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Original Article

EOF cold model-study of bath behavior

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ABSTRACT

The EOF reactor was developed in Brazil in the eighties with unique features. The preheating of scrap and distribution of injection points oxidizing gases and fuels make up these features. This paper aims to reproduce the behavior of the metal bath an EOF of 45 tons comparing their top three gas injection equipment: supersonic lances, atmospheric injectors and tuyeres. The lances and tuyeres promoted greater agitation of the bath with atmospheric injectors a great opportunity for improvement.

1. Introduction

According to KORTEC (1986) [1] manual, the traditional “Open Hearth Furnace”, depending exclusively on the fuel used to produce heating energy, had their limit prospected. The process then called “KORF – KORF OXI-REFINING FUEL” was an integrated system involving changes in the Siemens-Martin (Open Hearth) structure, changes in the coating of furnaces and changes in the methods and practices operation through a combination of regenerative processes and pneumatics. One of the key parameters was increased hourly productivity, approximately double, as a result of the reduction of cycle time. With the shortening of tap to tap, heat loss was reduced as well as the need for fuel, helping to increase the competitiveness of steel with reduced operating costs. With the fundamental principles of KORF, new developments have been made in Pains’s plant, resulting in EOF (“Energy Optimizing Furnace”), an oven with great flexibility in the process. Fig. 1 shows a schematic view of the first EOF.

In Fig. 1, according with the Catálogo da Companhia Siderúrgia Pains [2], it can be seen that the EOF originally had stages of preheating scrap indicated by numbers 1–3. Each step of preheating is a heat to be processed in the primary refining. In the design, the EOF had a system to pre-heat the air (N°. 10), helping the afterburner injectors (N°. 5) that could also be enriched with oxygen blow (N°. 9). It was possible to recarburate the bath by injection of carbon (N°. 8), or

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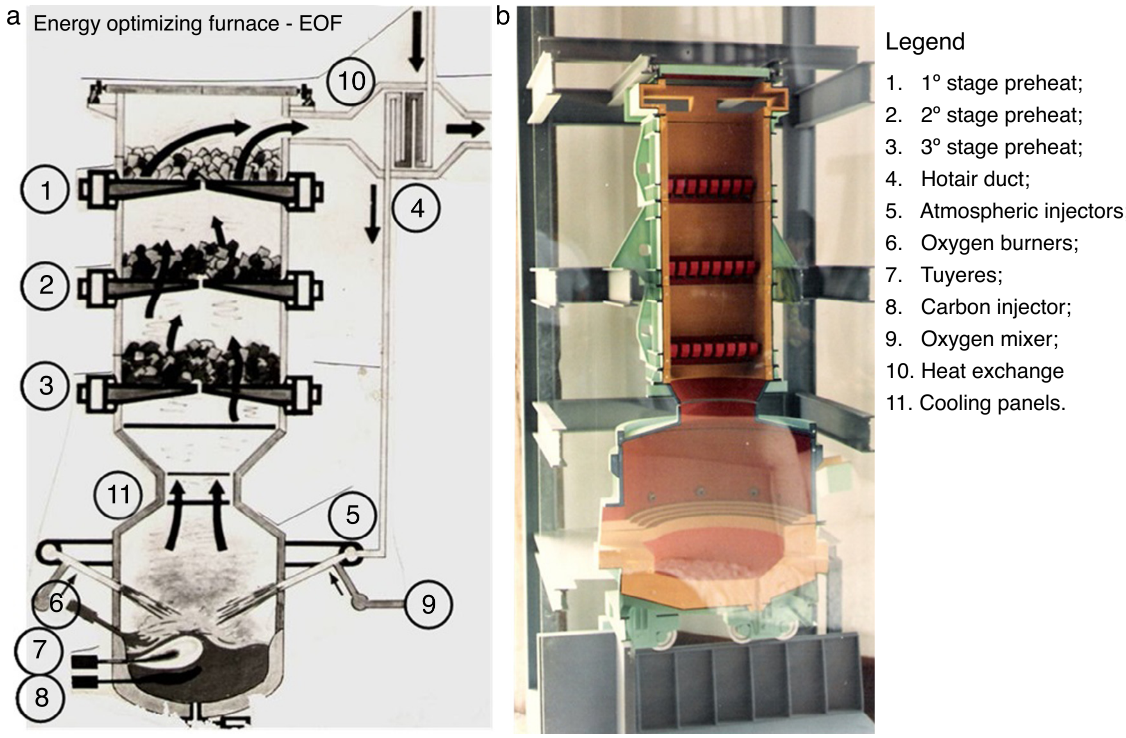


Fig. 1 – EOF conception: (a) Draft and (b) model (catalogue of Companhia Siderúrgica Pains, 1978) [2].

otherwise increase the decarburization through tuyeres (N°. 7). A major advance in the process was the inclusion of oxygen burners (N°. 6), which contributed to accelerate the oxidation reactions of the bath. Above the refractory line, all the way of the combustion gas, is contained by cooled panels (N°. 11). After recovering the energy to preheat the scrap, the remaining energy is still utilized in the heat exchange (N°. 10) to preheat the air also for post-combustion. From the original configuration to the current, many changes were made both with respect to the functionality of equipment and mainly on the concepts used face the real possibility of gain of this steel reactor, as will be explored further. The EOF – "Energy Optimizing Furnace" currently uses only one scrap preheating stage, simple and efficient with gas produced in the process through 8 injection points of oxygen in 3 different ways in the liquid pig iron with scrap [3].

