# JSW IMPROVEMENTS IN BOF LANCE BY SLAGLESS CLEAN UP® TECHNOLOGY*

*Breno Totti Maia*[1]
*Bruno Orlando de Almeida Santos (in memoria)*[2]
*Fabrício Silveira Garajau*[3]
*Marcelo de Souza Lima Guerra*[4]
*Wellington Morais de Andrade*[5]
*Raju PSJKK*[6]
*Abhijit Sarkar*[7]
*Veeresh Bellatti*[8]
*Prabhanjan Y*[9]
*Vishwanath SC*[10]
*Sekhar VR*[11]
*Ganapathi Prasad*[12]
*Murthy VSN*[13]
*Dinesh Kumar C*[14]
*Sadanand Naik*[15]
*Navin N Desai*[16]

**Abstract**

Steel Melting Shop One (SMS-I) has 03 BOF converters with 135 tons capacity each. The SMS-II has 04 BOF converters with 180 tons capacity each and SMS-III with 1x160 ton EAF Furnace. India's largest integrated complex intend in the near future to build SMS-IV and will reach 16 million tons of steel per year. The other side, common problems during operations of BOF happens like: Jam's formation of blowing lance and converters mouth with dirty skirt. Efforts are made every day to avoid and reduce these effects and increase productivity and reduce costs. This present paper, the focus was enhanced blowing lance operation, reduction of lance jam and converters mouths jam of BOF shops. A new concept of lance tips was introduced for the same to improve more stable conditions during long life lance tips called "Slagless Clean Up cartridge". The target of this work is shown new conditions to reach like: increase cartridges life, reduce jams around lance and mouth contribute for stable operations.

**Keywords:** BOF; Blow; Cartridge; Tip life; Jam.

[1] *Sócio da ABM; Doutor e Engenheiro Metalurgista Pesquisador Lumar Metals, Belo Horizonte, MG, Brasil;*
[2] *Mestre em Eng. Metalúrgica e Eng.Materiais, Pesquisador da Lumar Metals. Ipatinga, MG,Brasil;*
[3] *Mestre e Eng.Mecânico e Pesquisador da Lumar Metals. Ipatinga, MG,Brasil;*
[4] *Sócio da ABM; Mestre e Eng.Mecânico e Pesquisador da Lumar Metals. Ipatinga, MG,Brasil;*
[5] *Eng.Mecânico Lumar Metals. Ipatinga, MG,Brasil;*
[6] *Mechanical Engineer, Lumar Metals Asia. Hyderabad, Telangana ,India;*
[7] *Mechanical, JSW SMS II. Toranagallu, Bellary,Karnataka, India,*
[8] *Metallurgical, JSW SMS II. Toranagallu, Bellary,Karnataka, India,*
[9] *Metallurgical, JSW SMS I. Toranagallu, Bellary,Karnataka, India,*
[10] *Metallurgical, JSW SMS II. Toranagallu, Bellary,Karnataka, India,*
[11] *Mechanical,, JSW SMS I. Toranagallu, Bellary,Karnataka, India,*
[12] *Mechanical,, JSW SMS I. Toranagallu, Bellary,Karnataka, India,*
[13] *Mechanical, JSW SMS II. Toranagallu, Bellary,Karnataka, India,*
[14] *Mechanical, JSW SMS I. Toranagallu, Bellary,Karnataka, India,*
[15] *Metallurgical, JSW SMS II. Toranagallu, Bellary,Karnataka, India,*
[16] *Metallurgical, JSW SMS II. Toranagallu, Bellary,Karnataka, India..*

## 1 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. JSW – JSW Steel Limited is a producer of 12,000,000 metric tons steel per year, composed of 03 steel shop facilities. Steel Melting Shopping One (SMS-I) has 03 BOF converters with 135tons each. The SMS-II has 04 BOF converters with 180tons each and SMS-III with 160ton EAF furnace. This big integrated complex intend in the near future build SMS-IV and will reach 16,000,000 tons of steel per year. Figure 1 shows the JSW industrial complex.

**Figure 1** – Lay out of JSW industrial complex.

JSW Steel is India's leading private sector steel producer. The converters are equipped with the mainly technologies able around the world and compound a very strong source of information to produce high quality grades of steel.

The other side, common problems during operations happens like: jam's formation around lance and converters mouth, dirty skirt, life of tap hole. Efforts are made every day to avoid and reduce these effects and increase productivity and reduce costs. This present paper, the focus will be in the lance operation, lance jam and converters mouths jam. A new concept of lance tips will be introduced for the same time improves more stable conditions during long life lance tips called Slagless Clean Up cartridge. The target of this work is shown new conditions reach like: increase cartridges life, reduce jams around lance and mouth contribute for stable operations.

## 2 DEVELOPMENT

### 2.1 METHODS AND MATERIALS

OBSERVATIONS BOF OPERATION BEHAVIOR

The first steep consists at analyses average conditions for actual operations, checking values of raw materials, times for each process stage and mainly blow parameters like shown in Table I for converter C in SMS-I and converter D in SMS-II.

