

## Experiences Implementing the Smart Furnace Control System

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### INTRODUCTION

The Electric Arc Furnace (EAF) process is composed of several interrelated sub-systems, and each of these sub-systems requires a control system. In order to optimize the EAF process as a whole, it is required for the control system to monitor and adjust many different parameters in harmony, taking into consideration all the interactions between the different sub-systems. Many times this interrelation implies prioritizing the goals, since some adjustments may favor some goals but may negatively affect other goals. The approach here was to build a total control system taking into consideration the interrelated effects between the sub-systems and all the key variables involved.

### ELECTRIC ARC FURNACE DESCRIPTION

**Electrical System:** The EAF is equipped with an 80 MVA furnace transformer with an on-line tap changer and a 4 ohm reactor with five positions but no tap changer. See Table I for the furnace transformer nameplate data and Table II for the reactor nominal impedance table. The rated primary voltage is 34,500 volts.

Table I Transformer Name Plate data

Transformer Tap	Secondary Volts	Primary Current	Secondary Current	%Impedance
1	650	965	51200	25.51
2	670	994	51200	24
3	695	1031	51200	22.65
4	723	1073	51200	21.4
5	752	1116	51200	20.11
6	784	1164	51200	18.86
7	819	1215	51200	17.62
8	857	1272	51200	16.46
9	900	1336	51200	15.35
10	920	1339	50200	14.53
11	942	1339	49000	13.7
12	965	1339	47900	12.9
13	989	1339	46700	12.14
14	1015	1339	45500	11.39
15	1042	1339	44300	10.69
16	1070	1339	43200	10
17	1100	1339	42000	9.36

Table II Reactor Impedance

Reactor Tap	Ohm
1	4.075
2	3.27
3	2.6
4	2.021
5	0.985

**Electric Arc Furnace Dimensions:** The furnace has a 5.9 meters shell diameter with a tapping weight of 100 metric tons of steel. It uses 600 millimeter diameter electrodes with a pitch circle of 1.3 meters

**Burners and Lance System:** The burner system arrangement here is somewhat different from most places. It has six burners. The burners are controlled in groupings of three burners based on two oxygen and gas feeding lines. Line 1 burners are located to the left of the slag door as seen from the slag door. On the same side is a More Lance. Line 2 burners are located on the right side of the slag door, opposite to the Line 1 burners. Each group of three burners is controlled by one valve for the gas and one valve for the oxygen, so it is not possible to adjust each burner independently. Figure 1 shows the Burner distribution in the furnace and Figure 2 shows the oxygen lance.

