INCREASE IN THE BOF PRODUCTIVITY OF THE USIMINAS STEEL SHOP#2 THROUGH THE THERMAL INSULATION OF THE CONVERTER*

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Abstract

The performance of a Steel Shop depends on the stability of its equipment, and the thermal balance of the BOF is essential to guarantee the thermal stability of liquid steel, reducing downtime for reheating, adjusting the tapping temperature, as well as avoiding thermal losses to the metallic shell. One way to improve the thermal balance would be the use of insulators in combination with the working refractory material. This work is unprecedented in the use of insulators in BOF, with implementation at the Usiminas Steel Shop in BOF#4. The results observed during the campaign increased BOF productivity, reduced downtime for reheating, improved refractory lining and increased shell life.

Keywords: Thermal Insulation, Converter and Productivity.

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1 INTRODUCTION

The LD converter has been used as reactor int the steel manufacturing process in steel mills. Its structure is mainly composed of a metallic shell that is lined with refractory materials. Among the most used materials is the Magnesia-Carbon refractory. The selection of these materials was the result of extensive research and development to achieve high performance in use, ensuring safety, process stability, increased productivity, and lower costs of the LD converter. Figure 1 shows a schematic representation of the converter.

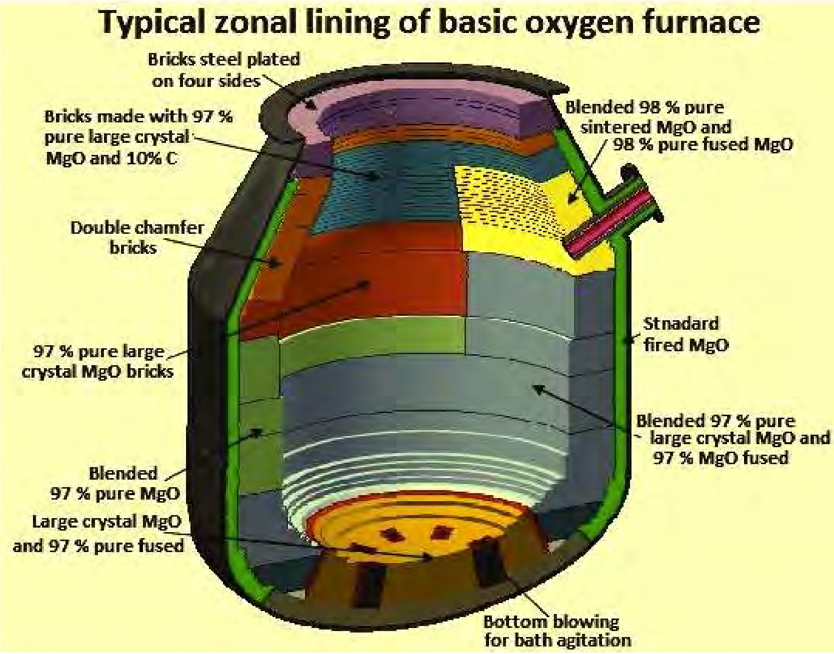

Figure 1 - Schematic representation of the converter (5)

After the steel tapping from the converter into the ladle, the liquid steel undergoes successive treatment routes to adjust its chemical and thermal composition. The main objectives are to ensure the final chemical composition and a stable temperature during casting. Therefore, the lining material should not have a negative impact on this process, i. e., it should not affect the chemical composition and should maintain the thermal energy of the liquid steel.

Controlling thermal losses has been vital for process improvement in the steel manufacturing process. This means reducing the number of returns from continuous casting and minimizing the high consumption of electrodes and electrical energy in the ladle furnace. Approximately 80% of the thermal losses in steelmaking occur through the refractory wall surface (3). Therefore, selecting the appropriate lining is essential to prevent such losses.

This study analyzed the influence of lining a LD converter with thermal insulation compared to a standard configuration (without insulation). It also developed a heat transfer model through the walls of the refractory lining, evaluating the heat transfer between the shell and the external environment, in order to design an appropriate project for maintaining the energy of the LD converter and ensuring a higher lifespan of the metallic shell, along with other expected benefits as saving energy of the LD converter during processing.