**Table I** - Lance dimensions and blow parameters.

| Parameter | SMS-I | SMS-II |
|---|---|---|
| Weight (tons) | 134 | 180 |
| **Lance Diameter (mm)** | **298.5** | **298.5** |
| **Number of nozzles** | 6 | 6 |
| **Nozzles angle (degrees)** | 14 | 14 |
| **Flow (Nm3/min.)** | 420 | 530 |
| **Tap to tap (min.)** | 48 | 55 |
| **Blow time (min.)** | 16 | 16 |
| **Slimness (H/D)** | 1.59 | 1.23 |
| **Specific volume (m3/t)** | 0,92 | 0.84 |

At Table I, it is possible to see the differences between steel shops. The capacity of converter in SMS-II is bigger than converter in SMS-I and the oxygen flow increase to keep the blow time around the same value. In both steel shops, operational routine in lances follow the same standard:

a) Every heat is necessary clean lance's jam. The length of jam is between 1 until 5 meters and can be three types: slag jam, metallic jam and mixer jam, like shown in Figure 2.

a) Slag jam b) Metallic jam c) Mixer jam

**Figure 2** – Kinds of jam's formation: a) slag, b) metallic and c) mixer.

This operations requires minimum two persons that spend around 3.5 minutes to clean by oxicut way and after clean, pait/coat lance with a mixer of water plus lime;

b) The average tip life is around 250 heats;
c) Tip design is over dimensioning that causes nozzles wear;
d) During day between 2 or 3 times is required a machine for mechanical mouth jam cleaning. This operation spend around 23 minutes, like shown in Figure 3.

e) Every heat during tapping steel, 02 persons keeping cleaning mouth's jam, like shown in 

f) Figure **4** .

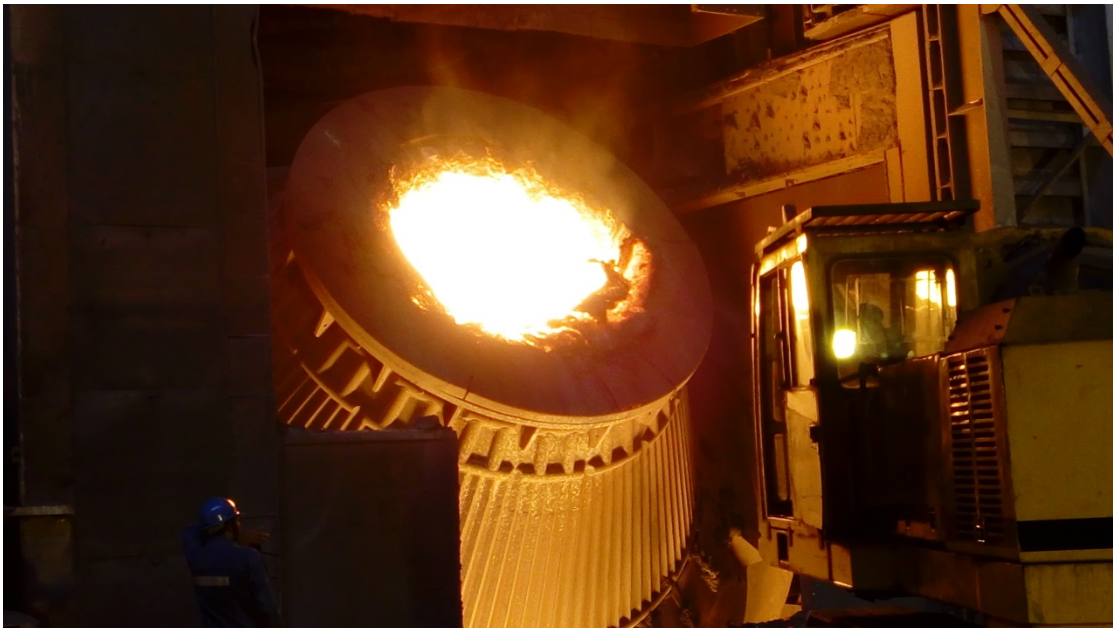


**Figure 3** – Mechanical mouth cleaning.

**Figure 4** - Oxicutting mouth's jam during tapping steel.

### 2.2 ANALYSES

After observed the behavior of two SMS's was made a balance between operational routine and targets to be reached.