Figure 1 Burner Distribution in the furnace

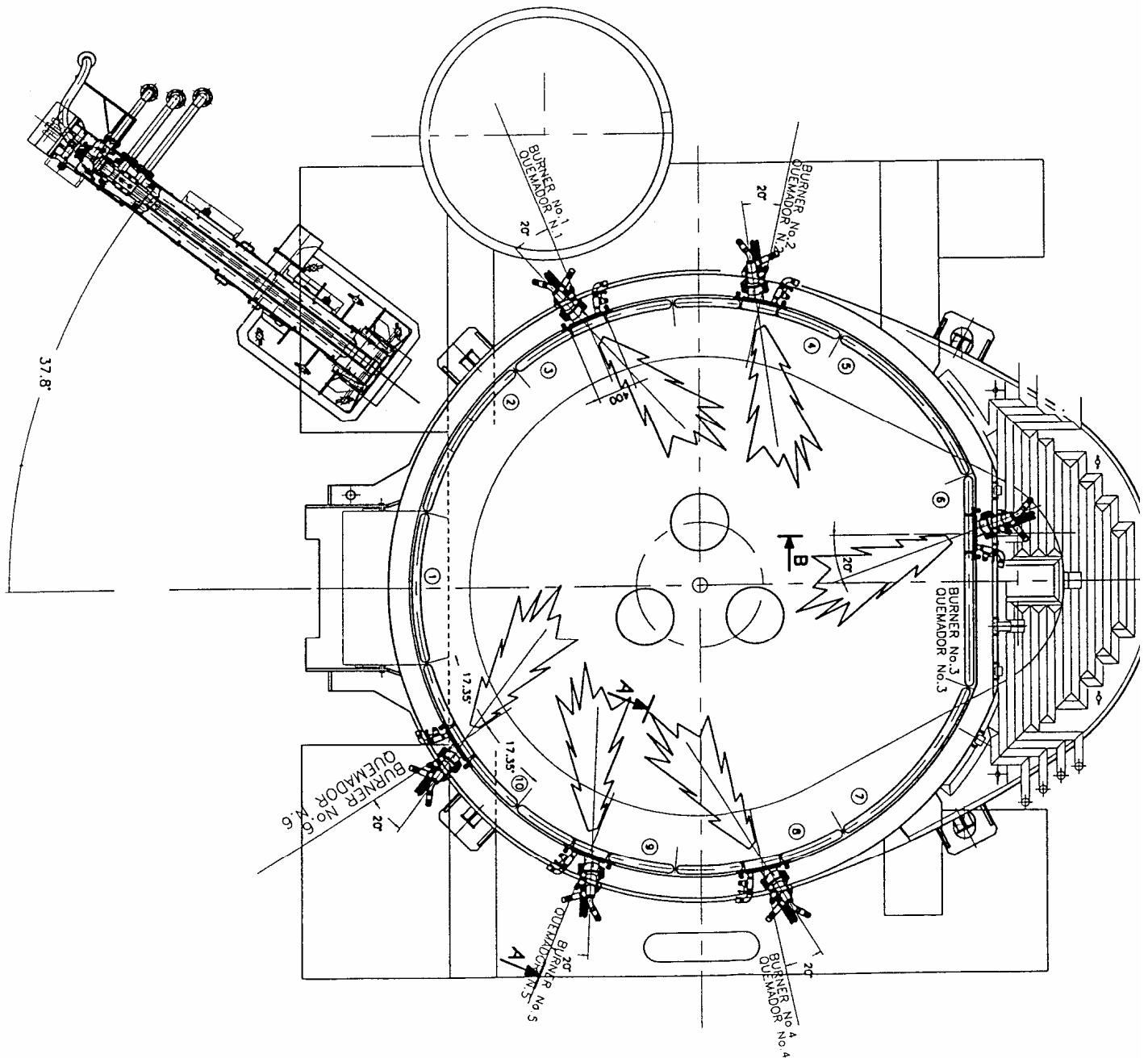


Table III in the next page show the burners capacity

Table III Burners Technical data

BURNER MW	6 X 5 Mw.
MAXIMUM GAS FLOW	6 X 500 Nm3/hr.
MAXIMUM OXYGEN FLOW	6 X 1250Nm3/hr.
FEEDING PRESSURE	9 BAR
MAXIMUM NITROGEN FLOW	40 Nm3/hr.
MAXIMUM AIR FLOW	600 Nm3/HR.
AIR FEED PRESSURE	5 BAR

Figure 2 Water Cooled Lance

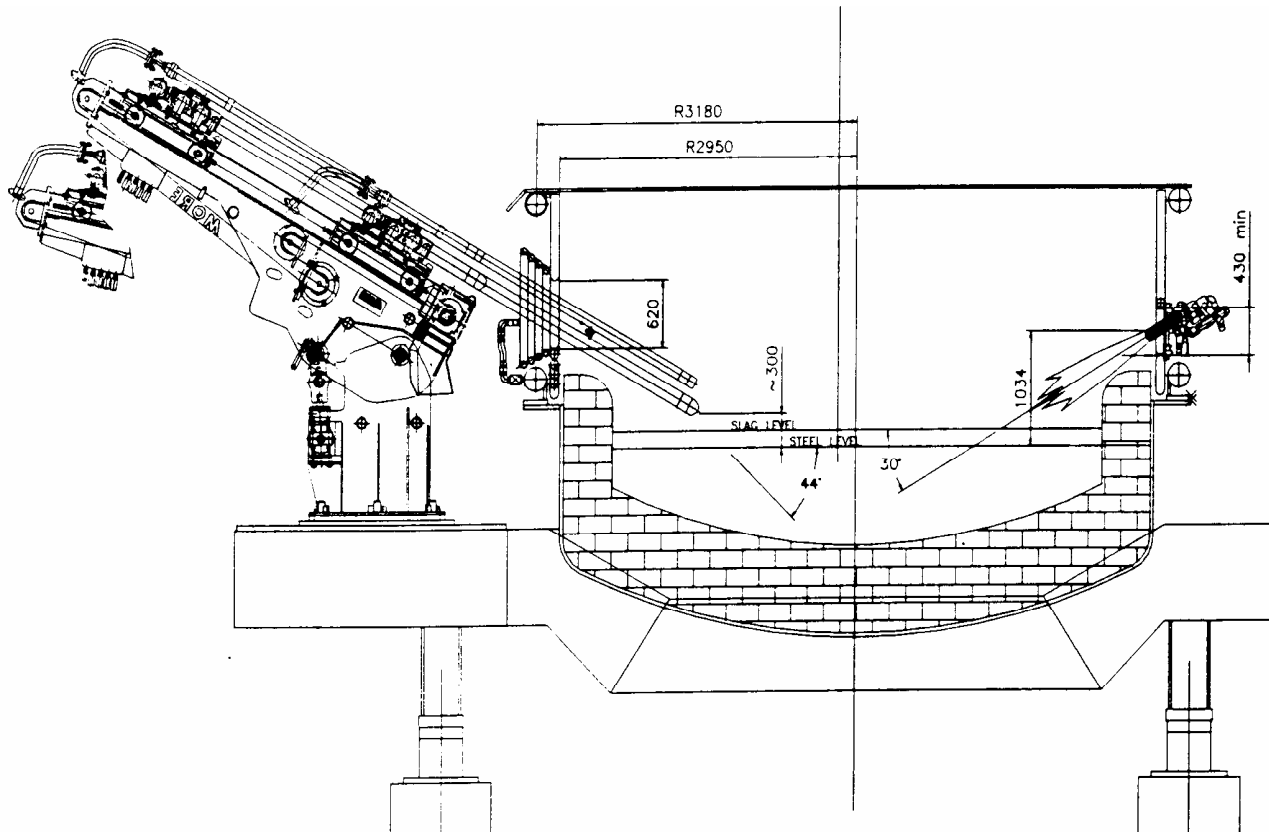


Table IV Technical data for oxygen lance

LANCE MODEL	PALMUR 2 1/2"
HEAD DIAMETER FOR CARBON	1 1/2"
HEAD DIAMETER FOR OXYGEN	2 1/2"
TILT ANGLE	29°
IMPACT ANGLE	44°
OXYGEN FEED PRESSURE	12 BAR
MAXIMUM OXYGEN VOLUME	2500 Nm3/hr.
WATER COOLING FLOW	120 m3/hr.

