ISSN 2176-3135

ICSTI
6th International Congress on the Science and Technology of Ironmaking - ICSTI
42th Ironmaking and Raw Materials Seminar/ 42ª Seminário de Redução de Minério de Ferro e Matérias-primas
13th Brazilian Symposium on Iron Ore/ 13ª Seminário Brasileiro de Minério de Ferro

BLAST FURNACE HOT STOVE CHANGEOVER BY THERMAL CONTROL[1]

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Abstract
CSN´s Blast Furnace 3 produces around 10,000 t of hot metal per day. It has got four hot stoves operating in an automatic sequence. The hot stoves are responsible to regenerate the blast furnace gas enthalpy energy, heating the refractory in the gas cycle, and blowing the hot blast into the blast furnace in the blast cycle. The temperature of the cold air coming from the motoblower is around 200 °C. After going through the hot stoves, the air temperature is raised to around 1350°C, then it is injected into the mixing chamber together with the cold air. Thus, the blowing temperature in the ring off wind inside the blast furnace can be controlled. The main hot stove equipments are the hot blast valves, the air and combustion gas control valves, shut-off valves, refractory, refractory chamber, expansion joints, flow, pressure and temperature transmitters, plus the PLC, which is responsible for control. There are about 112 valves operating every hot stove changeover. The hot stove original changeover sequence, design by NKK/Japan, was fixed timer by the operator between 40 to 50 minutes according to the desired temperature and blast furnace flow. When the timer is elapsed, the hot stoves start the changeover process. The next hot stove is put in the blast cycle, and the older hot stove in blow cycle is box-up and goes to gas cycle. The number of hot stoves changeover per day was around 28 up to 36 at single blow mode, and approximately from 14 up to 18 changeovers C-Parallel blow mode, when two hot stoves blows together. The new strategic based in the thermal control was design to preserve the hot stoves into blast until they can hold the desired temperature at that blast flow. The timers are hold just before they got elapsed according to the hot blast thermal capacity remained which is on-line measured and estimated. The thermal control changeover instead of fixed timers optimized the use of the hot stoves decreasing the pressure equalizations and valve operations in general. The number of hot stoves changeover per day with the new control decreased around 16 up to 20 at single blow mode, and approximately from 8 up to 10 changeovers C-Parallel blow mode, when two hot stoves blows together. The developments carried out raised the blast flow average temperature up to about 100°C, saving 10 kg/t hot metal in the coke rate.
Key words: Blast furnace; Hot stoves; Thermal control; Changeover.

[1] *Technical contribution to the 6th International Congresso on the Sicence and Technology of Ironmaking – ICSTI, 42nd International Meeting on Ironmaking and 13th International Symposium on Iron Ore, October 14th to 18th, 2012, Rio de Janeiro, RJ, Brazil.*
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ISSN 2176-3135

1 INTRODUCTION

CSN´s Blast Furnace 3 was started in 1976 and produces around 10,000 t of hot metal per day. It has got four hot stoves operating in an automatic sequence. The hot stoves are responsible to regenerate the blast furnace gas enthalpy energy, heating the refractory in the gas cycle, and blowing the hot blast into the blast furnace in the blast cycle. The temperature of the cold air coming from the motoblower is around 200°C.

After going through the hot stoves, the air temperature is raised to around 1350°C, and then it is injected into the mixing chamber together with the cold air. Thus, the blowing temperature in the ring off wind inside the blast furnace can be controlled.

Figure 1 illustrates the CSN´s Blast Furnace 3 blast flow diagram with four hot stoves, the motoblowers, the cold mixing valves as well as the blast thermocouple.

