Continuous Developments at the Steel Plant 1 Usiminas Ipatinga Through Slagless® Technology

Breno Totti Maia[1], Adeilson Roberto Ribeiro[2], Bruno Orlando de Almeida Santos (*in memoria*)[1], Carlos Alberto de Souza[2], Fabrício Silveira Garajau[1], Marcelo de Souza Lima Guerra[1]

[1]Lumar Metals Ltda
Rod. MG 232, km 09, Nº 100, Santana do Paraíso, MG, Brazil, 35.167-000
Phone: +55(31) 9399 3200
breno.totti@lumarmetals.com.br

[2]USIMINAS
Av. Pedro Linhares Gomes 5431, Bairro USIMINAS, Ipatinga, MG, Brazil, ZIP Code: 35.160-900
Phone: +55 (31) 8395 3006
c.souza@usiminas.com

Keywords: BOF; Blow; Cartridge; Tip life; Skull

INTRODUCTION

The BOF (Basic Oxygen Furnace) is most important reactor in steel production, with 53% of the total amount of steel produced around the world. USIMINAS, located in Ipatinga city, center of Minas Gerais state in Brazil, has two Steel Plants, both working with BOF converters. Steel Plant 1 has three 80-ton converters while Steel Plant 2 has two 175-ton converters. The BOF converters are steel vessels lined with refractory bricks and support for a belt that permits 360-degree rotation. The rotation allows for stages of the process such as charging hot metal and scrap and tapping steel and slag. Figure 1 shows the schematic drawing for a converter and some parameters.

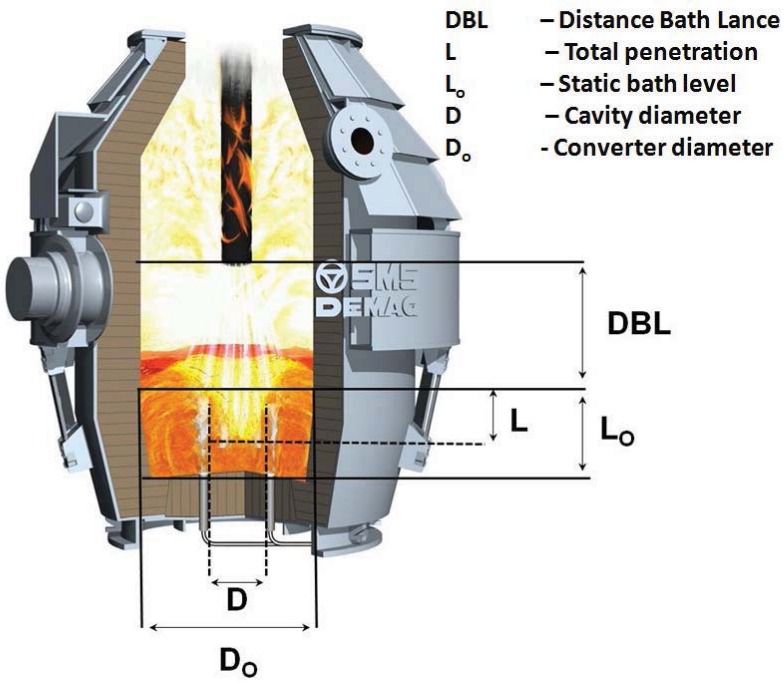


Figure 1 – Bath Deformation Formed by the Jet Impact. (Adapted from Odenthal *et al* [1]).

A water-cooled lance, constructed of concentric steel pipes, enters the converter from the top. At a specific height, oxygen is injected through the lance to promote steel refining reactions. A copper piece at the bottom of the lance, the lance tip, functions to spread the oxygen via the use of one or more de Laval nozzles. The design parameters of the lance tip and the nozzles depends on each converter, with one-hole lance tip nozzles aligned with the lance centerline and multiple-hole lance tip nozzles at various angles from the lance centerline.

