# COMPUTER SIMULATION WITH EXPERIMENTAL VALIDATION OF A GLENDON THERMODYNAMIC BEHAVIOR

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*Abstract. This paper concerns the performance improvement study of three heat exchangers. The objective is to reduce the consumption of the 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.*

*Key words: computer simulation, energetic efficiency, oxygen consumption*

## 1. INTRODUCTION

The industry where this study was developed 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).

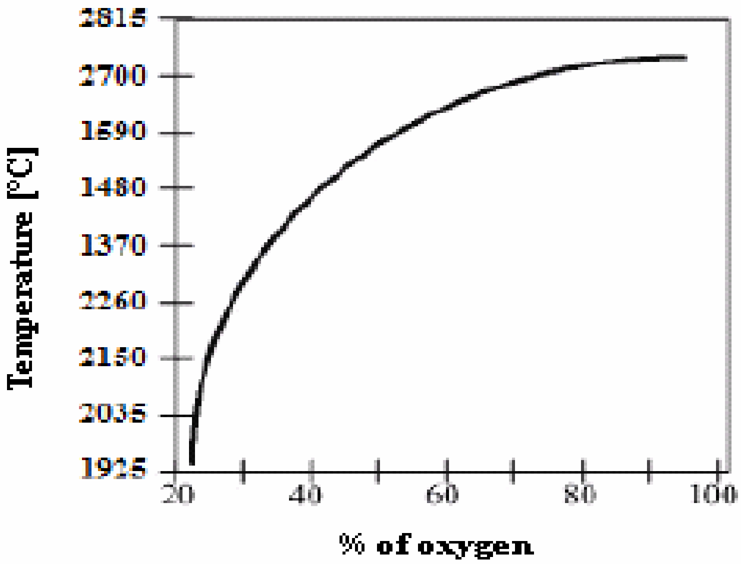



Figure 1. Effect of the oxygen concentration on the combustion flame temperature

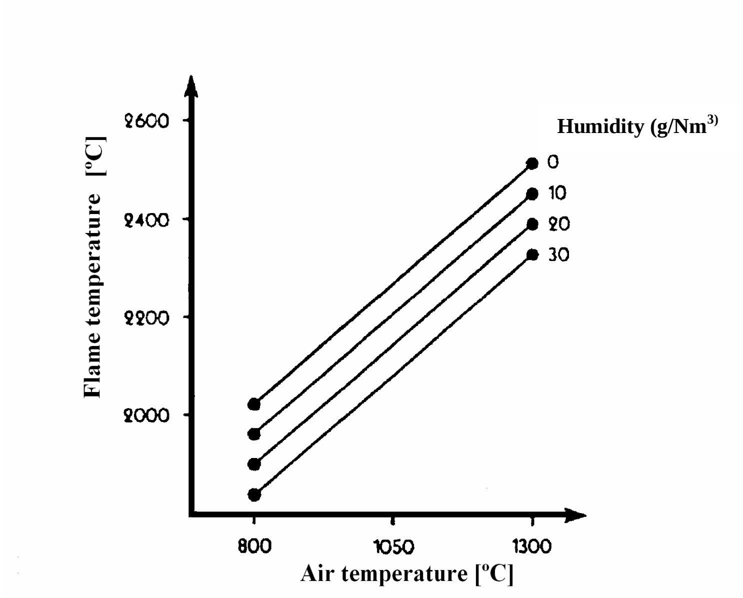



Figure 2. Effect of air temperature on the combustion flame temperature

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. The combustion air of this industry's blast furnace is heated by three heat exchangers called Glendons.

These heat exchangers work continuously and in their combustion chamber blast furnace off-gas 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 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 three heat exchangers.

