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HOT METAL ADJUSTMENT NEW TECHNIQUE DEVELOPMENT BASED ON COHERENT OXYGEN JET*

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Abstract
The hot metal produced in small blast furnaces runs with a highly heterogeneous charcoal. The result is a significantly higher hot metal chemical composition variation, especially for the silicon content, which varies from 0.4 to 1.5% in Mini Blast Furnaces - MBFs, designed to feed an EAF and/or a BOF. These MBFs operate with frequent variation in their productivities to feed preferably only one of the steelmaking reactors, that is, EAF or BOF. The hot metal suitable amount, chemical composition and temperature, to be delivered at the steelmaking vessel, become the major concerns in the integrated operation MBF to EAF or BOF. In order to cope with those undesirable frequent variations, a solution has been proposed based on the existing technologies of oxygen jets and ladle refining techniques adapted to a hot metal ladle or to a Torpedo Car. The proposed technique is not only able to adjust hot metal temperature and chemical composition, but it also generates the adequate conditions for refinement from P and S, as well as "cleaning" hot metal ladles and Torpedo Cars by melting pig iron skulls. Therefore, this new technique development results in high hot metal yield, an adequate chemical composition and bigger campaign of hot metal ladle.
Keywords: Hot metal; Mini blast furnace; Ladle; Torpedo car.

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1 INTRODUCTION

In Brazil there are five small integrated mills operating with the combination of MBFs and BOFs and one with EOF (Energy Optimizing Furnace). For some of them the charcoal made hot metal is delivered at the steelmaking shop in small batches varying from 15 to 80 tons of hot metal ladles. Some small BOFs and EAFs have to receive more than one ladle per heat. For that some mills have the old hot metal mixers reactor and one of them has Torpedo Cars that act as hot metal holding tanks and sometimes mixers. Those options are highly energy and hot metal losers and imply added capital, operational and maintenance costs. The **Figure 1** illustrates the major process demands between the MBF and one EAF typical of those Brazilian units.

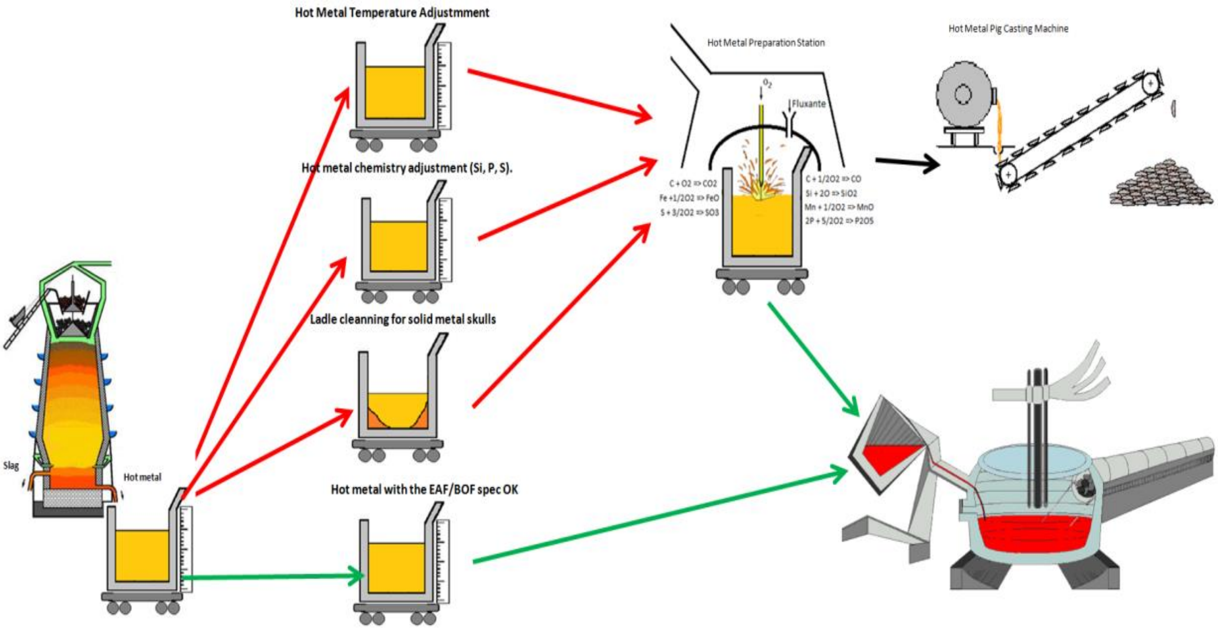

Figure 1- Illustration of a charcoal MBF feeding an EAF ad its major quality goals.