2 DEVELOPMENT

The currently work consisted of developing a thermal model of the refractory lining of the BOF (Basic Oxygen Furnace) in Usiminas' Aciaira#2. The model evaluated the properties of the refractory and insulating materials, the convection cooling conditions in the cone, assuming the emissivity and convective heat transfer coefficient provided by the manufacturer of the cooling system, and the results were analyzed after the steady-state heat transfer condition was attained.

2.1 NUMERICAL EVALUATION OF THERMAL LOSSES

2.1.1 Geometry and problem descritption

In this section, the conditions for the analysis of the temperature distribution in the lining of a converter are presented, aiming the investigation of the effects of adding an insulating layer in the cylinder region of the equipment. The lateral view and cross-section of the analyzed geometry can be seen in Figure 2.

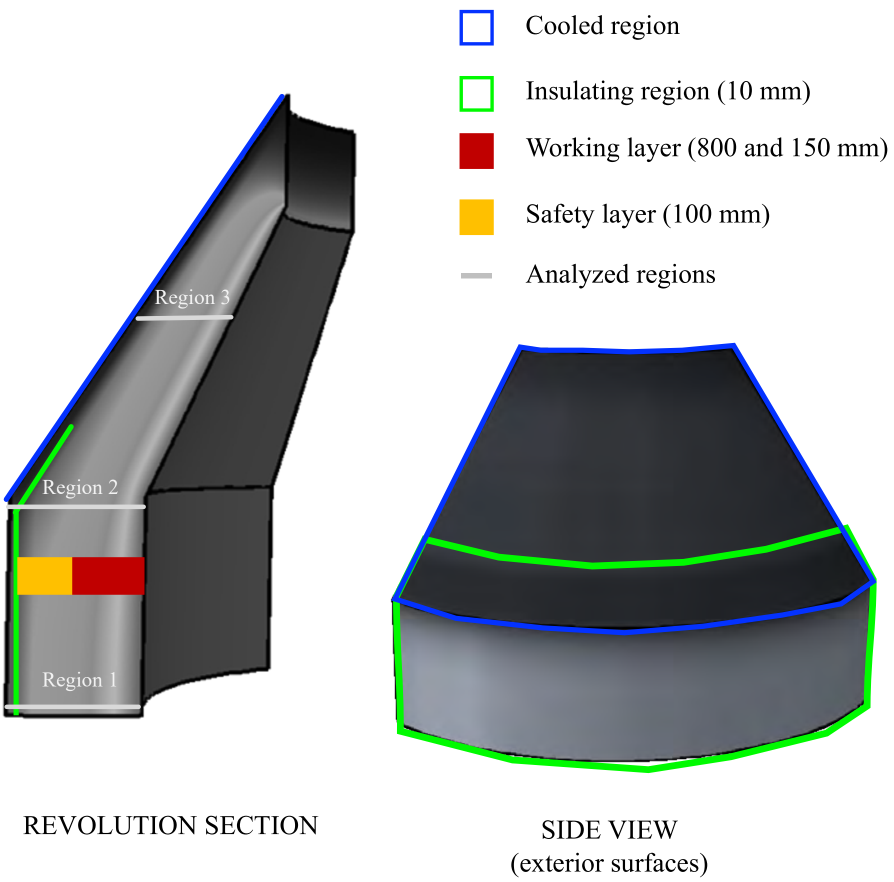

Figure 2: Cross-section and lateral view of the studied problem.

The analyzed geometry consisted of a section of the equipment corresponding to 1/3 of the equipment's circumference (120°) with a height equal to the upper 1/3. This region is chosen to consider the effects of the thermal insulation layer (green region) and the cooling in the upper cone (blue region). The lining consists of a metallic shell (0.030 m), a safety layer (0.114 m - without insulation and 0.104 m - with insulation), the presence or absence of an insulation layer (0.010 m), and a working layer (0.800 m - new condition and 0.150 m - final campaign condition).

The selection of the analysis region is made to ensure the investigation of the desired scenarios with low computational cost. Therefore, the materials properties are presented in Table 1.

Table 1: Thermal conductivity of the investigated materials.

