feed from the Azul mine at Carajás Brazil (90%) and lump ore from South Africa (10%).

The dimensions of the furnace have shown since the start-up of operations that the homogeneity and quality of the charge shape its performance. Due to this factor, SEAS has been developing an operational upgrade plan which is intended to enhance the homogeneity of this charge on one of its lines. The company decided to do this by gradually increasing the proportion of sinter in the charge. In addition to boosting homogeneity, this also guarantees increasing use of sintering machine, while furthering the interests of one of the shareholders, as the production process at the Azul mine generates substantial amounts of sinter feed.

As the result of these efforts, SEAS has improved its operation which culminated in the experiment of using only sinter from the Azul mine at Carajás as source of manganese in the charge. A detailed description of this operation, followed by the principal results obtained, are shown in this article.

Plant Description

Electric Reduction Furnace

The SEAS electric reduction furnace, manufactured by DEMAG, is a closed 102 MVA three phase furnace. Its characteristics are given in Table I.

Sintering Machine

The sintering machine of SEAS, Dwight-Lloyd type, has a burning area of 43m^2. Built to process iron ore and adapted for manganese, it initially produced about 350,000 tons a year. After some improvements - the most important was to increase the height of the layer - its annual capacity rose to 450,000 tons of manganese sinter. The principal characteristics of this machine are given in Table II.

Table I - Characteristics of the SEAS electric reduction furnace.

Electric power/transformer	36 MVA
Total electric power	102 MVA
Voltage supply	63 KV (50Hz)
Diameter of shell	15100 mm
Height of shell	8220 mm
Diameter of hearth	12800 mm
Height of hearth	3300 mm
Diameter of electrode	1900 mm
Points of top charging	16
Number of tap holes	2
Dust removal system	Theisen (10 mg/Nm^3)

Table II - Characteristics of the SEAS sintering machine.

Burning area	$43m^2$
Cooling area	$26\ m^2$
Length of grate	37m
Width of grate	2m
Number of wind boxes	15
Ignition fuel	furnace gas/propane
Dust removal - burning zone	electrostatic filter
Dust removal - cooling zone	multicyclone

Raw Materials

The ore used for operations with 100% sinter charge is the high grade sinter feed from the Azul mine at Carajás, whose principal characteristics are listed in Tables III, IV and V. Batches # 1 and # 2 were used to produce sinter, representing materials from different shipments.

Table III - Mineralogy for high grade sinter feed from the Azul mine, Carajás.

Ore	Todorokite	$(H_2O)_2(Mn..)_8(O,OH)_{16}$
	Manganopyrosmalite	$(Mn,Fe)_8(Si_6O_{15})(OH,Cl)_{10}$
	Cryptomelane	KMn_8O_{16}
Gangue	Gibbsite	$Al_2O_3.3H_2O$
	Goethite	$Fe_2O_3.H_2O$
	Kaolinite	$Al_4[Si_4O_{10}](OH)$

Table IV - Chemical composition of the high grade sinter feed from the Azul mine Carajás.

Type	Mn	Fe	SiO_2	Al_2O_3	CaO	MgO	P	K_2O	LOI	H_2O
Batch #1	48.90	4.30	2.57	6.40	0.17	0.22	0.086	0.93	15.0	14.31
Batch #2	47.90	4.58	2.48	6.71	0.16	0.17	0.080	0.93	15.2	17.76

Table V - Size distribution of the high grade sinter feed from the Azul mine, Carajás.

Size (mm)	+ 12.5	+ 9.52	+ 6.35	+ 4.00	+ 1.00	+ 0.15	- 0.15
% Retained	0.0	0.2	2.0	22.0	81.0	95.0	5.0

Results of Operation

When taking the decision to increase the percentage of sinter in the charge, using larger quantities of ore from Carajás, SEAS was faced with the challenge of adapting its operations to handle high alumina content slag whose volumes, reactivity, melting point, viscosity etc., would be adequate for the process, in addition to other alterations required to ensure that the principal figures for the process (power and coke consumption, as well as productivity etc.) remained at acceptable levels.

Operation using 100% sinter in the charge began in December 1994, followed by eighteen months of adjustments until operations were considered as ideal. The development of this process often took place in a complex manner, which for the purposes of simplification can be summed up in four basic stages, shown in Table VI.

Table VI - Stages in development of operations with 100% Carajas ore sinter.