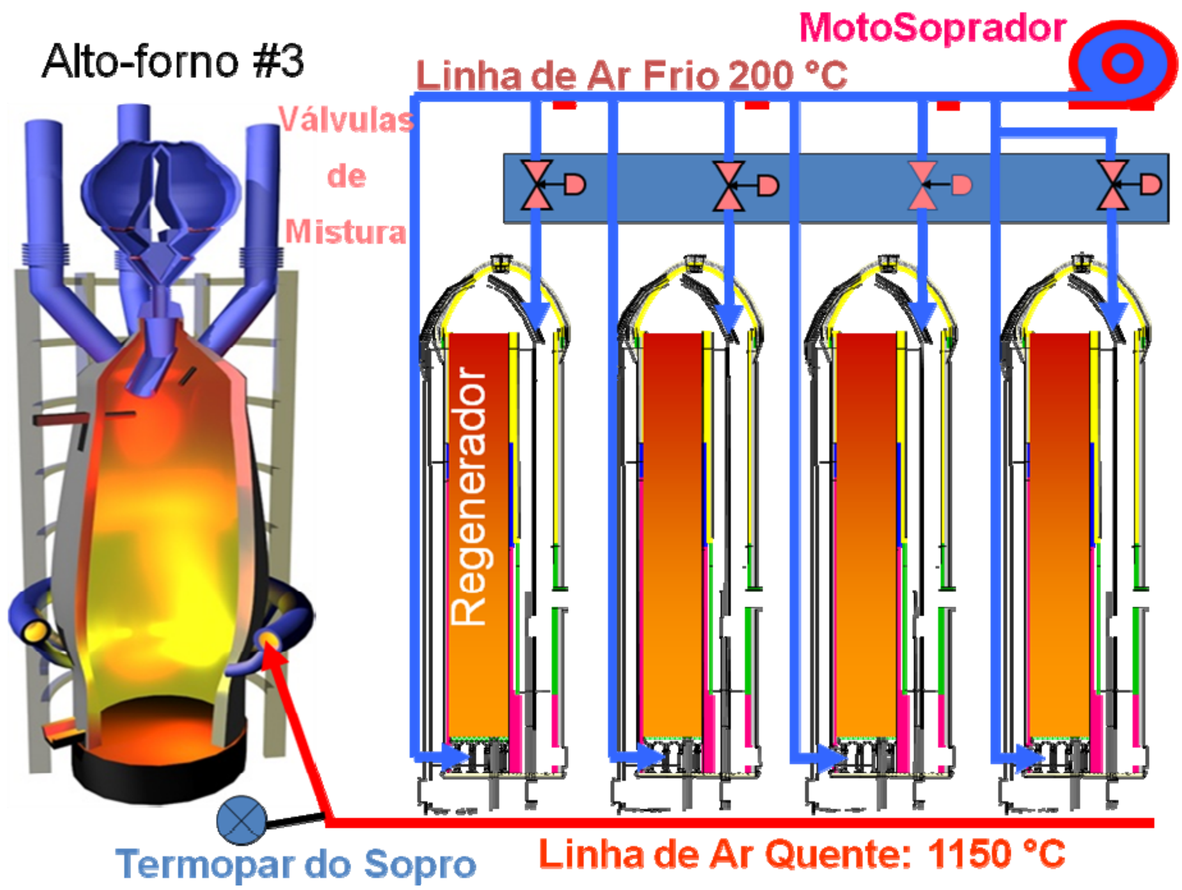

Figure 1 – Hot Blast Diagram for CSN´s Blast furnace 3.

The main hot stove equipments are the hot blast valves, the air and combustion gas control valves, shut-off valves, and refractory, refractory chamber, expansion joints, and flow, pressure and temperature transmitters.

At the start, the Blast Furnace was controlled by a PLC for the interlocks and sequence and a DCS for instrumentation and process control. An old article[1] from 1987 describes similar automation system architecture. After the 2001 Revamp, the PLC and DCS functions were jointed and now the PLC is unique and responsible for the temperature controllers, valves, interlocks and sequence control. There are about 112 valves operating every hot stove changeover.

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2 PROCESS DESCRIPTION

The hot stove original changeover sequence designed by NKK/Japan had fixed timers by the operator between 40 to 50 minutes according to the desired temperature and blast furnace flow. When the timer is elapsed, the hot stoves start the changeover process. The next hot stove is put in the blast cycle, and the older hot stove in blow cycle is boxed-up and goes to gas cycle again.

