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REDUCTION OF OXYGEN CONSUMPTION IN A BLAST FURNACE THROUGH THE IMPROVEMENT OF HEAT EXCHANGERS EFFICIENCY

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ABSTRACT

This paper concerns the performance improvement study of three heat exchangers. The objective is to reduce the consumption of oxygen used to enrich the blown air into a Blast Furnace through the improvement of the energetic efficiency of these heat exchangers. A CFD (*Computer Fluids Dynamics*) model was developed in order to simulate the thermodynamic behavior of the fluids inside the heat exchangers. Some geometric modifications were simulated with the objective of change the combustion gases flow characteristics. The simulation showed a potential of energetic efficiency improvement of 15,25%, which means an increase of 115ºC in the outlet air temperature. The simulated modifications were implemented in one of three heat exchangers and the actual temperature increase was 135ºC. After the implementation of the modifications in the others heat exchangers, the expected reduction of the oxygen consumption in the Blast Furnace is about 4.400.000 Nm³ per year.

NOMENCLATURE

T_{flame} flame temperature in the blast furnace
U_{air} humidity of air
T_{air} air temperature in the blast furnace
O_2 oxygen added to the air
I_{fines} fine injection rate in the blast furnace

INTRODUCTION

The heat exchangers of this paper belong to an industry located in Belo Horizonte – Brazil that produces annually 670 thousand tons of steel. Its main products are seamless tubes, supplying the oil and gas, automotive and mechanical industries. In order to obtain the pig iron necessary to produce the steel, this industry has two blast furnaces that work with charcoal and are able to produce 1900 tons per day.

The reduction process of the iron ore in the blast furnace occurs at determined values of combustion flame temperature. Generally, the flame temperature in a combustion process is proportional to two parameters at least, the oxygen concentration in the air and the air temperature, according to Fig. 1 (GASIN, 2006) and Fig 2 (Castro, 2005).