The formation of skulls on the lance is an undesired effect of oxygen blowing conditions. During oxygen blowing, slag and metallic droplets can adhere to the lance and heat-by-heat increase in size. In extreme situations, skulls can be responsible for impeding the flow of reaction gases out of the converter into the dedusting system.

Slagless® Lance is a new technology developed in 2006, introducing the cartridge concept. The cartridge features a seamless special tube design, the main target of which is to avoid skull formation on the lance. Together with this Slagless technology, the nozzles in the long-life lance tip are redesigned for each converter operation to improve blow stability.

METHODS AND MATERIALS

The methodology for developing this technology was based on failure reports or Method for Problems Solution (MPS), which consists of the following stages: Observation, Analysis, Actions Proposes, Execution and Results Checking.

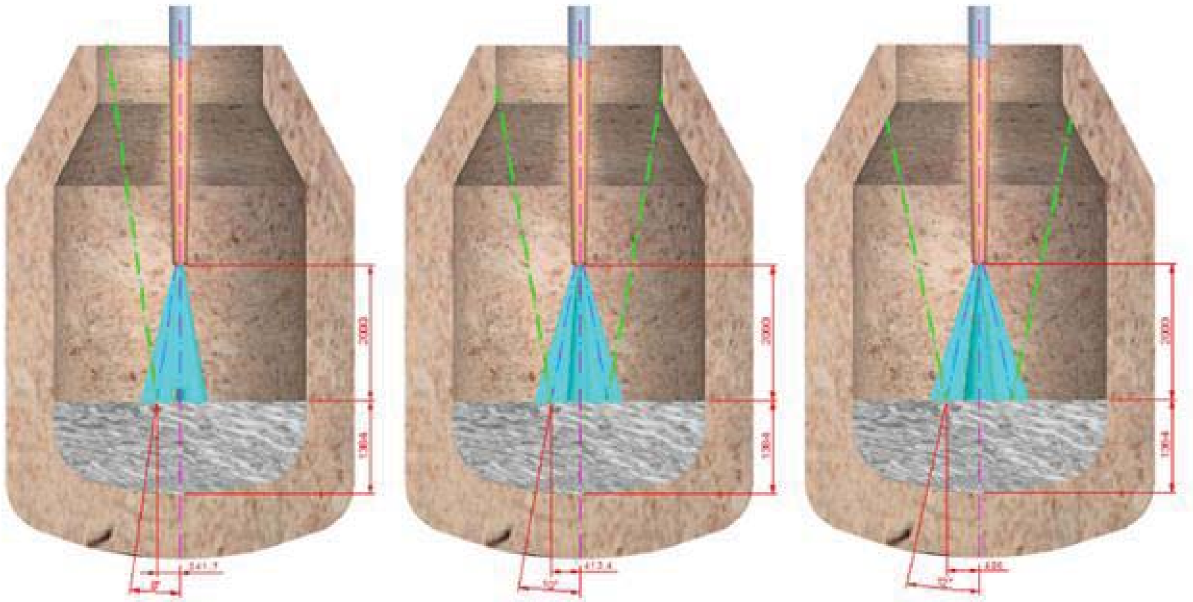
Observation

The operational routine at USIMINAS frequently resulted in lance slag and metallic skulls and specific situations where metal droplets and slag reached the dedusting system, hindering the flow of waste gases and leading to the possibility of deteriorated environmental conditions. There was no planned down time for duct cleaning. The original lance tip included three equally spaced angled nozzles plus one small central nozzle, the purpose of which was to help cool the tip face. This is shown in Figure 2.

Figure 2 – Photo of Tip with 3 Angled Nozzles and 1 Small Central Nozzle.

Analysis

A geometrical analysis was made to check the influence of the angle of the tip nozzles on line projections to the upper part of the converter, as shown in Figure 3.



a) b) c)

Figure 3 – Geometrical Comparison of Tip Nozzle Angles and Reflected Line at: a) 8º, b) 10º and c) 12º.