#### 2.2.1 JAM'S FORMATION

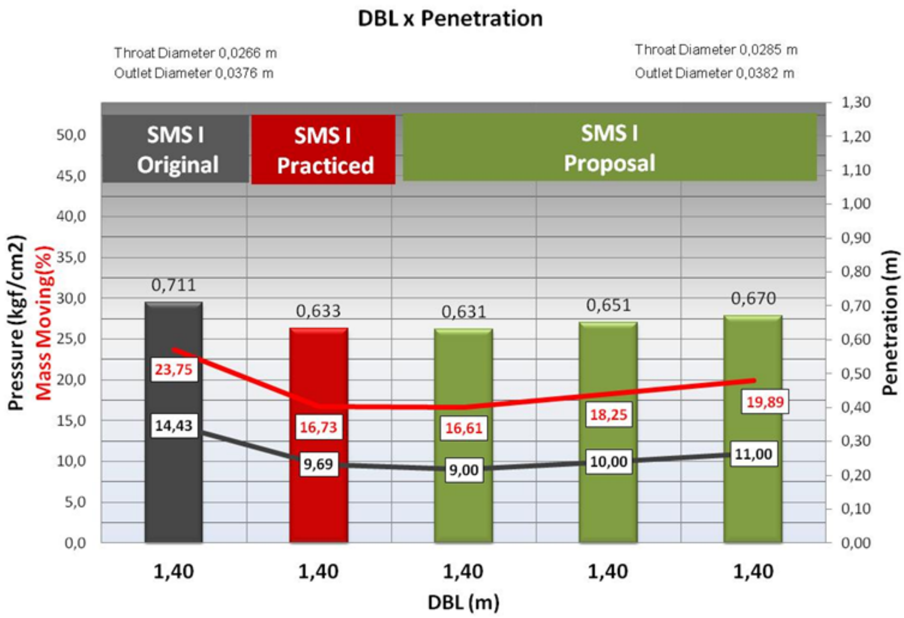
- Slag jam is formed due high Si content in hot metal and necessity to increase lime to keep phosphorous in the slag;
- Metallic jam has your origin at cooling materials added during blow, mainly, iron ore and mill scale. Jam from iron ore has aspects of crispy and jam's from mill scale looks like a thin plain uniform layer around lance. After deslagging practice, metallic jam is common;
- Mixer jam is a combination of both situations above.

Independent of jam's kind the conventional lance requires cleaning every heat.

#### 2.2.2 TIP DESIGN AND BLOW INFLUENCE

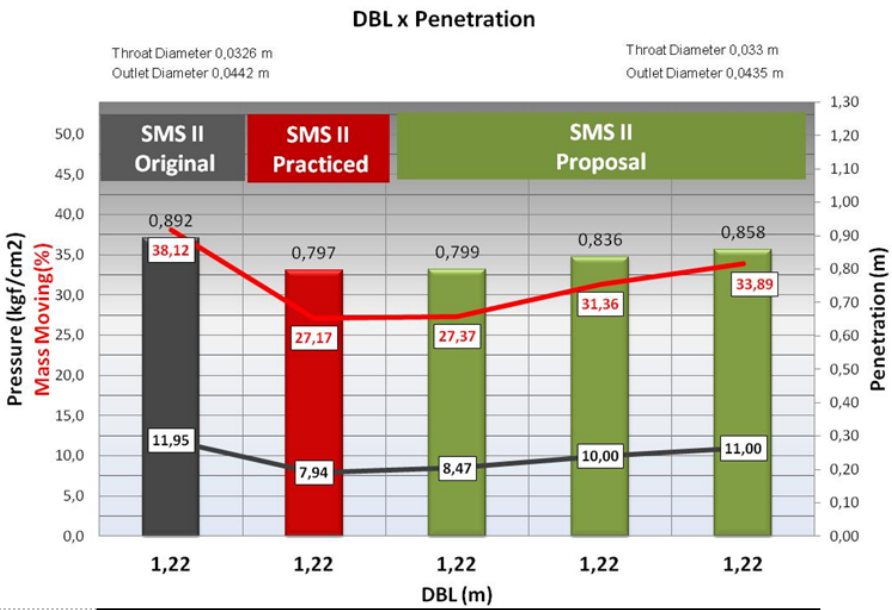
Before to propose some nozzles modifications, the actual conditions was observed and calculations were prepared trying understand effects during blow shown in Figure 5.

In Figure 5, represents the 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)[(1)], Meidani *et al* (2004)[(2)], Alam *et al* (2010 e 2011)[(3,4,5)], as proposed by Maia (2013)[(6)]:




| | | | | | | |
|---|---|---|---|---|---|---|
| Nm³/min | Flow | 450 | 380 | 380 | 398 | 415 |
| Nm³/h | Flow | 27000 | 22800 | 22816 | 23865 | 24872 |

a)




| | | | | | | |
|---|---|---|---|---|---|---|
| Nm³/min | Flow | 575 | 480 | 480 | 516 | 538 |
| Nm³/h | Flow | 34500 | 28800 | 28800 | 30947 | 32253 |

b)

**Figure 5**- Energy balance to check blow parameters influence: a) SMS I and b) SMS II.

$$\frac{\pi \times \rho_g \times V_e^2 \times d^2 \times \cos\theta \times n}{4 \times \rho_b \times g \times DBL^3} = \frac{2}{K_M^2} \frac{P}{DBL}\left(1 + \frac{P}{DBL \times \cos\theta}\right) \qquad (1)$$

Where "$\rho_g$" = gas density at nozzle exit (kg.m$^{-3}$), "$V_e$" = velocity at nozzle exit (m.s$^{-1}$), "d" = nozzle diameter (m), "$\rho_b$" = bath density (kg.m$^{-3}$), "g" = gravity (m.s$^{-2}$), "P" =

penetration (m), "DBL" = distance bath lance (m), "$K_M$" = empirical factor for each kind of nozzle, "$\theta$" = angle between nozzles and vertical, "n" = number of nozzles.