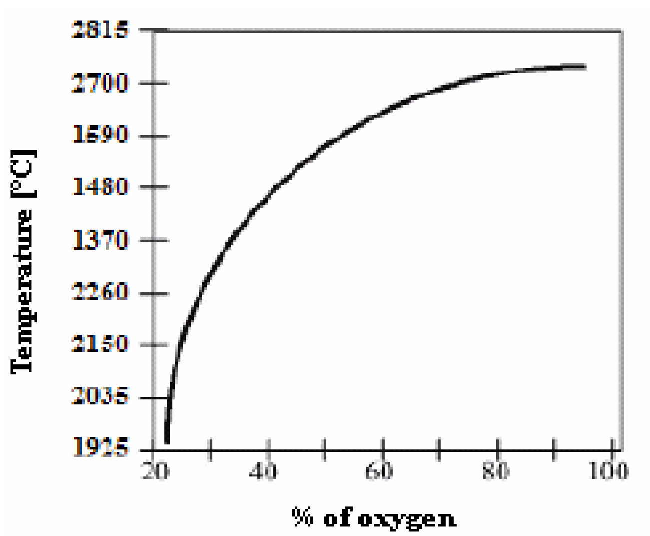

Figure 1. EFFECT OF THE OXYGEN CONCENTRATION ON THE COMBUSTION FLAME TEMPERATURE

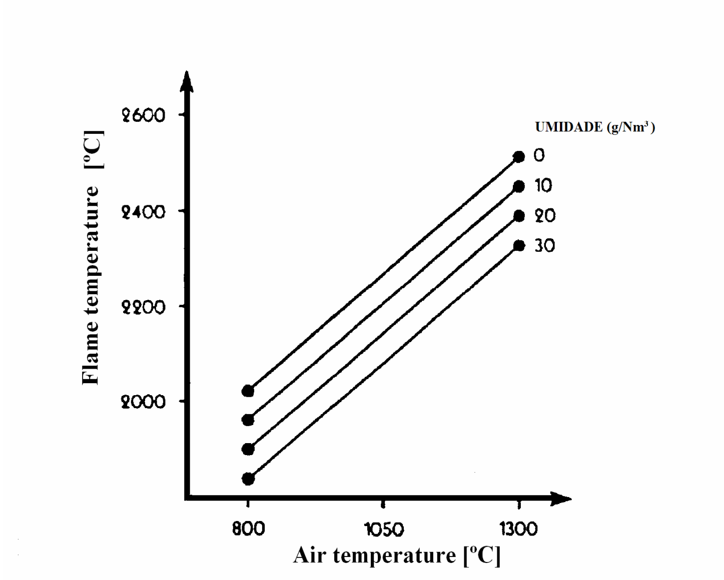

Figure 2. EFFECT OF AIR TEMPERATURE ON THE COMBUSTION FLAME TEMPERATURE

As greater the oxygen concentration is, greater the combustion flame temperature will be. However, to enrich the combustion air with oxygen means to increase the production costs and that is not desirable.

On the other hand, the flame temperature in the blast furnace can be increased through the increase of the combustion air temperature. At this industry, the combustion air of one blast furnace is heated by three heat exchangers called Glendons.

These heat exchangers work continuously and consist in a chamber with refractory wall where the outlet gas from the blast furnace is burnt. The heat generated by the combustion heats the air inside the coils, according to the Fig. 3. The heat exchange between the combustion gases and the air inside the coils is not enough to increase the temperature of the air to the values required by the process in the blast furnace. Thus, this air is enriched with oxygen in 4% of total volume, which means a daily consumption of 29000 Nm^3.

In order to reduce the consumption of oxygen in the blast furnace through the improvement of the energetic efficiency of Glendons, a computer model was developed in CFD (Computer Fluids Dynamics) and some geometric modifications in the heat exchangers were simulated. After the result analysis, these modifications were implemented in one of the three heat exchangers.

METODOLOGY

Even though there are three heat exchangers in the heating system of air, only one heat exchanger was analyzed due to the similarities between all of them (same geometry and same parameters), and the conclusions were extended to the other ones. This study was divided in three steps where the operational conditions were kept the same in all steps.