The number of hot stoves changeover per day was around 28 up to 36 at single blow mode, and approximately from 14 up to 18 changeovers C-Parallel blow mode, when two hot stoves blows together as Solomentsev and Ioffe[2] and Resnikov[3] show. A hot stove sequence mode in a simple for CSN´s Blast Furnace 2 is described in Motta et al.[4]

Figure 2 shows the hot stoves valves and process and diagram for CSN´s Blast Furnace 3 with the 31 minutes of blast time at the top left and blast temperature controller, TIC410, at the top right:

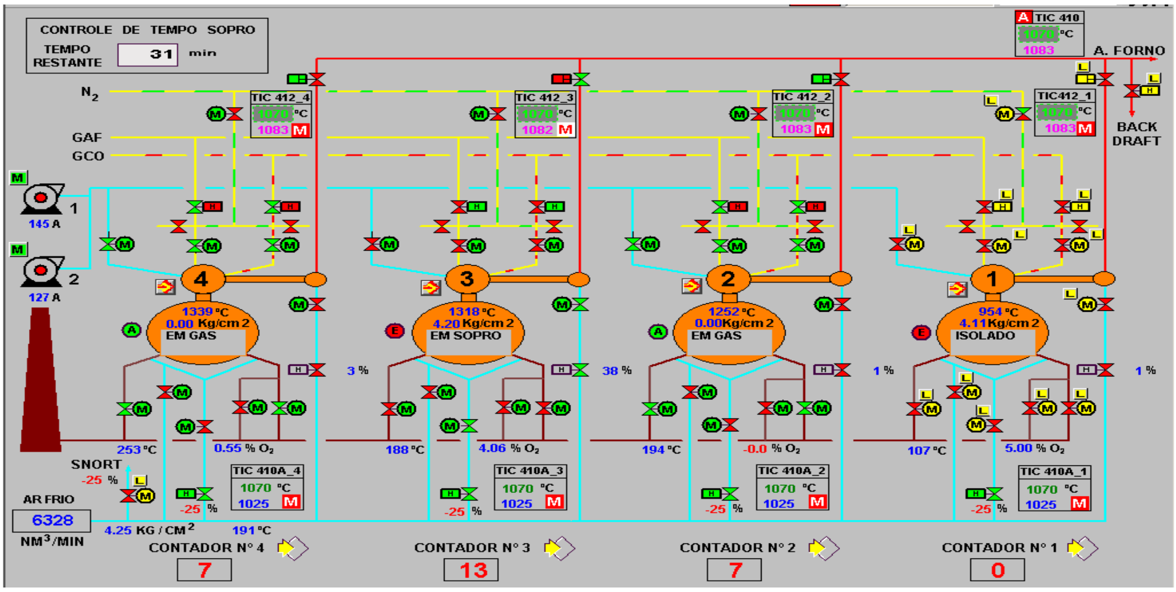

Figure 2 – Hot stoves valves and process and diagram.

3 CHANGEOVER BASED ON REMAINED THERMAL CAPACITY

Figure 3 describes the Flow chart of the new strategic for hot stoves changeover based on remained thermal capacity. The thermal capacity control was design to preserve the hot stoves into blast until they can hold the desired temperature at that blast flow.

The Blast timers are hold just before they get elapsed according to the hot blast thermal capacity remained which is on-line measured and estimated. The thermal control changeover instead of fixed timers optimized the use of the hot stoves decreasing the pressure equalizations and valve operations in general.

ISSN 2176-3135

A - Blast Temperature Process Variable > (SP-10°C)
&
B – Cold Mixing Manipulated Variable (MV>20%)
&
C – Remaining time for Changeover = 2 min
&
D – Next Hot Stove in Blast: (Its Chimney Temp. < 320 ºC or Is Box-up hot)

↓

Hold the exchanging timer until the hot stove thermal capacity is finished

Figure 3 – Control strategic for changeover based on remained thermal capacity

4 DECREASING OF BLAST TEMPERATURE STANDARD DEVIATION

This work is part of the main subject. A technical analysis of the current situation of opening the valves controlling the mixing of cold air at the time of exchange of the regenerators, and to describe the proposed project planned in order to decrease the variability of air temperature blown into the 3 blast furnace of CSN.

This task began with the observation and study of equipment and problems in the hot stove area that make it difficult to maintain the blast temperature as constant and smooth as possible, and continues to study the connection of the motorized valve with the PLC logic and analysis to be deployed.

The Blast Temperature Standard Deviation was high due to a lack of a good starting point at the changeover situation.

The cold mixing valves opening position after the changeover are essential to get a low blast temperature deviation.

The Hot Stoves must be modeled in order to get the thermal energy accumulated and to know what would be the best initial position according to the Blast temperature set-point as well as the blast flow.

As higher as the blast temperature is as lower the cold mixing valves opening position will be. By the other hand, as higher as the blast flow is as higher cold mixing valves opening position will be.

