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STOVES COMBUSTION CONTROL IMPROVEMENT*

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Abstract

The hot blast stoves are a regenerative heat exchange system, accounting for 10 to 20% of the total energy requirement in an integrated steel plant, responsible for the supply of about one-third of the blast furnace heat input and responsible for a constant flow of hot air to the blast furnace, according to the required production. Because of their important role in the hot metal production, a stable operation and an appropriate combustion control is necessary. This paper aims to present the results of an investigation and modifications performed as an operating multi-furnace plant, as well as the parameters considered to ensure thermal equilibrium, improving in the stoves heating cycle.

Keywords: Stoves; Combustion; Control; Software.

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1 INTRODUCTION

The hot blast stoves are a regenerative heat exchange system, responsible for the supply of about one-third of the blast furnace heat input, and responsible for a constant flow of hot air to the blast furnace, according to the required production. The stoves are able to do this by burning low heating value blast furnace gas, enriched by high heating gas. Because of their important role in the hot metal production, a stable operation and an appropriate combustion control is necessary.

Primetals has large experience on stoves design and control, and for this reason, was contracted by an Eastern European costumer to perform an investigation on their twelve stoves (four per blast furnace), identifying the causes of any inefficiencies and improving the combustion control.

This paper aims to present the results of the investigation and modifications performed, covering all the stages of the contract, as well as the improvements in the stoves heating cycle and blast furnace gas and coke oven gas savings.

Figure 1. Internal combustion chamber stove.

2 MATERIAL AND METHODS

The complete investigation was developed in four stages, during a period of nine months, without any interruption in the blast furnace production.

- Step 1: Site survey of the existing instruments, programmable logic controllers (PLC) and software, identifying their characteristics and functionalities.
- Step 2: Proposal of the necessary improvements to implement the new combustion control methodology.
- Step 3: New software program development according to the previous agreed improvements, respecting the limitations and characteristics of the existing system.
- Step 4: Implementation, test and tuning of the new software, on each stove.

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2.1 Site Survey

The site survey was the first stage in the identification of the characteristics and limitations of each system, from each stove, it was possible to detect opportunities to propose improvements and changes necessary to implement the new combustion control software.

2.1.1 Stove valves

The stove valves are strictly related to the combustion control, as they are responsible to initiate, control and finalize the heating cycles. Because of their importance in the process, it was necessary to identify the type and characteristics of every valve of each stove, in order to know their limitations and possible improvements, e.g. the replacement of shutoff valves by flow control valves.

2.1.2 Instrumentation

The stove instruments are responsible for the measurement and control of many variables (pressure, temperature, flow, etc.) in the production process. They play an important role collecting and transmitting the data, creating parameters and controlling the entire system, e.g. valves.

For a correct functioning of the any software program, various instruments are needed; therefore complete a survey of all existing instruments and their characteristics were required. With the site survey completed, it was possible to make a comparison with minimal instrumentation required for a good control of the process parameters, and so indicate possible points for improvement. In some cases it was necessary to install new instruments, such as thermocouples and new valve actuators, but generally, a simple redirection of readings between PLCs was enough to obtain the necessary control.

2.1.3 PLCs

Another very important part of the system, which can limit the combustion control capacity, is the PLC. The PLC is defined as a digital electronic device with a programmable memory for storing instructions that execute specific functions such as logic, sequence, timing, counting, and arithmetic to control an industrial machine or process accordance with the desired industry. Therefore the PLC is able to continuously process the input variables and provide the programming decisions at-will, so that the output controls the process valves.

Because they are electronics devices, with different processing capabilities, and limitations on the number of inputs and outputs, the assessment of the existing PLCs on each blast furnace was necessary. All the possible limitations were identified as well as the difficulties in the implementation of new software, such as ease of reprogramming, the type of language used and the communication with other PLC's to obtain the data required for the combustion control.