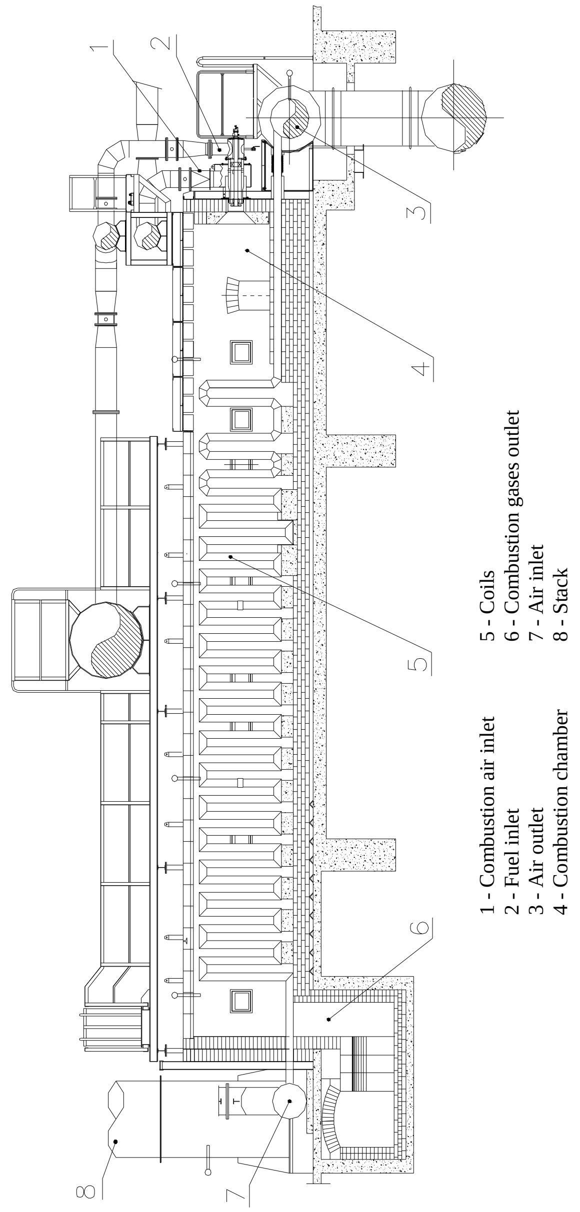

Figure 3. GLENDON SCHEMA

The first step consisted in develop the CFD model of the thermodynamic behavior of the fluids inside the Glendon and validate it with field measurements. The geometric model was generated in GAMBIT® and the meshes were generated in FLUENT®. In this analysis, some hypotheses were taken into account:

- Steady flow: stationary, compressible and turbulent;
- Fluid: air as a ideal gas, inside and outside of the coils

- Burners: the combustion was not modeled directly. The equivalent inlet of energy was supplied by a hot air flow
- Coil material: standard steel of FLUENT®
- Wall material: refractory (insulated walls)
- Inlet air temperature: 95ºC
- Inlet air pressure: 1,12 kgf/cm^2
- Air flow: 9969,3 Nm^3/h
- Air temperature in the burners: 1033°C
- Air pressure in the burners: 1 kgf/cm^2
- Emissivity: 0,8 (steel) and 1 (refractory)
- Air flow in the burners: 10063 Nm^3/h
- Air absorption coefficient: 0 at 95°C and 0,2 at 1100°C (linear variation).

The second step consisted in simulate the reduction of the combustion gases flow area in the cross section in order to increase the gas speed and the convection coefficient. The roof was lower 100 mm and the walls were brought near 100 mm.

The third step consisted in simulate the introduction of five plates which work as baffles, according to Fig. 4, in order to change the flow direction of the combustion gases, from counter way to cross way, increasing the heat exchange between the gases and the air inside the coils.

After the simulations in the CFD, a technical project was developed based on the simulated concept and the modifications have been implemented in one heat exchanger. Some tests have been carried out in order to establish the highest value of the outlet air temperature without damages to the equipment, increasing the set point 10ºC each two days.

RESULTS

The model of the thermodynamic behavior of the Glendon has not been totally validated. The actual outlet air temperature was 734ºC and the simulation obtained 693ºC. This difference could be corrected adjusting the combustion gas emissivity, but due to the lack of time it has not been done. Then, the results of the second and third steps were compared with the non-validated values, what has not disqualified the conclusions.

The table 1 shows the energy balance results of the three steps.

Table 1. ENERGY BALANCE RESULTS

Positions	Step 1	Step 2	Step 3
Burners (MW)	3,67	3,67	3,67
Air inlet (MW)	0,232	0,232	0,232
Combustion gases outlet (MW)	1,5	1,434	1,181
Air outlet (MW)	2,4	2,464	2,706

The table 1 shows that for the same inlet conditions (flow of energy in the burners and in the air) the flow of energy in the combustion gases outlet is smaller and in the air outlet is bigger at each step. An increase of the energetic efficiency of Glendon from 59% to 68% was reached and it can be noticed by the increase of the outlet air temperature and the decrease of the outlet combustion gases temperature, according to Table 2.