5 THE BEST OPENING POSITION FOR COLD MIXING VALVES DURING CHANGEOVER

The thermal capacity tells how much energy the hot stove accumulated. In parallel with the hot stove is the cold mixing valve which is responsible to mix the flow through it with the flow trough the hot stove into the mixing chamber just before the hot blast valve.

Through the cold mixing, the best opening position for cold mixing valves during hot stove changeover can be obtained in order to get the lower temperature deviation.

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The hot stoves can be modeled like a first-order heat exchange physical system according to Danilova.[5] Figure 4 illustrates the initial hot stove model, where T_{in} = 150ºC, typical temperature for inlet coming from motoblowers in summer time:

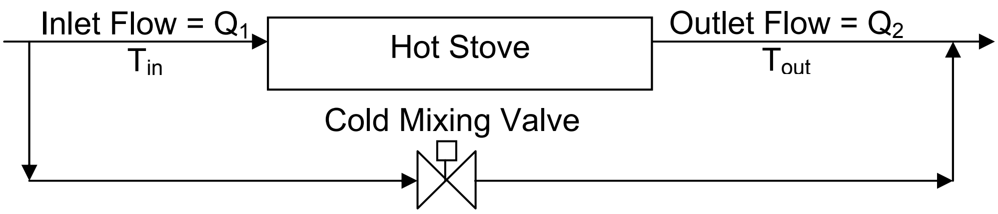

Figure 4 – Physical dynamic model for blast furnace hot stoves.

The heating quantity get by the blast flow is according to the equation (1) below:

$$\Delta Q = mC\Delta T = mC\left(T_{out} - T_{in}\right) \qquad (1)$$

The heating quantity in the period is given by equation (2).

$$T = T_0 e^{-\left(\frac{t_{atual}}{T_{Máx}}\right)} \qquad (2)$$

Where:
t_{atual} = Actual Dome Hot Stove Temperature;
$T_0 = T_{Máx}$

The thermal capacity in a range of 0 to 100% is given by equation (3).

$$Thermal\_Capacity = 2 - e^{0,69\times\left(\frac{1350-T_{Domo}}{1350-T_{SP\_Sopro}}\right)} \qquad (3)$$

Figure 5 shows the thermal capacity calculated during the hot stove thermal capacity cycles:

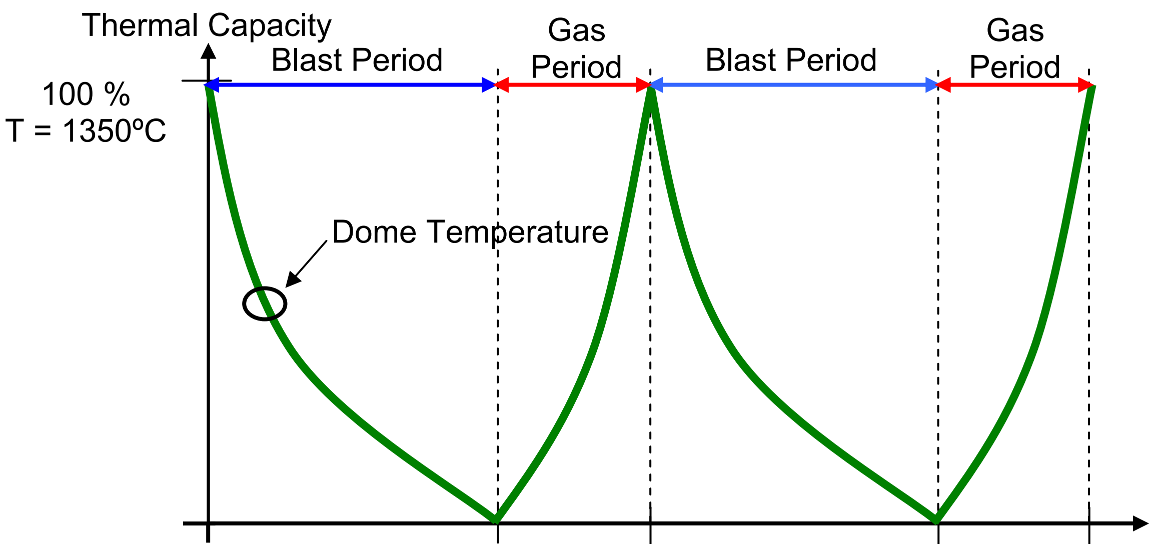

Figure 5 – Hot stove thermal capacity cycles

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The criteria adopted for the cold valve initial opening position after the studies of Soares [6], It was created a pond rated weights for three conditions below:

A – Initial opening related to thermal capacity = 0 to 50%;
B – Initial opening related to blast temperature set-point = 0 to 30%;
C – Initial opening related to blast flow set-point = 0 to 20%.

