NEW BOF PERFORMANCE AT GERDAU OURO BRANCO BY SLAGLESS® TECHNOLOGY*

Eric Almeida[1]
Wagner Assunção[2]
Manoel Fernando de Oliveira[3]
Breno Totti Maia[4]
Fabrício Silveira Garajau[5]
Marcelo de Souza Lima Guerra[6]
Wellington Morais de Andrade[7]
Wenderson Marciel da Silva[8]

Abstract
This work was a continuous and multidisciplinary development. Through studies of the blowing process and its parameters results, evolutions, improvements and adjustments were made on the lance's hot face with Slagless® technology, as well in the process parameters and mitigating actions of the projection of materials out of the converter. The main results are the increase in the nozzle's life with a "record mark" of 1785 heats, and water leakage occurrence in the cartridge decreased considerably reaching the mark of one year without any occurrence.
Keywords: BOF, cartridge, process control, tip life, lance skull, safety.

[1] *Eng. Metalurgista da Gerdau Ouro Branco, Ouro Branco, MG, Brasil;*
[2] *Eng. Metalurgista da Gerdau Ouro Branco, Ouro Branco, MG, Brasil;*
[3] *Eng. Mecânico da Gerdau Ouro Branco, Ouro Branco, MG, Brasil;*
[4] *Sócio da ABM; Doutor e Engenheiro Metalurgista Pesquisador Lumar Metals, Belo Horizonte, MG, Brasil;*
[5] *Sócio da ABM; Mestre e Eng.Mecânico e Pesquisador da Lumar Metals. Ipatinga, MG, Brasil;*
[6] *Sócio da ABM; Mestre e Eng.Mecânico e Pesquisador da Lumar Metals. Ipatinga, MG, Brasil;*
[7] *Eng.Mecânico Lumar Metals. Ipatinga, MG, Brasil;*
[8] *Técnico Mecânico da Lumar Metals. Ipatinga, MG, Brasil.*

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1 INTRODUCTION

Gerdau Ouro Branco steelworks started operations in 1986 with 02 BOF converters with initial capacity of 180 tons each. Currently converters with 224tons capacity have submerged bottom blowing system with 06 tuyeres, sub-lances, static and dynamic model aided by measurements from gas recovery system. A characteristic in relation to other national converters is the fact that it has the lowest slenderness ratio - height divided by diameter in trunnion region. Figure 1 presents Gerdau Ouro Branco BOF with other converters around the world and Figure 2 presents the main dimensions of this 224t converter. This converter, due to the geometric relations between the diameter, considering in the trunnions region and the height mouth until bottom, is often observed projections effect. A refrigerated lance realizes the oxygen blowing. This lance has as main parameters flow and height in relation to the bath called DBL - Distance Bath Lance. The blow projections are undesirable occurrences due to uncontrolled blow parameters. The blow projections are emulsified materials that project out of the furnace. The reasons for the projections are: low useful volume, usually expressed by the volume of the converter ratio divided by the charge charged into BOF, volume of slag with direct influence of the silicon contained at liquid hot metal, bottom level elevation and the addition of ferrous sources through top bins. The present study shows developments at blowing process of this 224 tons BOF in order to reduce skulls lance formation, increase nozzle life, after using an innovative concept called "cartridge", reducing possibilities of cartridge leakage and potential water leaks into BOF.

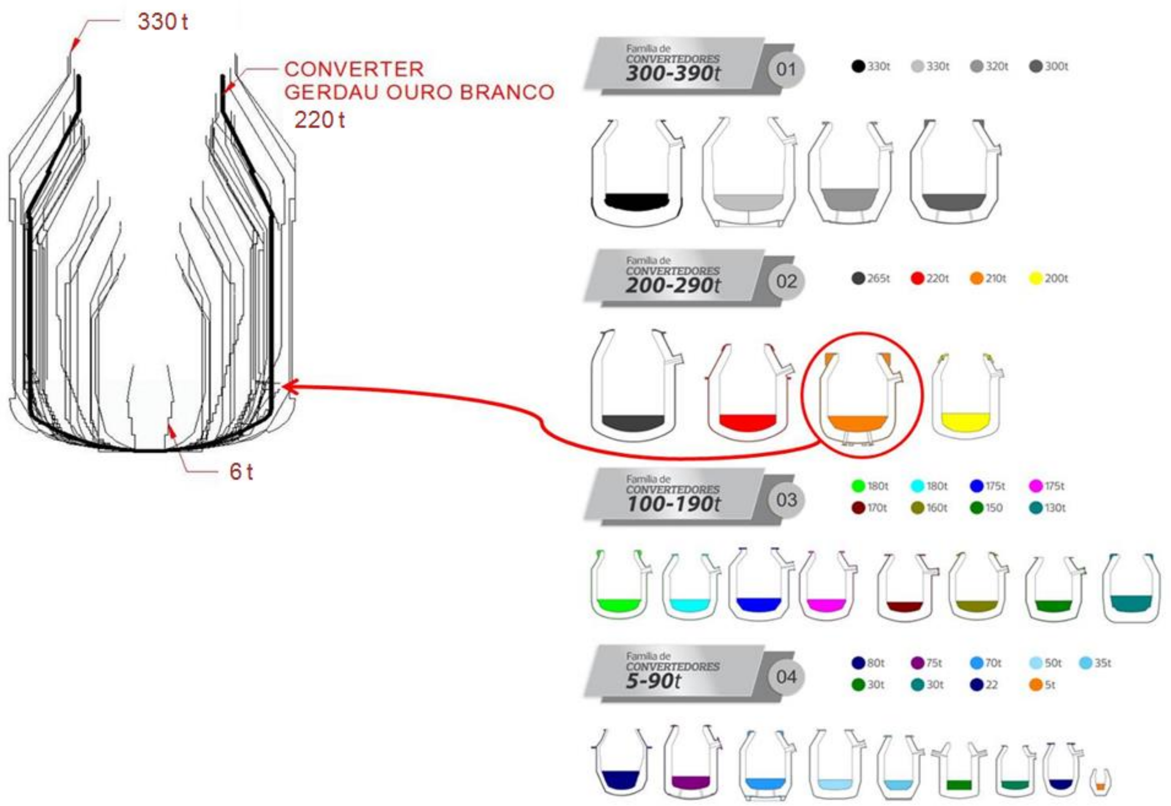


Fig. 1- Shapes and capacities of converters around the world[1].