MATERIAL	Temperature [°C]	Condutivity termic [$W\,m^{-1}\,K^{-1}$]
Brick MgO-C		
Magnafrax	500	18
	1000	16
Basic Brick		
Magfrax B	600	5,5
	800	4,5
	1000	3,8
	1400	3,5
Insolation Plate		
Silplate 1308	40	0,012
Insolation Layer	100	0,018
	300	0,042
	500	0,07
	700	0,102
	800	0,12
	1000	0,158
	1200	0,2
Steel		
Steel Shell	40	36,4
	400	35,4

The analysis highlighted the impact of the refractory lining on the heat transfer in steelmaking converters. Thus, the study aimed to evaluate the configurations with and without insulation in the cylinder region, in the initial and final campaign conditions, by estimating the temperature distribution. Consequently, the objective was to define the temperature T(x, y, z, t) for a heat transfer problem governed by the heat differential equation (Equation 1). The transient solution of this problem allows the calculation of the heat flux at each time increment, which indicates the amount of transferred energy, as presented below:

$$\rho(T)c_p(T)\dot{T} - \nabla \cdot [k(\dot{T})\nabla T] = 0 \quad (1)$$

where ρ is the material density (kg m^{-3}), c_p is the specific heat (J kg^{-1} K^{-1}), and k is the thermal conductivity (W m^{-1} K^{-1}). The latent heat associated with phase transformations was not computed. It is important to note that the properties of the materials were evaluated as a function of temperature, when available. The numerical problem was solved using the finite element method in Abaqus/CAE 6.14-1. Further details on the boundary conditions are presented below.

2.1.2 Initial and boundary conditions

The initial condition of the problem was defined so that at the initial time of the analysis, the temperatures in the entire region were set to room temperature, i.e., T(x, y, z, t=0) = T_{room} = 38 °C.

As for the boundary condition, there were two regions of interest. The first was the hot face (internal surface - working layer), which had a fixed temperature of 1691 °C. The second was the cold face (external surface - shell), which was divided into two other regions: upper cone and cylinder. In the cone, forced convection was considered (h_{water} = 1000 $W.m^{-2}.K^{-1}$) and T_{water} = 78°C, to reproduce the effects of a cooling system installed in the shell of the equipment in that region. In the cylinder region, the effects of convection and radiation from the surface to the environment were considered (h_{air} = 12 $W.m^{-2}.K^{-1}$ and T_{room}). The emissivity of the shell and the h_{air} values were defined based on similar problems (3). The heat fluxes by convection were estimated using Newton's Cooling Law (Equation 2):

$$q_{conv} = h\,(T_S - T_{room}) \quad (2)$$

where T_s is the temperature of the surface exchanging heat with the surrounding medium (cooling water or air), T is the temperature of the medium, and h is the heat transfer coefficient ($W\,m^{-2}\,K^{-1}$) for the considered mechanism. Radiation was estimated using Stefan-Boltzmann Law (Equation 3):

$$q_{rad} = \sigma\varepsilon(T_S^4 - T_{room}^4) \quad (3)$$

where Ts is the temperature of the surface transferring heat with the medium (ambient air), T_{room} is the temperature of the medium, σ is the Stefan-Boltzmann constant, and ε is the emissivity.

2.1.3 Study cases

The analyzed cases are summarized in Table 2 (configurations 1 to 4). The regions of interest are presented in Figure 1, where region 1 corresponds to part of the cylinder, region 2 to the end of the cylinder and the beginning of the cone, and region 3 the upper part of the cone. It should be noted that the analyses were performed when the temperature variations in the analyzed system were equal to zero. In other words, the temperatures of the lining were analyzed when the system reached a steady-state, as when considering a very long time in solving the problem described in Equation 1 (making its first term zero).

Table 2: Summary of the main changes between configurations.

	CASE 1		CASE 2		CASE 3		CASE 4	
	Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]
Working layer	Magnafrax	800	Magnafrax	800	Magnafrax	150	Magnafrax	150
Safety layer	Magfrax B	114	Magfrax B	104	Magfrax B	114	Magfrax B	104
Insulating layer (cylinder)	-	-	Silplate 1308	10	-	-	Silplate 1308	10
Shell	Carbon steel	30	Carbon steel	30	Carbon steel	30	Carbon steel	30

2.2 IN-SITU INSTALLATION OF THE THERMAL INSULATION

The initial installation of the insulation in the shell of the BOF took place in June 2021. In Usiminas' BOF#4, a new shell was used, as shown in Figure 3.

