CONTINUOUS CASTING TUNDISH INERTIZATION: A COMPARATIVE STUDY*

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Abstract

Inertization in continuous casting tundish is essential in first heats of a sequential to avoid reoxidation and hence the rising of non-metallic inclusions in steel. Nowadays steel shops are looking for the best practices in this concern. There are several ways to conduct this process in a continuous casting tundish in order to have proper steel cleanliness. In this paper, some techniques to carry out such process are discussed aiming to provide industry a source of information about the topic tundish inertization.
Keywords: Tundish; inertization; non-metallic inclusions.

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1 INTRODUCTION

The tundish inertization practice involves an inert atmosphere inside the reactor in the first heat of a sequence. This technique is widely used to avoid productivity losses and metallic yield from contact between steel and air in the transient steps of the continuous casting and initial filling of the tundish [1,2].
In case the contact is allowed, the present oxygen in air reacts with steel producing non-metallic inclusions (NMIs) and consuming alloy elements and deoxidants such as aluminum, titanium, silicon and calcium. The nitrogen, major constituent of the air, also dissolves in steel causing the pick-up of its content [3]. The deposition of NMIs is also favored in the submerged nozzle, which connects the tundish to the mould, leading to clogging phenomena [4,5].
Despite the inertization process being considered important, there are just a few papers spread over the web, about this topic. Because of this, it is evident some industrial solutions are done for each case. On the other hand, industries can have a bad inertization process, when a project is not well conducted; these practices are raised from the lack of information about the subject [1].
In this work a review about some papers focused in the topic of tundish inertization process (mathematical, industrial and laboratory) as well as reoxidation or oxidation rates measurements was carried out aiming to provide information for best practice in industry.

2 LITERATURE REVIEW

The more relevant studies are described as following.

2.1 Mathematical model

The author Braga [1,6] carried out a study about a non-isothermal three-dimensional mathematical model of tundish inertization. It consists of an only one gaseous phase compound by two components: argon and air. Turbulence was considered as a k-ε model. Calculations were done using the CFD Ansys CFX. Different configurations of the inertization system were simulated and a new approach was employed to discuss the model predictions. The results indicated the current setup is not efficient and new configurations were suggested. Furthermore, it was estimated the thermal loss resulting from tundish inertization with hot start and total oxygen pick-up, nitrogen and hydrogen that occur during tundish filling from the interaction steel-air. It was concluded that, since the purge is well dimensioned, thermal loss generated by inertization is negligible. It was also found the possibility to reduce hydrogen pick-up with inertization. Bragança et al [7] did a work about this subject. The results of their research showed that not only the control of the humidity content in refractory materials is critical, but the phase transformations that the materials suffer during the casting process are important as well.
Figure 1 presents contour maps of Braga study [6] at the end of purge in argon molar fraction for one configuration as well as the flow speed profile, in the region of low argon content in the tundish. However, the chemical bedding remains in the tundish with hot start the natural convection currents generate a preferential way of argon escape from the reservoir.