## CONTROL SYSTEM

The control system was built using the Visual KB platform, which is the same platform used for the Smart Arc system. The SmartFurnace application is designed to provide a robust control system capable of handling different furnace conditions, scrap mix, practice changes, etc. Due to the complexity of such a system two main design criteria were used in the implementation. First, the control system should be capable of self adjust based on different operating conditions. That is, for example if the power profile was changed, the exhaust gas extraction, the burner profiles and the carbon injection system should automatically adjust for the new power profile. So each module of the control system should be robust enough to self adapt up to a certain level. Second, when making system adjustments and changes, it is necessary to have always a base line to compare until a new better performance level is achieved. It should always be possible to go back to previous operation parameters without a painful effort to do so. So the operation mode selection was developed based on Master Programs. A Master Program is composed of several different sub-programs:

**Power Program:** This Power Program selects the Electrical Power Profile to be used.

**Balance Program:** It controls the current balance between phases during the heat.

**Back Charge Program:** Used to determine the best time to load the scrap buckets into the furnace.

**Burner Program:** Controls the basic Heat Profile for the Burners in the system.

**Post Combustion Program:** This module modifies the flows for burners and lances based on measurements from the exhaust gas analysis.

**Carbon Injection Program:** Modifies the carbon injection rate based on Slag conditions in the furnace.

**Exhaust Gas Program:** Sets the required fan speed to maintain a proper gas draft through the fourth hole.

So with this arrangement it was possible to select a Mater Program with a particular selection of sub-programs that will take care of different operation requirements. This gave us the capacity of archiving and keeping the original control settings of performance proven parameters. And by creating new Master programs with new sub-programs it was possible to test new settings without destroying previous proven adjustments. For complying with the first design criteria it was necessary for one single Master Program to take care of a wide spectrum of operation requirements. In order to achieve that, the different sub-programs were developed with several special functionalities. The functionality of each control module is described on more detail next:

**Power Program:** The power program is based on the Smart Arc control system. The idea behind the power profile is to provide the capabilities to start with a very simple program and then start adding more flexibility and functionality as needed. It provides with the following features:

- **Furnace refractory protection:** During the refine stage of the heat, the system checks the slag conditions continuously in order to maximize the power input while protecting the refractory.
- **Variable arc length:** It helps to compensate for scrap composition during the melting stage. It is very important to control the time to reach the bottom in order to maintain an efficient melting
- **Cross arc detection:** Sometimes conductive gases are generated in the furnace, mainly due to several conditions: high CO content, high carbon in the bath, and long arc operation. When this happens, the system reduces the operating voltage in order to avoid damage on water cooled panels and furnace refractory.
- **Power demand monitoring:** This logic is used for maintaining the maximum power utilization without requiring disconnections. This logic does not substitutes the actual power demand controls, but avoids triggering disconnection events.

**Balance Program:** The Balance Program modifies the balance if the current set-point in order to provide a more even distribution of heating energy in the furnace. It is not adjusted for a perfect energy balance between the three phases, but for reducing the heating energy unbalance caused by the other energy sources and energy extraction processes in the furnace. As an example, the points of oxygen injection are hot areas, and the air infiltration and gas extraction are cold areas, like the fourth hole and the slag door. The system is capable of using dynamic balance but that feature is not being used right now.

**Back Charge Program:** The back charging of the furnace is a very important issue in this plant, so a more intelligent algorithm was implemented in order to provide a more dependable back charge operation. The compensations used are:

- **Delay compensations:** An increased amount of energy is required in order to provide a proper melting when big delays happen. This module increases the back charge energy required depending on the size of the delay.
- **Burner usage compensation:** The shop has a lance manipulator which automatically comes in based on the lance oxygen control module. Sometimes there is scrap blocking the lance port so the oxygen lance is not always as uniform as we'd like. This compensation helps to reach the proper back charging point even if there is a failure on the burners or lances. Each device has an independent compensation so it is possible to automatically adjust the

required compensation for each burner or lance depending on how critical it is in the melting process. This correction was set by setting a base-line, so it automatically compensates in both directions (for charge sooner than scheduled or later than scheduled) and it also provides an automatic correction when the burner profiles are being modified for any purposes or in case of a failure.

- **Scrap density compensation:** The scrap density information is not available in the system, but the charge weights are very reliable, so we make an estimation of the scrap density based on the charge weight. This has been very helpful in order to determine the energy requirements for charging.

**Burner Program:** The Burner Program is the base of the burner control system, but by itself is not robust enough in order to cope with the different operation conditions. This is a profile based on electrical energy consumption, and also arc stability. Adding the arc stability as one more variable capable of switching burner modes provides the system with advantages over conventional control systems because the arc stability is a good indicator to determine when the melting stage is finished. A burner program is shown in Table V next.

Table V Burner Program

Step	Gas Line1	O2 Line1	Gas Line2	O2 Line2	Lance O2	Carbon Flow	Limit KWH/Ton	Limit MWH	Limit SF
1	750	1500	850	1700	0	0	0	0.8	0
2	750	1650	850	1870	0	0	0	1.7	0
3	750	1725	850	1955	0	0	55	0	0
4	750	2250	850	2250	2000	0	75	0	0
5	750	2250	850	2250	2400	0	95	0	0
6	750	2250	850	2250	2500	0	130	0	0
7	750	2250	850	2250	2500	0	160	0	0
8	0	1800	0	1800	2500	10	220	0	0
9	0	1200	0	1200	2500	10	250	0	0
10	0	0	0	0	2500	10	350	0	0
11	0	0	0	0	2500	10	0	0	0
12	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0

In the previous table, if any of the limits is met, the program will move to the next step. It is important to mention that using the stability to make improvements was not an easy task. The stability can be used for some purposes but not for everything. It is important to understand that this variable is affected by the arc length, the oxygen injection and the carbon injection as well. Anyway it proved beneficial for ensuring safe usage of lancing modes resulting on panel protection purposes.