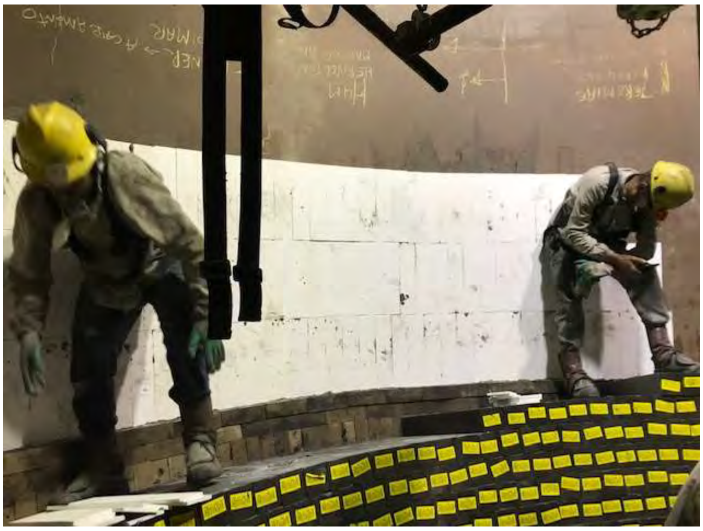

Figure 3. Installation of the thermal insulation in the Cylinder of BOF#4.

3.0 RESULTS

3.1 Results of BOF Thermal Model

The results were defined for the following evaluated configurations:

Configuration 1:

- Working lining: MgO-C;
- Burned MgO safety lining;
- Insulation: No insulation.

Configuration 2:

- Working lining: MgO-C;
- Burned MgO safety lining;
- Insulation: Silplate 6 mm, only in the taphole region.

Configuration 3:

- Working lining: MgO-C;
- Burned MgO safety lining;
- Insulation: Silplate 6 mm, in the cylinder-down region.