2.1.4 Software

The software is the programmable part of the PLC memory, and it is developed according to the equipment to be controlled, and the control needs. The control program is made of instructions, and instructions are codes that manipulate the inputs and output to act as desired, i.e. the input data is received, processed and the outputs are generated according to the programmed instructions.

During the survey it was possible to extract the instructions of each PLC, assess the equations and identify the problems in each software program. Some of the problems identified were of simple resolution, such-as constants used for the calculation of flow rates, and were readily adjusted, with immediate improvements in combustion control. Other areas of the software, such-as the calculation of the heat capacities of gases and calculation of combustion air volume had to be completely reassessed.

2.2 Software Development

Considering the conclusions of the existing hardware investigation, an evaluation of the most economical and effective way for the new software implementation was agreed. As a result, it was decided that the creation of combustion control parameters for all stoves, would be done in an external computer in constant communication with the PLC's responsible for control of flow control valves. This solution proved to be fast and effective in addition to having a low-cost and rapid implementation, since PLC's that could not be re-programmed to receive a new software were able to operate only receiving the set points from the external computer, without any communication problem.

2.2.1 Gas flow correction

Many flow meters measure the actual flow rate, at operating conditions, rather than the mass flow rate. Mass Flow is the measurement of the flow rate without consideration of the process conditions. As the pressure and temperature change, the volume and density change, however the mass remains the same. The conversion between the volume at actual conditions and the volume at standard conditions is based on the ideal gas law.
The first step in the software development was the inclusion of the gases correction from recorded actual, at the instrument, to normalize at temperature 273.15K and pressure 101325 Pa. Existing temperatures and pressures readings were replicated to the PLC responsible for the stoves combustion control, and when found that these were not present, new instruments were installed.

2.2.2 Humidity of the gases

During the evaluation of the old software, it was verified that the calorific values of the blast furnace gas was constantly calculated, but the amount of saturated water in the gas was not considered. For the calculation of heat capacity, only the dry gas composition (0% H_2O), obtained from the furnace top, was utilised. In the new software, were included temperature readings of blast furnace gas and coke oven gas at the stoves main, therefore being possible to quantify the volume of saturated water on each gas, and consequently the real wet calorific value.

2.2.3 Combustion air

Another important parameter included in the software was the evaluation of combustion air. With the recording of air temperature, entering the stoves, and its relative humidity, it was possible to determine the composition, including moisture, optimizing the calculations of air volume needed to burn the fuel gases.

2.2.4 Combustion control set point

The existing PLC software program did not include control parameters for the mixture of the fuel gases, i.e. the operator was unaware the calorific value of the gas burned,

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or the percentage of enrichment of blast furnace gas by coke oven gas, as the gas flow rates were controlled individually without any correlation to a required mixed gas calorific value.

The new external computer was programed for the implementation of three possible set points: dome temperature, mixed gas calorific value and the coke oven gas enrichment percentage. In all three parameters the software automatically calculates the distribution of the total mixed gas volume, between the blast furnace gas and coke oven gas, based on the heat capacities of gases, constantly updated, thus seeking to ensure that the set points are achieved.

Another important set point implemented in the combustion process is the control of oxygen concentration in the flue gas (waste gas). This parameter allows the operator to check if there is enough air to burn the gases and also if the burning is being undermined by excess air, thus reducing the flame temperature.

This parameter was adjusted during the new software implementation, by checking for which value the highest flame temperature was achieved. This set point is constantly controlled by the existing PLC software, through the variation of the combustion air flow and the comparison with actual values of oxygen measured in the flue gas according to the set point requested by the operator.

2.2.5 Combustion air set point

During the analysis of the existing PLC software, utilized to control the combustion, it was verified that the equation responsible for calculating the volume of air required to burn the gases, utilized only the calorific value, without considering the compositions of each gas. It was also verified, in most cases, that the calorific value of the gases was a constant, not reflecting the real heat capacity of gases. In the new software, with the use of the composition of the gases, it was possible to include the calculation of the minimum required air to ensure a complete combustion of each component of the mixed gas, resulting from the set point requested by the operator. This procedure, together with the oxygen control in the flue gas, guarantees the complete combustion of the gas, thus reducing CO emission rates, ensuring the highest temperature of the flame, as well as the end of the gas waste.