	ISSUE	ACTION TAKEN	REASON	RESULTS
STAGE #1	✓ What conditions are needed to produce with 100% Carajás ore sinter ? * slag (%MnO, %Al2O3, basicity, tapping temperature, viscosity etc.) * Type of sinter	✓ Use self-fluxing sinter without MgO and B_3 = 1.3 ✓ Increase thickness of layer during sintering (more resistant sinter) ✓ MnO targeted: 27 - 30%	✓ Prior experiences under similar conditions	✓ High MnO in slag ✓ Low tapping temperature ✓ Build-up of alkali in furnace
STAGE #2	✓ Increase tapping temperature ✓ Eliminate alkali in slag	✓ Manufacture sinter without additions (not self-fluxing) ✓ add fluxing elements directly in furnace ✓ Work with 2 - 4% MgO in slags	✓ High flexibility control over basicity of slag ✓ Increase tapping temperature	✓ Tapping temperature increased ✓ High top gas temperature ✓ MnO adjusted for basicity - still high ✓ Removal of alkalis increased, but still irregular
STAGE #3	✓ Reduce top gas temperature ✓ Make removal of alkalis normal	✓ Increase average sinter size * Less degradation of sinter (sinter fed directly into the furnace with shorter charge cycles)	✓ Increase permeability * improve heat exchanges * elimination of crust formation	✓ Top gas temperature adjusted ✓ Removal (accumulation - de-accumulation cycle) of alkalis normal

Some process data showing the development of operations and which in some cases supported the actions taken are given in Figure 1. This data reflects the monthly operating averages with 100% sinter charges. The coke reactivity corresponds to the material weight loss in a CO_2 atmosphere at a temperature of 1120°C. During the periods not presented, the production was shifted to FeSiMn or to HCFeMn utilizing appreciable proportions of lump-ore in the charge.

The Sintering Process

Since its start up, SEAS has built up a wide range of experience in sintering Azul ore, either by itself or in blends. When operating with high proportions of sinter in the charge, after the process optimized, it was decided to manufacture a sinter with basicity ($CaO+MgO/SiO_2$) close to 1.1. This sinter features the characteristics given in Tables VII, VIII and IX.