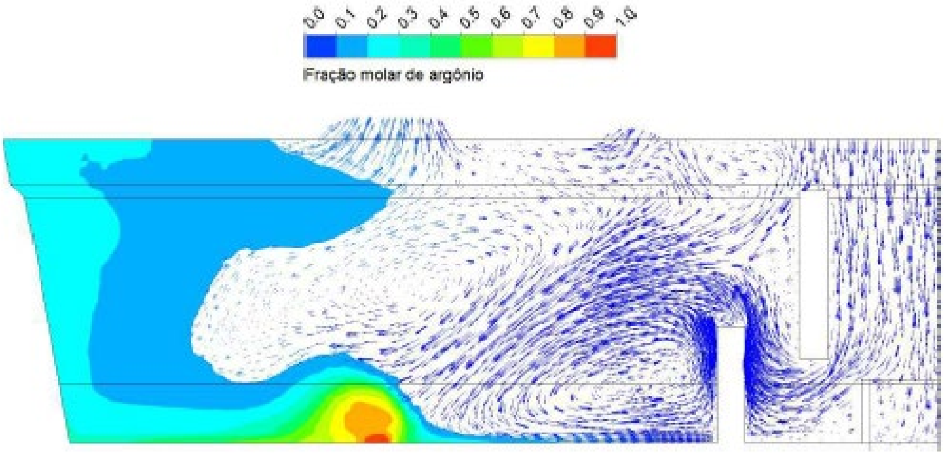
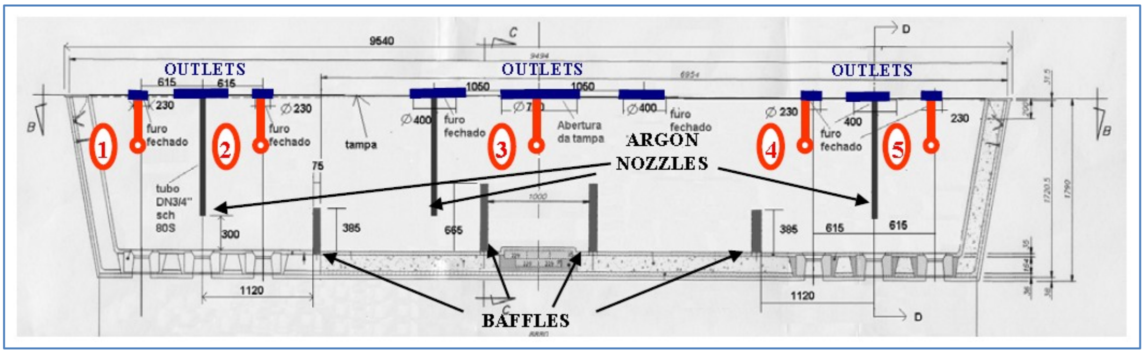


Figure 1. Argon molar fraction contour and speed predicted by mathematical model for configuration Q1 plug at the end of the purge (after 150s) [6].

On the plane region with molar fraction of argon inferior to 0.1 it was plotted the speed profile of the fluid in the tundish. The highest speed in this region, corresponding to the big arrow, is 1.35 m,/s. [6]
This "plumbing" phenomenon that exists in the tundish with hot start deteriorates the porous plug inertization benefit observed in a cold start reactor.
Other findings of this work were that for the studied tundish the inertization practice recommended for cold or hot start is an argon flow of 140 Nm^3/h and closing the holes on the tundish covering. The minimal purge time for the cold start is 3.2 minutes while for the hot start is 52 seconds. It is also advisable increase the number (from 4 to 12) or the diameter (from 25.4mm to 75.2mm) of the injectors to make the inertization process robust against a possible bad sealing of the openings on the tundish covering lid.
The increasing of the argon flow can lead to a lesser purge efficiency in case the environment air entrapment in the tundish is not prevented. Inertization done in tundish without covering by argon injection through the surface tubular ducts or the purge in tundish placed on the coverings are not efficient processes.
In case the tundish has porous plug and the cold start of the equipment is done, its use for inertization is advantageous against ducts below the covering due to modification of mixture between gases in the reservoir. In case of hot start, it is originated a preferential way for the escape of argon and the benefit disappears.
On the other hand, Guimarães et al. [8] carried out a set of simulations aiming the determination of the most suitable arrangement of the injectors. Therefore, CFD simulations used PHOENICS and compared with the data obtained from the experiments (low and high oxygen concentration ranges). The study aim was to obtain a maximum residual oxygen content less than 2% (v/v) by inertization time of 5 minutes.