In this specifical situation, when the hot metal ladle is with the necessary specified temperature and chemistry to feed the EAF it goes directly to the EAF's hot metal feeding dock. If the temperature of hot metal is too low or too high the hot metal in the ladle has to be cooled or heated. For cooling, many coolant options are available, e.g., granulated pig iron, scale, etc. If it needs to be heated at a given temperature to reach the EAF hot metal dock specification, O_2 supersonic jet is blown in the necessary amount to bring the hot metal to the desired transfer temperature. Similarly, to what happens at the first minutes of a BOF start of blowing, elements such as silicon are first oxidized to SiO_2 and for that needs to have a kind of lime based flux to better form a slag that will be needed to be skimmed before be sent to the hot metal EAF feeding dock. With increasing blowing time and O_2 amount the carbon start to be also oxidized. All of this results in temperature increase up to the desired value.

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2 MATERIAL AND METHODS

2.1 Thermodynamic of hot metal partial oxidation

The basics behind the proposed development are illustrated on **Figure 2**. The real kinetics of each ladle system is a matter of measurement in the real process that is being constructed to feed EAF and another for a BOF in Brazil.

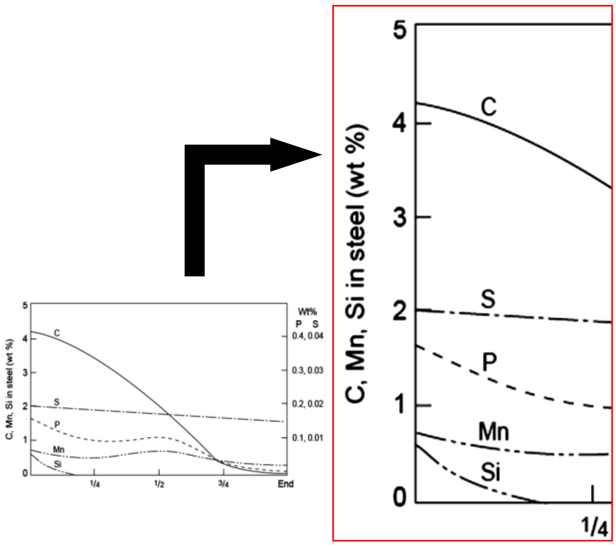

Figure 2- BOF first phase of hot metal oxidation

2.2 Pre evaluation of hot metal ladle heat losses

Only for a matter of preview the potential losses due to radiation and convection of a typical hot metal ladle a heat transfer static model was done to simulate the relative influences of hot metal amount inside ladle, ladle geometries, ladle skull or not and refractories lining. Besides that, in the real existing hot metal for the charcoal hot metal being transferred by ladle to BOFs and EAFs are on the order of 0.5 ^{o}C/min. Those real values will be measured frequently in a real process. Figure 3 illustrates the ladle parameters utilized in the static model. The losses was calculated using the Equations (1), (2) and (3).

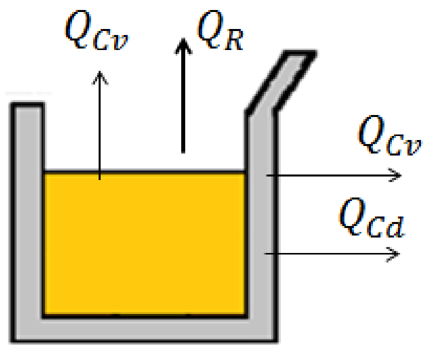

Figure 3 – Hot Metal Ladle heat losses static model illustration

Equation 1 - Heat transfer (Q) by Conduction

$$Q_{Cd} = \frac{k.A(T_{hot} - T_{cold})}{d} \qquad \textbf{(1)}$$

Where, "k" is the thermal conductivity of the material, "A" is the cross sectional area, "T_{Hot}" is the higher temperature, "T_{Cold}" is the cooler temperature and "d" is the thickness of the material.