From Figure 3 it is possible to see that with the 8º tip the reflected line projects slag and metallics slopping directly into the dedusting system. An increased nozzle angle is required for the projection lines to intersect the converter cone area, thereby avoiding dedusting system skull build-up. Even if this results in increased mouth skulls, there are methods to deal with this problem while eliminating skulls in the ducts, as shown in Table I.

Table I - Comparative jet's effect under blow conditions

Tip	Dedusting	Mouth	Tuyere
3 Nozzles @ 8°	Strong slopping can reach into hood area	No Interference	No Interference
4 Nozzles @ 10°	No Interference	Increased time to clean mouth and during slopping falling around vessel	No Interference
4 Nozzles @ 12°	No Interference	Skull formation around mouth requires use of Slagless Clean-Up® (Post-Combustion)	No Interference
6 Nozzles @ 17.5°	No Interference	Skull formation around mouth requires use of Slagless Clean-Up (Post-Combustion)	Jet lines can reach tuyeres plunge. Need to check DBL and trunnion wear

Calculation of the theoretical values of jet penetration into the static bath involves a correlation of momentum jet balance and energy balance on the cavity formed using a modified Froude number and equations developed by Szekely (1971)[2], Meidani *et al* (2004)[3], Alam *et al* (2010 e 2011)[4,5,6], as proposed by Maia (2013)[7]:

$$\frac{\pi \times \rho_g \times V_s^{\,2} \times d^2 \times \cos\theta \times n}{4 \times \rho_l \times g \times H^3} = \frac{2}{K^2}\frac{P}{H}\left(1 + \frac{P}{H \times \cos\theta}\right)^2 \qquad (1)$$

where "ρ_g" = gas density at nozzle exit (kg.m^{-3}), "V_s" = velocity at nozzle exit (m.s^{-1}), "d" = nozzle diameter (m), "ρ_l" = bath density (kg.m^{-3}), "g" = gravity (m.s^{-2}), "P" = penetration (m), "H" = distance bath lance or DBL (m), "K" = empirical factor for each kind of nozzle, "θ" = angle between nozzles and vertical, "n" = number of nozzles.

With Equation 1 it is possible to predict the jet behavior on the static metallic bath considering the oxygen pressure and flow specifically for the original nozzles in Steel Plant 1.

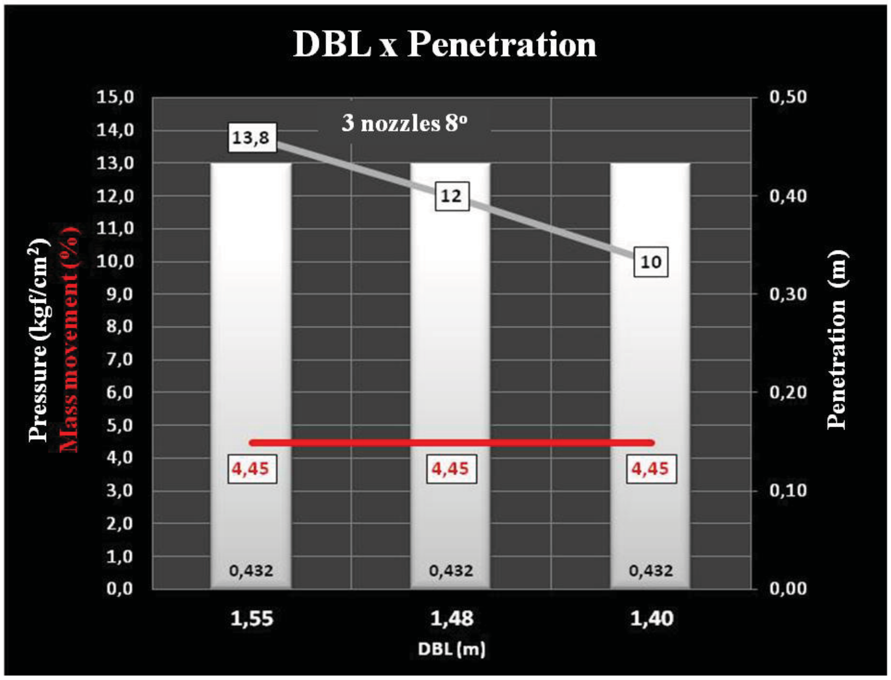


Figure 4 – Energy Balance for 3-Nozzle Conditions at Steel Plant 1.