The Figure 2a schematizes the existing operational prototype used and chosen of sample points. Three tests (03) have been performed and a total of five (5) sample points have been measured to analyze the dynamic behavior of the process. Although the results obtained by two turbulence models fitted well this data, the k-ε Chen-Kim (KECHEN) was chosen because the simulations results have shown that it had a little better mean correlation value and first step result fitted closer to the experimental curve. After each simulation the dynamic behavior of the system was analyzed (velocity and pressure profiles) and the injections were relocated in order to avoid stagnation points and recirculation zones. The mass flow was also adjusted to acquire the specified maximum residual oxygen concentration. The optimum injection pattern, which was implemented for daily inertization procedure, obtained a maximum residual oxygen concentration of 2.08 % v/v as shown in Figure 2b.

a) 

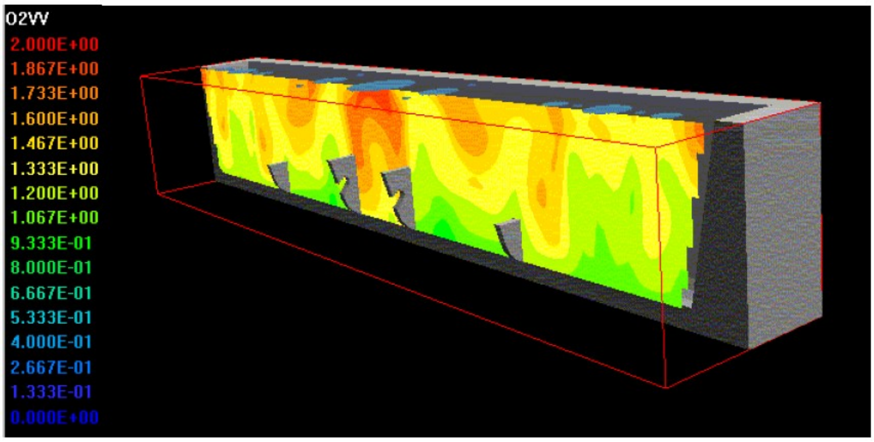
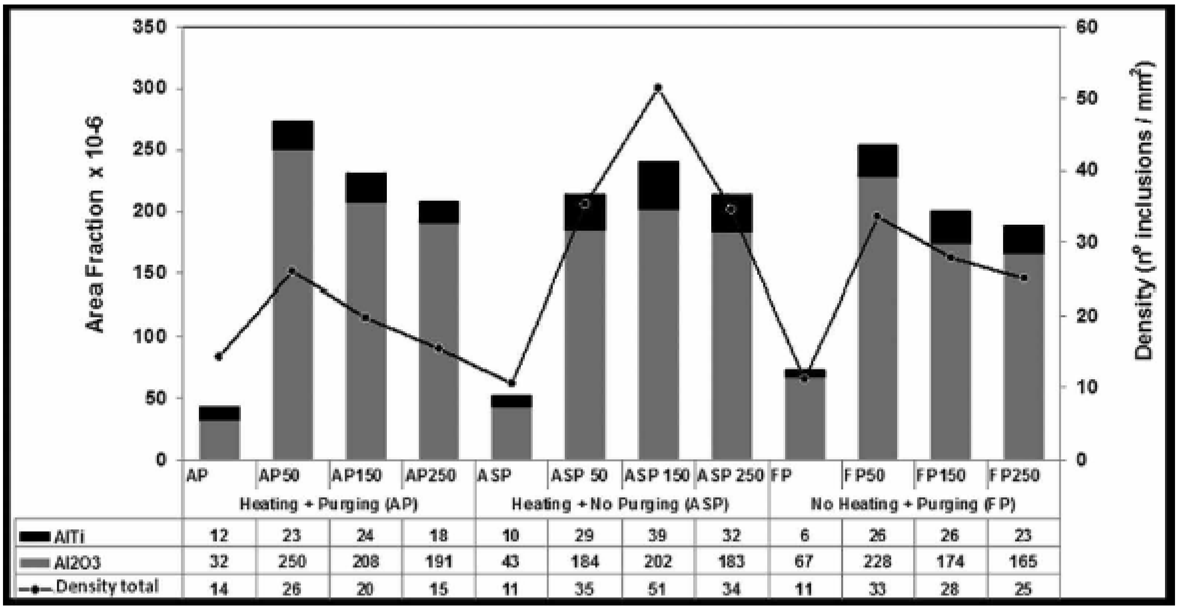
b) 