2. Methodology

The experiments were conducted in the physical model of the "Laboratório de Simulação de Processos" (LaSiP) of the School of Engineering at UFMG. The cold model was made in scale 1/6 of plexiglass in comparison to 45 tons tap steel EOF furnace. The EOF geometry is complex, made for two pieces of plexiglass like showed in Fig. 2.

In Fig. 2, the crucible comprises a cylindrical base and above an inverted truncated cone. The dome also consists of a cylindrical base and above it a truncated cone. The geometry of the crucible was inserted into the slag door or "barrado" and the steel pouring channel, while the dome holes were included which represent the locations of oxygen injection

Table 1 – Dimensionless number to EOF cold model.

		Supersonic lances	Atmospheric injectors	Tuyeres
			Industrial	
Fr*	#	0.11	9.511E−05	4.56
Re*	#	2.803E+05	1.825E+05	1.879E+05
We*	#	2.028E+03	2.727E+01	2.509E+03
			Cold model	
Fr*	#	0.11	7.064E−04	4.83
Re*	#	8.419E+04	4.810E+04	6.280E+04
We*	#	1.606E+03	5.116E+01	2.573E+03

and exhaustion of gases. It can be seen that the holes are located asymmetrically. This is necessary in the manufacturing process. Thus, to represent the process the arrangement of holes for insertion of the air guns in the physical model is shown in Fig. 3.

In Fig. 3, points 1, 2, 3 and 4 are the positions of atmospheric injectors. The atmospheric injectors are stationary and low penetration in the bath. Points 5 and 6 are related to supersonic lances that have movement forward and backward in addition to sufficient pressure to form a cavity in the metal bath or decarburization basin. A photo of the assembled apparatus is shown in Fig. 4.

The dimensionless numbers considered to ensure the similarity of the system are presented in Table 1 and the test matrix in Table 2 in according to the developments cited by Barbosa [4] and Carneiro [5].

According to the test matrix of EOF, the passing liquid throw slag door was collected. The volume of water, representing the metal loss in the slag door was quantified in milliliters.

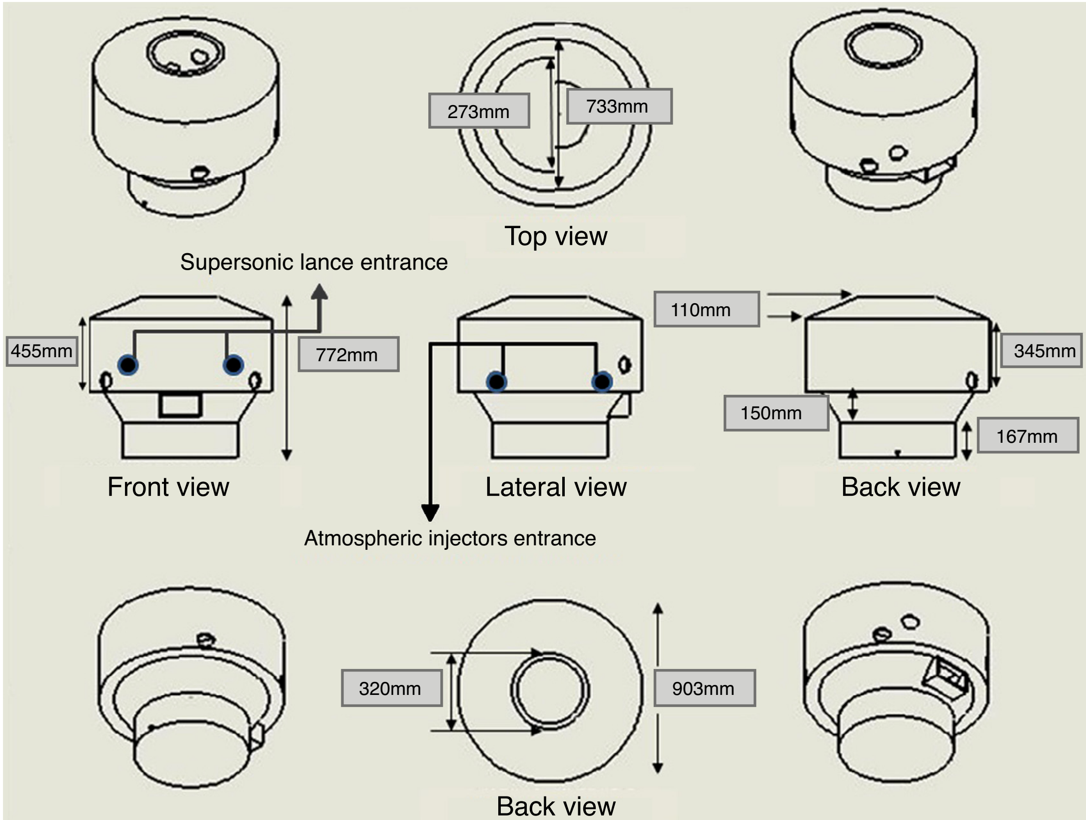
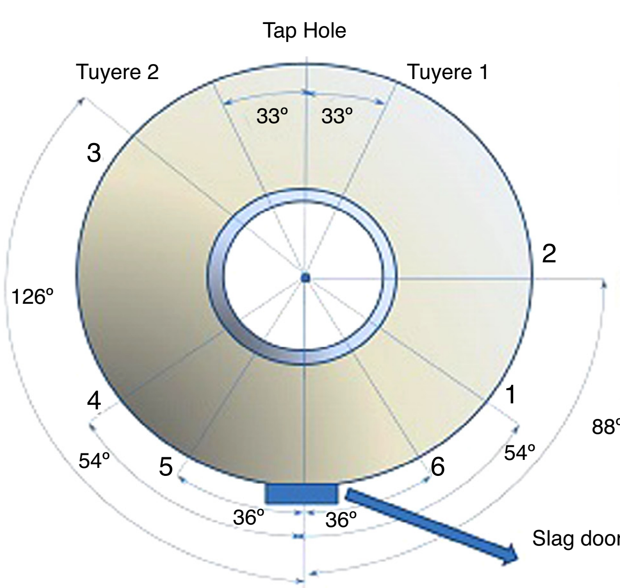


Fig. 2 – View and dimension of the EOF furnace physical model.