As seen in Figure 4, for the same jet penetration, if the DBL is corrected upward to avoid damage to the tip face, the oxygen pressure needs to be increased while the amount of mass movement is small but the same in all cases, 4,45%.

While the purpose of the center nozzle is to help cool the tip face, it can also lead to increased foaming oxidation and slopping during the blow. The blowers could avoid slopping and skull formation in the dedusting system by decreasing the DBL and the oxygen flow rate. In both cases, the conditions are not good for the copper tip, the first due to increased heat load causing tip face wear and the second due to over-expanded oxygen jets causing wear around the nozzle exits, as shown in Figure 5.

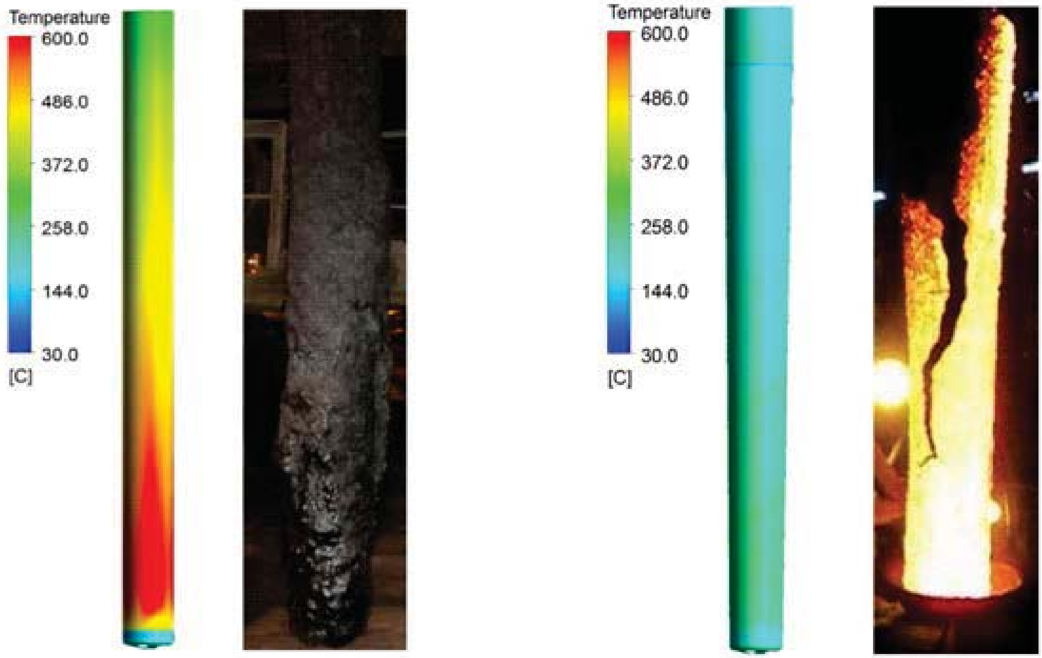
Figure 5 – 3-Nozzle Tip with Damage Around Nozzle Exits Due To Over-expanded Jet.

Actions Purposes

Actions were determined for the purposes of reaching the following targets:

- Reduce skull formation on lances;
- Eliminate skull formation in dedusting system;
- Increase the lance life;
- Increase the blow stability.