**Post Combustion Program:** The post combustion program modifies the burner flow and the gas flow in order to optimize the use of fuels inside the furnace. Applying simple rules to increase or decrease oxygen and reduce gas consumption did not work in the expected way according to well known chemistry formulas. When the oxygen flow is increased for a burner, the CO percentage should be reduced and then the oxygen percentage or the CO2 percentage increased. But what happened is that the CO level would go even higher. The reason for this seemed to be extra fuel in the form of oil or charge carbon being consumed by the oxygen when increasing the flow. While studying the phenomena some graphics were created for understanding better the behavior of the burner system in the furnace. It shows the relationship between CO (Carbon Monoxide) on the X axis, CO2 (Carbon Dioxide) on the Y axis and the Z axis shows the H2 (Hydrogen content) all values in percentages. At first this graphic did not show any correlations, but when it was made independently for the time when the burners were operating, it became clear that the CO2 measurement did not affect at all the CO and the H2 content measured. Also it showed a nearly proportional relationship between the CO content and the H2 content. Figure 3 (next page) shows this correlation. The same correlation was observed when the chart was generated with the burners off (no gas usage). Figure 4 (next page) shows the same graphic with the burners off condition. The only difference with both graphics was the amounts of CO and CO2. But still the only meaningful variable for control was the CO content. This finding helps simplify the algorithms employed for control. In order to consider this, the approach was to divide the control requirements in two segments based on the operation of the burners: Burner Mode, and Lance Mode.

- **Burner mode:** When in burner mode, the control will modify the burner gas and oxygen references within a certain valid range. The idea is to maintain a good level of fuels in the furnace.
- **Lance mode:** In this segment of the heat, the system will optimize the use of oxygen in the lance in order to run within a certain optimal range in order to generate as much energy as possible while avoiding excessive oxidation of steel.

Adjusting the best values for the operation was not an easy task. The chemistry formulas alone provide a guideline for adjusting the system, but the reactions that take place inside the furnace also depend on contact between the elements and that does not always happens in the expected way. It depends on how the scrap is melting in the furnace and the extraction force dynamics.