In C-PARALLEL mode, two hot stoves blow together in parallel. Thus, there will be always one hot stove boxed-up hot going to blast and another remaining in blast during the changeover process. The original sequence from NKK design was preserved in order to avoid two much interlock changes. This sequence has got 15 steps, and the changeover events occur on step 13 and step 14.

A - Cold Blast Mixing Valve Opening Position for Step 13

Hot Stove blasts to the furnace on the step 13 when it has just box-up hot from combustion cycle (or gas cycle). The cold blast mixing valve opening position for Step 13 is given by equation (4):

$$A_{Total}13(\%) = A_{Cap.Term} + A_{Temp.}(\%) + A_{Vazão}(\%) \qquad (4)$$

This results in the general equation (5):

$$A_{Total}13(\%) = \left(2 - e^{0{,}69\times\left(\frac{1350-T_{Domo}}{1350-T}\right)}\right) + \left[\left(\frac{1200-T}{100}\right)\times K\right] + \left(\frac{V-5000}{100}\right) \qquad (5)$$

Where:
T_{Dome} = Hot stove dome temperature during changeover [ºC];
T = Blast temperature set-point value [ºC];
V = Blast flow set-point value [Nm³/min];
K = Constant

B – Cold Blast Mixing Valve Opening Position for Step 14

Step 14 is the condition when the younger hot stove blowing in parallel remains in blast. Its step was Just 13 and now after the changeover it will be step 14. Thus, it Will be the older hot stove in blast because has still thermal capacity and the blow mode is C-Parallel.

The cold blast mixing valve opening position for Step 14 is given by equation (4):

$$A_{Total}14(\%) = A_{Total}13(\%) - 10\% \qquad (6)$$

This results in the general equation (7):

$$A_{Total}14(\%) = \left\{\left(2 - e^{0{,}69\times\left(\frac{1350-T_{Domo}}{1350-T}\right)}\right) + \left[\left(\frac{1200-T}{100}\right)\times K\right] + \left(\frac{V-5000}{100}\right)\right\} - 10\% \qquad (7)$$

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Table 1 shows the general equations for the best opening position for cold mixing valves according to the new criteria. In the new operator screen it can be chosen the equation to be used by the PLC or it can be enter others parameters values.

Table 1 – General equations the best initial opening for cold valve mixing

Class	Equations	% Open Temp. Max.	% Open Blast Max.	% Open Thermal Capacity
Strong K = 20	$A_{Total}13(\%) = \left(2 - e^{0{,}69\times\left(\frac{1350-T_{Domo}}{1350-T}\right)}\right) + \left[\left(\frac{1200-T}{100}\right)\times K\right] + \left(\frac{V-5000}{100}\right)$	30%	20%	50%
Medium K=13,67	$A_{Total}13(\%) = \left(2 - e^{0{,}69\times\left(\frac{1350-T_{Domo}}{1350-T}\right)}\right) + \left[\left(\frac{1200-T}{100}\right)\times K\right] + \left(\frac{V-5000}{100}\right)$	20%	10%	70%
Weak K = 6,67	$A_{Total}13(\%) = \left(2 - e^{0{,}69\times\left(\frac{1350-T_{Domo}}{1350-T}\right)}\right) + \left[\left(\frac{1200-T}{100}\right)\times K\right] + \left(\frac{V-5000}{100}\right)$	10%	5%	85%

6 THE NEW COLD MIXING VALVES ACTUATORS

The original actuators were hydraulics types from the sixties. They were not accuracy and not fabricated anymore. Therefore, they do not have any spare parts for maintenance purpose making the maintenance more expensive.

These kind of actuators were replaced by Rotork motorized actuator[7] which are more accuracy and efficient. Those Rotork actuators are modern and used worldwide including in our company. Nowadays, there are about 32 installed in the blast furnace area and auxiliary facilities with no fails since 2007.