Description	Unit	Value
Distance Bath Lance	mm (max)	3095
Distance Bath Lance	mm (min)	2110
Static Bath Level	mm	1798
H/D	#	0,94
Specific Volume	m³/t	0,84
Tuyere	#	6
Tuyere flow	Nm^3/h	600

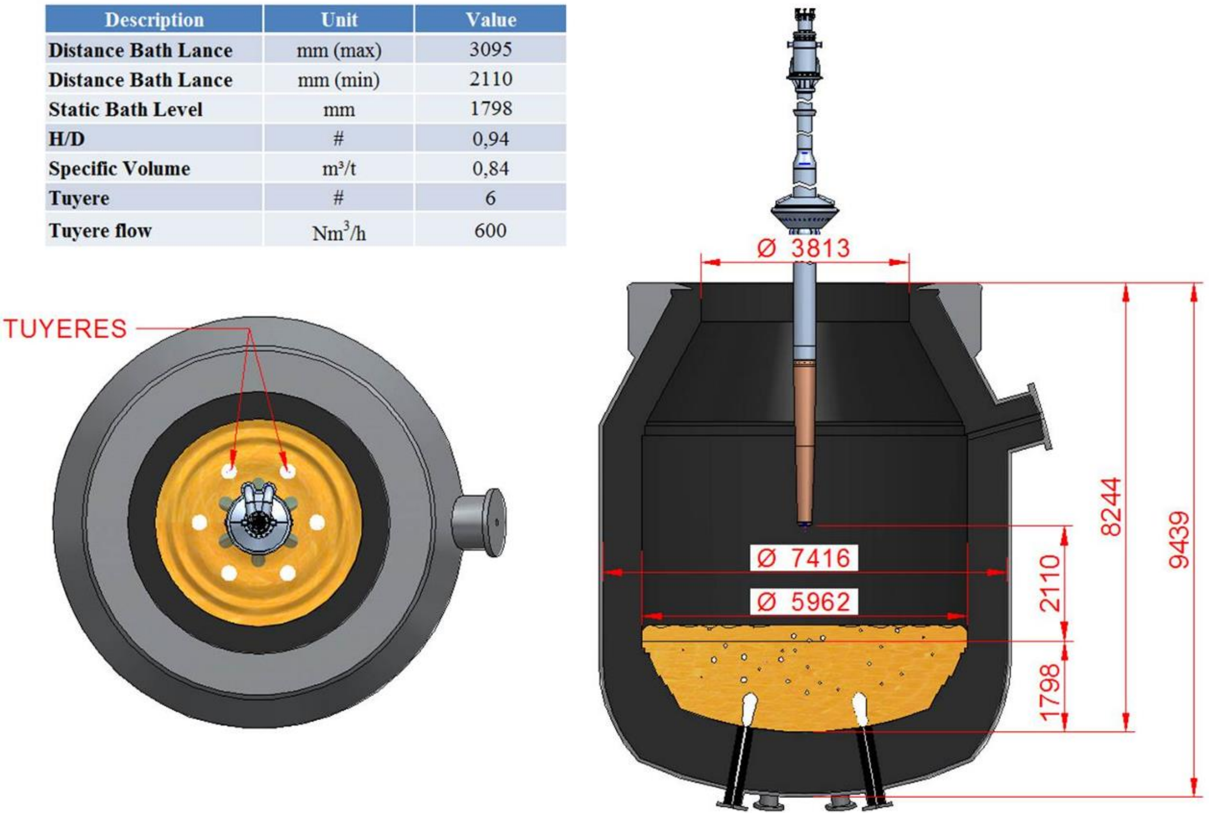


Fig. 2 - Main dimensions and parameters of Gerdau Ouro Branco converter.

2 MATERIAL AND METHODS

The methodology of this study was based on successive cycles of PDCA[2] according to the scheme presented in Figure 3 accompanied by a commercial model based on cost reduction according to the performance increment of joint component lance tip and lance.

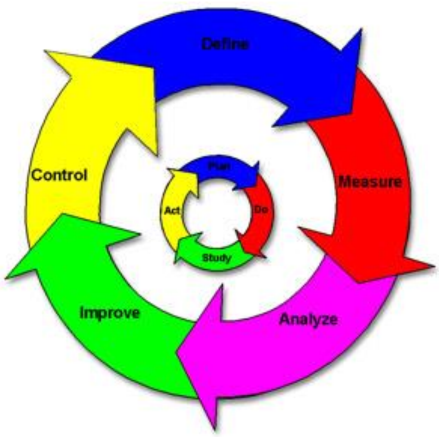


Fig. 3 - PDCA cicle.

In this case the use of an innovative concept: the cartridge - an extension of traditional length of the lance tip associated with a new external tapered copper dimension and enhancement of the internal refrigeration capacity christened Slagless®[3].

The cycles created a positive spiral of knowledge about productive process at blow stage and the parameters influence on the cartridge life and formation of undesirable skull lance. The skull lance is the solidification of the emulsified material on the lance surface. The skull may be metallic, formed only by slag or mixed composed of metallic parts, slag and additions of flux and unmelted refrigerators.

Also regarding the safety aspect, the skulls cleaning operation was a great concern due to the high number of occurrences as well as the conditions of execution of the activity, especially the vertical oxicuts as shown in Fig.4.

Fig. 4 - Vertical oxicut cleaning lance.