Figure 3 CO versus CO2 versus H2 with the burners on burner mode

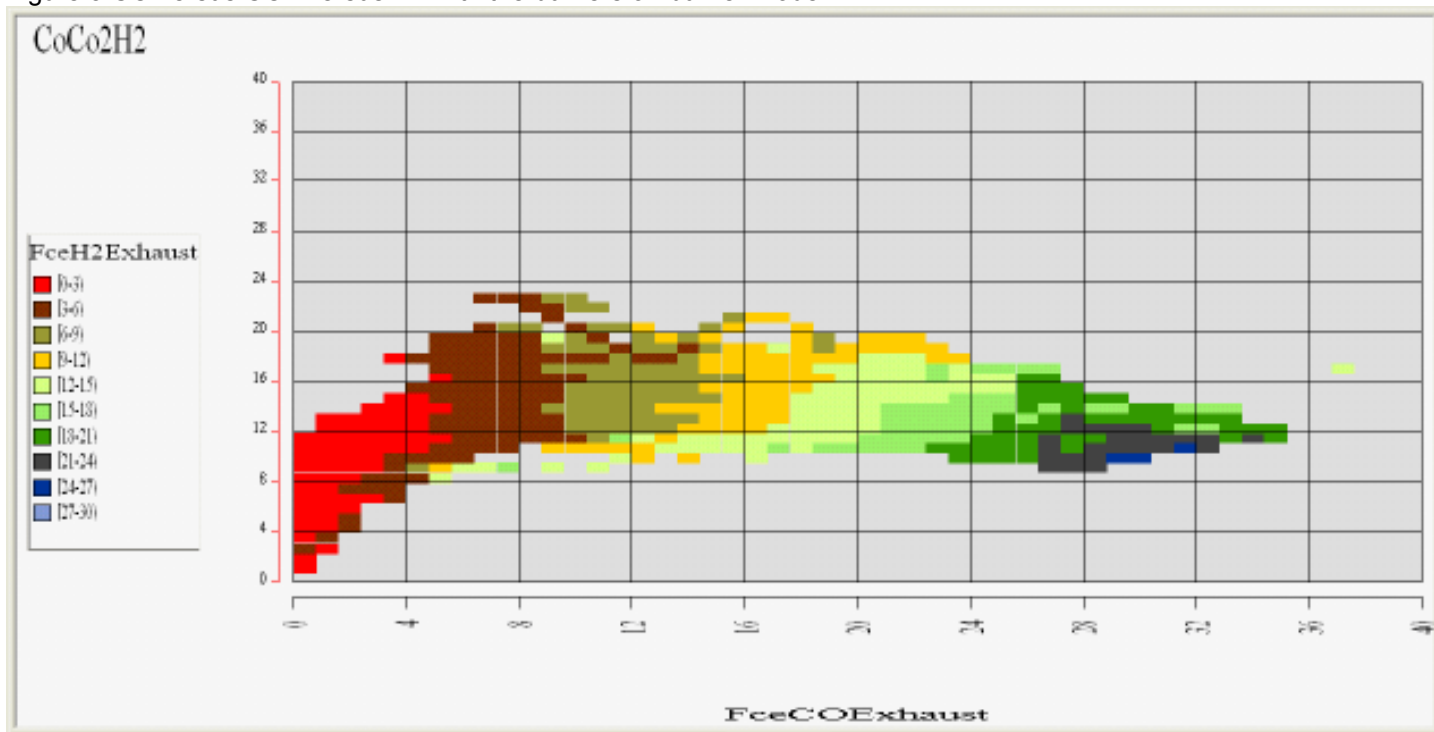
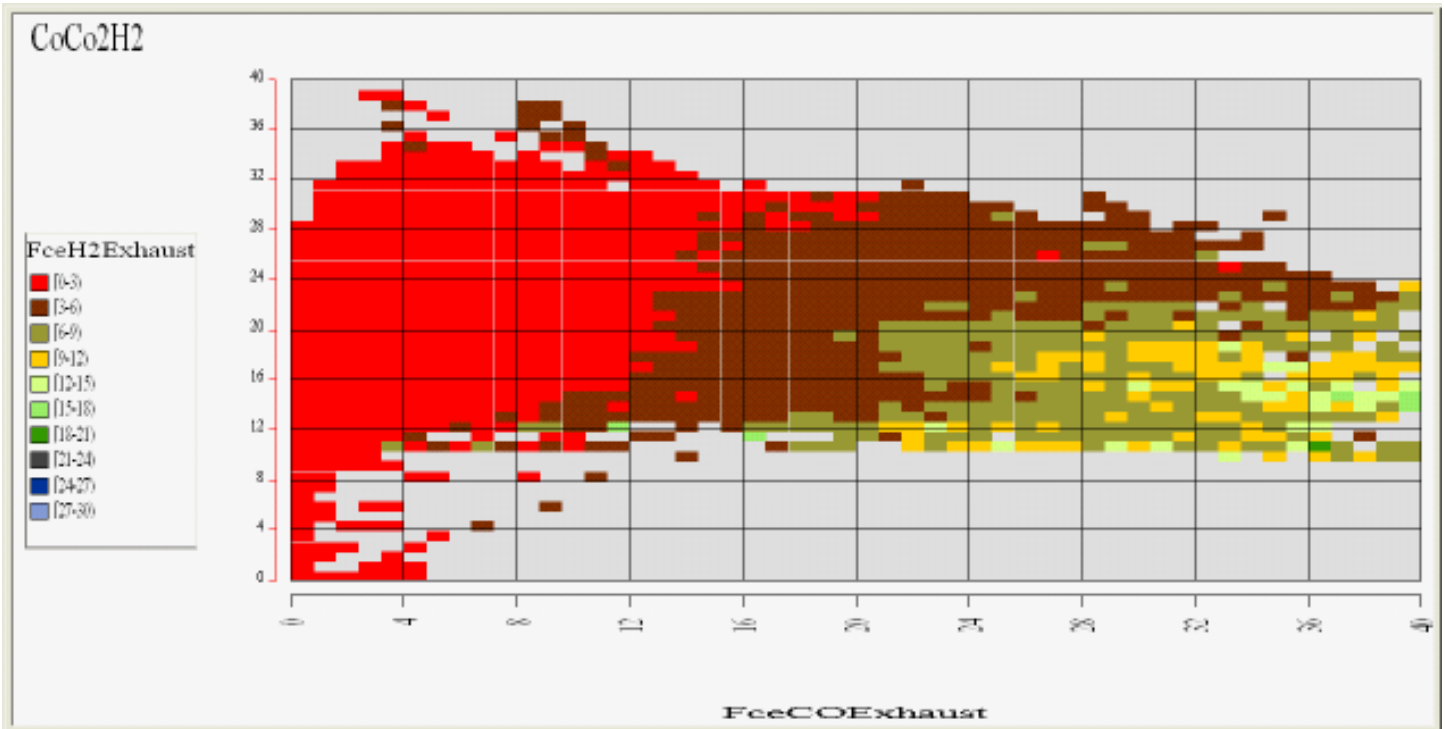
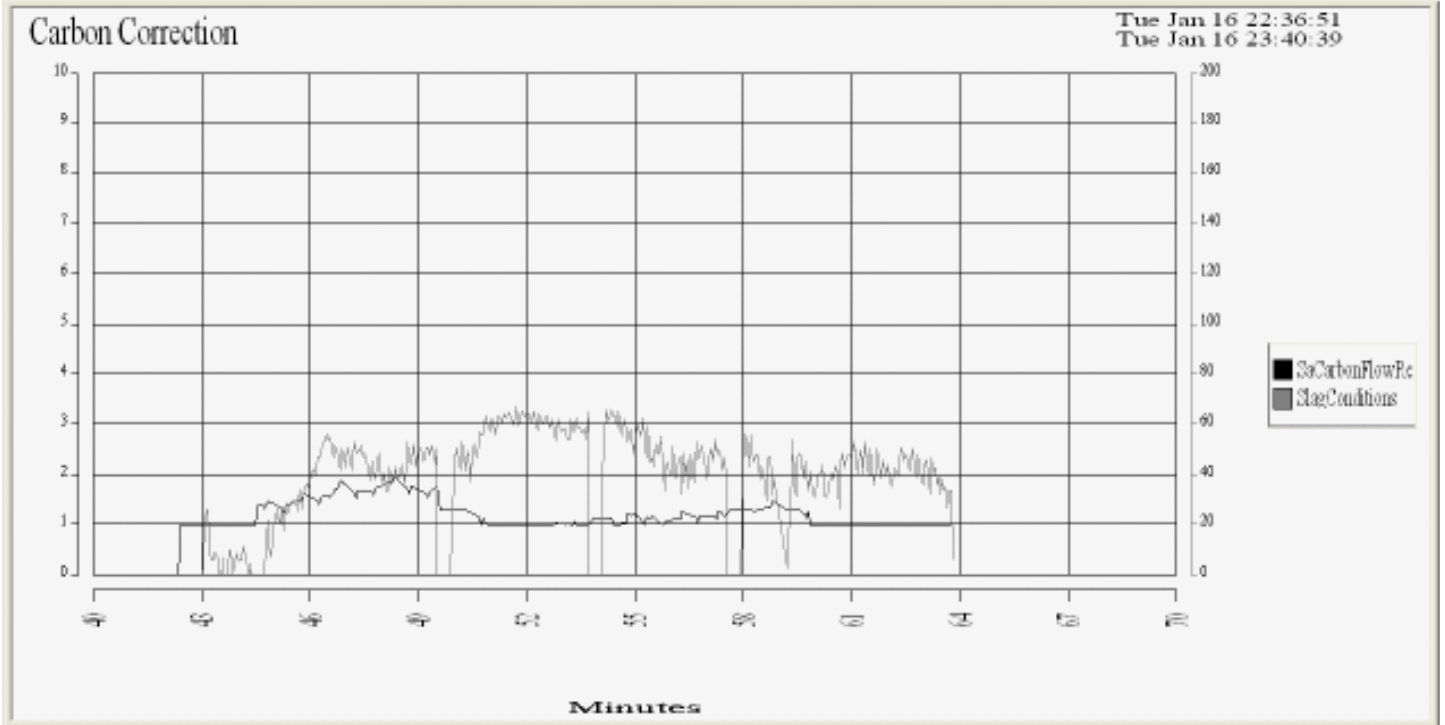