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Equation 2 - Heat transfer (Q) by Radiation

$$Q_R = \sigma . A . (T_{hot}^4 - T_{cold}^4) \qquad \textbf{(2)}$$

Here σ is the Stefan Boltzmann Constant

Equation 3 - Heat transfer (Q) by Convection.

$$Q_{Cv} = h_c . A . (T_{hot} - T_{cold}) \qquad \textbf{(3)}$$

Where "h_C" is the heat transfer coefficient.

2.3 Hot Metal Oxidation Model

The Figure 4 shows the integrated model input and major output variables for the developed model.

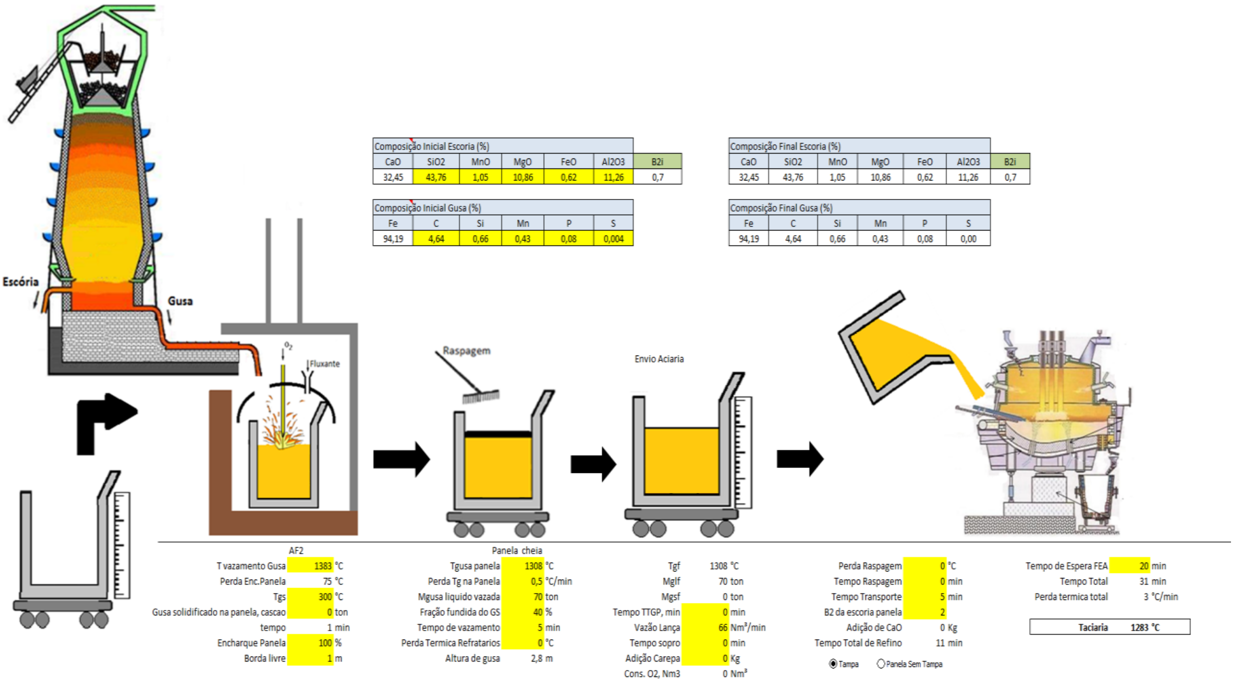

Figure 4- Mini Blast Furnace Hot metal thermal, chemical and logistic tool to feed an EAF.

The developed hot metal treatment model simulated examples for typical occurrences. The minimum temperature necessary to be delivered at the EAF hot metal launder at the moment of feeding into the EAF cannot be feeded due to low temperature of hot metal at the blast furnace. The model was used to study some conditions:

- First Condition (**C1)**: When the hot metal is lower than the minimum temperature necessary to reach the EAF.
- Second Condition (**C2**): When the hot metal is higher than the necessary temperature to be sent to EAF.
- Third Condition (**C3**): When the hot metal is much higher silicon content than accepted by the steelmaking reactor.
- Fourth Condition (**C4**): When the hot metal ladle is with high amount of metal skulls.
- Fifth Condition(**C5**): When the hot metal needs to have its P and S content reduced.
- Sixth Condition(**C6**): When you need to hold the hot metal for a long time in the ladle (breakdown).