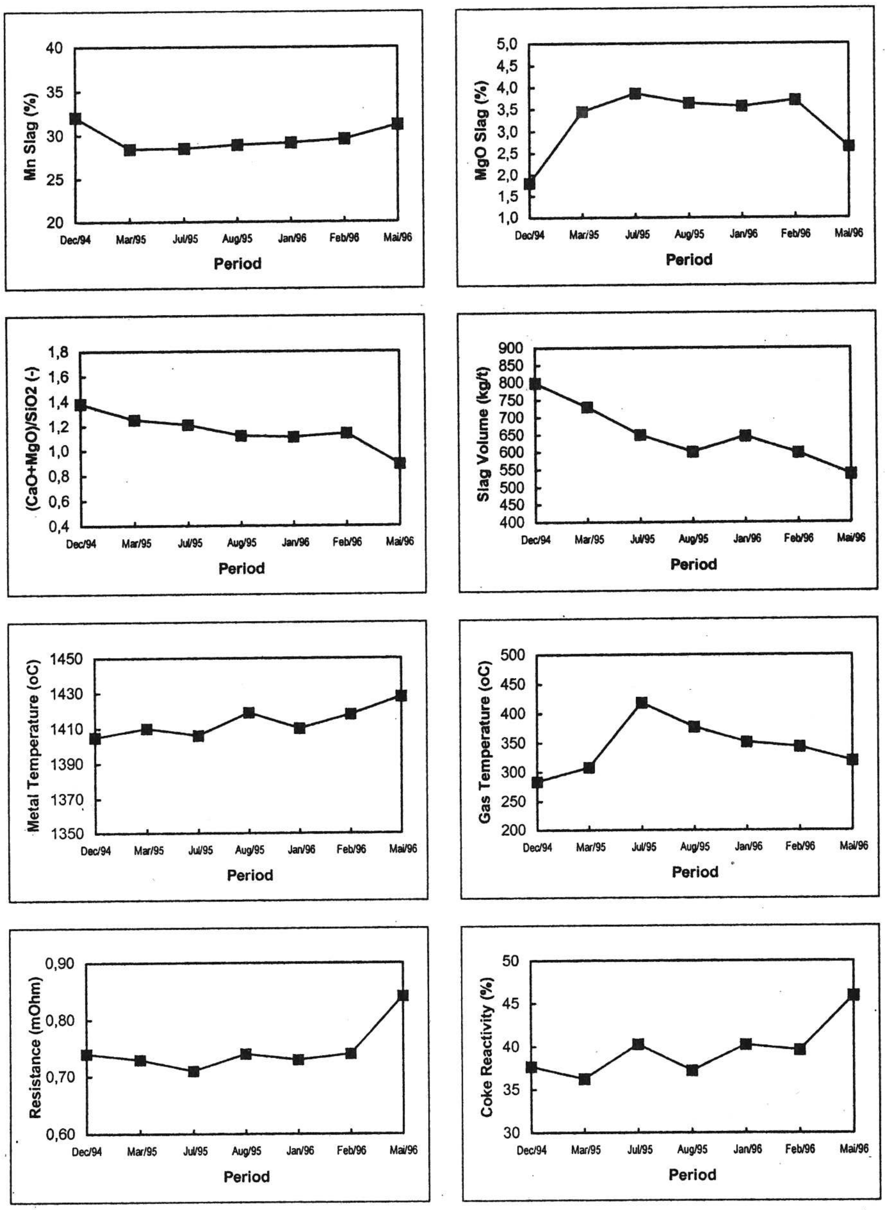

Figure 1 - Process data for HCFeMn production period with 100% Azul ore sinter.

Table VII - Chemical composition of sinter produced at SEAS with 100% Azul ore, Carajás.

Type	Mn	MnO_2	Fe	SiO_2	Al_2O_3	CaO	MgO	P	K_2O	TiO_2
% Mass	55.27	17.81	5.16	3.62	7.69	3.22	0.86	0.10	1.04	0.48

Table VIII - Size distribution of the sinter produced at SEAS with 100% Azul ore, Carajás.

Size (mm)	+ 80	+ 50	+ 25	+ 10	+ 5	- 5
% Retained	11.8	32.8	65.1	94.5	98.5	1.5

Table IX - Average Size and Tumbling Index of sinter produced at SEAS with 100% Azul ore, Carajás.

Average size (mm)	40.5
ISO Tumbling Index (% + 6.35 mm)	76.0

The mass balance and principal operating parameters obtained in the production of this sinter are given in Tables X and XI.

Table X - Burden for sinter production with 100% Azul ore, Carajás.

ELEMENT	% (relative to sinter feed)
Limestone	2.50
Dolomite	2.50
Solid Fuel	9.32
Return Fines	33.04

Table XI - Operating parameters for sinter production with 100% Azul ore, Carajás.

Thickness of layer (mm)	560
Moisture content of blend (%)	10.5
Depression burning region (mm H_2O)	760
Depression cooling region (mm H_2O)	550
Solid Fuel consumption (kg/t sinter)	120
Electric power consumption (Kwh/t sinter)	52.5
Gas consumption for ignition (Nm^3/t sinter)	0.70
Return Fines (kg/t sinter)	479
Productivity (t/m^2/day)	27.5

HCFeMn Production Process

SEAS basically produces two types of HCFeMn, known as low phosphorus type, with a minimum of 78% Mn and maximum of 0.15% P and standard, with a minimum of 76% Mn and a maximum of 0.20% P. The process slag has been used in house to produce FeSiMn, or sold to third parties. The typical analysis of the HCFeMn and the slag produced, as well as the principal process data obtained after optimizing production with 100% sinter, in May 1996, are given in Tables XII and XIII, respectively. It should be noted that the reducing agent used by SEAS is a blend of cokes from a variety of origins which may include up to six components. During the optimized period, the average fixed carbon content was 89%.

Table XII - Chemical analysis of the alloy and slag obtained during HCFeMn production with 100% Azul ore sinter, in the optimized phase (average values, May 1996).

Alloy				
%Mn	%Fe	%Si	%C	%P
76.77	15.47	0.02	7.00	0.19

Slag					
%Mn	%Fe	%SiO_2	%Al_2O_3	%CaO	%MgO
31.14	0.72	14.70	25.55	10.46	2.80

Table XIII - Process data obtained during HCFeMn production with 100% Azul ore sinter (average values, May 1996).