The inconvenience caused by the skulls lance are shown in Table I as well as the proposed increase peoples to keep lances available for operation.

Table I – Lance skulls numbers at 2010.

Item	Number	Unit
Man Power for lance maintenance	13 – 24 (proposed for 2011)	Peoples
Skull lance rate	6,7	Heats/skulls
Skulls per month	236	Skulls/month
Metallic yield losted	532	t/month

Analyzes in the checking cycles, anomaly treatment, technologies offer at market comparison and control items were the necessary subsidies for determination to use and improvements over the basic Slagless® technology.

The work carried out in partnership with Lumar Metals which following PMBOOK[4] stages of project engineering analyzed and programmed the necessary developments. Fig. shows the steps of technological improvement determined by PMBOOK.

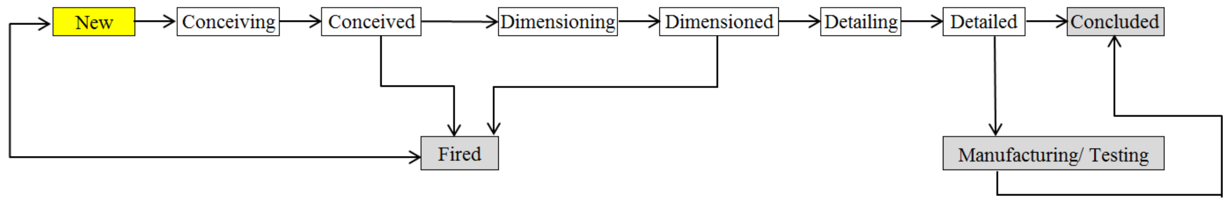


Fig. 5 – PMBOOK[4] system to new developments.

The process began in 2010 with preliminary studies before the first heat blown with Slagless® technology as can be seen in Figure 6.

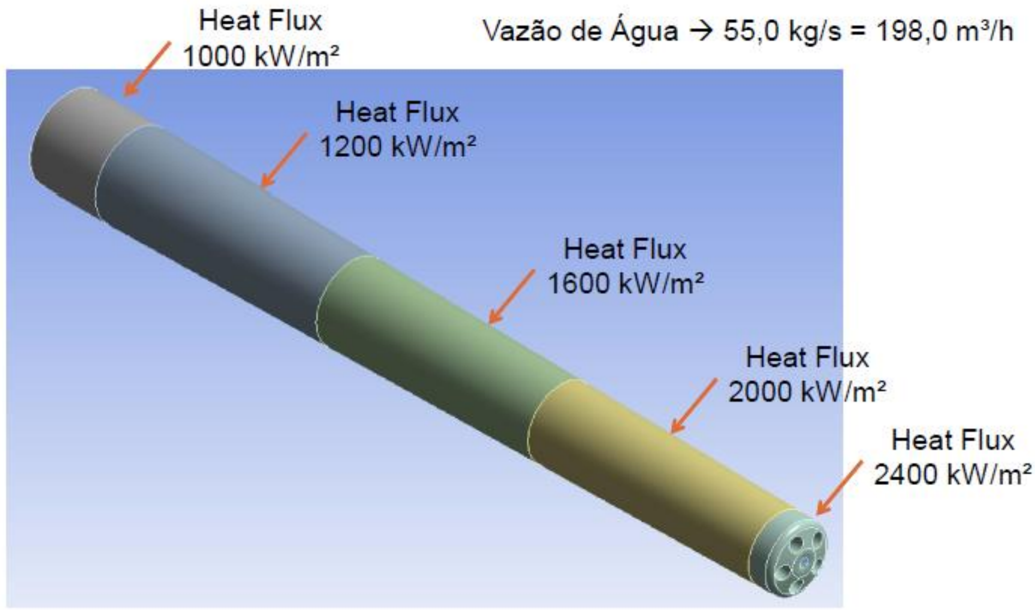


Fig. 6 – Slagless® – condições de troca térmica ao longo do cartucho.

In Fig. it is possible to note that Slagless® technology introduces the concept of "cartridge". The cartridge consists of a extension 3 meter longer, specially shaped copper. Copper's heat conduction properties associated with geometry and studies of flow and heat exchange by commercial software "Ansys CFX" give Slagless® technology the ability to rapidly extract heat from the skull forming around the lance. The consequence of rapid heat extraction is the skull sticker rapid solidification which cracks by thermal contraction and releases from the lance.

3 RESULTS AND DISCUSSION

In this item will be presented the improvements and results over years that culminated in results considered unique in the world steel mill. Achievement of the partnership between GERDAU OURO BRANCO and LUMAR METALS.

Immediately with the introduction of Slagless® technology the results with a reduction in the number of generation of skulls lance and consequently need for cleaning are expressed according to. Fig 7.

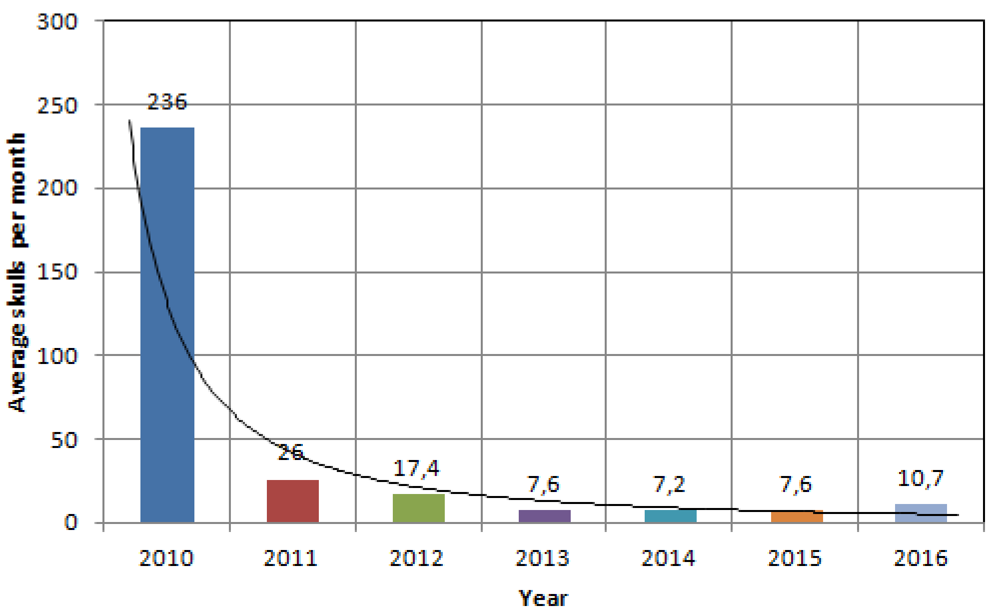


Fig. 7 - Average lance skulls per month.