3 RESULTS AND DISCUSSION

The majority of the savings, obtained after the new software implementation, came from an appropriate mixture of the fuel gases, and mainly from the calculation and control of the right amount of combustion air necessary to ensure the complete combustion, without cooling the flame.

3.1 Flows Correction

During the site survey, it was possible to confirm that none of the gas flows were corrected from actual to normal, but in one of the furnaces, an equation utilised to adjust the flow readings, of an existing combustion air orifice plate, was working with a constant temperature value of 168°C. This temperature was fixed as there was a waste gas heat recovery system in place, but not enough space in the PLC to receive the signal from the thermocouple. Since the deactivation of the waste gas heat recovery system, this value was never corrected, and therefore calculating a flow almost 20% lower to move the controller, compared to an actual combustion air temperature of 20°C. This lower figure was leading the combustion controller to

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introduce an average excess air of 20%, cooling down the flame, and forcing the operators to increase the coke oven flow, to compensate for the low temperatures.
A comparison between the resulting flame temperature with 5% excess air and 20% excess is presented, as well as the necessary COG enrichment to compensate the losses in the flame temperature:

Table 1. Resulting flame temperature for different excess air and COG enrichment

BFG MJ/Nm^3	COG MJ/Nm^3	COG Enrichment (%)	Excess Air (%)	Flame Temperature (°C)
3.23	16.01	3	5	1310
3.23	16.01	3	20	1252
3.23	16.01	7.35	5	1377
3.23	16.01	7.35	20	1310

It can be seen that the system was utilising COG enrichment 145% greater than it was required, just to compensate the losses caused by the excess air.
The case presented above was happening in only one of the furnaces, but in all the furnaces, after the flow corrections, it was possible to detect further savings.
As all the flows were not being corrected, the raw flows were being utilised to control the set points. Particular for the combustion air, this raw flow could be indicating higher values during the summer and lower during winter:

Actual (Instruments)		
Flow	Temperature	Pressure
m^3/h	°C	Pa
30000.00	**30**	**5400**

$$Nm^3/h = Sm^3/\mathrm{h} \times \left(\frac{273K}{273K+T}\right) \times \left(\frac{P+101325}{101325}\right)$$

T = Actual temperature
P = Actual pressure

Corrected		
Flow	Temperature	Pressure
Nm^3/h	K	Pa
28470.22	273	101325

$$Nm^3/h = \mathbf{30000} \times \frac{273}{273 + \mathbf{30}} \times \frac{\mathbf{5400} + 101325}{101325}$$

Nm^3/h = 28470.22

Figure 2. Corrected flow during summer.

Actual (Instruments)		
Flow	Temperature	Pressure
m^3/h	°C	Pa
30000.00	**0**	**5400**

$$Nm^3/h = Sm^3/\mathrm{h} \times \left(\frac{273K}{273K+T}\right) \times \left(\frac{P+101325}{101325}\right)$$

T = Actual temperature
P = Actual pressure

Corrected		
Flow	Temperature	Pressure
Nm^3/h	K	Pa
31598.82	273	101325

$$Nm^3/h = \mathbf{30000} \times \frac{273}{273 + \mathbf{0}} \times \frac{\mathbf{5400} + 101325}{101325}$$

Nm^3/h = 31598.82

Figure 3. Corrected flow during winter.

During summer, considering an actual flow of 30000 m^3/h, a pressure gauge of 5400 Pa and a temperature of 30°C, the corrected flow should be 28470.22 Nm^3/h, 5% lower than the actual. And for the same parameters, during winter, but with a temperature of 0°C, the corrected flow should be 31598.82 Nm^3/h, 5.3% greater than actual flow.
Again these parameters interfere in the overall control of the combustion, sometimes with less air, resulting in an incomplete combustion of the fuel gases, and sometimes with excess air, cooling down the flame temperature.