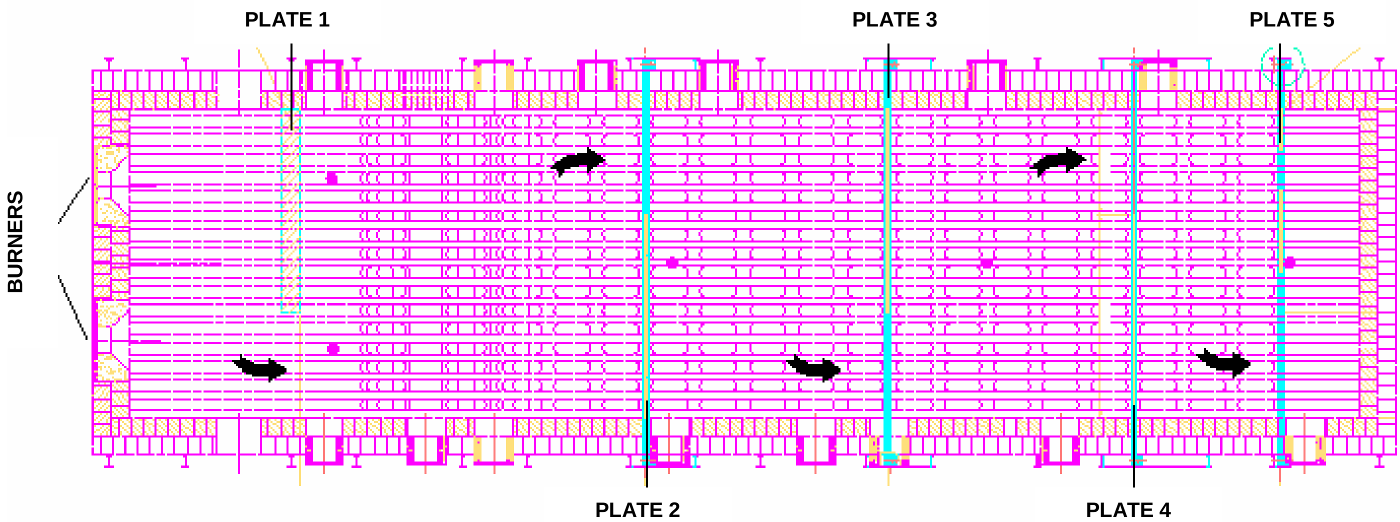

Figure 4. SCHEMA OF FIVE PLATES WORKING AS BAFFLES

Table 2 OUTLET TEMPERATURES

Position	Step 1	Step 2	Step 3
Outlet air (ºC)	693	710	808
Stack gases (ºC)	381	378	317

The increase of the energetic efficiency is due to two main reasons: the increase of the combustion gases turbulence, because as greater the fluids speed is greater the convection coefficient will be, and the change of the flow, from counter to cross way.

Figure 5 and Fig. 6 show the evolution of the temperature profile in each step of the simulation.

In the first step, there are two regions with high temperature in front of the burners in the combustion chamber and then a gradual and symmetric decrease of the temperature in the longitudinal section. In the cross section, it is noticeable that the combustion gases have a preferential path on the top of the equipment due to the low resistance, which is not good because the combustion gases do not exchange heat in this region leaving the equipment with high temperatures.

In the second step, the most significant change occurred in the cross section, where the temperature profile becomes more homogeneous. This homogeneity is because the preferential path was reduced, increasing the temperature in the low regions. Even though the heat exchange is increased, the temperature gain in the outlet air is small.

The greatest change occurred in the third step, when the flow direction changed. There is no symmetry in the temperature profile anymore and it is noticeable that the combustion gases exchange more energy because their temperature is lower in all equipment long. In the cross section, there is a little area where the combustion gases have high temperature at the upper corner and another area with low temperatures on the opposite side. But, in this configuration it is not a problem because both areas take turns their position at each plate section, which means a better soaking of the heat exchanger.