Fig. 7 shows a sharp decrease in the occurrence of skulls lance from 2010 to 2011. The numbers have suffered a further drop from 2012 to 2013 due to the improvement of Slagless® technology as shown in Fig. 8

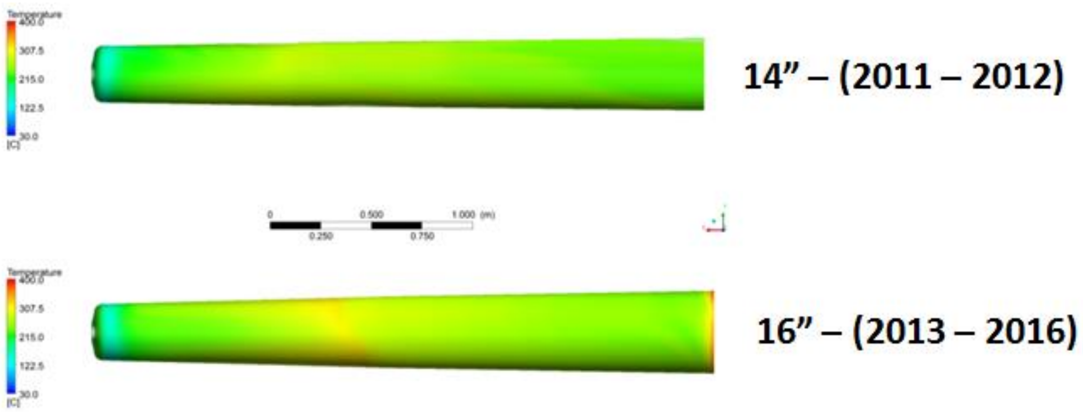
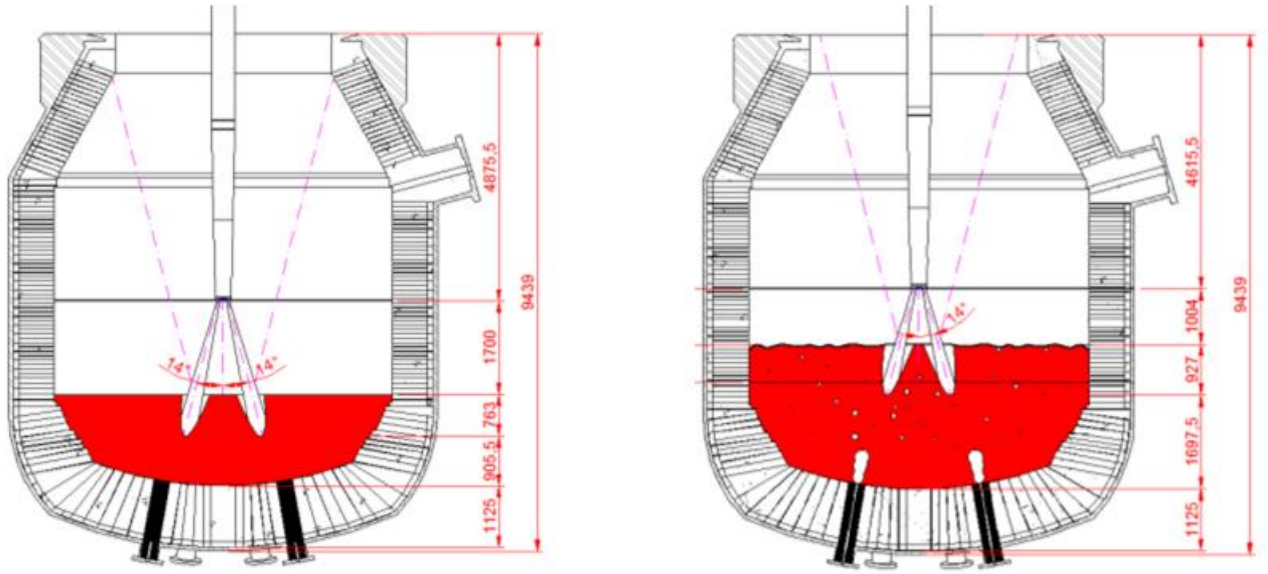


Fig. 8 - Slagless® models.

In 2013, Slagless 16 "was introduced in order to increase the heat extraction capacity due to the increased conicity, thereby increasing the rate of contraction of the potential skulls and thus intensifying the reduction of the formation of skulls lance. With this change the results had a beneficial evolution.

The understanding of the process and other variables was essential in the continuous improvements. A study was carried out considering the converter geometry with special attention to the submerged tuyeres positions. Fig. shows the bubbling effect of the tuyeres on the static bath level.



a) b)

Fig. 9 – Bath level height scheme: a) Static bath = 1668mm and b) Bubbling bath at 600Nm^3/h = 2624mm.

