MANGANESE ORE AND ALLOYS PILOTING TOOLS AT ERAMET RESEARCH

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ABSTRACT

In a presentation at the 12th INFACON conference, the same authors gave an overview of the last 10 years history of piloting in ERAMET RESEARCH on both the ore sintering pilot and the Mn alloys smelting facility. For the latter equipment, we explained that as expertise increased, limitations mainly resulting from the energy supply design became clearer. This had led us to scale our piloting facility from 150–250 kW up to 1.3 MW. The objective of this paper is to present the real characteristics of this new equipment and the process performances, measured during a 4 week campaign, studying kinetics of the pre-reduction reactions occurring in the burden of a HCFeMn furnace operated with Comilog ore and sinter. Characteristics will be compared to design parameters while process performances will clearly show that ERAMET RESEARCH has met its challenge to develop a piloting tool that will contribute to improve ERAMET furnace production performances.

INTRODUCTION

In a presentation at the last INFACON conference [1], we stated that, from its birth in 1972, ERAMET Research Center has contributed to develop new processes and improve the performances of the mineralogical, hydrometallurgical and pyrometallurgical plants of its customers and that it has a long experience in continuous piloting of electric arc furnaces. Because the group has evolved and because progress will come from deepest knowledge and description of the phenomena involved in the processes, the pyrometallurgy department needed to build a new equipment to contribute to the improvement of the Manganese Branch electric arc furnaces. A highly instrumented research furnace, free of production constraints was therefore built on a flexible platform in Trappes.

The description of the new piloting facility was presented in [1]. In this paper, we will present the real characteristics of the furnace that was built and tested on smelting HCFeMn alloy and compare these values to those retained for design purposes. We will also present the most significant results obtained during the first piloting campaign. We will conclude that the new furnace built in Trappes is a powerful tool to study Manganese alloy smelting processes.

DESIGN OF THE NEW LOW IMPEDANCE PROCESS PILOTING PLATFORM

Geometry of the furnace

Industrially, Mn is produced in 3 phase furnaces as well as in single electrode DC furnaces. Obviously, an axis-symmetric geometry allows for simpler instrumentation and makes interpretation of the results and modelling easier. Since our first campaign was devoted to study the chemical reactions taking place in upper part of the furnace, decided to build a single electrode furnace. However, we designed our power supply to function in both modes.

Determination of the design current value

The new power supply was designed for low impedance processes, since Mn smelting is the EAF process to smelt ferroalloys which requires the lowest resistance [4]. The target power load dissipated in the furnace was 1 MW, which we considered as a sufficient size to reproduce, at a smaller scale, phenomena that are observed in industrial furnaces, and which generated a manageable material flow.

To design the power supply, we decided to follow the rules presented by J. Westly in [3]. These rules apply to industrial 3 phase furnaces, with a different geometry and much larger than our piloting tool. We thus decided to consider that the resistance of a 1 MW single-phase furnace would be that of a 3 MW 3-phase furnace, which is to say that, for design purposes, a 3-phase furnace could be considered as 3 single-phase furnaces in parallel.

J. Westly established the following empirical relationship power load and the current of industrial furnaces:

$$I = C_3 P^{2/3}$$

Where:

- I is the current in kA
- P is the power load in MW
- C_3 is the proportionality coefficient

Still according to J. Westly, for FeMn furnaces, one should expect:

$$9.2 < C_3 < 13.3$$

For a 3 MW furnace, this yields to the following current in each electrode:

$$19 \text{ kA} < I < 28 \text{ kA}$$

This is to say that the process resistance for a single phase HCFeMn pilot with 1 MW power load will lie in the range of 1.3 mOhms to 2.2 mOhms.

J. Westly's relation between I and P was established on industrial data, on furnaces whose power load varied from about 10 to 50 MW. We therefore cross checked our results. First, a similar value of the resistance was found when we applied the method presented in [6].

Then, S. Yoneka et al. described the electrical characteristics of a 2.5 MW, 3-phase furnace in [5]. The resistance of the circuit was then found to be 2.3 milliohms, close to the upper limit found earlier. However, this resistance includes the bus bar and electrode resistance, for which no value has been reported in [5].

Finally, from our industrial experience, we know that, with the usual mixes of raw materials used in ERAMET plants, the actual C_3 values are closer to the larger than to the lower limit given in [3]. Therefore, to be able to regulate the electrode current at maximum power load, we set the specification for the current in the electrode at 30 kA.

Design of the new power supply

The 15 kV power supplied to Eramet Research is reduced in 2 steps to 140 V by a 3-phase variable transformer and 3 single-phase transformers whose maximum secondary current is 10000 A.