The collection time was a factor influenced by the configurations tested, so the volume found was divided by the time, generating an average rate of fluid loss.

In all tests, caustic soda was added in water. It was considered the time since from the compressor activation, achievement of stability in maximum capacity, added a solution of phenolphthalein until homogenization in pink color at the bath. This was an alternative method used by Maia [6] and Diaz et al. [7], to measure the mixing time in turbulent environments.

To determine the mixing time, during testing, phenolphthalein was added to the static bath and then the points of air injection were triggered. With the activity profile achieved, it was added 50 ml of caustic soda solution 0.2 g/ml. The mixing



Equip.	#	Vertical an gle (°)	Distance bath lance (m)
Injector 1	1	35	0.333
Injector 2	2	30	0.450
Injector 3	3	35	0.425
Injector 4	4	30	0.433
Supersonic 1	6	23	0.066
Supersonic 2	5	25	0.066

Fig. 3 – EOF cold model and injector's position.

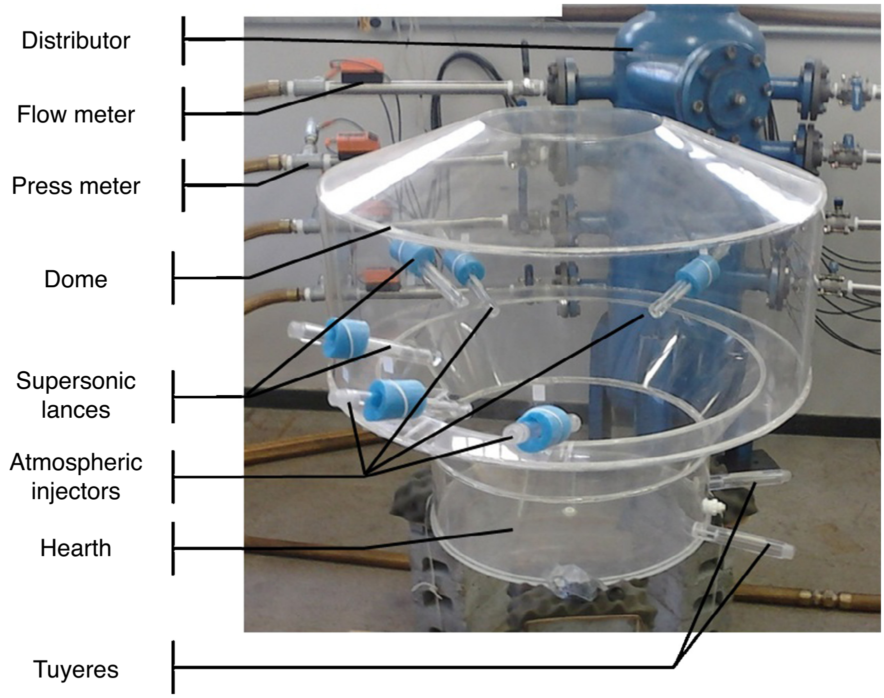


Fig. 4 – EOF apparatus for cold model.

Table 2 – Experiments array to EOF.

Supersonic lances (#)			Atmospheric injectors position	Tuyeres (#)
0	1	2	1-4	0
				1
				2
			2-3	0
				1
				2
			1-2-3-4	0
				1
				2

time was determined when the entire volume of water in the reactor changes from colorless to pinkish as shown in Fig. 5.

3. Results and discussion

3.1. *Bath behavior*

The EOF as described was designed so that the decarburization reactions were carried out through the mechanism of diffusion of carbon from the atmosphere to the oxidant liquid bath above the slag. The equipment also had oxygen burners to accelerate scrap melting. With the enhancements were introduced supersonic lances that produced a reduction in distance lance-bath through its movement into the reactor,