In Fig. is important to note that was considered that in the same time all bubbles gas are dispersed in the bath. This is not a fact verified in the industrial processes, but was used to create a different reference from that with the traditional static bath level represented by Figure 6 a). Another benefit of this study was the verification of the interference between the oxygen supersonic jet and the bubbling gas plume through submerged tuyeres possibility. The gases sources must work independently, just as in the oxygen nozzles of the Slagless® cartridge. Coalescing between jets must be avoided. By coalescing is understood as the union of two distinct jets with kinetic energy degradation to be transferred by both individually. The recommended configuration to maximize results consists of the oxygen jets of the supersonic nozzles being inscribed into tuyeres diameter. Aiming at the independence of gaseous sources, the assembly of Slagless® cartridges was standardized as shown in Fig. 4.

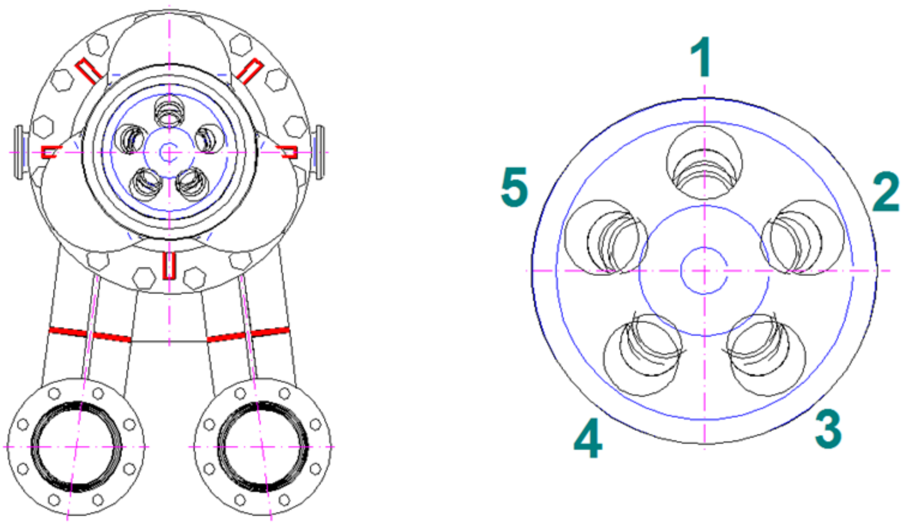


Fig. 4 - Slagless® cartridge mounting pattern in relation to the position of the BOF windows.

Associated with the wear behavior of the cartridge face, it was possible to create a reference for the wear behavior, allowing adjustments in the DBL (Bath Lance Distance) through the energy balance described by Maia et al [5-10], different from other mathematical models in force in the converters according to Fig. 5.

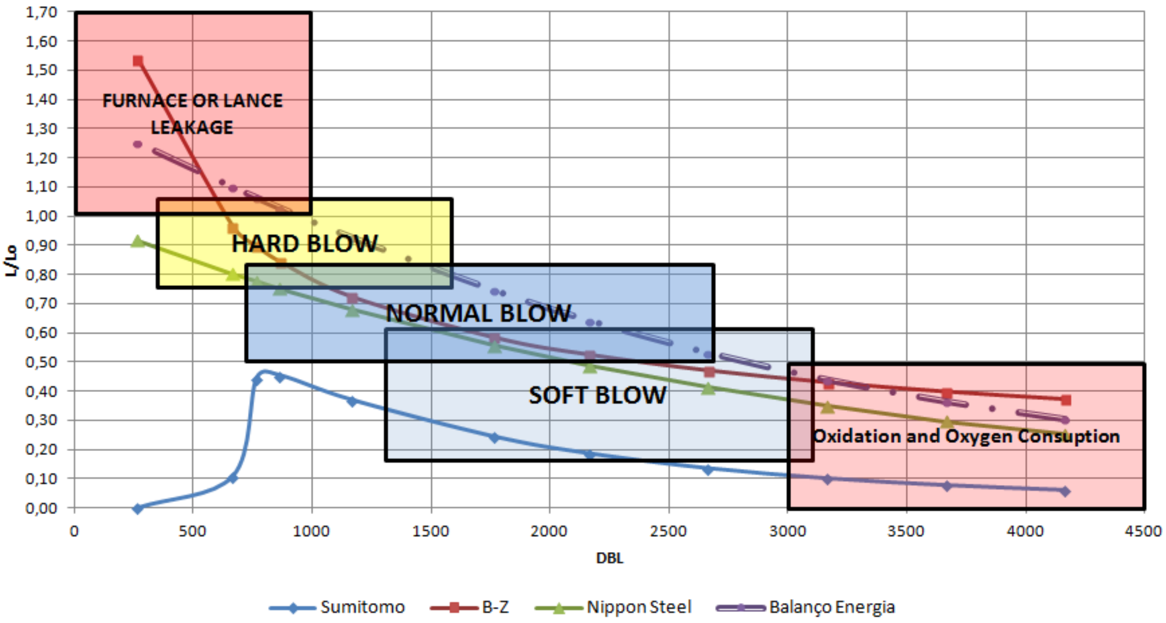


Fig. 5 - Behavior of different mathematical models of lance height [7].

Changes in the pattern of flux additions have also been developed, mainly for facilitating the formation of first slag purpose. The scales were programmed for weighing in parallel and alternated mainly with sources of ferrous oxides, materials that by their nature release gases during dissolution and melting with the metal bath, promoting changes in the emulsification patterns of the bath and generally associated to the skulls formation.

With the objective of provoking a smoother transition blow stages, new logic was developed in the control mesh as well as adjustments in the blow flow modulation system. In the past there was an abrupt descent in just three steps accompanied by oscillations in the oxygen flow, responsible for the projection of material during the change of lance heights (DBL) from the formation of slag to the decarburizing level. With the change, there are more stages for change of height being a graded descent in small but numerous stages.

The ideal, would be an integrated descent, but for the moment not being possible by the current control system, but listed for future improvements. However, a significant reduction in the occurrence of projections was achieved, meaning stability blow and consequently reductions of lance skulls. To avoid human mistakes due amount of controls, were reduced the number of blow pattern and included all lance set ups to work completely automatic.