Figure 4 CO versus CO2 versus H2 with the burners on burner mode



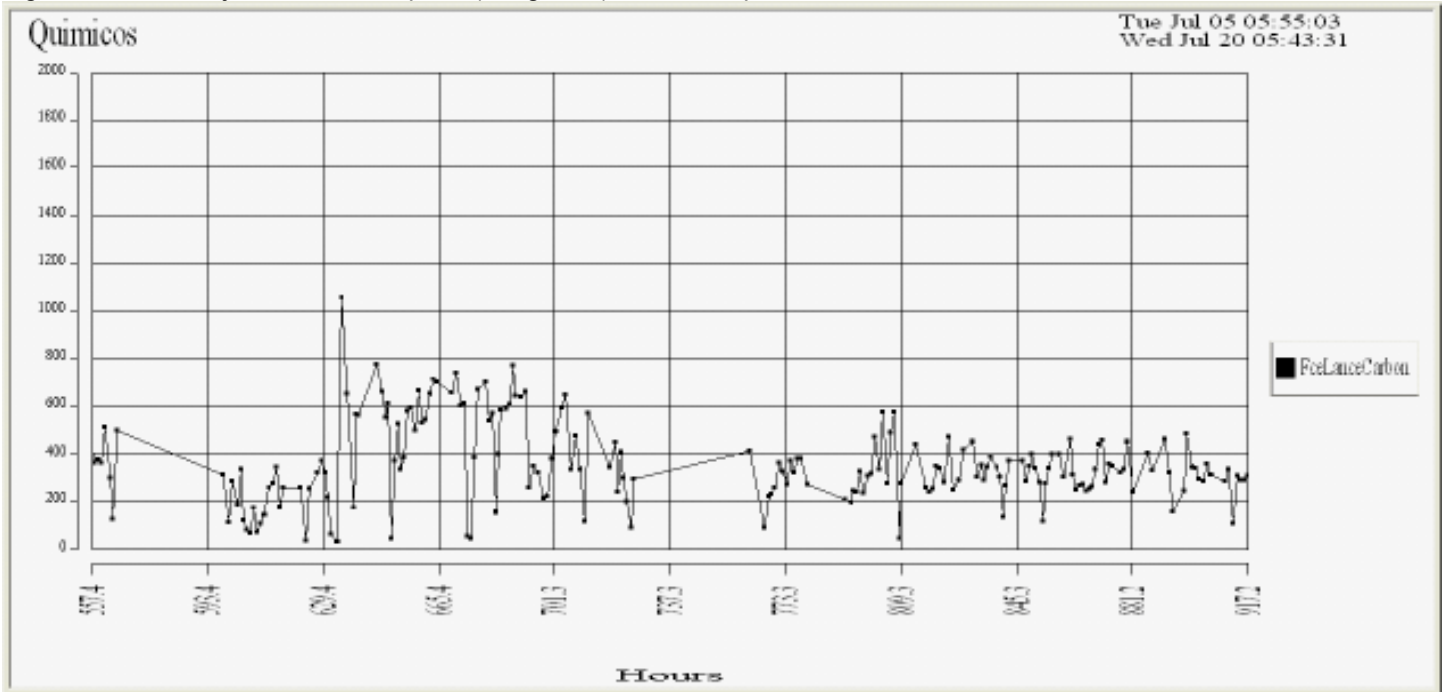
**Carbon Injection Program:** The carbon injection program complements the burner program. It provides a correction on the carbon injection flow based on the slag conditions. For robustness, the system is checking the carbon flow range so it is automatically disabled if there is a problem with the carbon injection machine. It is been working anyway about 95% of the time without the need to disable it. The next graphic in Figure 5 (next page) shows the Behavior of the carbon injection flow compensation during the heat. In this case it was a regular heat when the carbon injector worked properly. The reference to the carbon injection machine is