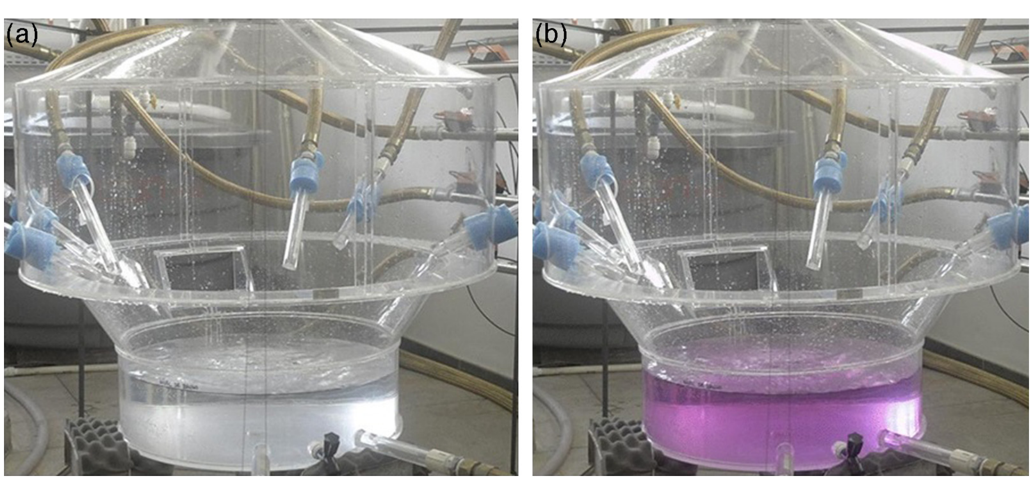


Fig. 5 – Colorimetric method. (a) Water plus phenolphthalein and (b) Water plus phenolphthalein plus caustic soda.

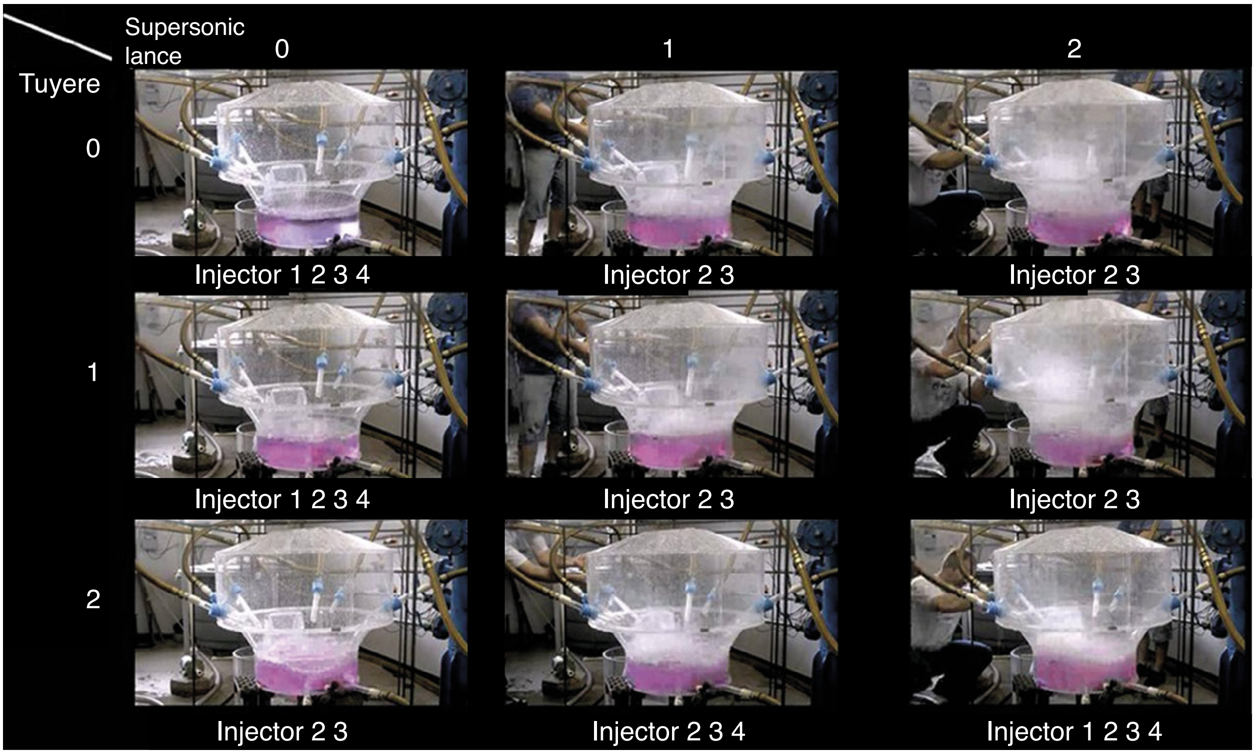


Fig. 6 – EOF movement profile with all injectors.

but also due to the considerable increase in the speed of oxygen.

Nowadays, the EOF has eight points of oxygen injection being two points submerged in liquid bath through tuyeres, four points through the injectors atmospheric, which has low penetration in the bath due to the character of post-combustion, and two points with supersonic speeds and large proximity to bath through the lances with forward motion. However, the discussion is in the amount of oxygen, about 70% applied in the four atmospheric injectors for energy during the post-combustion, given the need to increase the rate of decarburization of the bath. After nearly three decades since its start-up, it is believed that this is an unprecedented study to describe the behavior of the liquid bath in this reactor.

Depending on the test matrix, the analyses were carried out on two conditions. The first analyzing the presence of all the injectors in operation and the second only in pairs. Fig. 6 displays a frame image, from left to right tests with the increased use of supersonic lances and bottom upwards the increased use of tuyeres. Below are presented the four injectors that were in operation.

During execution of the test matrix shown in Fig. 6, it was found a standard drive joint bath characterized by a rotation in a counterclockwise direction. The behavior observed during tests was described by Lee et al. [8] in previous work. The bath liquid showed light waves rotation in the counterclockwise direction without the formation of pits (dimpling), as shown in Fig. 7.

With just one tuyeres, it can be seen bubbling close to the center of the furnace and the incidence of gush. The tuyeres enhance the speed of the bath. The air injected through tuyeres causes a reduction in apparent density of water in this region. The liquid alongside with greater density force to the flow direction of the densest to least dense in the counterclockwise direction. Fig. 8 shows the behavior of the interaction of tuyeres with the metal bath.