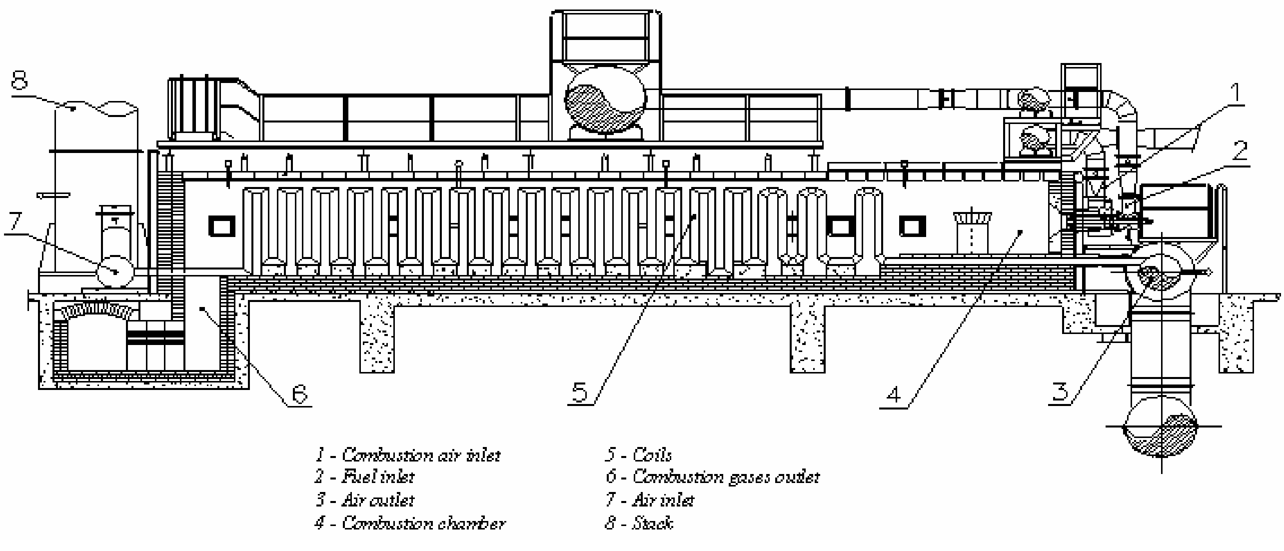



Figure 3. Glendon schema

## 2. METHODOLOGY

Even though there are three heat exchangers in the air heating system, 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.

In the first step, the CFD model of the thermodynamic behavior of the fluids inside the Glendon was developed and validated 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) e 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).

In the second step, the reduction of the combustion gases flow area in the cross section was simulated 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.

In the third step, the introduction of five plates which work as baffles, according to Fig. 4, was simulated in order to change the direction of combustion gases flow, from a parallel way to a cross way, increasing the heat exchange between the gases and the air inside the coils.

After the simulations in the CFD, a project was developed based on the simulated concept and the modifications have been implemented in one of three heat exchangers. Some tests have been carried out in order to establish the highest value of the outlet air temperature, increasing 10ºC in the set point every two days.