Active Power (MW)	48.60
Resistance (mOhms)	0.84
Intensity of current (kA)	138.7
Cos Phi	0.52
Tension (V)	201.9
Metal Temperature (°C)	1428
Gas Temperature (°C)	319
Specific power consumption (kWh/t)	2554
Coke Consumption (kg/t)	355
Electrode paste consumption (kg/t)	8.4
Slag volume (kg/t)	538
Dust (kg/t)	30
Gas volume generated (Nm^3/t)	500
CO content in gas (%)	81.3
CO_2 content in gas (%)	9.4
Productivity (t/day)	442

The typical mass and heat balances for HCFeMn production using 100% sinter are shown in Tables XIV and XV. The manganese recovery is 81.3%, and the basicity ($CaO+MgO/SiO_2$) of the slag is 0.90.

Effects of the Use of 100% Sinter in HCFeMn Production

Electrical conditions - Operation Stability

One of the most outstanding characteristics of the use of 100% sinter charge was the stability of furnace operations. The blow-outs and eruptions in the furnace were virtually eliminated; the permeability of the charge increased; the charge became far more constant and homogeneous; and stable operations were noted from the electrical viewpoint.

Another very important point for SEAS was the appreciable reduction in the amount of dust generated, which allowed the gas-cleaning system to work at slower rates, reducing maintenance and consequently down-time for the furnace.

Table XIV - Typical mass balance for HCFeMn production with 100% sinter.

			INPUT (kg)							
	Qty	Unity	Mn	Fe	SiO_2	Al_2O_3	CaO	MgO	P	C (*)
Carajás Sinter	1707	kg	943.5	88.1	61.8	131.3	55.0	14.6	1.7	0
Iron Ore	100	kg	0.4	67.5	0.6	0.8	0.0	0.1	0.1	0
Limestone	0	kg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
Coke	355	kg	0.0	3.2	17.8	6.2	1.8	0.6	0.1	317.0
Electrodes	8	kg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.1
Total			943.9	158.8	80.1	138.3	56.8	15.3	1.9	324.2
			OUTPUT (kg)							
	Qty	Unity	Mn	Fe	SiO_2	Al_2O_3	CaO	MgO	P	C (*)
Alloy	1000	kg	767.7	154.7	0.2	0.0	0.0	0.0	1.9	70.0
Slag	538	kg	167.5	3.9	79.1	137.5	56.3	15.1	0.0	0.0
Gas	500	Nm^3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	243.0
Dust	30	kg	8.7	0.3	0.8	0.8	0.5	0.3	0.0	3.0
Total			943.9	158.8	80.1	138.3	56.8	15.3	1.9	316.0

(*) Assuming a loss of 2.5% C during the tapping

Table XV - Typical heat balance for HCFeMn production with 100% sinter.

HEAT BALANCE (BASE 1 TON HCFeMn)		
INPUT (%)	Slag formation	1.0
	Oxidation C → CO	16.1
	Oxidation C → CO_2	6.7
	Electric Power	76.2
	Total	100.0
OUTPUT	Alloy enthalpy	11.3
	Slag enthalpy	8.1
	Reduction of higher oxides (Mn, Fe) to MnO/FeO	7.3
	Reduction (MnO, FeO, SiO_2, P_2O_5)	51.0
	Gases enthalpy	1.8
	Heat losses	20.6
	Total	100.0

Dust Generation

In addition to the benefits mentioned in the previous paragraph, the reduction in the amount of dust resulting from the use of sinter also reduced manganese losses through flues, which reached at around 1% in this operation.

Process Slag

One of the major challenges faced when operating with 100% sinter made from Carajás ore was the need to work with high alumina slags. After some adjustments in the MgO content and basicity, as mentioned previously, a slag composition was reached allowing normal furnace operation. As shown in the cross-section given in the diagram CaO-MgO-SiO_2, for 40% MnO and 20% Al_2O_3, constructed by IRSID[2] and shown in Figure 2, the *liquidus* temperature of the slag is fully compatible with HCFeMn production.