In Fig. 9, with the input of only one supersonic lance is possible to notice the penetration in the liquid bath and the initial formation of a deep pit, formed by the penetration of the jet. The plunge of mass moved with the formed wave with the hole is toward the center of the furnace.

It was prepare a matrix considering a pair of injectors like showed in Fig. 10. One difficulty faced during the execution of the experiments was to ensure orthogonality between the supersonic jet and the surface of the bath. The setting was not prepared to contain the high speeds applied at the point. This change was reflected in the behavior of the bath. With increasing supersonic lances and tuyeres, the movement of the bath is enhanced by reducing the mixing time.

In Fig. 10, the behavior was similar to that of the bath with the use of all the injectors and again showing the preponderance of supersonic lances and tuyeres in bath motion and, as seen earlier in the mixing time.

During the execution of the test matrix to determine the mixing time in EOF by the colorimetric method, we prepared a device for collecting the bath that was going through the slag door. The collected volume was divided by the test time, resulting in an average loss. The results of this evaluation are presented in Fig. 11.

Fig. 11 shows that the greatest loss occurs with the use of the two supersonic lances. The behavior expected was that the rate was higher with two tuyeres in operation. The tests were

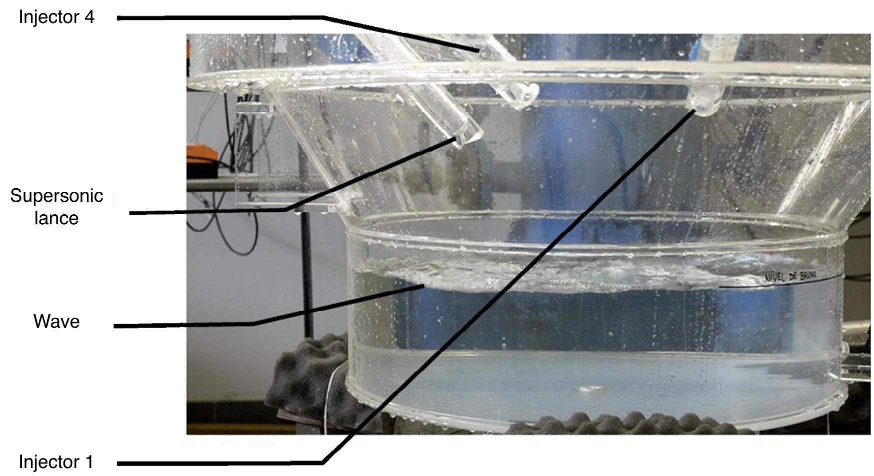


Fig. 7 – Interaction behavior between injectors and liquid bath into EOF.

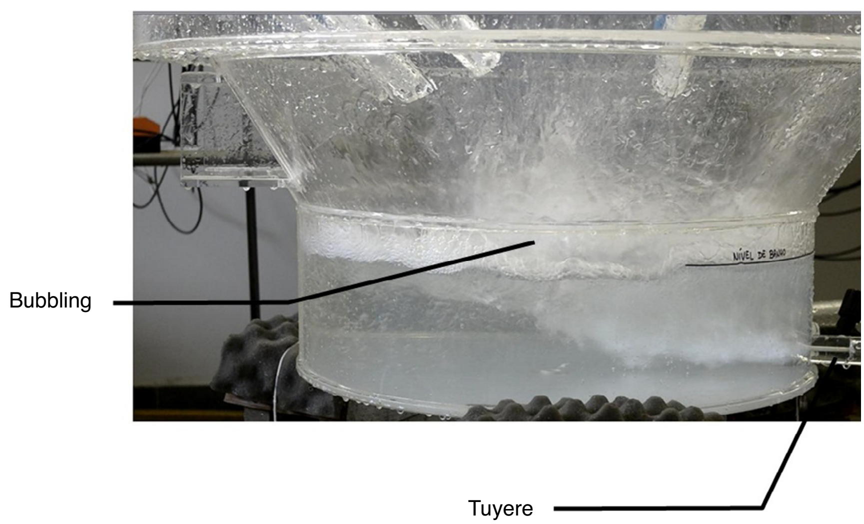


Fig. 8 – Interaction behavior between tuyeres and liquid bath into EOF.

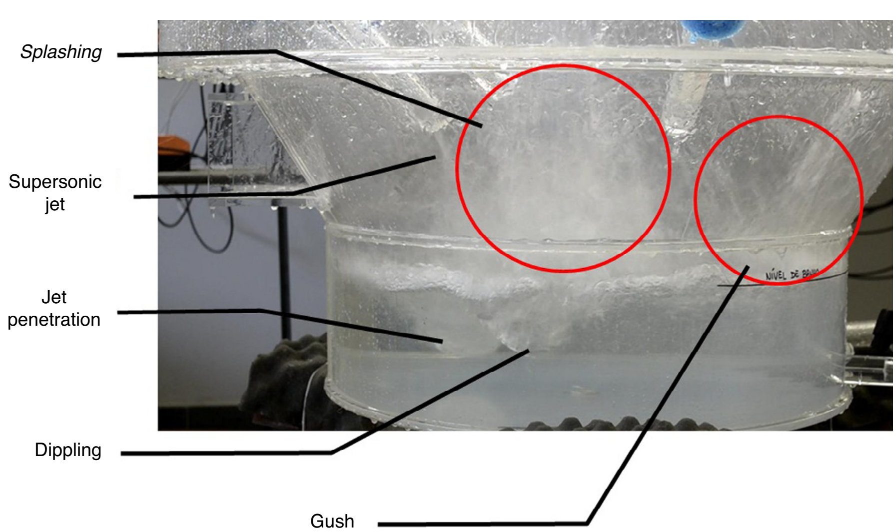


Fig. 9 – Interaction behavior between supersonic lances and liquid bath into EOF.