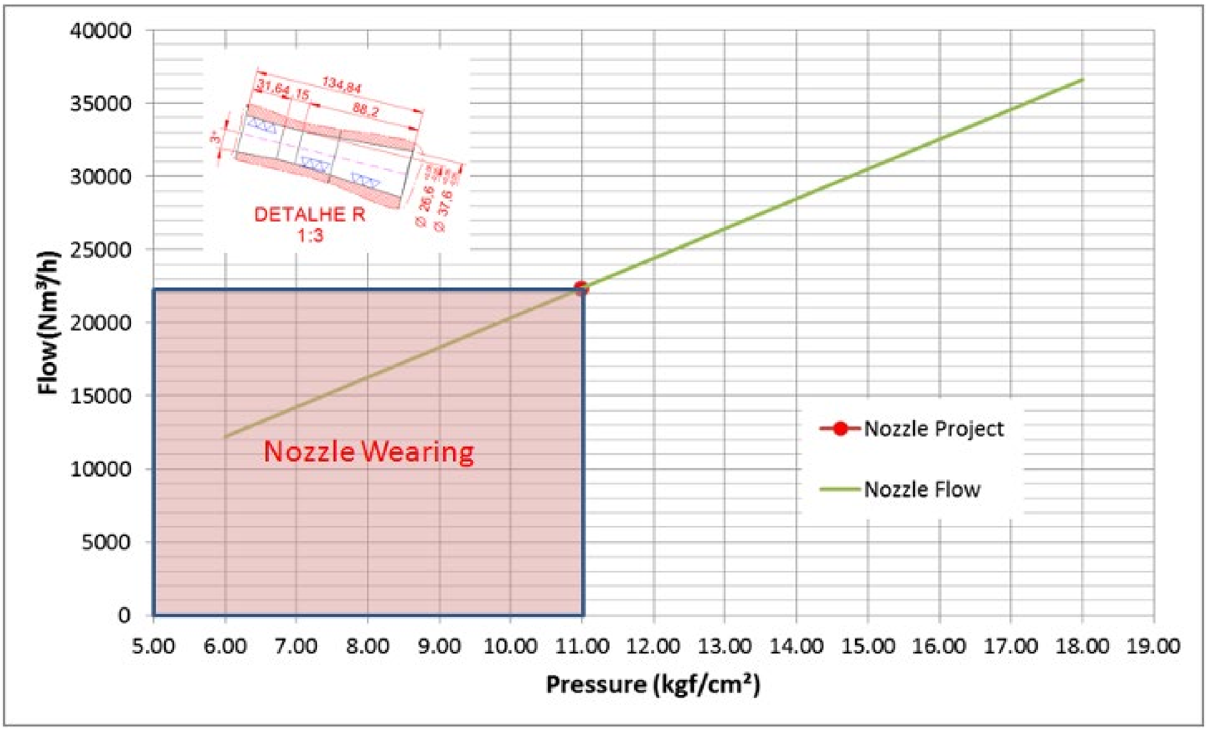
In equation 1, all parameters are kneed. Just factor $K_M$ needs to be empirical determined, but in previous papers Maia (2015)[7,8]used the value 8,3 due cold models developed.

In Figure 5, the gray column represents the jet penetration considering that flow was calculated from oxygen back pressure informed at a fixed distance between bath and lance, called DBL. The results of these calculations are oxygen flow, percentage of mass movement caused for reactions surface and jet penetration. The red column is cross checking that from the flow informed in Table I, oygen back pressure was calculated. It is possible to see a difference between information. Normally in operation, blowers' men follow the oxygen flow, but tip is design to obey the oxygen back pressure.

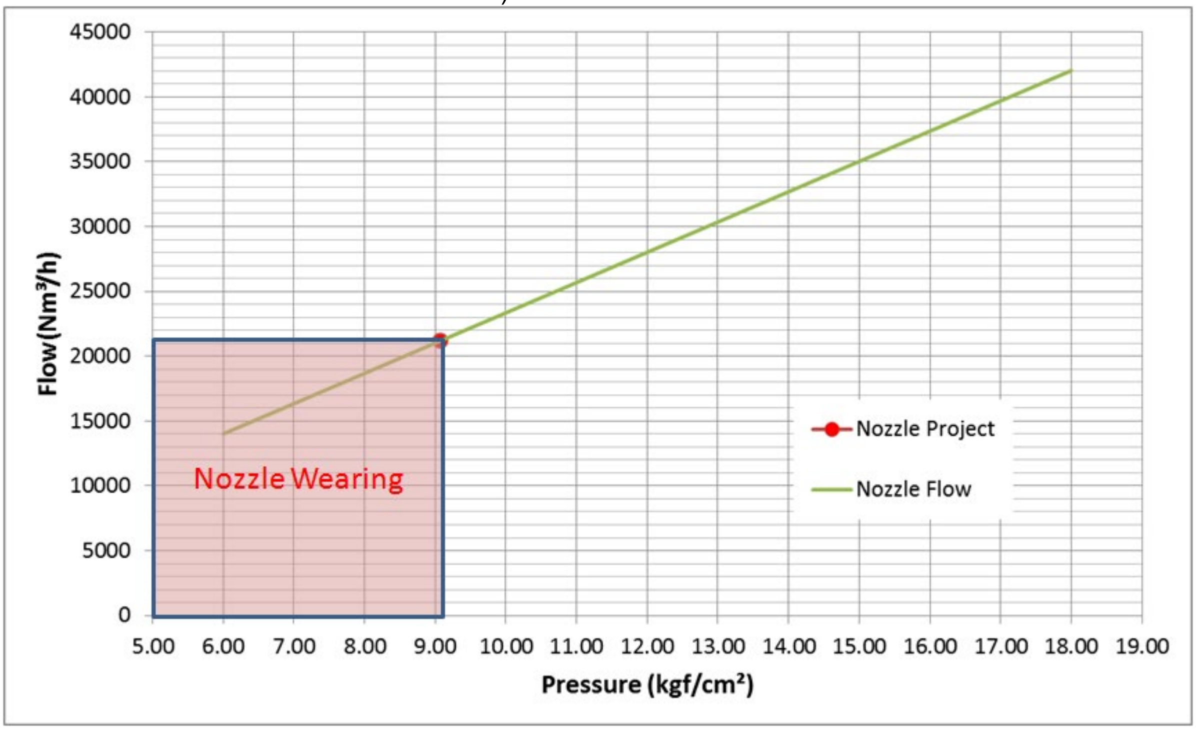
The green columns are conditions for new tip design nozzles dimensions considering the correct back pressure for the flow required and possibilities to increase flow, directly proportional to increase the back pressure. The new nozzles dimensions has target to increase cartridges life and avoid damage in tip face like shown in Figure 6.