3.2 Humidity of Fuel Gases and Combustion Air

With the introduction of the moisture analysis on the fuel gases, the correct composition and calorific value could be calculated, and consequently the correct amount of air for the combustion.

Table 2. Blast furnace gas dry and wet analysis and calorific values

Blast Furnace Gas		
Components	Dry (%)	Wet (%)
O2	0.40	0.383
N2	52.71	50.509
CO2	21.77	20.863
CO	22.24	21.308
H2	2.28	2.182
H2O	-	4.180
CH4	0.60	0.575
C2H4	0.00	0.000
C2H6	0.00	0.000
C2H2	0.00	0.000
CnHm	0.00	0.000
Total	100.00	100.00
MJ/Nm^3	3.27	3.13

The moisture content of the gas was found with the support of the table Properties of Saturated Air at Atmospheric Pressure [1], considering a temperature of 30°C.
The resulting calorific values, dry and wet, presented a stoichiometric air to fuel ratio of 0.65 and 0.62 respectively. It means that, to burn $1Nm^3$ of blast furnace gas, it is necessary 0.65 Nm^3 and 0.62 Nm^3 of combustion air. In this situation, if the wet analysis is not considered, a resulting 4.6% excess air is included in the final combustion air, as well as a lower flame temperature.
Similar conditions affect the combustion air. With the support of the same table used for the gases, and including the relative humidity, the correct moisture content can be estimated. Utilising the blast furnace gas analysis presented above, it is possible to evaluate the impact of the moisture content in the combustion air, and consequentially the air to fuel ratio:

Table 3. Combustion air moisture

Air Temperature (°C)	Air Relative Humidity (%)	BFG wet calorific value (MJ/Nm^3)	Combustion Air Moisture (%)	Air to Fuel Ratio
0	80	3.13	0.48	0.5987
10	80	3.13	0.97	0.601
20	80	3.13	1.85	0.607
30	80	3.13	3.34	0.6164

Considering the table extremes, representing winter and summer, with fixed relative humidity, it is possible to see a difference of 2.8% in combustion air between the two cases.

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3.3 Flow Control Valves Tuning

In all the furnaces, the tuning of the flow control valves was essential to maintain a stable and correct flow. Generally the adjustment of the proportional-integral-derivative controller (PID controller) was enough, but in one of the furnaces it was necessary to change the actuators responsible for the coke oven gas control.
These changes represented not only savings, but also the possibility to maintain the correct flows, for different gases analysis, keeping a constant heat input.

3.4 Set Point

The introduction of the set points for the combustion and the automatic adjustment of the flows by the software, according to the different temperatures, gas analysis and oxygen readings in waste gas, also contributed for a stable control. Utilising the model the operators do not have to keep adjusting the flows manually, avoiding incorrect adjustment of the set points, and poor decisions concerning the combustion control.

3.5 Old Software x New Software

After the implementation of all modifications presented above, the flows and set points control differences between the old and the new software became clear. In the graphs presented below it is possible to see the difference in the fuel gases (BFG green and COG light blue) and combustion air flow control (yellow), as well as a higher and stable dome temperature (red), due to an effective control of the oxygen in waste gas (pink).