The furnace can be operated in both single-electrode and 3-electrodes configurations:

- In the former case, the 3 transformers are connected in parallel for one phase operation;
- In the latter case, they are connected in a Y or Δ circuit for 3-phase operation.

A battery of capacitors is connected between the 2 stages of transformation to increase the power factor of the equipment. This also allowed us to limit the apparent power load of the first transformer to 2 MVA.

Design of the furnace

For the first campaign of this new platform, we decided to study the kinetics of the pre-reduction reactions that take place in the burden of a HCFeMn smelting furnace. The furnace that was specially designed to achieve this scientific objective presented the following characteristics:

- Single phase furnace: for the current objective, this type of geometry is better adapted than a 3-phase furnace. Indeed, it makes interpretation of the data and use of models much easier than with a 3-phase furnace, whereas it has no impact on the phenomena we want to study.
- Power load/unit surface area: this ratio will define the CO gas velocity at the bottom of the burden, therefore, for a given permeability, the gas velocity in the burden. It was decided that this ratio will be identical to industrial values, typically 350 kW/m^2.
- As mentioned, the design power load for this furnace was 1 MW, therefore the crucible diameter was set to 2 m.
- Side wall lining: previous pilot campaigns in Trappes have led to the conclusion that freeze lining was well adapted for FeMn alloys smelting. Magnesia bricks were used for the walls.
- MgO ramming paste was used for the lining of the hearth. A multiple steel pin electrode, embedded in the hearth, constituted the bottom electrode.
- Furnace height: since we wanted to study the pre-reduction reactions, we set this parameter as close to that of the industrial furnaces as possible in our building, i.e. about 4 m.

RESULTS OF THE HCFemn pilot CAMPAIGN

Objectives of the piloting campaign

The objectives of the first pilot campaign were:

- Commission the new tool that was designed and built at Eramet Research ;
- Establish a reference operational point and measure the performances of the pilot furnace ;
- Demonstrate that the new furnace was an appropriate tool to study the kinetics of the pre-reduction reactions in the HCFeMn smelting process.

The reference raw material mix that was used in these trials was a blend with 65% MMR Comilog ore and 35% Comilog sinter.

Electrical set point

Short circuit resistance

At ER, we consider the short circuit resistance of the equipment to be the resistance that is measured at the point when the lowered electrode enters the liquid metal pool at the bottom of the furnace. This resistance was measured several times during the pilot campaign. Since the circuit includes the electrode, we have plotted on the figure below the evolution of the short circuit resistance with the position of the electrode holder, which gives an indication of the electrode length.

It can be seen on the graph that:

- The average short circuit resistance for our equipment was 609 µOhms, with a standard deviation obtained with 7 measurements of 48 µOhms ;
- With such a procedure, we cannot see any significant evolution of the short circuit resistance with the electrode length. Because the electrodes are 560 mm diameter graphite electrodes, the contribution of only 600 mm of electrode is smaller than the standard deviation of the measurements.

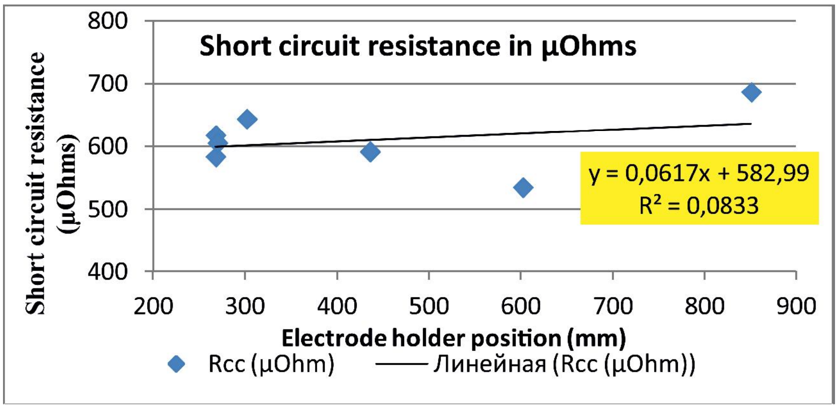

Figure 1: Evolution of the short circuit resistance with the electrode holder position

Reactance of the circuit

Figure 2 shows the evolution of the short circuit reactance of the furnace as a function of the electrode holder position, which is an indication of the electrode length.