Look for the furnace was very important to guarantee stability of bottom level and bath level for well lance work. In this way were implemented into math model automatically bottom and bath level control considering laser scans and math regression, combined real measures of converters conditions and rules for basicity and fluxes that additions needs or no to be included and preventive actions to be converter dimensions under control, like shown at Fig. 6.

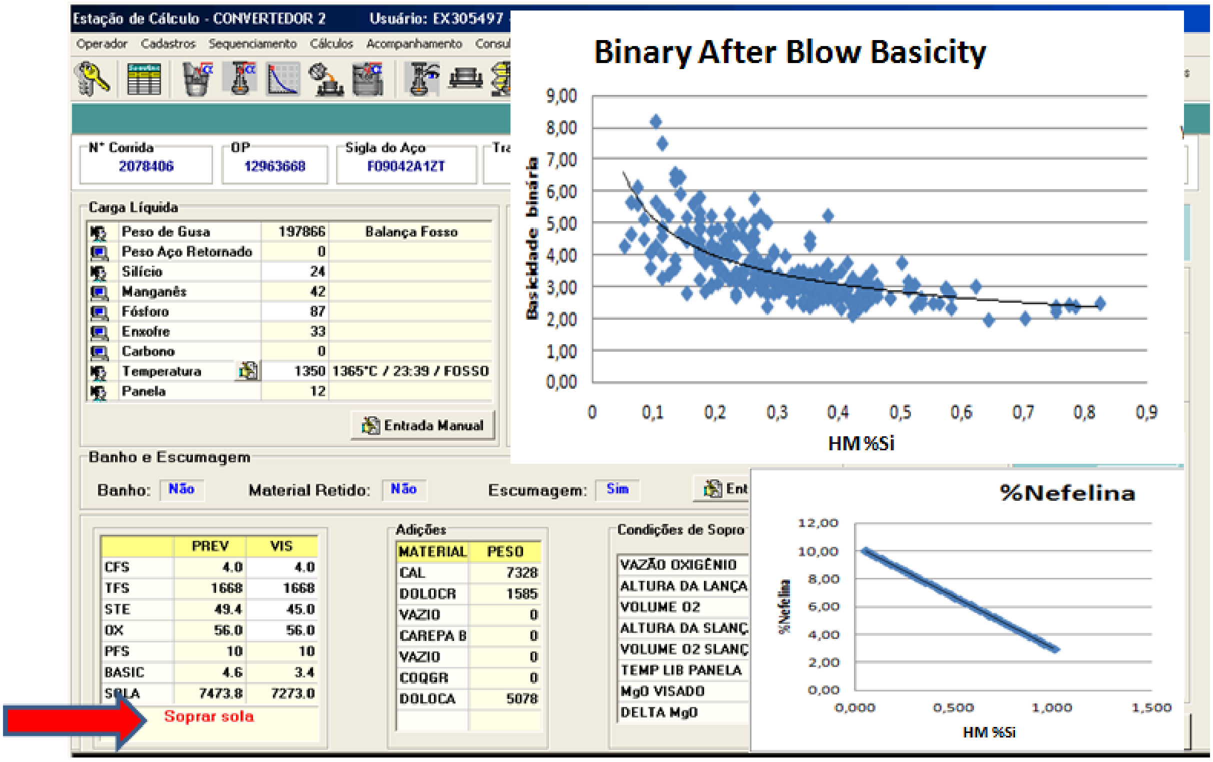


Fig. 6 – Preventive actions to be converter dimensions under control.

At Fig. 6, is pointed that for that example situation the rule is: BOTTOM BLOW. Process observations were also carried out with the main objective being the correlation between hot metal silicon and the skulls lance formation. Fig. 7 shows the cause and effect relationship between these parameters over the same period.

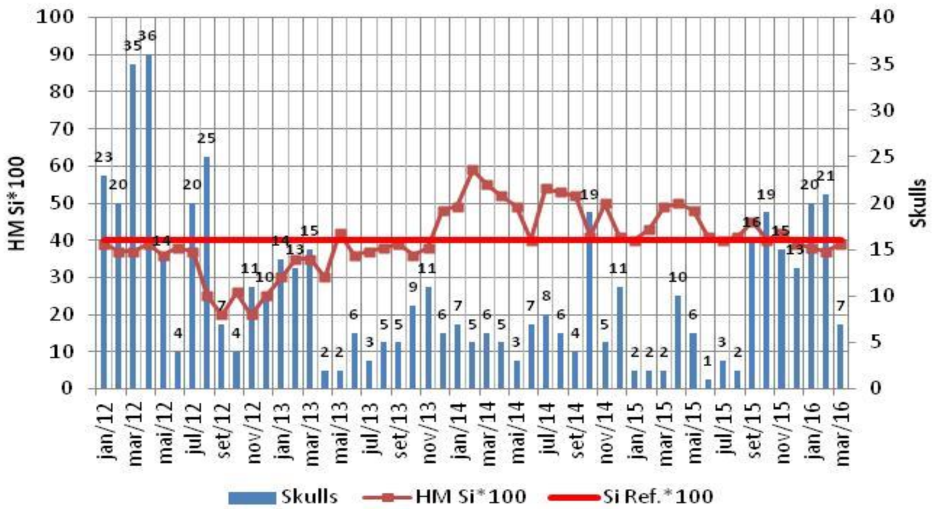


Fig. 7 Relation cause and effect between the silicon of the hot metal and skulls lance formation.

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Fig. 7 shows that increase in periods of low silica of the hot metal promotes the increase of the occurrence skulls lance formation. In turn, frequent lances cleaning contribute to damaging the pipes and consequently increasing the likelihood of rebar adhesion. This vicious cycle leads to reduced cartridge life, but is inherent to the process, being the solution, frequent checks of cartridge conditions and inspections on the face and nozzle outlets.