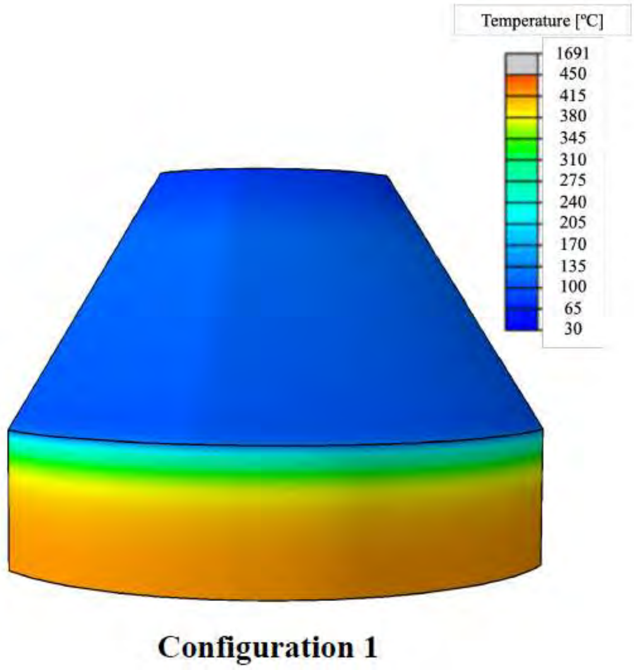

Figure 4 – Configuration 1

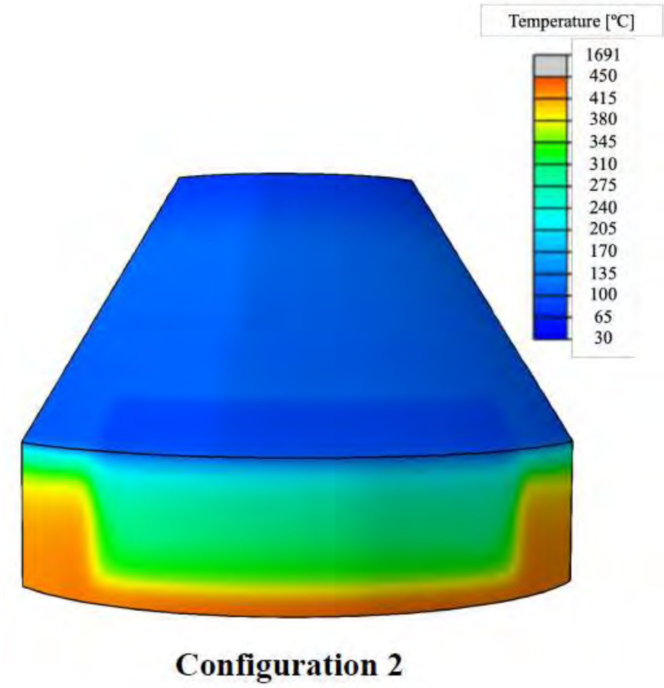

Figure 5 – Configuration 2 (insulation only in the taphole region)

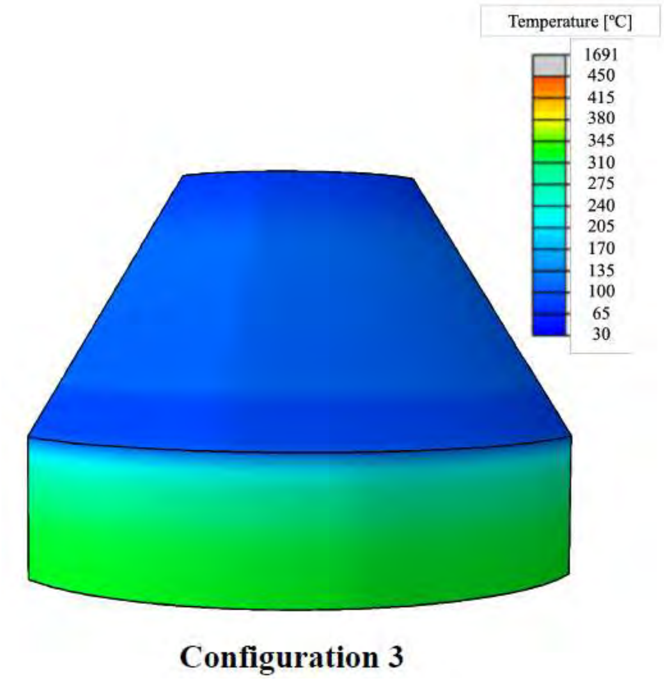

Figure 6 – Configuration 3 (insulation throughout the cylinder)