The actuator provide a very good positioning besides the position transducer and high reliability. There are made with modern electronics and advanced mechanical parts with no oil tank like the hydraulic actuators.

To reduce the variability, the hydraulic actuators of the 60s, the air valves were replaced by blending modern motorized actuators of high precision. The control logic blast temperature was developed to calculate a new value of the exchange during the initial opening of the regenerators.

It was incremented a special PLC routine to calculate the IAE (integral absolute error) of the blast temperature controller deviation. This is essential to have a tool to evaluate standard deviation of the temperature variability before and after the improvements described.

Equation 8 shows how the IAE is calculated over one day (1440 minutes) for a deviation temperature controller as a discrete variable in the PLC ladder program:

$$IAE = \sum_{n=1}^{1440} \left|DV(nT)\right| \times T \qquad (8)$$

T = PLC data acquisition period;
DV(nT) = Blast temperature deviation or TIC controller error.

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Figure 6 shows the IAE results over three days analysis just before and after the changes:

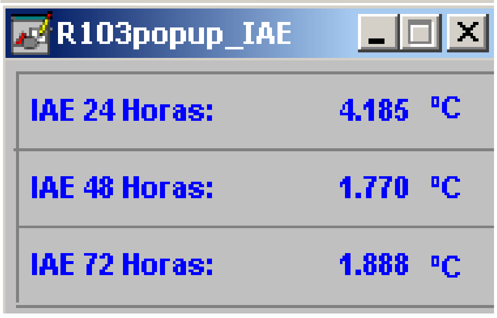

Figure 6 – IAE results before and after the changes.

7 THE HOT BLAST TEMPERATURE VARIABLE PROCESS

The instruments that gather the blast temperature variable process must be robust to support the high and rough conditions inside the hot blast pipeline near the bustle.

At the start, the project foreseen a Platinum-Rhodium 13% thermocouple type R, with a single wire of 0.50 mm diameter.

The new system provide three sources of hot blast temperature variable process for the main hot blast temperature controller in the PLC coming from two thermocouples and one pyrometer.

The thermocouple was doubled and their platinum two wire elements had theirs diameters increased from 0.50 to 1 mm. Although the new double thermocouple price is 3 times more than the single one, it has been worth since is working without any fail for almost five years, i.e., from 2007 till 2012.

A pyrometer was implemented for back-up reasons. However, it depends on the thermocouple value to be calibrated.

In the PLC, an automatic selector switch of one pole and three positions was configured to choose the right signal in case of thermocouple or pyrometer fails.

8 RESULTS

The number of hot stoves changeover per day with the new control decreased around 16 up to 20 at single blow mode, and approximately from 8 up to 10 changeovers C-Parallel blow mode, when two hot stoves blows together.

Figure 7 illustrates the measurements of blast times spent for each hot stove:

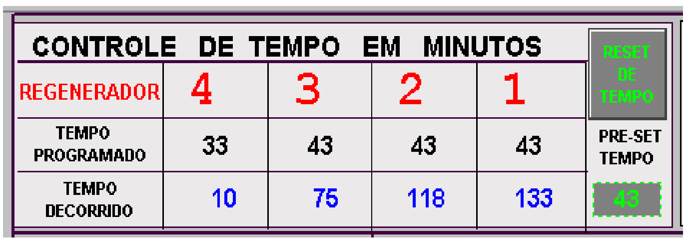

Figure 7 – Hot Stoves elapsed blast timers.

It is clear that the blast time for Hot Stove 1 and 2 are 1.5 times greater than the original design of (2x43 min) = 86 min.

ISSN 2176-3135

Figure 8 shows the main result of this work: The elapsed blast time measured in minutes as a function of the blast temperature in Celsius degrees required by the blast furnace operation conditions. It can be seen that as higher as the blast temperature as lower will be the blast time, because the thermal demand will be bigger.