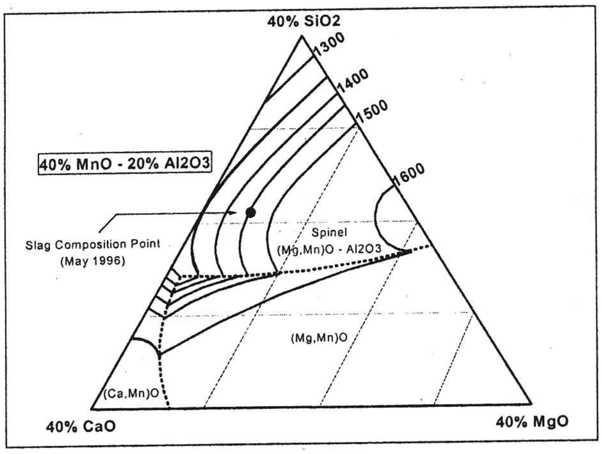

Figure 2 - Cross-section of CaO-MgO-SiO_2 diagram for 40% MnO and 20% Al_2O_3, showing the slag composition point used. Original IRSID[2].

Coke Consumption

Another striking characteristic of this operation was the fact that coke consumption remained very low throughout the entire operation, as shown in Figure 3.

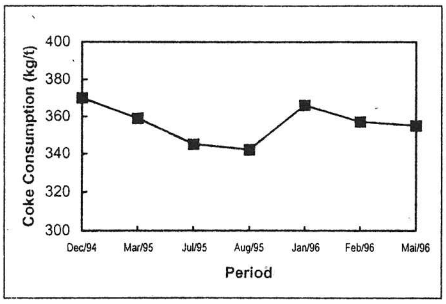

Figure 3 - Coke consumption during periods when 100% sinter was used in the charge.

This reduction was expected due to the decreased inflow of oxygen through the sinter. However, this drop was very marked, which makes this option even more attractive as this input material plays an important role in SEAS production costs.

Electrode Paste Consumption

Electrode paste consumption dropped appreciably, reaching 8 kg/t in May 1996.

Metallic Charge Oxidation

The oxidation of the charge stands out as one of the most important factors in imposing constraints on the use of sinter to manufacture HCFeMn. Charges with low oxidation levels may adversely affect the heat balance of the process, as the reduction reactions of higher manganese oxides are exothermic.

The MnO_2 content in the sinter produced at SEAS with 100% Carajás ore has been around 18%, considered a low figure. SEAS has been carrying a number of experiments designed to increase the oxidation level of the sinter, with relative success. However, this level should not increase much more because the Carajás ore features high LOI and high fuel consumption during sintering (120 kg/t of sinter).

Despite this, the advantages obtained through the use of sinter on a large scale at SEAS, as mentioned previously, have to a large extent offset the negative effect of the low oxidation level of the charge.

Active Power - Resistivity of Charge

During the periods when the charges consisted of 100% sinter, there was a clear increase in the resistivity of the charge, making it possible to work with higher powers. During May 1996, the sum of the various factors - including the use of more reactive coke, reduction in the basicity of the slag, and reduction in slag volumes, together with the use of sinter - allowed SEAS to reach its highest-ever productivity levels until then, operating the furnace with a high active power and high electrical resistance.

Furnace Safety

Another important factor to be taken under consideration in the use of high proportions of sinter in the charge is related to the security of the equipment. Even when stored, the sinter absorbs very small amounts of water, reducing the entry of this element into the furnace, helping reduce the risk of damage to this equipment.

Conclusions

SEAS has a large furnace that is very dependent on a high grade and homogeneous charge, and a sintering plant whose installed capacity is sized to cover the doubling of the reduction area which is currently idle. These facts prompted the company to move towards operations based on high proportions of sinter in the charge, culminating in the experiment of producing HCFeMn with 100% sinter in the charge, manufactured solely from ore mined at Azul, Carajás, Brazil.

The principal results of operations with 100% sinter show that:

- it was possible to work with a high level of Al_2O_3 in the slag under conditions compatible with the process;
- fairly stable operations were achieved with high permeability of the charge and lack of blow-outs and eruptions;
- dust generation was reduced appreciably, lowering manganese loss to under 1%;
- consumption levels for coke and electrode paste were very low;
- it was possible to work with very high powers due to the increase in the resistivity of the charge;
- the relatively low level of oxidation of the charge could be offset by gains in reductant.
- increase efficiency of the gas cleaning system due to the minor volume of gas generated.

The conclusion of the experiment is that the use of 100% sinter in the SEAS electric furnace to produce HCFeMn is an alternative that is technically feasible, in comparison with other ore blends used by SEAS.

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