**Figure 6** – Tip face photo SMS-I: a) nozzle due over dimensioning for tip, b) Slagless Clean Up after 523 heats.

Figure 7 shows the difference for back pressure effects over tip damage in comparison with conventional and cartridge for SMS I. The red area represents damage around tip nozzles and it is possible to see that conventional lance has the nozzles over dimensions because was used high back pressure and works with pressure below than this.




a) Conventional lance




b) Cartrigde

**Figure 7** - Effects of back pressure at nozzles dimensions for SMS I.

The solution proposed to lances jam is a Slagless cartridge. Slagless®(9) cartridge is designed in high pure copper conical pipe associated with inner particular geometry system for water that permits a effective heat exchange between copper wall and water. This combination, copper plus water system avoid skulls formation due every time force a strong contraction of solid skulls, generating cracks and falling down. Top part of the copper pipe was introduced a post-combustion module, called Slagless Clean Up®. The post-combustion module consists of small nozzles that are designed based on the of converter capacity point directly to the converter cone region.

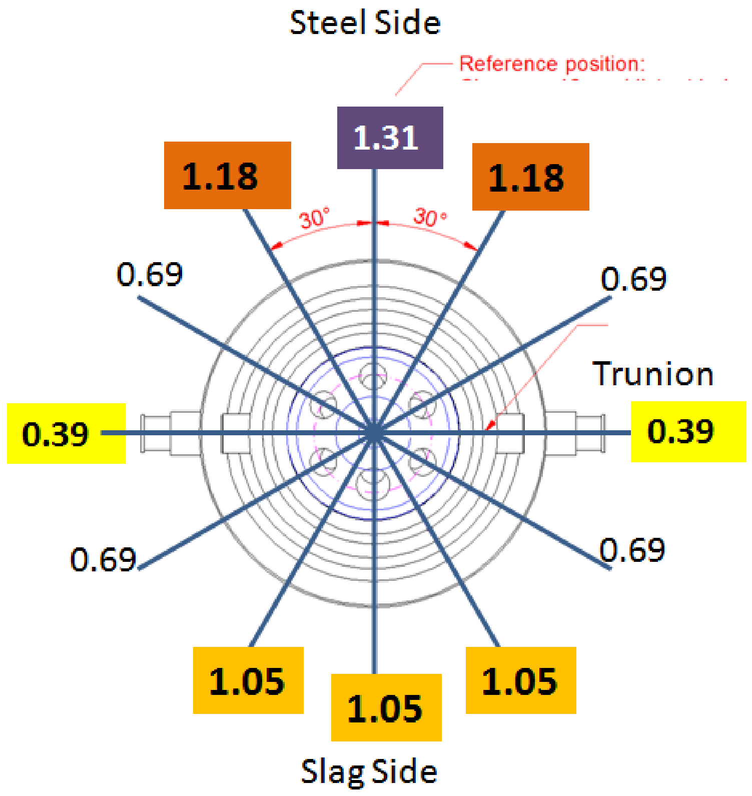
### 2.2.3 MOUTH CLEAN

At the same time that jam sticks around lance, sticks too around mouth. At both SMSs the mouth jam shows the same behavior like shown in Figure 8.