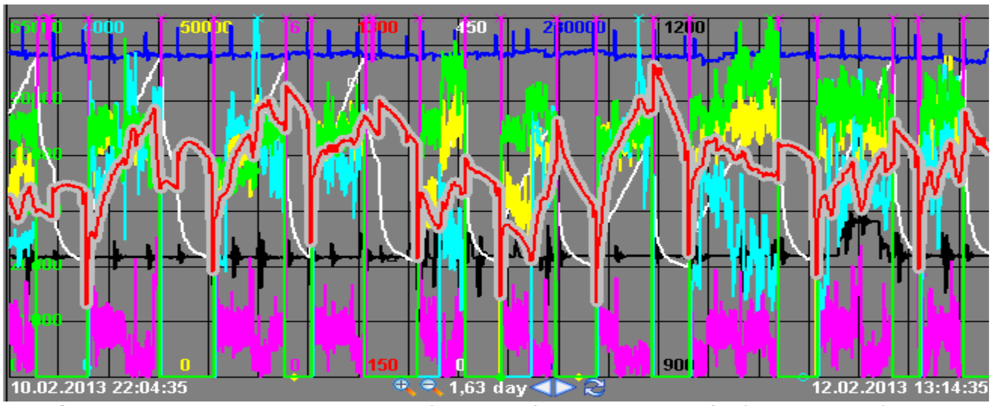

Figure 4. Blast Furnace 2 stove flows and temperatures before new software

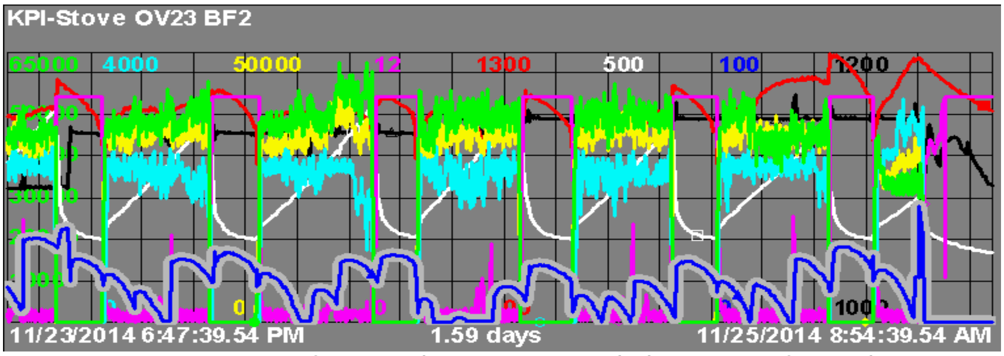

Figure 5. Blast Furnace 2 stove flows and temperatures during new software implementation and tuning

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4 CONCLUSION

During the site survey and investigation of the philosophy utilized by the customer, to control the stoves heating cycle, the lack of control of the parameters involved in the process became evident. The original combustion philosophy was probably right, although incomplete, and after years being carelessly modified, and mainly after the waste gas heat recovery decommissioning, the problems were intensified, resulting in an unstable and inefficient heating cycle, with low dome temperatures, variable gassing and heating periods, fuel gas energy waste and the impossibility to maintain hot blast duties.

After the site survey, the new software development and implementation, the improvements were immediately realised. With the correct readings and calculations in place, the operator’s interventions to correct the old software’s wrong outputs were not necessary anymore. The software was able to process all the information received from instruments and HMI inputs, and turn them into stable flows, as demonstrated in section 3.5. The improvement in the flows was reflected in a stable operation, and for the first time in many years, it was also possible to evaluate the real capacity of each stove, being possible to adjust the heating parameters, according to the blast duty.

Overall the new software is directly responsible for:

- stable self-adjusted flows;
- stable flame;
- constant heat flux;
- higher blast duties;
- correct air/fuel ratio;
- lower excess air;
- higher flame temperatures;
- lower mixed gas enrichment;
- lower blast furnace gas utilization;
- high stove efficiency;

And indirectly responsible for:

- knowledge of the heating input;
- correct adjustment of the heating input;
- low heat reserve in stoves.

The new philosophy implemented, demonstrated great improvements, but there are still many possible areas to be explored. Further improvements in other areas of stoves operation have been suggested to the customer.

REFERENCES

1 J. W. Rose, J. R. Cooper, Henry Michael Spiers. Technical Data on Fuel. The British National Committee; 1947