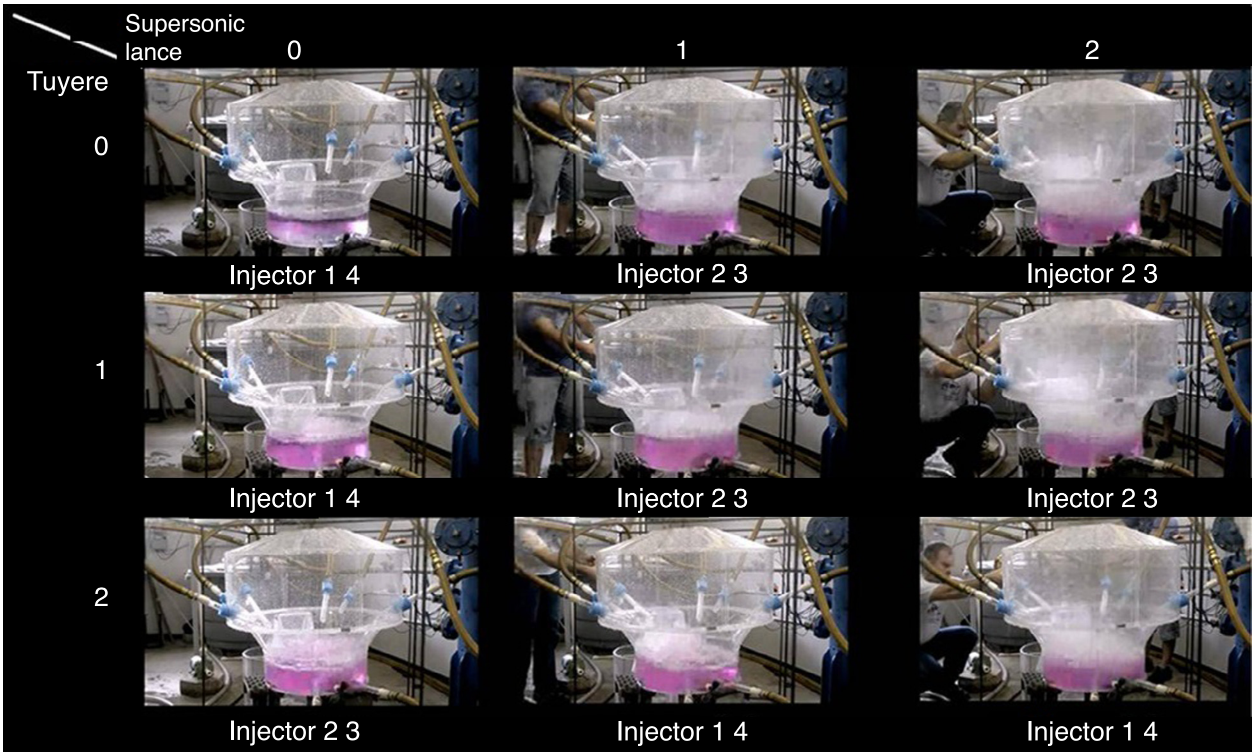


Fig. 10 – EOF movement profile with injectors in pairs.

performed with only the EOF position 0°, without any tilting. The observation of the images allows describing bath behavior. The tuyeres promote reduction of the apparent density and rotation in the counterclockwise direction. This makes the bath, passing the region of supersonic lances, to be atomized, generating mix fraction. When the supersonic lances are the only ones blowing, the apparent liquid bath density is close to real, increasing the resistance to jet penetration and the incidence of spills and splashes in the opposite jet. As the supersonic lance is positioned perpendicular to the liquid bath and close to the slag door increases the volume of fluid passing through this opening.

Atmospheric injectors present in all matrices did not affect the rate of loss, and may be noted in Fig. 11 for the condition that tuyeres and lances supersonic were not in operation.

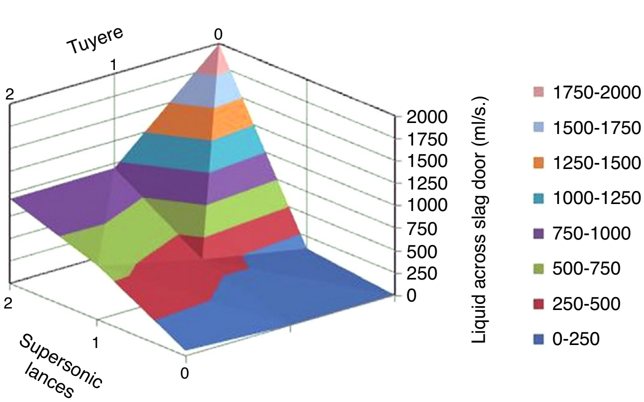


Fig. 11 – Rate liquid lost by EOF slag door.

Based on these results, a suggestion for improving the EOF process is the redistribution of supersonic lances, mainly for the steel casting region, a position in which the EOF remains tilted to +8° to replace atmospheric injectors.