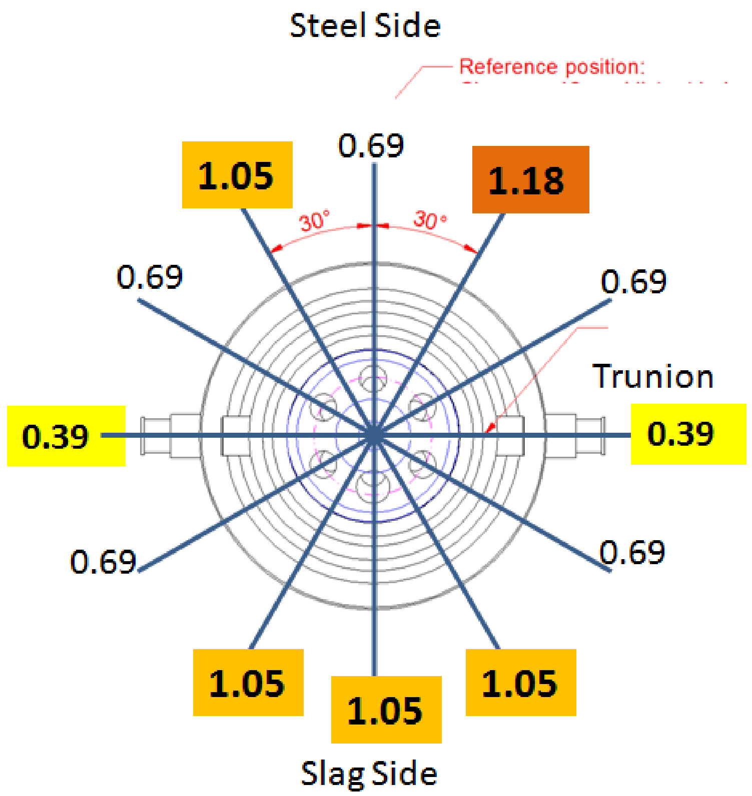
**Figure 8 -** Jam mouth formation before Slagless Clean Up.

Figure 8 it is possible to see mainly three behaviors. Due oxicutting heat by heat the trunnion are keeps clean. The steel tap side directly in front of that tap hole keeps clean but in positions that bath reduce itself volume during taping some amount of jam build up. The slag side all times jam is present due position during tap and the slag isn't able to cut with oxygen. The solution to keep mouth in good conditions to charge hot metal and scrap and easy inspections in refractory's conditions was developed a post combustion above the taper cooper part.

This technology is called Slagless Clean Up. The post-combustion module consists of small nozzles that are designed based on the converter capacity point directly to the converter cone region. For well mouth conditions a first trial was planned with 12 nozzles with same flow distributed around lance. The clean profile behavior was compared and adjustments were made like shown in Figure 9, for each SMS.




a) SMS I




b) SMS II

**Figure 9** - Slagless Clean Up configurations flow in $Nm^3$/min.: a) SMS I and b) SMS II.

## 2.3 DISCUSSION AND RESULTS

### 2.3.1 LIFE

After 06 cartridges for each steel melting shop (SMS) the results are show below. The first important result is cartridges life. Table II shows comparison between Slagless, Slagless Clean Up cartridges and conventional lance average and standard deviation of life.

**Table II** - Average cartridges life for Slagless and Slagless Clean Up for SMS I and SMS II.

| | SMS I | SMS II |
|---|---|---|
| **Slagless** | **691** | **613** |
| **Slagless Clean Up** | **603** | **628** |
| **Conventional (reference)** | 250 | 250 |

It is possible to see in Table II that life of cartridges is most than 2 times in SMS I and 2 times in SMS II when compared with the conventional lance. To reach this life results during heats was important take under control cooling conditions shown in Table III.

**Table III** - Water parameters of cartridges Slagless and Slagless Clean Up.

| Description | Unit | SMS I | SMS II |
|---|---|---|---|
| Inlet water flow | $m^3/h$ | **144 – 157** | **161 – 163** |
| Inlet water pressure | $kgf/cm^2$ | **12,80 - 15,39** | **15,00 - 15,39** |
| Outlet water flow | $m^3/h$ | **145 - 159** | **163 - 164** |
| Outlet water pressure | $kgf/cm^2$ | **3,00 - 3,85** | **3,68 - 3,85** |

In Table III it is possible to see that water flow keeps near same that conventional and in SMS I was a little bit less, but in all cases the pressure values has same values. It means that a special internal cooling design to increase life of tip face was well dimensioned to avoid water drop pressure and a little flow reducing can be made for a design way for water around special shape of the cartridge. Other expects behavior, the increase temperature outlet water, normally more strongly at firsts four heats but near conventional lances after this time.

The increase of cartridge life means save maintenance time to replace the tip and represents more lances able for operation.

### 2.3.2 JAM'S FORMATION

This important target was reached like shown in Table IV.