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2.4 The O2 Supersonic Jet

Traditional hot metal refining for sulfur and or phosphorous normally utilizes refractory lined lances that penetrates into the hot metal to deliver the necessary reagents, gases and also to supply the necessary mixing energy. This proposal goes towards the use of O_2 supersonic lance for jet penetration into the hot metal in depth enough to deliver the necessary partial oxidation and mixing thus eliminating the traditional consumable lances.
To perform the proposed tasks an appropriate O2 lance design needs to be done and with the necessary flexibility for different amounts of hot metal in a given ladle. The hot metal free border becomes a relevant ladle design's parameter.

2.5 FlexOx Lance

To achieve the hot metal bath and obtain the necessary penetration to occur combustion reaction with the silicon and to promote an environment at high temperatures with the objective to maintain or raise the temperature of the hot metal and/or ladle refractory, also known as soaking temperature, developing suitable lance is required. The Lumar Metals developed the technology called FlexOx Lance as shown in Figure 5.

Figure 5 - FlexOX for Hot Metal Ladle.

The equipment of Figure 5 is composed of cooling tubes on face of injector, secondary oxygen pipe, gas pipe and main oxidizer oxygen tube. For the reason of maintaining the temperature of hot metal ladle is used the burner mode power ranging from 0.5 to 1.5MW. For refining function, the main oxygen tube is provided at its end supersonic nozzle configuration, with the final speed or Mach number determined by available oxygen pressure. Depending on the application the FlexOx will have a refrigerated shirt made with cooper protecting the pipe to the connection. For heating the Torpedo Car has a unique design, Hammer Shark, as shown in Figure 6.

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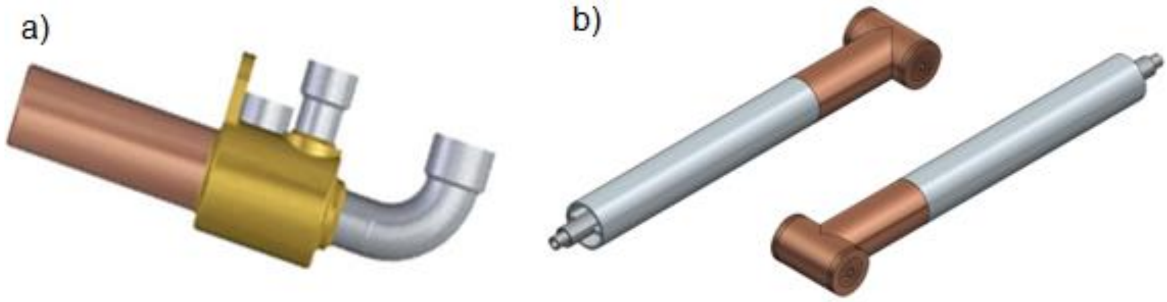

Figure 6 – a) FlexOx refrigerated shirt b) Hammer Shark

2.6 Coherent Jet

The coherent jet is the use of a fuel gas such as NG or LPG, to promote an engaging flame in supersonic jets of oxygen. Figure 7 shows a picture of Coherent Jet, obtained in laboratory.

Figure 7 – Coherent Jet (VIANA, 2003)

The fundamental concept of this technology is linked to the design of lance and its beak to give coherence to the supersonic jets of oxygen through the protection flame formed by oxygen and LPG or NG. Therefore, they retain their original features for a distance greater than that presented by jets originating conventional nozzles. This allows control of the breath with a penetration force in the bath that gives the process greater flexibility and stability.