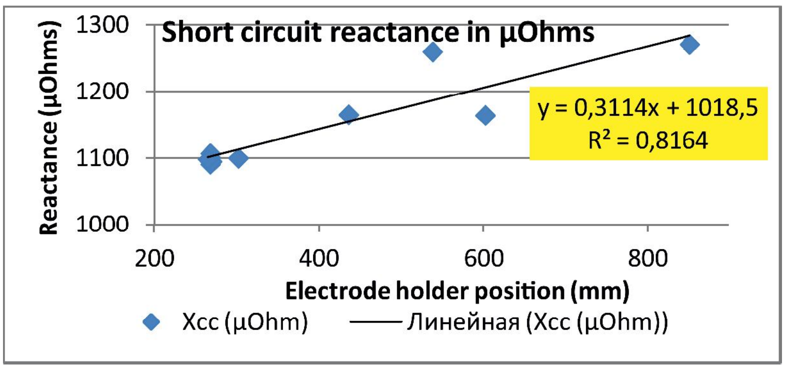

Figure 2: Evolution of the short circuit reactance with the electrode holder position

It can be seen that the reactance increases when the electrode holder position is higher: the surface area of the loop formed by the copper cables, bus bars and the electrode increases.

Operational electrical set point

The electrical measurements performed during the piloting campaign are shown on the figure below (start up and shut down periods have been removed).

It can be seen that, for steady state operation:

- The current in the furnace was stabilized at about 27000 A ;
- The voltage on the secondary side of the transformer was about 51to 55 V ;
- The power load was 1200 kW ;
- The resistance set point was therefore established at about 1.6 mOhms.

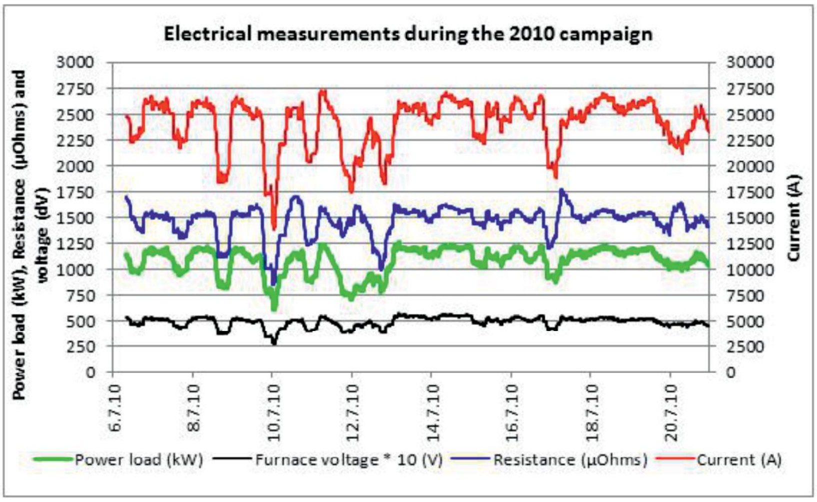

Figure 3: Electrical characteristics measured during the piloting campaign

Discussion of the electrical measurements

With a current of 27000 A, for a power of 1200 kW, the electrical operating point was in the middle of the range that was determined by calculations to design the equipment.

We can differentiate 2 different contributions to the resistance of the operating furnace:

- The short circuit resistance, as defined in the previous chapter ;
- The process resistance. In our case, the process resistance was 0.99 mOhms. 722 kW was directly transmitted to the coke bed.

The short circuit resistance is a characteristic of each set up which contributes to the dispersion of the C_3 value computed in [5]. There are 3 main contributions to the short circuit resistance of an EAF:

- The resistance of the copper bars, contact clamp, wires as well as contact resistance which, in our case, assuming perfect contact between the various constituents of the circuit, was estimated to less than 0.1 mOhms. Since our circuit is quite long, one could expect this contribution to be slightly higher than on industrial equipment. The Joule energy generated in this part of the circuit is not transferred to the material in the furnace. It is therefore a pure electric loss.
- The resistance of the graphite electrode itself: with its 5 m length, it was calculated to be about 0.150 mOhms, and probably a little more because it was made of 3 different cylinders, which presented contact resistances at their joints. Since most of the electrode was in the furnace, and even

in the burden, the Joule energy dissipated in the electrode, which amounted to about 108 kW according to our calculation, could therefore be considered as transferred to the system.

- An apparent resistance due to eddy currents in the nearby beams and metallic equipment that lie in an intense alternative magnetic field. The energy dissipated by the eddy currents is a pure electrical loss.

Hence, during the stable period of our piloting campaign, we can consider that 830 kW out of 1200 kW was transferred to the system, which is to say that the electrical yield of our pilot furnace was 69%. From a scientific point of view, it is this figure that should be used to compare the energy balance of different furnaces. However, the short circuit resistance of the industrial furnaces are very seldom available, so in the next sections of this paper, we will use the total energy fed to the furnace circuit and the total resistance of the circuit.