**Table IV** - Lance jam's formation comparison.

| SLAGLESS | | |
|---|---|---|
| **Heat/jam** | SMS I | SMS II |
| **BEFORE** | 1 | 1 |
| **AFTER** | **100** | **65** |
| **SLAGLESS CLEAN UP** | | |
| **Heat/jam** | SMS I | SMS II |
| **BEFORE** | 1 | 1 |
| **AFTER** | **100** | **56** |

Almost time the cartridge avoid jam's build up. It is common after blow a thin layer of mainly metallic jam keeps sticker in cartridge, but during slag splashing fall or in next blow fall and a new one is formed like shown in Figure 10.

a) Clean Lance b)Thin metallic jam

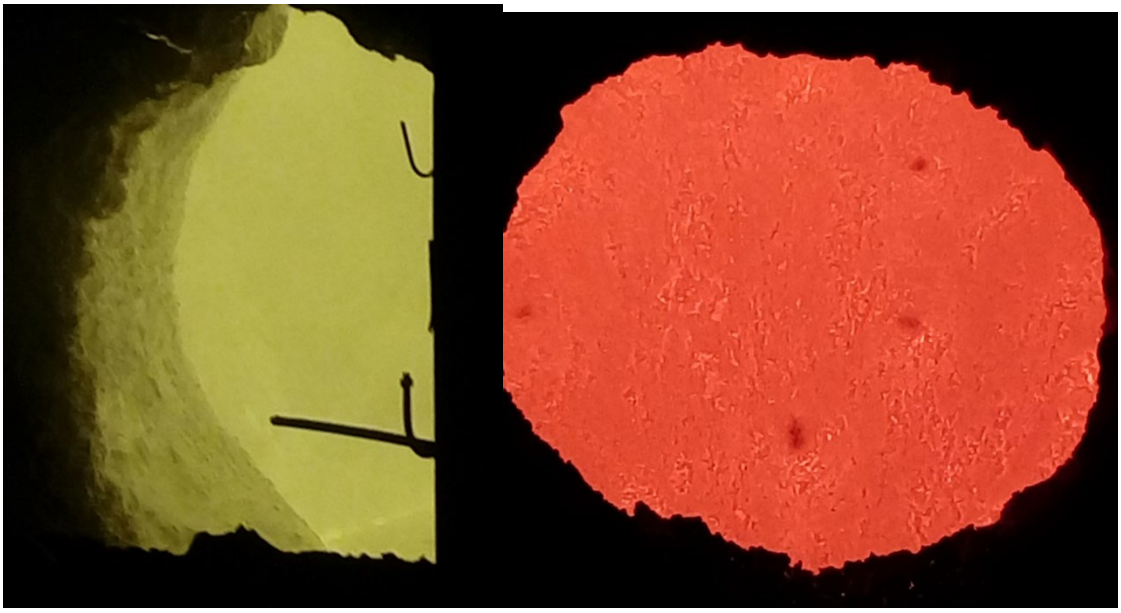
**Figure 10** - Lance comparison.

When jam is mainly slag seconds after end of blow automatically falls. The reason for this behavior is due a special external shape of cartridges and stronger heat transfer coefficient that obey jam a fast contraction, start cracks and avoid stickers around lance.

Table shows to this new behavior save time in process that can represent more productivity in same way that isn't necessary keeps persons to clean the lance every heat. For this conditions blowers man are important to inspect cartridges conditions every heat.

### 2.3.3 MOUTH CLEAN

After work with the slagless clean up the mouth keeps clean constantly and isn't necessary to keep two persons to cutting during every tapping time. Figure 11 shown a comparation before and after Slagless Clean Up.



a) b)

**Figure 11** - Mouth conditions after Slagless Clean Up: a) trunnion side and b) general mouth conditions.

In this figure, it is possible to see that mouth after Slagless Clean Up that jam no build up and keept a small amount of layer material to protect the refractory bricks. Other important observation is slag side, normally a hard place to clean due the behavior of jam's mouth formation the time and amount times to realize an external clean with a machine decrease, like shown in Table V.

**Table V -** Time comparation with external machine mouth cleaning.

| | **Without Slagless Clean Up** | **With Slagless Clean Up** |
|---|---|---|
| **Time to external clean with machine** | 35 minutes | 7 minutes |

The proposal of Slagless Clean Up technology is, more of direct benefits to reduce lance and mouth jam and increase life of the cartridge, to contribute to improve process parameters and contribute to increase production, save costs. This work is more that commercial relationship and buy and sale, but needs a deep spirit of partner and mutual trust. Table VI shown the comparison operational results and short comments obtained at SMS II.

**Table VI** – SMS II comparison results between 24/10/2016 and 14/02/2017.

| Items | Conventional lance tip | Slagless Clean Up |
|---|---|---|
| **Heats blowed** | 705 | **629** |
| **Máx de lance_life** | 313 | **629** |
| **Counter purge_flow** | 667 | **612** |
| **Average HM Si** | 0,509 | **0,504** |
| **Average O2 ppm** | 618 | **674** |
| **Average O2 blowed** | 9454,24 | **9406,95** |
| **Average Slag FeO** | 24,40 | **24,30** |
| **Average Binary Basicity** | 4,03 | **4,22** |
| **Average End Steel Carbon** | 0,0340 | **0,0324** |
| **Average HM charged** | 179,112 | **179,533** |
| **Average Scrap charged** | 4,089 | **4,186** |
| **Average Mill Scale charged** | 2,661 | **2,347** |
| **Average DRI charged** | 3,255 | **3,582** |
| **Average Steel temperature** | 1643,14 | **1654,06** |
| **Counter Slag Splashing** | 591 | **507** |
| **Average Splashing duration** | 2,24 | **2,19** |
| **Counter intermediated Slag** | 254 | **241** |
| **Average Blow Time** | 21,98 | **22,29** |
| **Counter Reblow** | 51 | **43** |
| **Lance Tips / Cartridge** | 3 | **1** |
| **% of heats Deslagging** | 36 | **38** |
| **% of heats with Slag splashing** | 84 | **81** |

At table VI, Slagless Clean Up was compared with 03 lance tips. In this comparison, Slagless Clean Up worked with more Mill Scale and DRI, cooling materials that help jam´s formation and the results were better that in conventional lance like showed at table IV. Blow time was a little bit more but when reblows were much less as end carbon for %FeO in the Slag. Number and time of Slag Splashing reduce too. This permit to create a hypothesis, that refractory bricks in top cone and mouth were well cleaned but without damage, and better, well protect, that permit save 3% time (01 heat) and costs with Slag Splashing time .