During the process it was investigated the relation between flow blow and nozzles design being one causes of the premature nozzles and face wear of the cartridges as shown in Fig. 8.

Fig. 8 - Nozzle wear and cartridge face due to differences between design conditions and operating conditions.

Then, in parallel with the process adjustments, the size of the nozzles and cooling conditions, the current operating conditions were adjusted in order to maximize the life of the cartridge and eliminate the possibility of water leaks during the blow[10-11] As shown in Fig. 9.

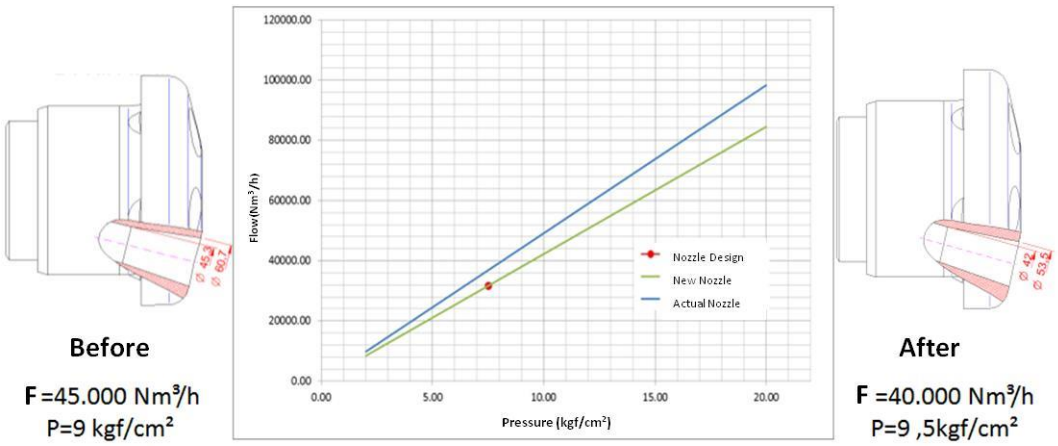

Fig. 9 - Resizing the Slagless® cartridge supersonic nozzles.

In Figure 15, on the left side shows the configurations of nozzles designed for high flow rates, but in industrial practice these flow rates were not practiced, meaning premature wear of the nozzles. Then the nozzles were resized for the flow rates practiced as well as the available oxygen pressure. In this resizing, low-flow periods were considered, such as during sub-lance measurements and due to occurrences of uncontrolled emulsion projections, represented by the red dot in Figure 11. Any pressure below that indicated by the red dot will represent premature wear of nozzles. An innovative practice was also developed and applied, measures to predict the size of the nozzles and wear on the face of the cartridge.

In mid-2015, a filter was introduced into the cooling water system to eliminate the possibility of contamination of water with solid waste as detected by Fig.16.

a) b).

Fig. 16 – Bad water cooling quality and effect over cartridge tip face: a) Solid material into water pipe lance and b) Cartridge tip face and damage due bad heat transfer.

In Fig. 16 a) shows the presence of large amount of solid material in the cooling water which reduces the flow and thereby the thermal exchange capacity in the critical part of the cartridge, the face, leading to the accentuated wear shown in Fig. 16 b) with the premature withdrawal of the operation cartridge by water leakage in the generated cracks. The installation of the filter was responsible for a notable reduction in cartridge leaks as well as contributing to the increased life of the Slagless® equipment and safety of operations.

Fig. shows the reduction in the number of cartridge face leakages or traditionally referred to as lance tips.

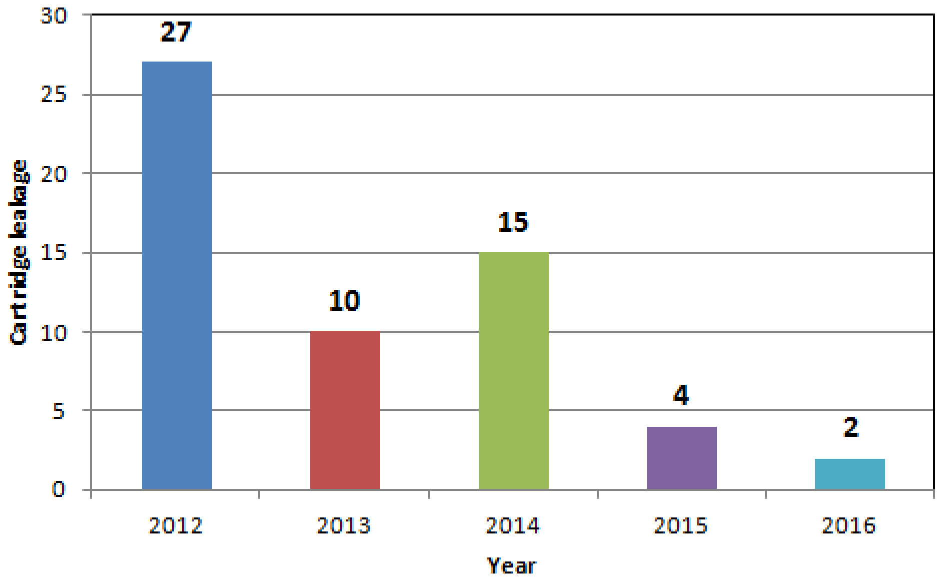

Fig. 17 - Occurrence of cartridge face holes.

It is possible to note in Fig. , as the change in cartridge cooling design, resizing and nozzle adjustment, together with the predictive practice of inspection, have ensured safer operation of BOF converters. In order to reinforce the safety aspect incorporated with Slagless® technology, it is presented in Fig. like a way of quantifying the occurrences of leakages in the face of the cartridges in relation to the number of annual heats.