Figure 5 Carbon Injection Reference modified by the slag conditions



the opening time for the valve in seconds. The total time in the cycle is ten seconds. So the valve is opening from 10 to 20 percent depending on the slag conditions. It is important to notice that the carbon injection automation is very critical, since small variations of the carbon flow would change the furnace performance. When the system was first implemented, the original automated carbon flow control was an open loop control. This caused numerous problems affecting mainly the consistency in the operation. The second graphic is Figure 4. It shows some heats when the carbon machine slightly shifted its flow due to variations on the granularity of the carbon material being used. Figure 6 is showing the total carbon usage for injection for several heats. Each dot or sample represents the consumption for one heat. After the implementation of a closed loop control the behavior of the carbon injection became reliable. It makes no sense to optimize the carbon flow set-point if the carbon feed rate is not consistent.

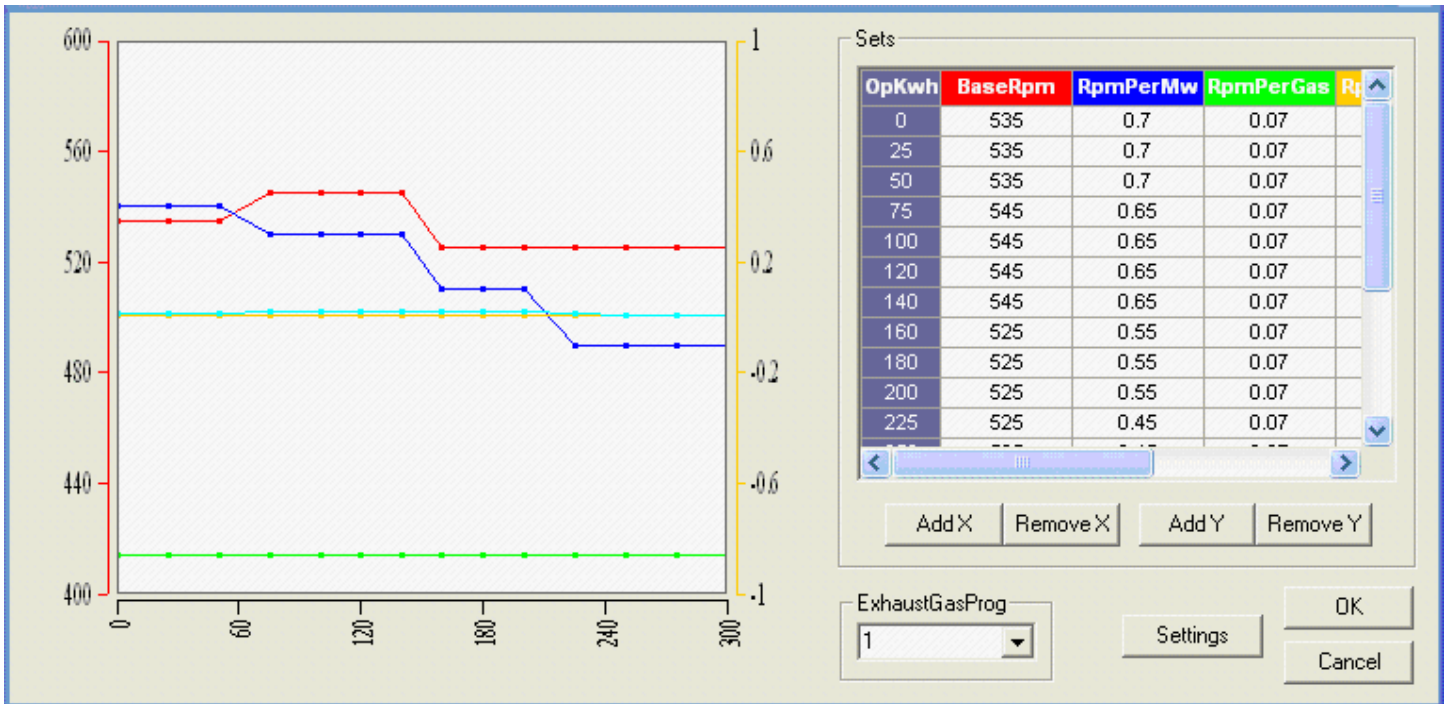
Figure 6 Carbon Injection Consumption (Kilograms). Each sample is one heat



**Exhaust Gas Program:** The furnace at Hylsa Ternium North Plant does not have a furnace pressure transducer, so it is a little more difficult to maintain a good level of exhaust gas during the different stages of the heat. Two approaches were taken in order to make a better control, since it was difficult to make changes in the burner programs and at the same time adjust the exhaust gas system. The control device for the exhaust gas is a Fan which is powered by a drive in order to change its speed. It was required to modify the speed of the fan depending on the burner mode at operation, the oxygen lance usage, the average power input and the stage in the heat.

The first solution proposed was to use Fuzzy Logic, so a set of rules were tuned to respond depending on the actual flow from the burners and lance and that was added to a base profile set similar to the original profile. This work fairly well for a few weeks but it was not easy to optimize. Also the effect of the burners depended on the heat stage obviously due to the presence of more fuel and waste gases. So another solution was proposed and tested, this time with better results in terms of the plant visibility and the automatic synchronization with the process requirements. This was implemented as a profile which depended on the actual lance and burner flows. Figure 7 shows a typical profile for the exhaust gas system.