3 RESULTS AND DISCUSSION

After simulations in the model, considering the value of reason CaO/SiO_2 was fixed at 2.0 and the DBL 1m. The results were:

Table 1: Results of simulations

Condition	Temp. MBF (°C)	Temp. T_0 (°C)	DBL (m)	% Si initial	Time to blown (min)	Mass FeO (Kg)	%Si end	Temp. T_{end} EAF (min)	Tap to tap MBF-EAF (min)
C1	1350	1280	1	0,66	3	0	0,41	1303	28
C2	1400	1330	1	0,66	0	500	0,53	1298	22
C3	1300	1230	1	1,50	10	0	0,67	1301	60
C4	1370	1300	1	0,66	5	0	0,25	1296	32
C5	1370	1300	1	0,66	4	1000	0,06	1305	45
C6	1370	1300	1	0,66	7	0	0,07	1285	120

Temp MBF – The temperature of hot metal during the tapping;
Temp. T_0 – The temperature of hot metal in the ladle;
DBL – Distance bath lance
Mass FeO – Mass of iron scale added.
Temp. T_{end} EAF – The temperature of hot metal ready to tap.
Tap to tap MBF-EAF – the time spent between the tapping of MBF to the EAF.
On Figure 8 shows what is the penetration and DBL.

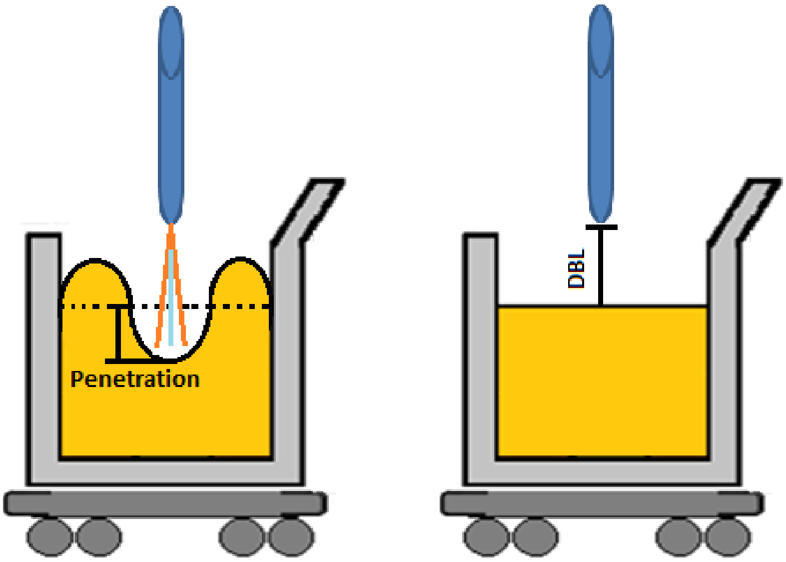

Figure 8 – Penetration and DBL

For the safe conditions and a ladle with capacity of 70 tons, the supersonic nozzle model was designed for a flow 67Nm³/min @ 5kgf/cm². The flow rate was kept fixed due to the free edge of hot metal. During the filling of the ladle, the effect of distance bath lance (DBL) as shown in Figure 9.