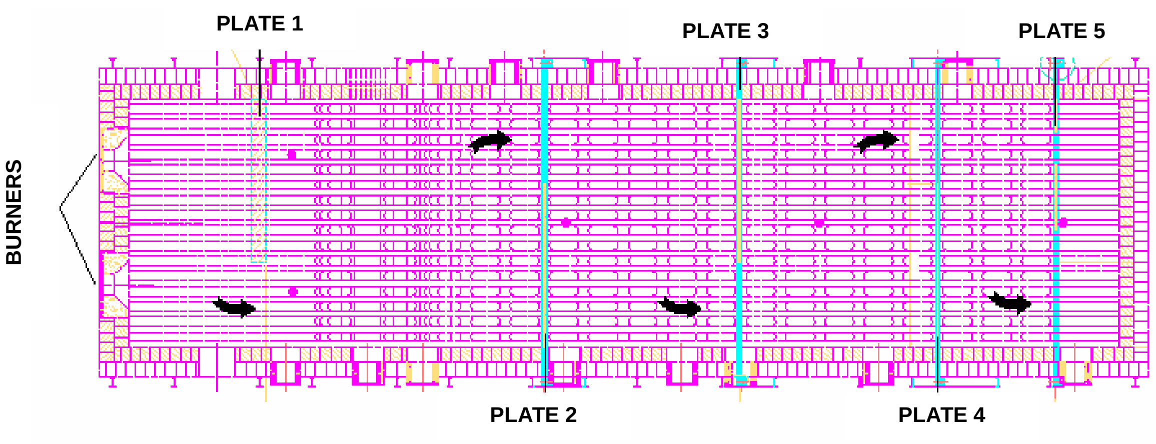



Figure 4. Schema of five plates working as baffles

## 3. 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 the results of the second and third steps were compared with the non-validated values, what has not disqualified the conclusions.

Table 1 shows the energy balance results of the three steps.

Table 1. Energy balance results

| Position | 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 |

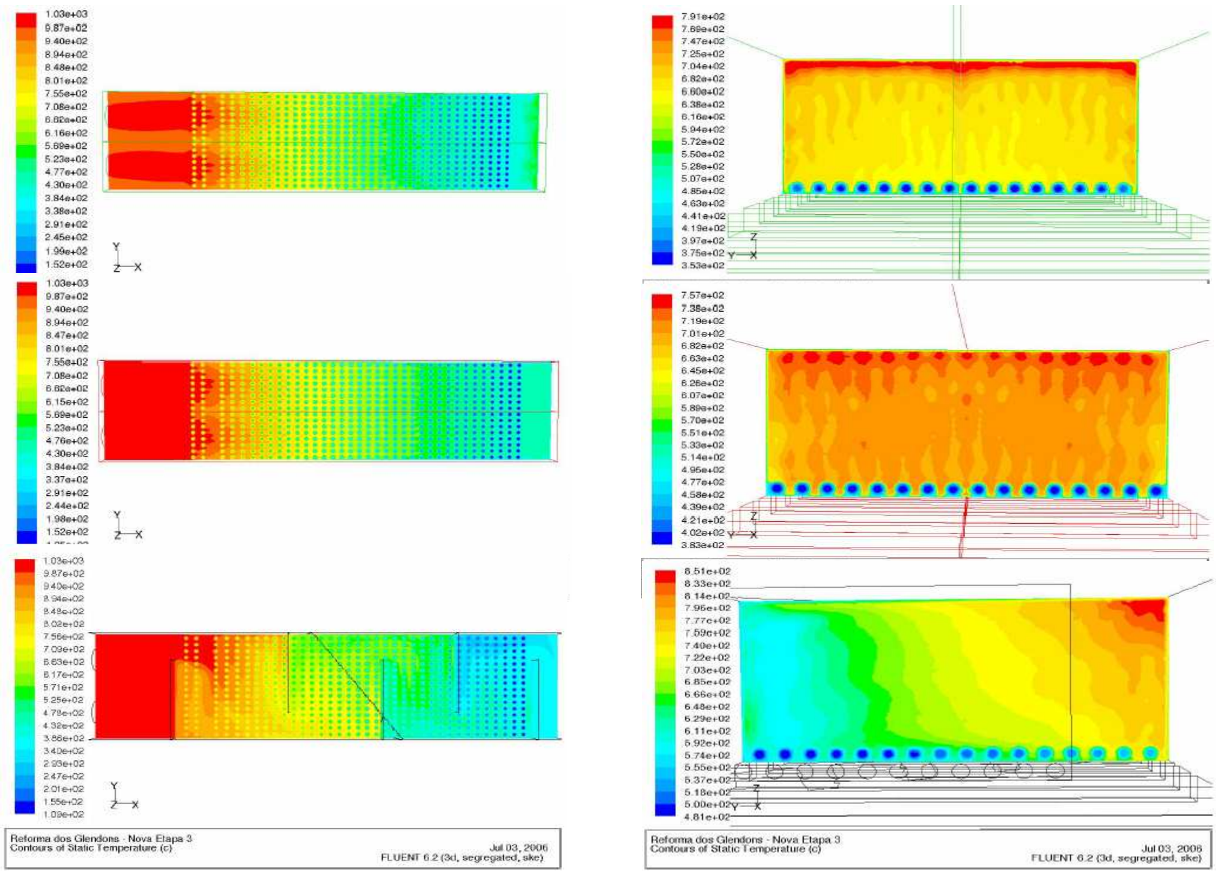
Table 1 shows that for the same inlet conditions (flow of energy in the burners and in the air) there is an increase of heat exchange to the air in each step. The model showed an increase of the energetic efficiency of the Glendon, from 59% to 68%. This increase is due to two reasons, the increase of the combustion gases turbulence and the change of the flow, from a parallel to a cross way.