To reach these targets, attention was concentrated on the oxygen lance and the introduction of Slagless technology. Slagless technology is group of lance modifications with the goal to increase heat exchange and easy removal of metallic droplets and slag that adheres to the lance body. The main modification is the cartridge introduction, in place of the conventional tip, as shown in Figure 6.



a) b)

Figure 6 – Comparison of Skull Formation and Capacity of Heat Exchange: a) Conventional Tip and b) Slagless Cartridge.

In Figure 6 it is possible to see comparison between Slagless cartridge and conventional lance. To increase the conditions for slag formation and mass movement at the same jet penetration while working with oxygen pressures below the normal pressure to avoid premature damage around the nozzles, the tip was changed from 3 to 4 nozzles, as shown at Figure 7.

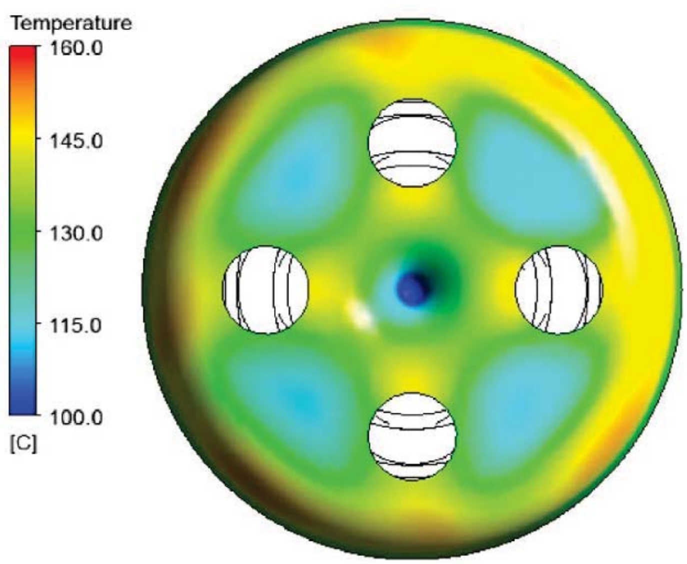


Figure 7 – New Tip Design for 14.000Nm^3/h @ 10kgf/cm^2 and 10º Degree Nozzle Angle.

The new lance tip shown in Figure 7 was specific designed. This action has the target to consider the necessity of the blowers to reduce the flow during vessel slopping or sub-lance operation and keep the nozzles with uniform jets under low flow.

The angle with vertical was increased and by geometric lines as shown in Figure 3 it was possible to check the potential to reduce slopping occurrence into the dedusting system. After the new geometry proposal for the tip with 4 nozzles was made, a new energy balance as shown in Figure 8 was calculated.