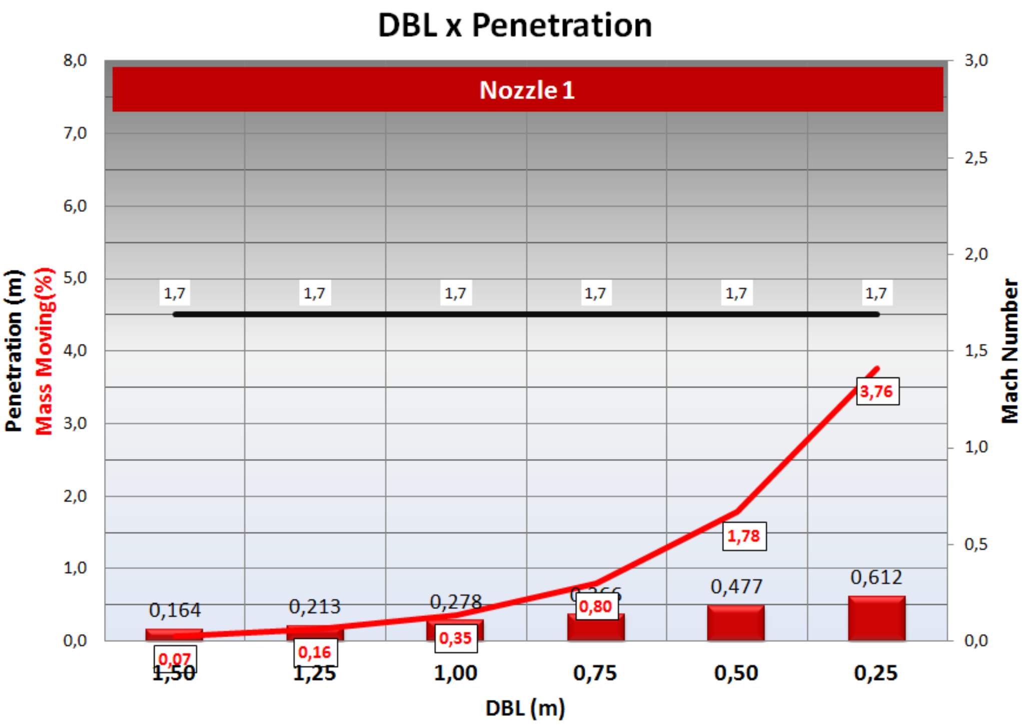

Figure 9 – Penetration and Mass moving (Inject mode)

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Figure 9, the abscissa axis shows the distance from the nozzle to the bath. The black line shows the Mach number, the red columns represent the penetration of the jet into the liquid hot metal bath and the red line is the busy hot metal mass or displaced by the penetration jet of the bath, according to Equation (4).

Equation 4 - Penetration and Mass moving

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

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.

It was considered in this study, the injector in burner mode, operating in conjunction with injector mode and providing a temperature around the main jet 1000°C changing the jet behavior, as shown in Figure 10.

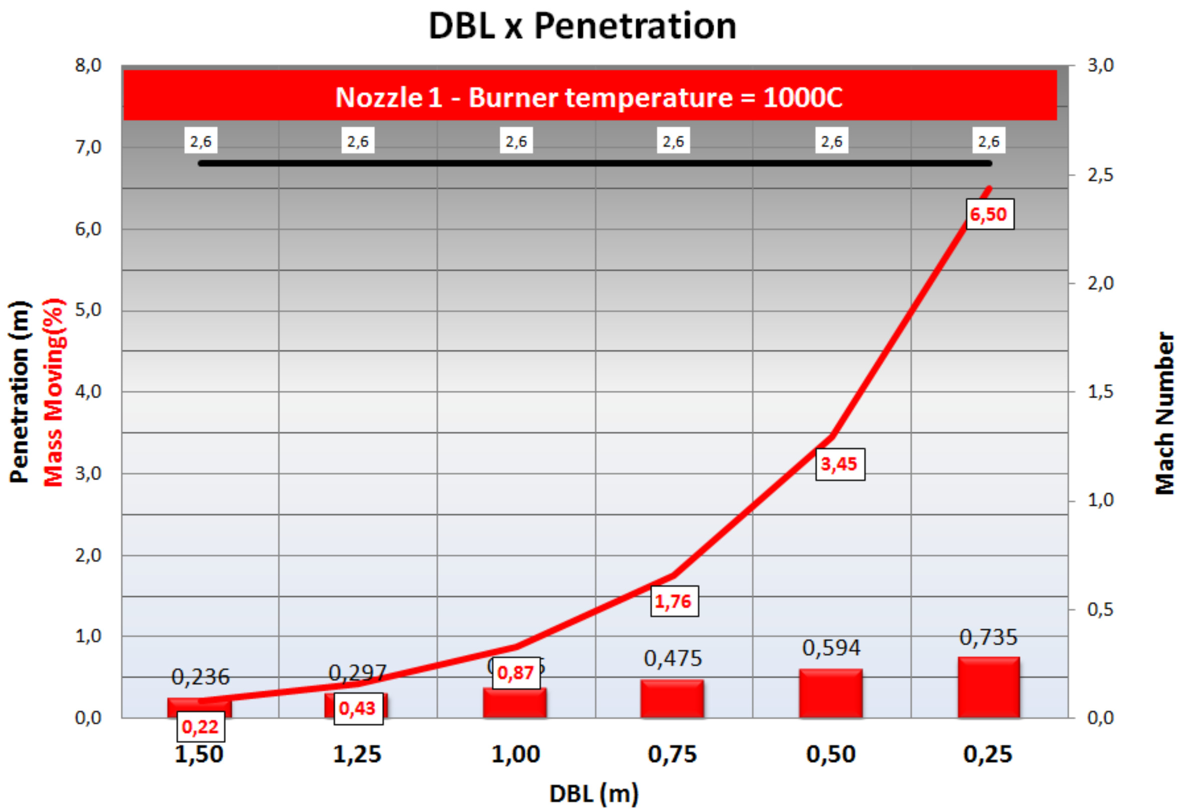

Figure 10 – Penetration and Mass moving (Burner + Inject mode)