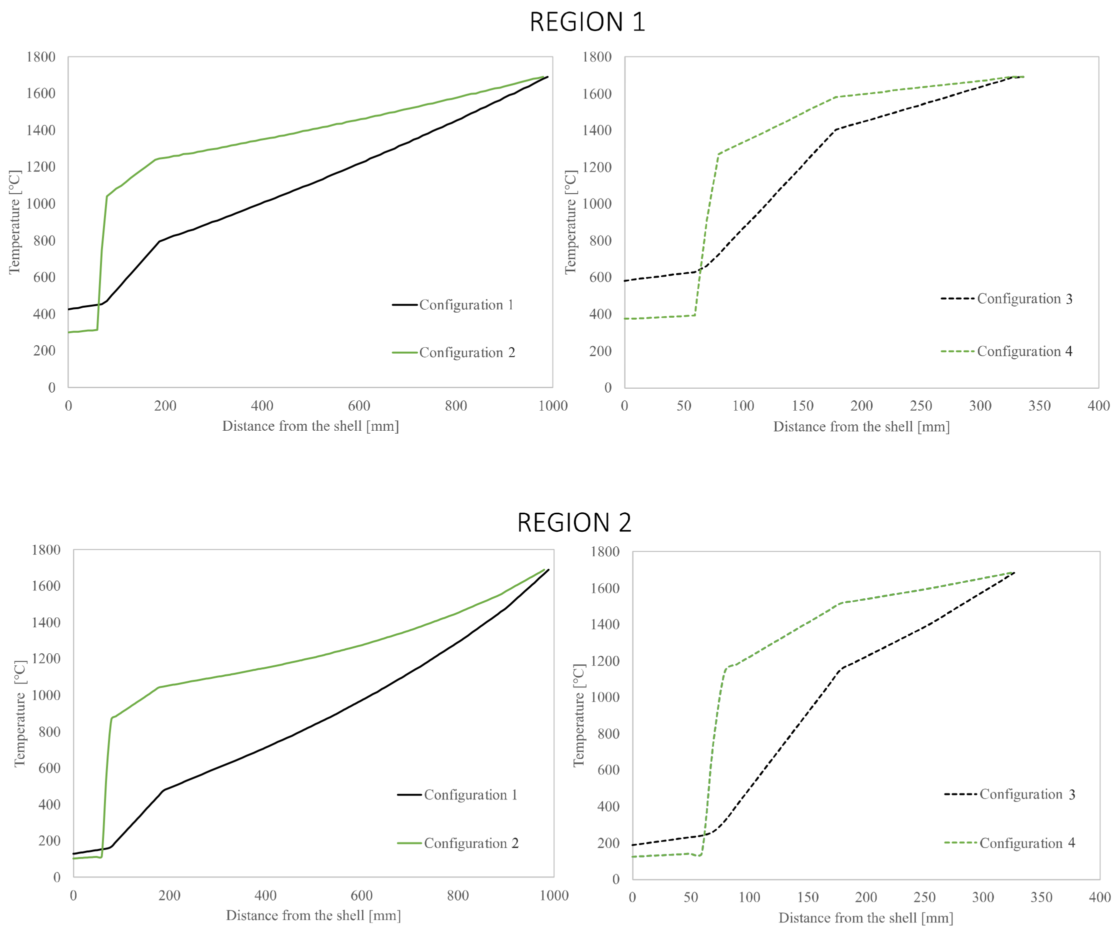

Figure 7 – Thermal profile along the material

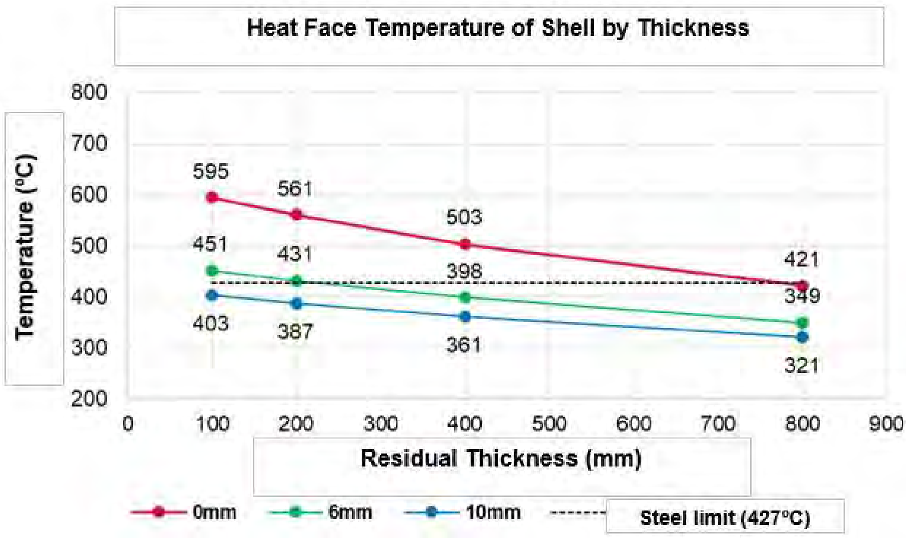

Figure 8 – Evaluation of final shell temperature as a function of residual thickness.

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3.1 Thermal images tests of BOF#4

After 400 heats, thermographic images were taken from BOF#4.