The injectors did not have any influence in the rate of liquid lost by slag door. This result shows an opportunity for the EOF. First, to promote new arrangement of the devices, mainly a new distribution of supersonic lances for the tap side, that needs more penetration and in operation, most part of the time, the EOF is tilting 8° for the tap side. Second, remove the environmental injectors due work with low pressure and low penetration.

3.2. *Mixing time*

In Fig. 12, it can be seen the behavior from the benchmarks of the equipment, in this case: Injectors 2 and 3, a tuyere and a supersonic lance. Considering only a supersonic lance, in the picture on the top right hand side, you can see that only one tuyere is responsible for reducing the mixing time. This fact is characterized by the tendency of the lines of iso-mixing time being close to the horizontal. Using just the four injectors it is observed a slight decrease tendency, showing its low influence on the mixing time of the EOF.

On the top left hand side frame, the surface is generated based only on the operation of one tuyere. In this condition, the shortest time was obtained only for the operation of the two supersonic lances. The curves also demonstrate that the entry of all jets increases the mixing time. From these first two analyses it is possible to verify that the injectors do not have a large influence on the mixing time. On the bottom left

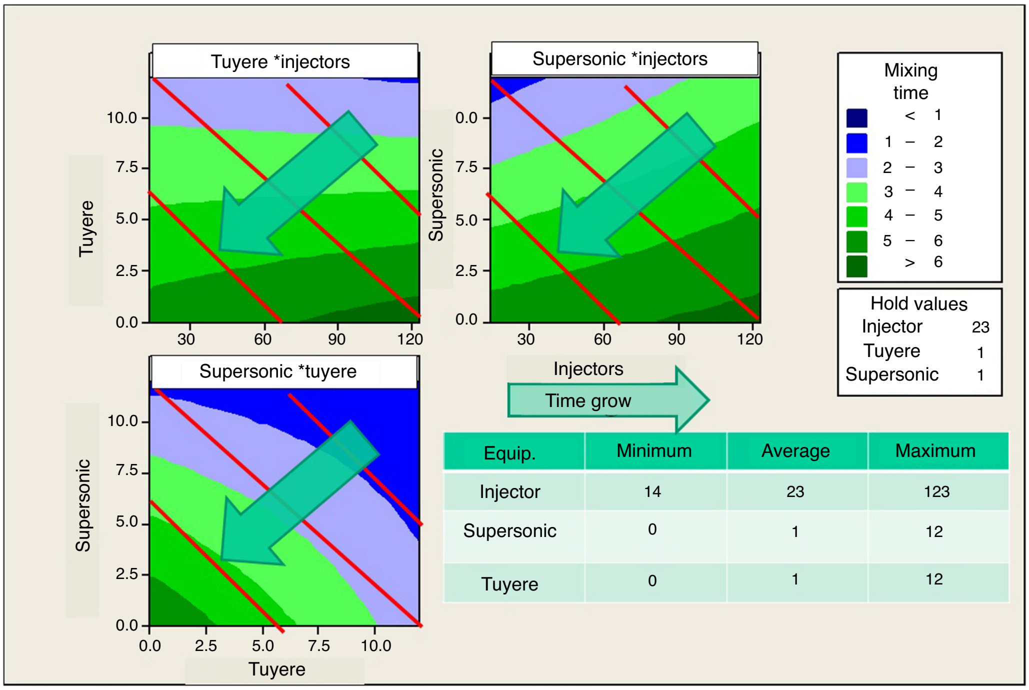


Fig. 12 – Contour surface for mixing time in EOF – Average hold values.

hand side frame, the response surface was generated based on the operation of the injectors 2 and 3, and the amount of mixing time exceeds 5 s when the supersonic lances and the tuyeres are turned off. In this condition, it is possible to note that the lowest mixing time was achieved with the use of the two tuyeres and two injectors. Furthermore, for the condition of maximum utilization of the equipment, the results are shown in Fig. 13.

In Fig. 13, the left hand side frame compares the performance of injectors and tuyeres considering the operation of two supersonic lances. It can be notice a large area with time between 1 s and 2 s from the origin of the axes until the operation with two tuyeres. This result demonstrates the influence of supersonic lances at the time of mixing. The injectors have low penetration and so, low mixing time of the bath. On the top right hand side frame, the value fixed considers the operation