Is possible to note in Figure 10 an increase in the penetration and mass movement caused by the effect of increasing the temperature around the jet. This fact is due to the decrease in density around the oxygen gas jet, increasing differential pressure before and after the supersonic nozzle, increasing the Mach number and the energy transferred to the bath.

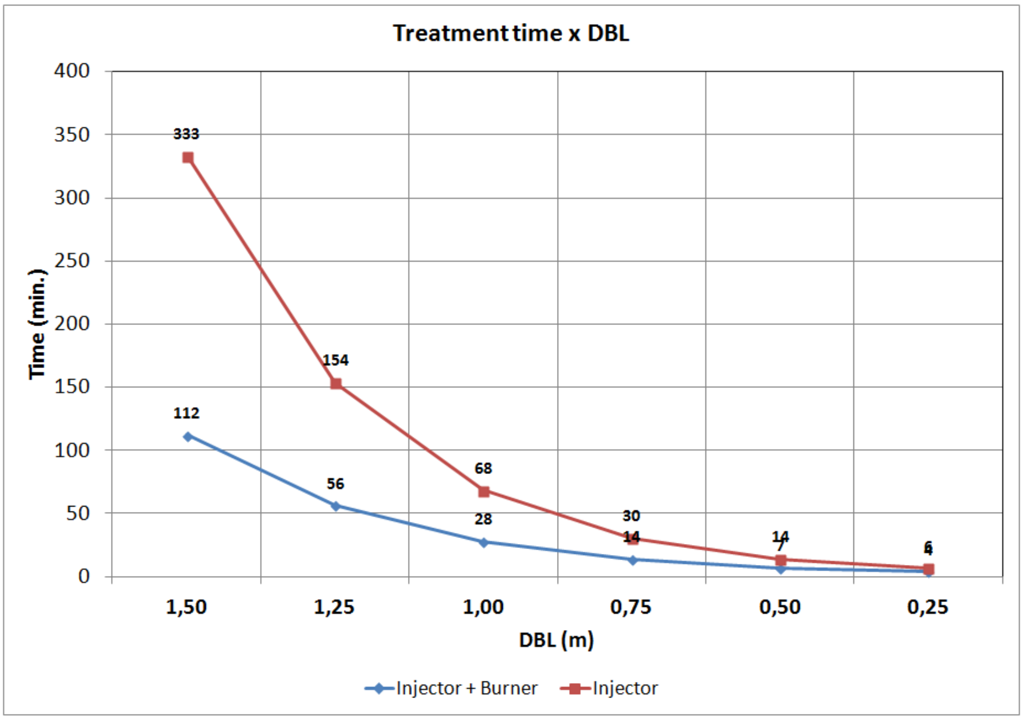

Figure 11 – Time of treatment x DBL in different modes: Injector and Injector + Burner.

Analyzing the Figure 11, is possible to note that the Burner mode contributes to the increasing of penetration and reduce the treatment time. In this simulation the silicon content was reduced by 0.5%.