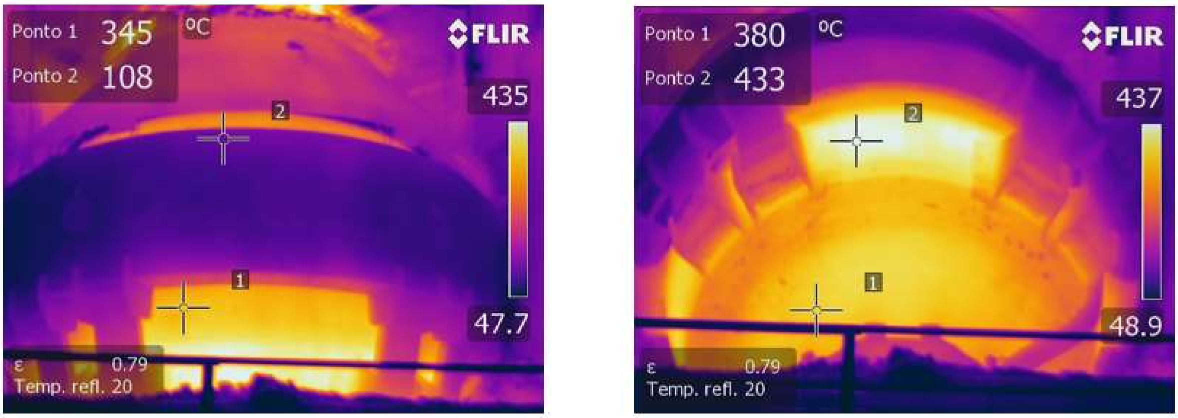

Figure 9 – Thermography performed on BOF with 400 heats.

In Figure 9-A, point 1 in the insulated region had a temperature of 345ºC. And in Figure 9-B, point 2 in the lower cone region (without insulation) showed a temperature of 433ºC. A difference of 88ºC. The temperature in the insulated region was significantly lower than the target temperature of 400ºC for the project.

After 3500 heats, a new thermography test was performed on BOF#4.

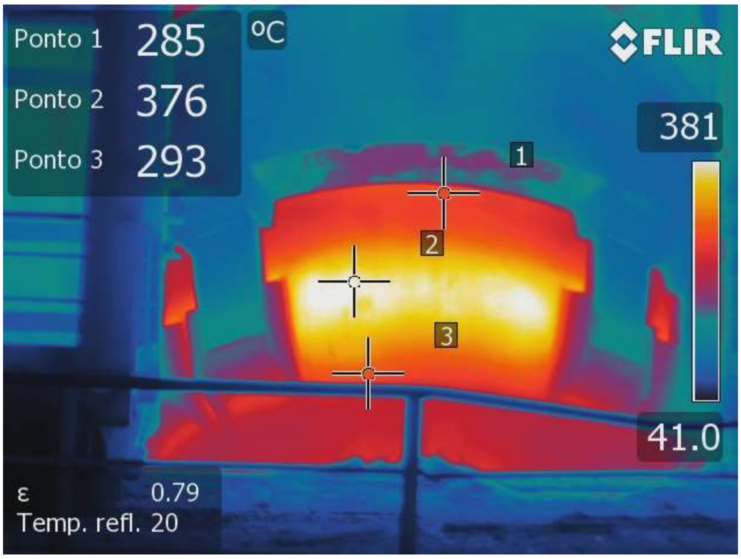

Figure 10 – Thermography of BOF#4 with 4000 heats.

In this thermography, the difference was maintained between the insulated region (point 1) at 285ºC and the region without insulation (point 3) at 376ºC.

The temperature differences between the thermographic tests were more related to the BOF's thermal cycle, but when compared between the testse, they maintained the temperature reduction predicted by the thermal model in question.

3.2 Refractory Wear

During the monitoring of BOF#4's refractory wear, a significant improvement in our wear controls was observed. Figure 11 shows the wear curve as a function of the BOF's life. At all residual points, it exceeded the optimal curve (green curve in the graph). This means that the BOF could run for more heats without opening the permanent lining of the trunnions, resulting in reduced repairs with gunning and fewer shutdowns.

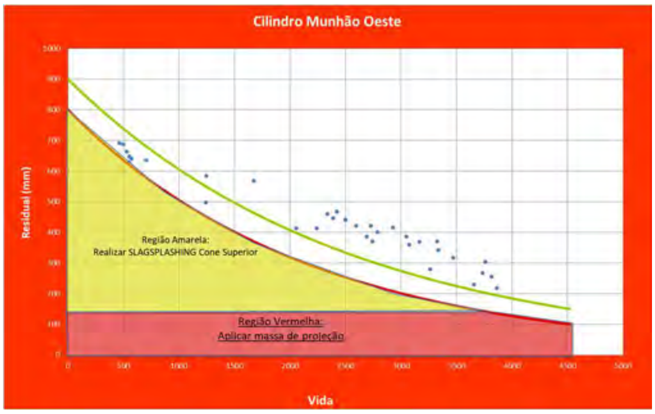

Figure 11. Trunnion wear curve.