Figure 2. Tundish prototype: a- Location of the sample points (in red); b- Oxygen residual concentration profile (0% to 2% v/v). [8]

2.2 Industrial trials

Junior et al [9] performed a study with Interstitial Free (IF) Ultra Lower Carbon steel samples collected in RH at the start, in the middle and at the end of the continuous casting of the tundish first heat in three different conditions of tundish processing, alternating between heating and purging. Figure 3 shows the average area fraction and average inclusionary density of Al_2O_3 and TiAl inclusions together in the three studied processes. The outcomes showed that more than 90% of the oxide inclusions generated in that type of steel are Al_2O_3 and AlTi.



	AP	AP50	AP150	AP250	ASP	ASP 50	ASP 150	ASP 250	FP	FP50	FP150	FP250
AlTi	12	23	24	18	10	29	39	32	6	26	26	23
Al2O3	32	250	208	191	43	184	202	183	67	228	174	165
Density total	14	26	20	15	11	35	51	34	11	33	28	25

Figure 3. Area fraction and density average of Al_2O_3 and AlTi inclusions in the three different studied processes. AP50 stands for 50t, while AP150 and 250 for 150t and 250t, respectively.[9]

It can be seen the smallest occupied Area Fraction by AlTi inclusions in the three cases, the inclusionary total density plotted in the secondary axis show similar evolution in the three processes.

Al_2O_3 and AlTi inclusions are the two majority impurities groups presented in an IF aluminum killed steel, representing around 90% of total inclusions. Alumina inclusions occupies proportionally seven times more area than AlTi inclusions and its volumetric size distribution was found as follows: 85%<=10μm; 15% between 10 and 20 μm and 0%>20μm. The size distribution was not affected by the different studied processes. All the three processes presented inclusion pick-up from RH to the tundish and expected, tundish purging showed to be more efficient than with no preliminary purging, especially during a tundish sequence. The heating process showed a similar tendency evolution when compared to the cold tundish. And also, it was concluded that previous purging of the tundish has an important role in minimizing RH inclusion pick-up for continuous casting, proving more importance than heating the tundish. The reservoir without purging had the worst outcome and the cooling tundish with purging had the best general performance.

Similar results were obtained by P. Kaushik [10] in a slab caster tundish. In this study, the results showed that initial reoxidation during tundish filling led to a higher inclusion content in steel even in the heats produced using pre-heated tundishes but without Ar purging. Indicated that Ar purging in the tundish is more important than tundish pre-heating to control reoxidation on first heat of a sequence

CHEN et al [11] evaluates slab caster tundish inertization efficiency in order to obtain low oxygen concentration using a 1/4 laboratory scale physical model (two injector) and later tests in the industry (single injector). In both, the oxygen level was measured at 75% of the tundish height below in the center of the opening in the lid.

Figure 4 shows the results of the oxygen content for injectors with different outlet diameters test in the physical model. It can be seen that larger injectors are more efficient than those with smaller diameters and which was later applied to the plant.