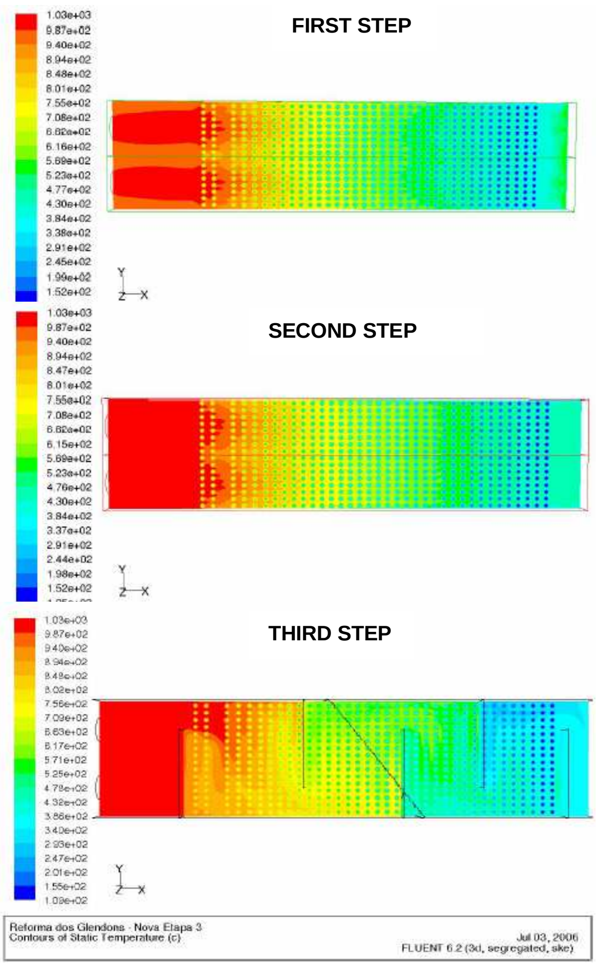

Figure 5. EVOLUTION OF THE TEMPERATURE PROFILE OF THE COMBUSTION GASES – UPPER VIEW

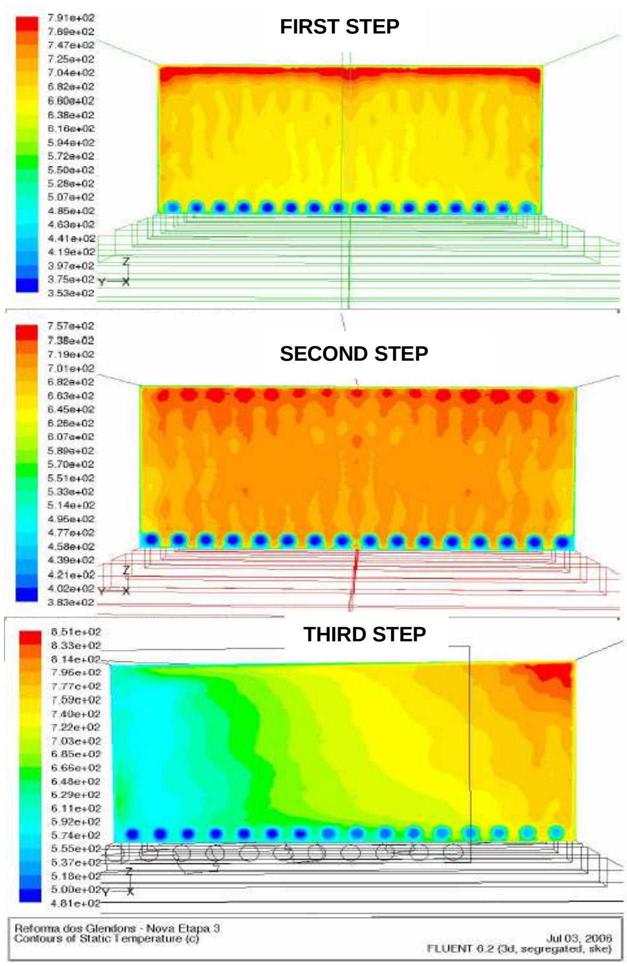

Figure 6. EVOLUTION OF THE TEMPERATURE PROFILE OF THE COMBUSTION GASES – CROSS SECTION VIEW

After the implementation of all modifications (assembly of 5 plates and improvements in the process control), the actual result was an outlet air temperature of 925ºC, not keeping the inlet conditions constants. This temperature could be higher but the coils have their temperature limit in order to not be damaged.