Figure 7 Fan Speed (RPM) Program as a function of Electric Megawatt input, Gas usage, and Oxygen



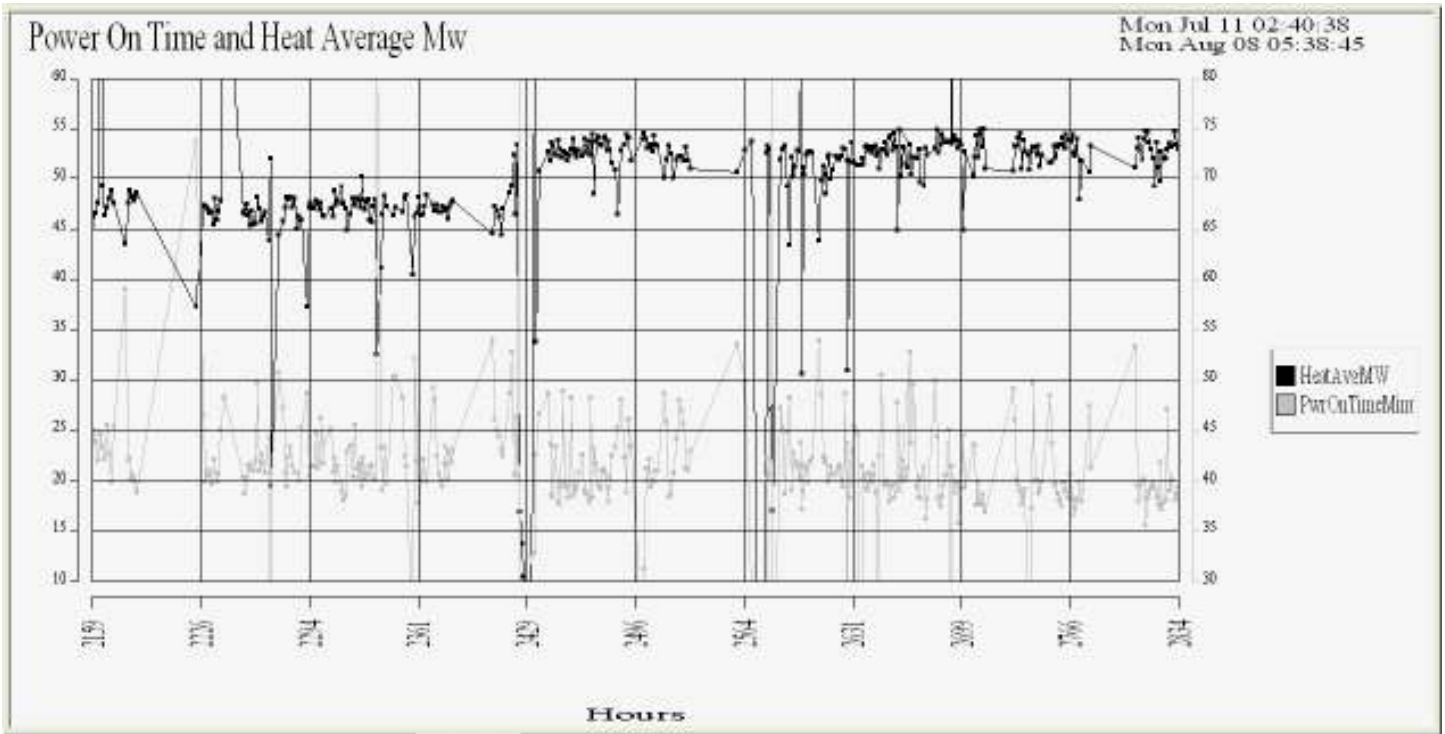
Another advantage of using it as a profile is that it allowed for modifications without losing previous operation parameters. Anyway only two different programs have been needed for one year and a half. It also helped to cope with sporadic burner or lance failures, or lance sub-utilization. This gave us the flexibility to modify at will the burner and lances usage with different criteria without the need to worry about the exhaust gas system

## OPERATION RESULTS

There are different limitations and restrictions in every meltshop. When the project was started, the main priority was to optimize the cost, but after four months of operation, the productivity became the main goal and it is so until today. Also at the same time the scrap market started to drift in such a way that scrap was expensive and scarce, which put even more pressure on the productivity issue.

The next graphic (Figure 8) shows the improvements on power on time when the average power input was increased. A decrease of about three minutes was obtained by increasing the average power input from 48 to 54 Mw. Each sample in the graphic is the final result of one heat.

Figure 8 Average Power On Time in Minutes and Average Megawatt input



The electrode consumption was reduced from 1.73 to 1.66. The energy consumption has been maintained at the same level, but the scrap availability is not as good as it was one year ago, so it is considered a plus. The number is now around 390 KWH/Ton of liquid steel (metric tons). There is been savings also on other consumables. The only increase on the consumption was on carbon usage. A table showing the consumables change is shown below in Table VI as well as productivity results on Table VII.

Table VI Consumables usage 2005 to 2006

Item	From	To	Units
Gas	4.87	4.69	Nm <sup>3</sup> /Ton
Oxygen	33.40	32.10	Nm <sup>3</sup> /Ton
Carbon	19.00	26.00	Kilos/Ton
Refractory	1.33	1.26	Kilos/Ton

Table VII Productivity in Tons

Year	2005	2006
Good Billet	505	544
Liquid Steel	517	556