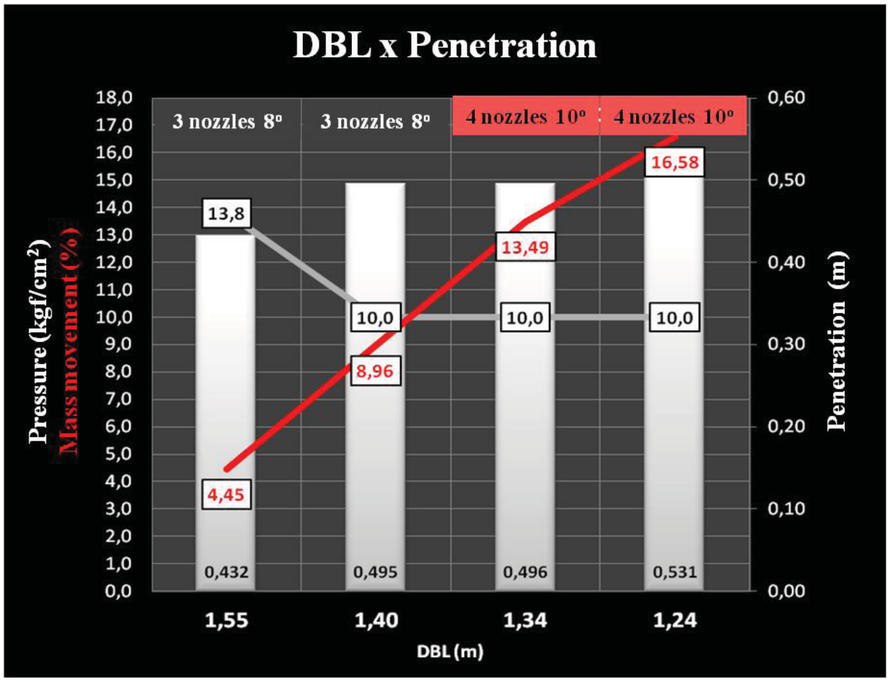


Figure 8 - Energy balance for 4 nozzles condition at Steel Plant 1.

Figure 8 shows that the 3-nozzle and 4-nozzle tips produce virtually the same jet penetration (~0.495m) at the same oxygen pressure (10kgf/cm^2), and with a required DBL reduction of less than 100mm (1.40m to 1.34m).

Mass movement increases (8.96% to 13.49%) with the 4-nozzle tip as compared to the 3-nozzle tip at the same penetration. And, if it would be necessary to reduce the 4-nozzle DBL 100 mm more, the mass movement would increase to nearly 17%, a value approximately 4 times the mass movement created by the 3-nozzle tip at higher oxygen pressure.

DISCUSSION AND RESULTS

Cartridge Life

After implementing the actions, the life of cartridge increased as shown at Table II. For the year 2014 through August, the average life of the Slagless cartridge with a 4-nozzle tip was 579 heats. This value is more than three times the average life of the standard 3-nozzle tip during 2014. After the Slagless technology was introduced and adjustments in DBL were made, cartridge life increased and reached the maximum of the 1428 heats in August 2014. Table II considered all reasons to remove the cartridge included operational, mechanical and electrical causes during the converters operation.

Table II – Average and Maximum Slagless Cartridge Life.

Average l Year	Month	Total
2013	1	45
	6	354
	7	165
	8	132
	9	31
	10	95
	11	364
	12	685
2013 Average		**246**
2014	1	695
	3	385
	4	448
	5	313
	6	1175
	8	1428
2014 Average		**579**
Aver. 2013-2014		**417**

Max. Life Year	Month	Total
2013	1	45
	6	354
	7	165
	8	341
	9	68
	10	95
	11	658
	12	685
2013 Maximum		**685**
2014	1	777
	3	606
	4	891
	5	313
	6	1175
	8	1428
2014 Maximum		**1428**
Max. 2013-2014		**1428**

Considering only reasons related with the cartridge, the average life increased to 856 heats, as shown in Figure 9.