## 3 CONCLUSION

The main conclusions are:

a) The Slagless technology increase life and reduce maintenance time most double times;
b) The Slagless reduce lance jam formation to around 100 times at SMS I and 50 times at SMS II;
c) The Slagless Clean Up technology kept mouth conditions to charge for long time and reduce time to mechanical cleaning in around 5 times.

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**REFERENCES**

1 SZEKELY, J. THEMELIS, N. J., Rate Phenomena in Process Metallurgy. 1 ed. Montreal: John Wiley & Sons, 1971. 784p.
2 MEIDANI, A. R. N., ISAC, M., RICHARDSON, A., CAMERON, A., GUTHRIE, R. I. L. Modeling Shrouded Supersonic Jets in Metallurgical Reactor Vessels. ISIJ International, 2004, v.44, n.10, p. 1639-1645.
3 ALAM, M., IRONS, G., BROOKS, G., FONTANA, A., NASER, J., Inclined Jetting and Splashing in Electric Arc Furnace Steelmaking. ISIJ International, 2011, v.51, n.9, p. 1439-1447.
4 ALAM, M., NASER, J., BROOKS, G., FONTANA, A. Computational Fluid Dynamics Modeling of Supersonic Coherent Jets for Electric Arc Furnace Steelmaking Process. Metallurgical and Materials Transactions B, volume 41B, p.1354-1367. Dec. 2010.
5 ALAM, M., NASER, J., BROOKS, G., FONTANA, A. Computational Fluid Dynamics Simulation of Supersonic Oxygen Jet Behavior at Steelmaking Temperature Metallurgical and Materials Transactions B, volume 41B, p.636-645. Jun. 2010.
6 MAIA, B. T., Modelamento Físico e Matemático do Escoamento de Fluidos nos processos BOF e EOF. Belo Horizonte: Escola de Engenharia da UFMG, 2013. 238p. (Tese, Doutorado em Engenharia Metalúrgica).
7 MAIA, B. T, RIBEIRO, A. R., SOUZA, C. A., SANTOS, B. O. A., GARAJAU, F. S., GUERRA, M. S. L. Continous Developments at the Steelplant 1 Usiminas Ipatinga through Slagless Technology. AISTECH Proceedings 2015.
8 MAIA, B. T, SANTOS, B. O. A., GARAJAU, F. S., GUERRA, M. S. L., BARCELOS, H. S., TEIXEIRA, O. A. C. AOD Mouth Cleaning Results in APERAM South America Usina Slagless Clean Up. AISTECH Proceedings 2015
9 SARDINHA, I. A., Slagless Lance Recent Results at BOF Steel Plants Have Shown a Better Flexibility in Oxygen Blowing. Anais do 6th European Oxygen Steelmaking Conference, Stockholm, Sweden, 2011.
10 MAIA, B. T., GARAJAU, F. S., BATISTA, F. S., LIMA, W. R., GUERRA, M. S. L., CARVALHO, D. A. G., TAVARES, R. P. Estudo Trigonométrico para Bocais de Lança de BOF com Múltiplos Jatos. In: SEMINÁRIO DE ACIARIA - INTERNACIONAL, 47., 2016, Rio de Janeiro. Anais eletrônicos. São Paulo: Associação Brasileira de Metalurgia, Materiais e Mineração, 2016. Disponível em: http://www.abmbrasil.com.br/anais. Acesso em: 03/10/2016.
11 GARAJAU, F. S., CETLIN, P. R., GUERRA, M. S. L., MAIA, B. T., MOREIRA, D. A Case Study: Wear in Supersonic Nozzle of Tip Lance in Vallourec Brazil Steelmaking, AISTech. p.1365-1375 2017 Proceedings. © 2017 by AIST
12 ALMEIDA, E. N., ASSUNÇÃO, W., OLIVEIRA, M. F., MAIA, B. T., GARAJAU, F. S., GUERRA, M. S. L., ANDRADE, W., SILVA, W. M. New BOF Performance at Gerdau Ouro Branco by Slagless® Technology. p.1273-1288 AISTech 2017 Proceedings. © 2017 by AIST
13 MAIA, B. T., GARAJAU, F. S., GUERRA, M. S. L., TAVARES, R. P., BALAJEE, S. R., CARVALHO, D. A. G. Effects of Oxygen Temperature and BOF Pressure Under Jet Penetration, p.1327-1334. AISTech 2017 Proceedings. © 2017 by AIST.