By the time of the experimental tests, the outlet air temperature was 790ºC and not 734ºC anymore, because during the study other modifications were implemented. Thus, the actual increase of the outlet temperature was 135ºC (925 ºC minus 790ºC).

The reduction of oxygen consumption can be calculated through the Eq. (1), which is used by the blast furnace operational people.

$$T_{flame} = 1463 + 0{,}7T_{outletair} + 44O_2 - 5U_{air} - 1{,}5I_{fines} \quad (1)$$

The Fig. 7 shows the annual saving of oxygen as a function of the air temperature increase, keeping the required flame temperature, the humidity of air and the fine injection rate constant.

Due to structural issues and to avoid any damage to the equipment, the increase of air temperature has been established in 105ºC, which means a saving of oxygen around 4.400.000 Nm³ per year.

CONCLUSION

The computer model was an important tool to understand the thermodynamic behavior of the fluids in Glendon heat exchangers. The model allowed simulating two geometric modifications in order to improve the energetic efficiency.

The implementation of five plates that close two thirds of the cross section of the heat exchanger improved the energetic efficiency from 59% to 68%.

The computer model forecasted an increase of 115ºC in the outlet air temperature, keeping the same inlet conditions. However, the actual temperature increase was 135ºC.

The temperature increase was limited in 105ºC and it would save an amount of 4.400.000 Nm³ of oxygen per year.

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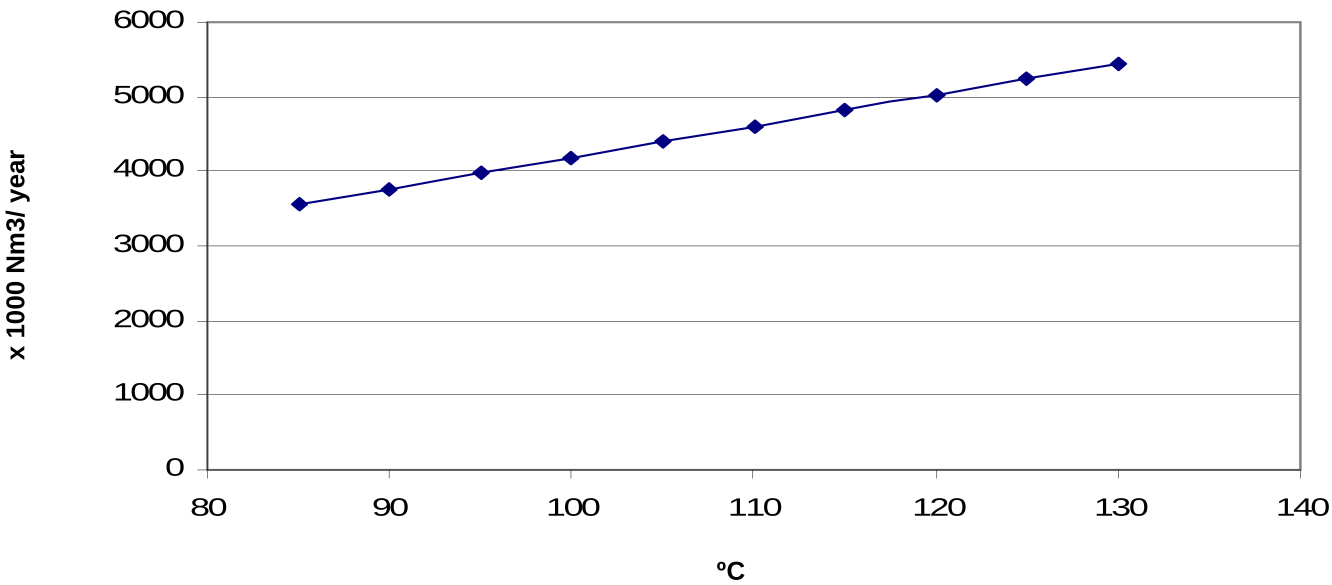

Figure 7 ANNUAL SAVING OF OXYGEN AS A FUNCTION OF AIR TEMPERATURE INCREASE