The increase of energetic efficiency is proved by the increase of the outlet air temperature, according to Tab. 2.

Table 2. Outlet air and stack gases temperatures

| Position | Step1 | Step 2 | Step 3 |
|---|---|---|---|
| Outlet air (ºC) | 693 | 710 | 808 |
| Stack gases (ºC) | 381 | 378 | 317 |

Figure 5 shows the evolution of the temperature profile in each step of the simulation.




a) Upper view

b) Cross section view

Figure 5. Evolution of the temperature profile

The actual result of all modifications (the assembly of 5 plates and the improvements in the process control) 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 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.

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

Figure 6 shows the potential 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 equipment limits and the needs of the process, the increase of air temperature has been established in 105ºC, which means a saving of oxygen around 4.400.000 Nm³ per year.

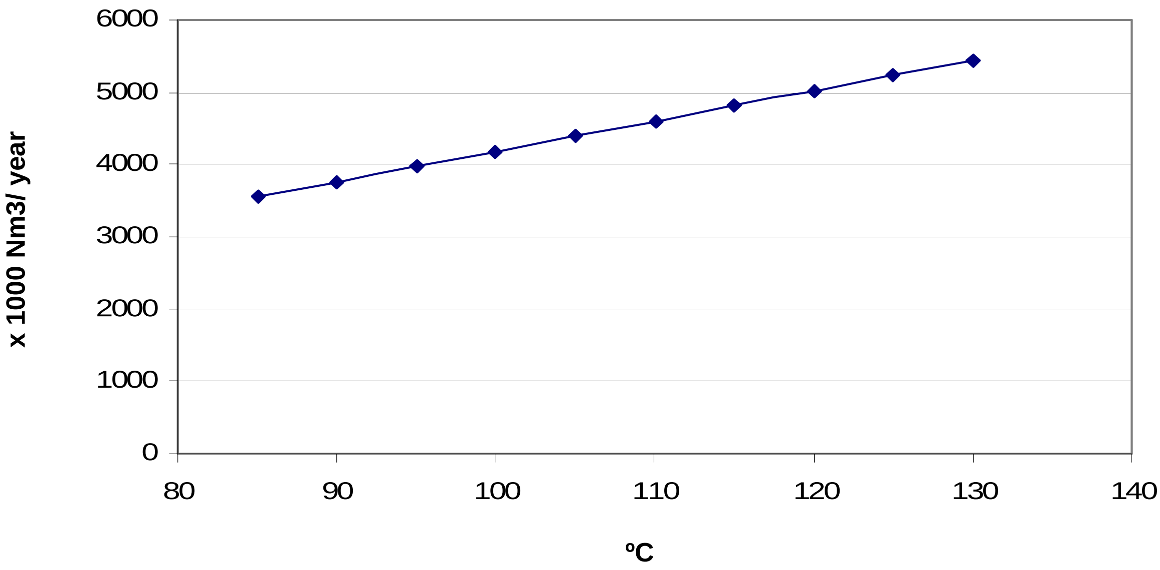



Figure 6. Annual saving of oxygen as a function of air temperature increase

## 4. CONCLUSION

The computer model was an important tool to understand the thermodynamic behavior of the fluids in the Glendons 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 in order to not damage the equipment, and this would save an amount of 4.400.000 Nm³ of oxygen per year.

## 5. REFERENCES

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## 6. RESPONSIBILITY NOTICE

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