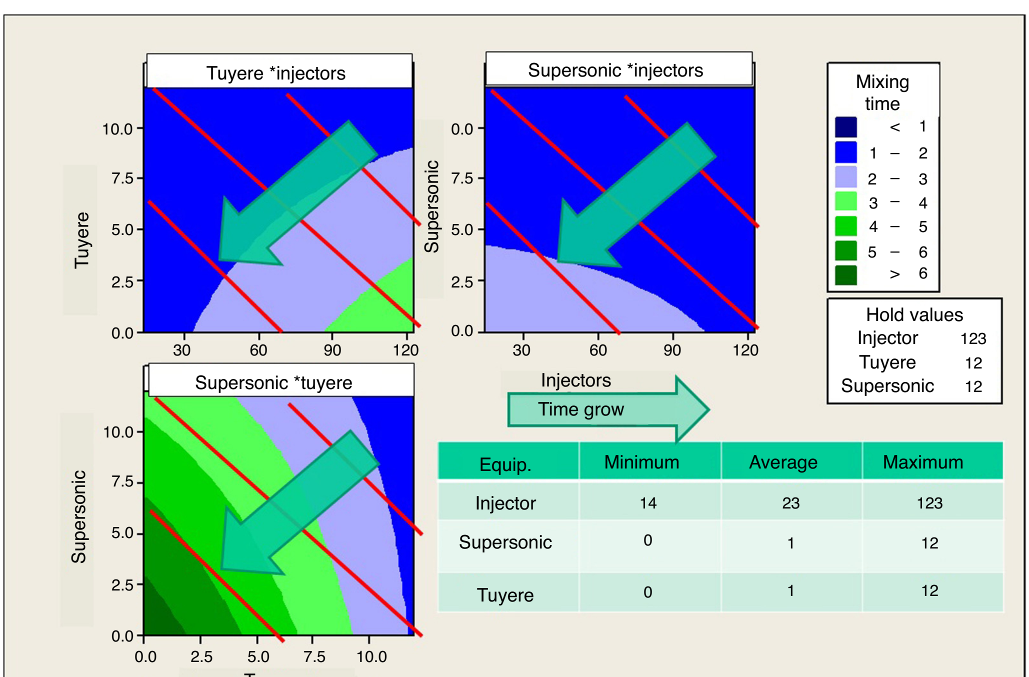


Fig. 13 – Contour surface for mixing time in EOF – Maximum hold values.

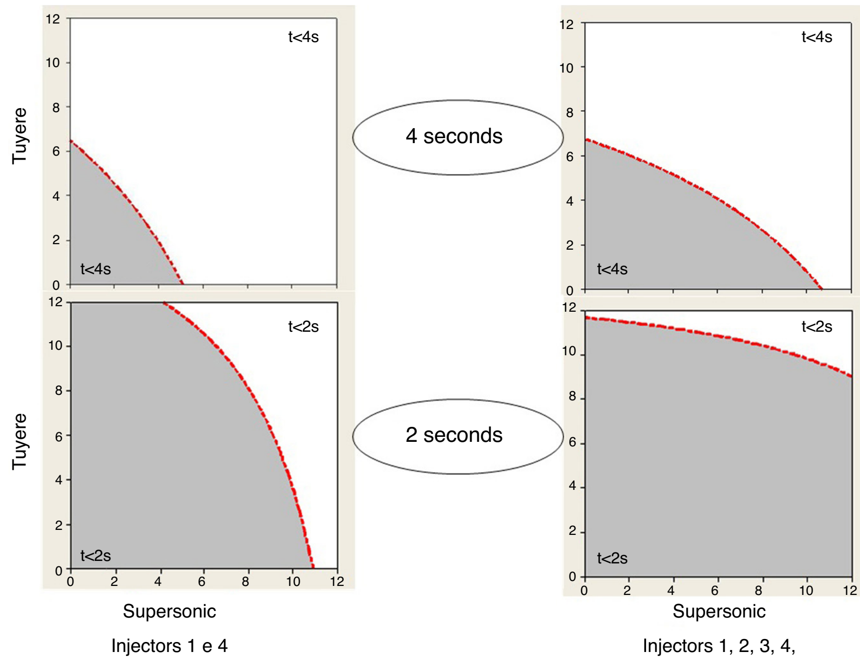


Fig. 14 – Contour surface over layer for 2 s and 4 s in EOF cold model.

of all tuyeres. In this configuration, the reduction of the mixing time is determined by the number of supersonic lances in operation. Only in the field of operation of the four injectors, it is possible to note a reduction in the mixing time of 1 s. Finally, on the bottom left hand side frame, it is possible to note the low efficiency of the four injectors working with mixing times longer than 6 s. As tuyeres and lances supersonic come into operation, the mixing times are reduced. From the analysis of the behavior of the equipment and its variations of configurations, we designed a graph showing overlapping areas for a mixing time pre-set, as shown in Fig. 14

Fig. 14 shows that the mixing time of 4 s is achieved in half of the equipments, but it demonstrates a contrary behavior to expectations with regard to the injectors. The behavior that was expected was to reduce the mixing time with the increasing of agitation of the bath sources. In this case, the reduction of two injectors provided a wider field of values less than 4 s. The same behavior can be detected for a mixing time of 2 s, drastically limiting this field. This strengthens the indication that the supersonic lances and tuyeres are the main agents handling the bath. Because of the flow, supersonic lances have a predominant role in the production process by elevating rate of decarburization.

4. Summary

The main conclusions drawn from the analysis of the activity profile EOF are:

- The bath features rotational movement in a counterclockwise direction for all tested configurations;
- The use of atmospheric lances only form small pits on the surface of the bath with insignificant penetration;
- The use of tuyeres causes bubbling in the surface of the bath with the formation of squirts;
- Gas injection by tuyeres causes a reduction in effective density of the liquid, contributing to the movement of the bath;
- The supersonic lances penetrate the bath, forming a deep ditch which moves toward the leakage channel;
- The supersonic lances make a scattering region ahead of the initial pit;
- Atmospheric injectors, due to bath's slow movement did not causes significant losses of the bath liquid throw the slag door;
- The supersonic lances caused the greatest loss because of the proximity of the slag door;
- The supersonic lances, when associated with the tuyeres, show a loss for the slag door below the use of only supersonic lances.

About the mixing time the conclusions are:

- EOF is excellent to promote a mixer gas-bath;
- The atmospheric injectors have little influence on mixing time;
- The supersonic lances and tuyeres are responsible for smaller mixing times;
- The tuyeres promote changes in the density of the bath, providing rotational movement;
- The supersonic lances have sufficient flow to ensure good penetration in the bath.

Conflicts of interest

The authors declare no conflicts of interest.

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