The BOF ended with 4683 heats, the best result since 2016. Then after the demolition of the lining was carried out, it was possible to verify that the residual lining could allow a potential life of more than 5000 heats, without the need for repair with gunning (trunnion's region). Figure 12 shows the profile found in the demolition. With thicknesses greater than 300 mm.

Figure 12. Residual of more than 300 mm.

3.3 Gunning Consumption – Repair Stops

After the end of the 315 test campaign with the new design of the combined blower, he evaluated the campaign's consumptions. Historically, since 2016. The same in the demolition, presented potential for more 5000 heats.

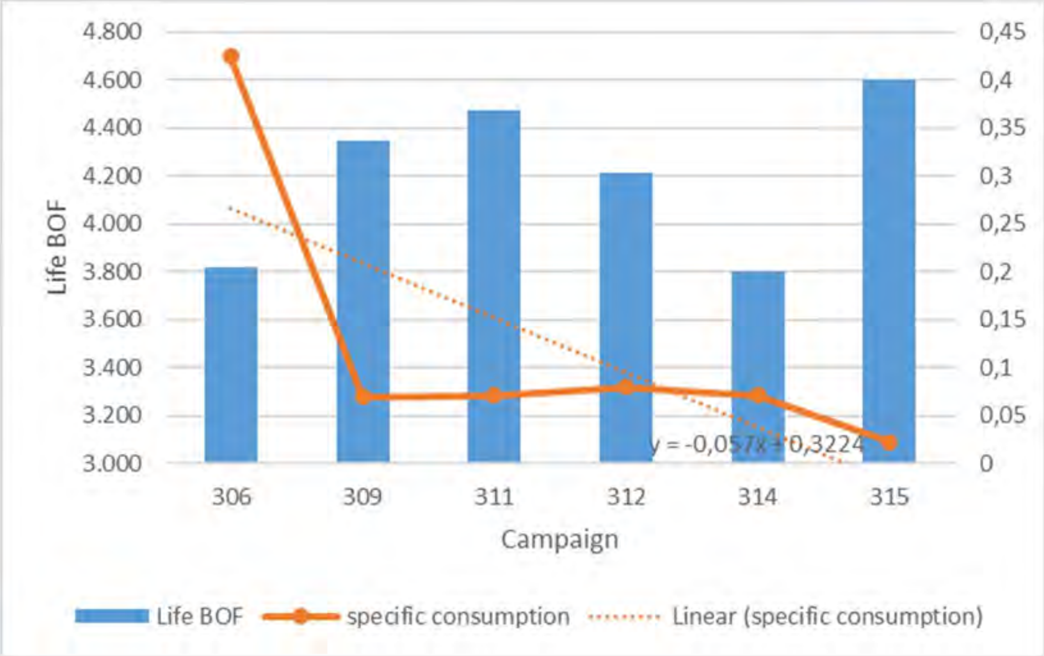

Figure 13. Evolution campaigns.

Repair refractory consumption of the test campaign was 17,1 ton (projection in the trunnion's region). The previous consumption (average of the last 5 campaigns) was 94,3 tons per campaign. There was a reduction of 77 ton of refractory per campaign. In addition to the reduction in refractory costs, other important issue is the stoppages for projection. Considering that the projection rate is 1 ton in 30 minutes, this reduction represented a decrease of 2300 minutes spent in repair, which means higher availability of the installations for production.

3 CONCLUSION

According to the obtained results, it was possible to reduce the shell temperature, which reflects a more favorable thermal balance for the LD converter. The gains for BOF#4 were significant, including increased refractory lifespan, reduced shutdowns for reheating, reduced shell deformation, and energy savings.

In summary:

- BOF life increase (campaign record);
- Reduction of specific consumption;
- Reduction in shell temperatures;
- Increase in converter availability due to non-stop for projection;
- Reduction in shutdowns for reheating.

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