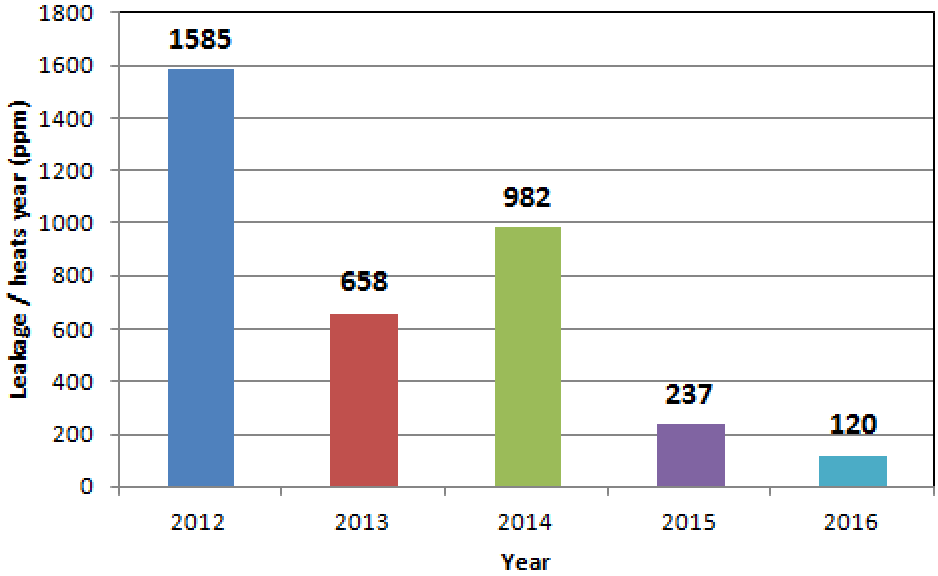

Fig. 18 - Cartridge face holes per heat per year in ppm (part per million).

Fig. shows a relative measure that can be used as a reference for plotting a performance goal for other converters. For example, considering a converter whose average number of heats per year is 10,000 and considering the performance of 2016, the number of leaks in the year is only 1. Comparing with 2012, potentially there would be at least one leak in the face of the cartridge per month. The efforts of process improvements and cartridge improvements have resulted in an average cartridge life increase as shown in Fig. .

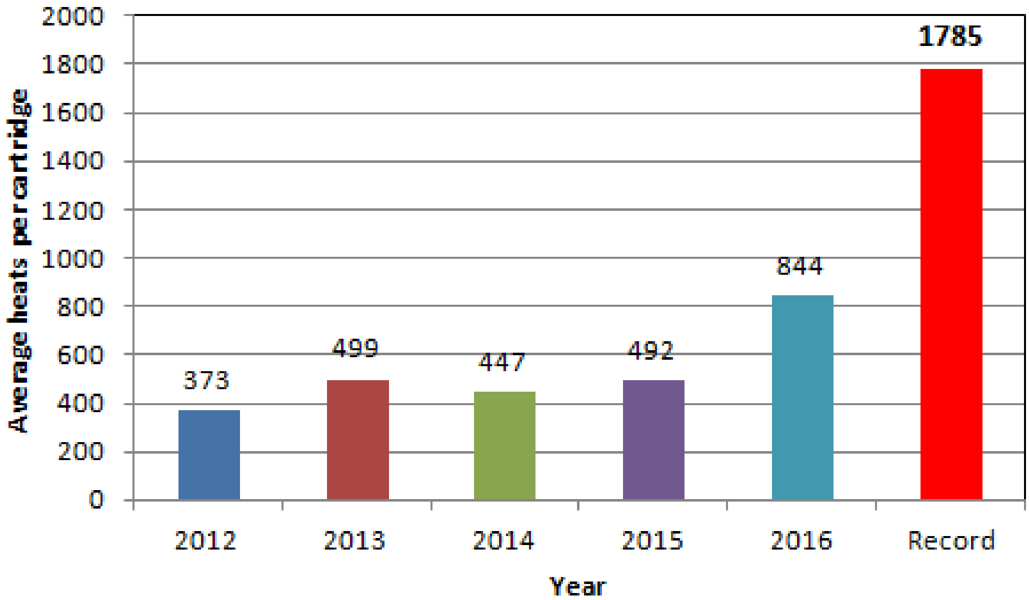

Fig. 19 - Average life of Slagless® cartridges.

Fig. shows that the results between the years 2013 and 2015 were stabilized around 450 heats, despite the reduction of cartridge face leaks. By mid 2015 the partnership developments were intensified, resulting in a significant improvement in the average values that culminated in the record value of 1785 heats. Fig. 10 shows the face of the cartridge after blowing 1785 heats.

a) 1604 heats

b) 1785 heats

Fig. 10 - Photo of cartridges after: a) 1604 heats and b) 1785 heats.

Fig. 10 shows the good appearance of the oxygen outlet nozzles, despite the occurrence of flame rebounds.
With the results achieved in the shows a comparison of the parameters between 2010 and 2016.

Table II. – Lance skulls numbers comparison 2010 and 2016

Item	2010	2016	Unit
Man Power for lance maintenance	13 – 24 (proposed for 2011)	3	Peoples
Skull lance rate	6,7	130,1	Heats/skulls
Skulls per month	236	10,7	Skulls/month
Metallic yield losted	532	24,1	t/month
Lance tip / Cartridge life	180	844	Heats

Table II shows the main results obtained by the partnership between Gerdau Ouro Branco and Lumar Metals in the continuous development of products and mainly processes

4 CONCLUSION

The main conclusions of the study were:

- The PMBook methodology was effective in implementing improvements to the Slagless® cartridge;
- The safety premise of not allowing BOF to operate with water leaks was decisive in the development of Slagless® technology;
- Adjustment in the nozzles and cooling circuit of the cartridges allowed to operate without water leaks in the BOF for 1 year;
- Predictive inspections of face wear and nozzles are critical to ensure increased cartridge life in a safe operating condition leading to a 1785 heat record mark;
- Adjustments in the process parameters at which lance height, lance displacement practice and addition of fluxes have contributed to reduction of the formation of skulls, even in periods of low Si.

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