PROCESS PERFORMANCE

Raw material feed

To determine the performances of this furnace, we decided to use MMR Comilog ore and sinter as Mn sources. The proportions were: 65% ore and 35% sinter, both screened to 6-40 mm. Carsid coke, iron pellets and calcined dolomite were the other raw materials used in these trials. The chemical composition of the raw materials is given in the table 1 below.

Table 1: Raw materials chemical analysis

	C	**Mn**	**Fe**	**Al**	**Si**	**Ca**	**Mg**	**K**	**P**	**Moisture**
Comilog Ore		49.90%	4.56%	3.21%	2.08%	0.10%	0.05%	0.65%	0.13%	7.16%
Sinter		58.50%	4.02%	3.83%	3.60%	0.26%	0.05%	0.61%	0.12%	0.27%
Coke	85.70%		1.29%	1.53%	2.96%	0.63%	0.17%	0.18%		3.48%
Pellets			63.58%	0.15%	0.81%	0.39%	0.48%			1.80%

Slag and metal produced

During the pilot campaign, we managed to run the pilot with constant feed and high operating time (> 98%) for several periods of 5 to 6 days. The slag and metal chemical compositions obtained during these stabilized periods are given in the table 2 below. They are the average compositions measured on 80 taps of about 1020 kg of metal and 520 kg of slag.

Table 2: Metal and slag chemical analysis

	Mn	**Fe**	**Al**	**Si**	**P**	**C**			
Metal	78.40%	11.90%	0.60%	0.21%	0.23%	6.80%			
	MnO	**FeO**	**Al_2O_3**	**SiO_2**	**CaO**	**MgO**	**K_2O**	**BaO**	**TiO_2**
Slag	34.80%	0.47%	23.4%	21.0%	7.8%	5.4%	2.2%	0.9%	1.3%

As can be seen in table 2, the slag and metal compositions are consistent with the expectations (mass balance based on raw materials compositions) and with industrial data.

Average slag temperatures when tapping were 1420°C, and the slag to alloy ratio was 0.51, also consistent with expectations and industrial data.

Furnace performance

For industrial furnaces, the global key process indicators are the specific fixed carbon consumption and the specific energy consumption. We therefore calculated these KPI for our furnace, for the same reference period:

- Specific fixed Carbon Consumption (SCC): 335 kg/t of HCFeMn produced.
- Specific Energy Consumption (SEC): 2260 kWh/t.

The values for these KPI are similar to those obtained on industrial furnaces fed with the same Mn source mix, indicating that our furnace is a highly efficient reactor to produce HCFeMn.

As shown in [2], Comilog ore is highly oxidized, which means that it essentially contains MnO_2. We also know that the pre-reduction reaction:

$$MnO_2 + CO \rightarrow MnO + CO_2 \text{ [reaction 1]},$$

is thermodynamically possible in the upper part of the furnace and is highly exothermic (-148.5 kJ/mol at 1000°C). A thorough mass balance performed on C showed that the pre-reduction efficiency reached 56% during these trials, that is to say that 56% of the MnO_2 that could react according to reaction 1 indeed reacted in the furnace.

Another way of presenting this result is to consider the average degree of oxidation of Mn in the feed. Since it was a blend of MnO_2 from Comilog ore, and MnO and Mn_3O_4 from Comilog sinter, it was calculated to be about 1.65. Upon reaction with CO in the upper part of the furnace, the average degree of oxidation of Mn oxide became 1.29. This explains le low value of the SEC observed in our trials.

The pre-reduced Mn oxide is then reduced by C in the coke bed of the furnace according to the following reaction:

$$MnO_{(1+x)} + (1+x)\ CO \rightarrow Mn + (1+x)CO_2.$$

Obviously, a low the degree of oxidation of Mn when this reaction starts is necessary to obtain low specific carbon consumption, the lowest specific C consumption being obtained when x= 0.

CONCLUSION

In this paper we presented how we designed a pilot furnace to study the smelting of HCFeMn. The electrical set point of our first piloting campaign was fairly close to what we anticipated. This shows that we can extend the domain of validity of the empirical relationship found by J. Westly [3] on industrial furnaces towards much smaller furnaces.

For our research tool, we have been able to split the equipment resistance into 3 components: the process resistance, the circuit resistance and an apparent resistance due to eddy currents. The latter components depend exclusively on the design of the equipment. Only the former component depends on process data such as the reductant properties and slag chemical analysis.

The performances of the furnace show that similar phenomena take place in this pilot reactor and in industrial furnaces. Improvement or degradation of these performances induced by the alteration of an entry parameter will therefore be readily transposed to our industrial tools. In that sense it is fully representative of larger furnaces.

Our pilot campaign has also confirmed that, because of its high degree of oxidation of and high reactivity towards CO process gas, the use of Comilog ore in HCFeMn furnaces resulted in both low specific energy and carbon consumptions.

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