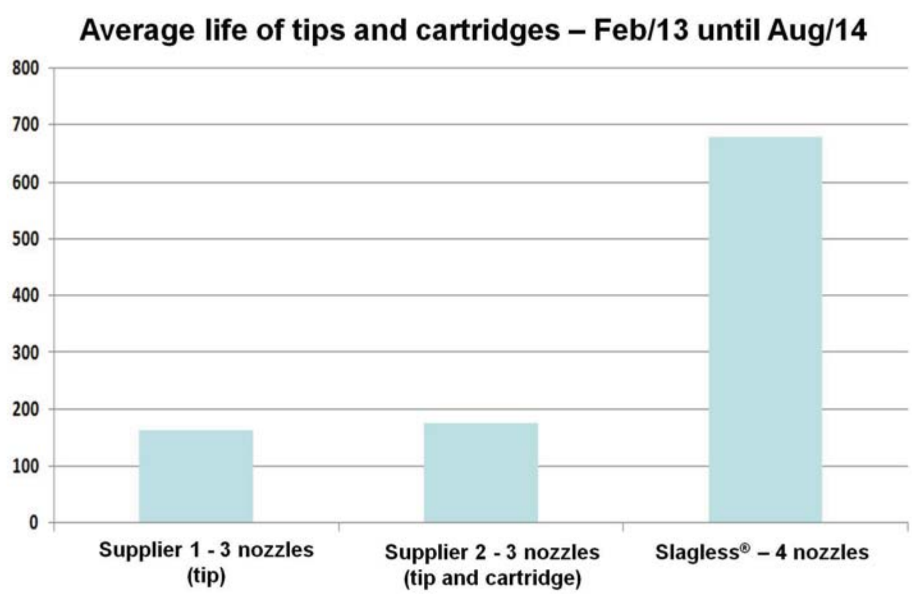


Figure 9 – Average Life of Tips and Cartridges – Feb/13 – Aug/14

Skulls lance formation

At the same time, the lance skull formation was compared as shown in Table III

Table III – Comparative of Lance Skull Formation.

Kind of lance	Conventional Tip	Slagless Cartridge
Heats / skull	**16**	**560**
Skull incidence (Skulls/month)	**78**	**2,2**
Man Power per shift	6 mechanicals (2 per shift)	**0**
Man Power during day	2 mechanicals	**1**

After the introduction of Slagless technology, the heat exchange increased and the copper and steel pipe remained in good condition, avoided maintenance and damage during oxy-cutting to clean lance skulls.

Skulls in dedusting system

Table IV shows the 2-year history of skull events into the OG dedusting system of Steel Plant 1.

Table IV – History of Skull Formation into OG System Between 2011 and 2012.

Converter	Date	Down time (days)	Reason
1	October, 2011	8	Skull between movable and fixed hood
1	February, 2011	5	Skull between movable and fixed hood
3	August, 2011	10	Skull between movable and fixed hood + change hood
1	February, 2012	8	Skull at skirt, working without water and need to change

Like the previous study, after introducing Slagless technology, correcting nozzle dimensions and increasing nozzle angles no failure due skull around hood area was observed. On this point, following the adoption of Slagless technology, OG component parts were changed, water leaks were repaired and skull buildup was removed. The system is working until nowadays with no hood skull occurrence.

Nozzles conditions

As shown in Figure 10, the Slagless tip nozzle conditions were preserved in good order due to two points: more efficient design for the internal cooling system and recalculated dimensions of the nozzles.

Figure 10 – 4-Nozzle Tip Face from Steel Plant 1 with 247 Heats.

In Figure 10 it is possible to see that there is no wear between the nozzles after 247 heats. This means the cooling system is working efficiently. It is common to observe small wear in nozzle exit diameter, mainly in areas near the tip center due to reduced oxygen flow during sub lance operations or slopping in the converter. It is once again emphasized that the correct nozzle dimensions, considering operational fluctuations of flow during blowing, allowed the maintenance of good nozzle integrity.

CONCLUSIONS

The main conclusions are:

a) Slagless technology reduced the incidence of lance skulls by 35 times as compared with the conventional lance;

b) New nozzle dimensions plus Slagless® technology reduced the required manpower and increased the safety conditions due to less lance maintenance, fewer lance changes and fewer dedusting system repairs, all strongly due to reduced skull formation;

c) Slagless technology permits assigning maintenance manpower to other activities with more aggregated value like predictive and preventive maintenances;

d) Continuous developments, such as changing from 3 nozzles for 4 nozzles in the cartridge contributed to increasing the lance life 2 times when compared years 2013 and 2014 when considering all causes;

e) The life of Slagless technology is 4 times more than conventional lance when considering only operational causes;

f) The high life and stable metallurgy of the blow with low slopping and skull formation guarantees good operational conditions for USIMINAS Steel Plant 1 and contributes for high competitiveness.

ACKNOWLEDGMENTS

The speakers of the paper thank Lumar Metals and USIMINAS for continuous incentive in research and developments. Thanks PSJKK Raju and Theodore J. Leczo for comments and language corrections. Bruno Orlando de Almeida Santos, eternal friend.

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