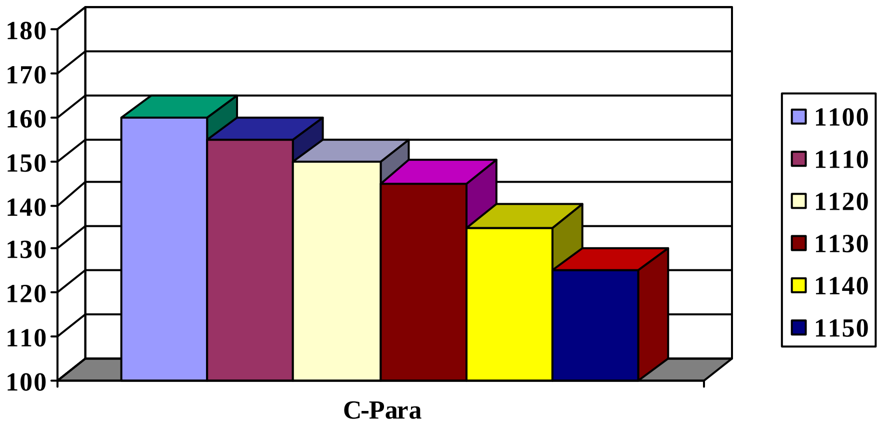

Figure 8 – Hot stove elapsed blast time measured x blast temperature required.

The developments carried out raised the blast flow average temperature up to about 100°C, saving 10 kg/thm in the coke rate. The results were the reduction of the standard deviation of blast temperature from 50 °C down to 30 °C and the decrease in 50 ° C down to 20 º C during the hot stove changeover.

The reduction process has become more stable with the decrease of coke rate and the variability of the hot metal silicon content.

The tests were carried out watching time elapsed and ΔT during hot stove changeover in steps 13 and 14. The results are shown in Table 2:

Table 2 – Tests results for Changeover variability

Hot Stove	Step	Blast Temp. _SP (ºC)	Blast Flow Set-Point (Nm³/min)	Manipulated Variable (%)	ΔT Blast (ºC)
2	14	1070	5250	62	15ºC
3	13			72	
3	14	1070	6100	70	15ºC
4	13			80	
3	14	1070	6300	82	18ºC
1	13			72	
1	14	1070	6450	74	18ºC
2	13			84	

It can be noticed that the calculation for strong equation (K=20) and its results are the best choose among the equations.

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Table 3 shows Blast temperature variation during changeover (ΔT) before and after the implementations described.

Table 3 – Blast temperature variation during changeover

Hot Stove Changeover	Blast temperature deviation ΔT in (ºC)	
	Before the changes	After the changes
1/2	31	18
2/3	35	15
3/4	28	15
4/1	32	15

Among the benefits brought by the new instruments for process variables measurements, control strategies, architecture and position controllers, it can be also noticed:

- The process register a smaller standard deviation on blast temperature during hot stove changeover:

A – Old situation: Original design without criteria for cold mixing valve best opening position and old hydraulics actuators with low performance:

$$\Delta T = T\max - T\min = 1081 - 1050 = 31^{o}C$$

B - With the changeover strategy, criteria and new high accurate motorized actuators for cold mixing valve:

$$\Delta T = T\max - T\min = 1075 - 1060 = 15^{o}C$$

- The control system now guaranties the hot stove with higher thermal capacity has its cold mixing valve coming in a smaller position according to the equations in Table 2.
- The energy saved in the hot stoves of CSN´s Blast Furnace 3 became this Idea very profitable and the return on invest very high due the adopted solutions described in this article.

9 CONCLUSIONS

The new way of hot blast changeover based on thermal capacity was successfully implanted at CSN since 2007 with no collateral effects noticed. The maintenance demand to repair hot stoves equipments decreased reliving people for other issues. The blast temperature standard deviation for blast furnace decreased from 5 ºC down to 2 ºC in a media during the 24 hours analysis.

The developed technical study and told in this work, it intended to act in the best efficiency of the equipments, in search of a possible more automated operating system, looking for the decrease of the variability of the temperature of the air blown for the CSN´s Blast Furnace 3, besides propitiating a more modern system and of larger energy efficiency in the valve driving.

ISSN 2176-3135

So that it was possible theses results, studies were accomplished on motorized actuators supplied by Rotork, study of the plants of the project, understanding meshes of blow of the regenerators, improvements in the graphic screens and finally a new value of initial opening for the position controllers of the cold air for mixing.

The obtained results were the expected ones, where the new values of initial opening of the cold mixture valves position controllers, provided a smaller variability of the temperature of the air blown in the hour of the change of the regenerators, it guaranteed that the regenerator with larger thermal capacity enters with larger opening of the valve and it decreased the movement of the valve due to a command of smaller opening.

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