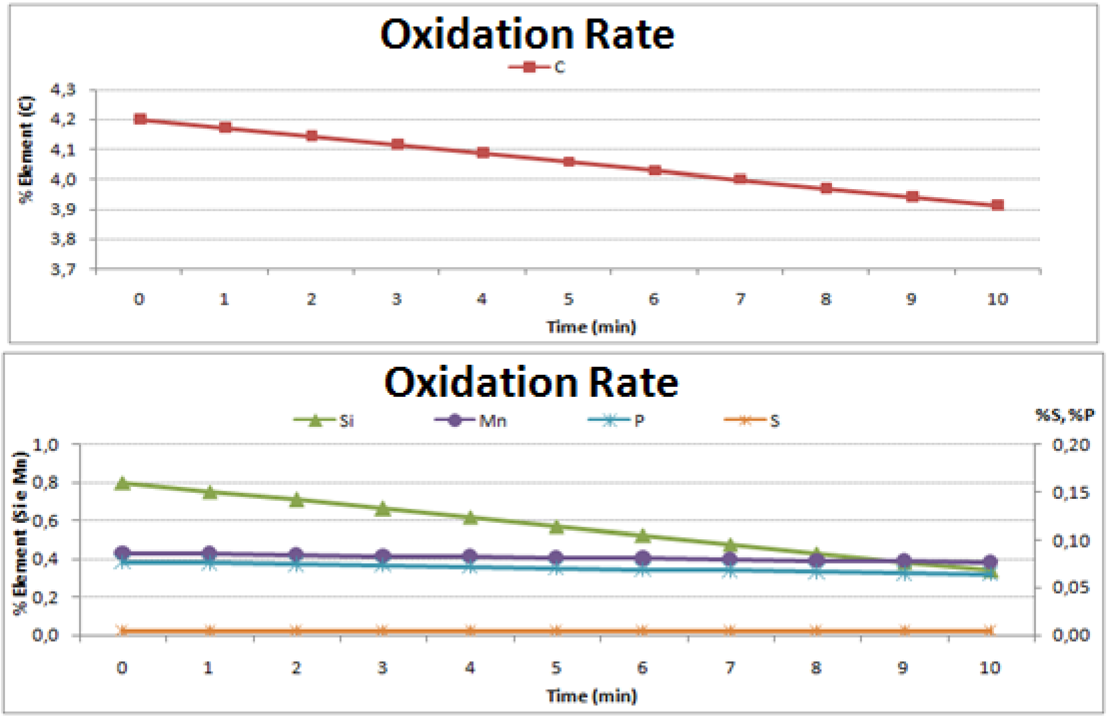

Figure 12 – Oxidation rate x blown time

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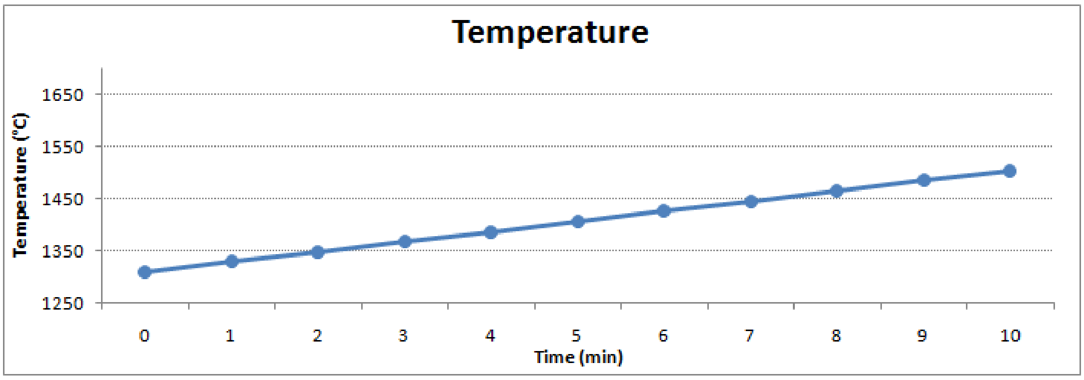

Figure 13 – Temperature increase vs blown time

4 CONCLUSION

Based on existing process and technologies a simple technology was proposed to optimize energy and metallic yields between the Blast Furnace and the steelmaking reactor and also to improve the synergies between the reduction and refining areas of a small integrated steelmaking mill.
The use of oxygen supersonic lances with additional features, design to cope with lime / flux powder injection to slagging and hot metal refining, if needed, became possible reduce the hot metal stock in Torpedos Car and Ladles to feed the steelmaking reactor with the maximum use of the hot metal produced.
The added features of the process improve the existing skull removal method to clean hot metal ladles and torpedo cars resulting in high hot metal yield and bigger campaign of hot metal ladle.
The proposed process combinations also permit hot metal refining for P and S.

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