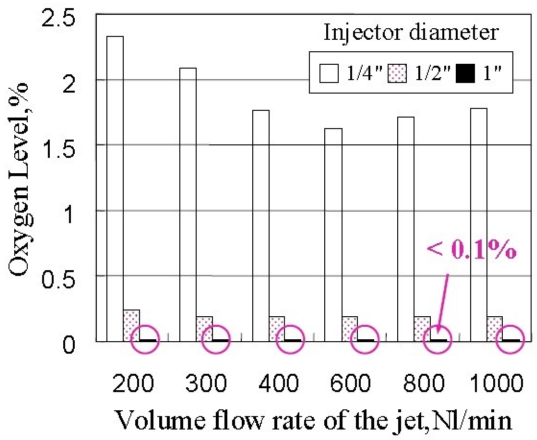
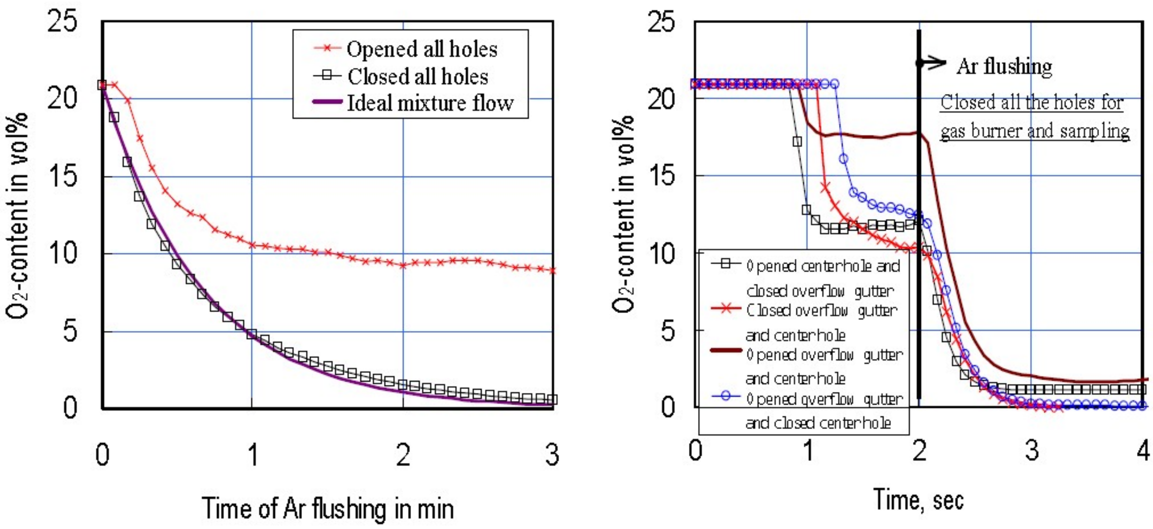


Figure 4. Oxygen level from air entrainment for injector with different outlet diameter.[11]

Figure 5a-b shows the results of industrial trials of the oxygen content variation during the argon flushing time with a cold and hot tundish.



a) b)

Figure 5. Inertization test results during the argon flushing time a) Cold Tundish; b) Hot Tundish (pre-heated).[11]

Figure 5a shows tundish with open holes - 50% of the air in the tundish is replaced by argon within 2 min, no further significant reduction of oxygen was observed after prolonged argon flushing. On the other hand, tundish with all holes covered - oxygen content of around 0.5% was achieved within 3 min. For the tundish preheated, Figure 5b shows, only around 1 min later, the oxygen content dropped down to below 0.1%, provided that the tundish was sufficiently sealed.

Based on previous results, the configuration of multi-injectors in the distributor was chosen, which should seal more efficiently flushed with argon.

2.3 Reoxidation and Oxidation Rate

The reoxidation of steel contributes to the formation of new non-metallic inclusions (NMIs) deteriorating its cleanliness. In industrial practice, this has been evaluated using the PDF (population density function) analysis technique of the size distribution of non-metallic inclusions. [12-15] PDF curves are calculated from equation 1, where the values obtained for PDF are plotted against the diameter of the equivalent inclusion.

$$PDF = n_v(Lxy)/(Ly - Lx) \qquad (1)$$

where: n_v represents the total number of inclusions per volume unit in the range (or bin) and the denominator, $(Ly - Lx)$, indicates the width of the range (or bin).

As shown in Figure 6, size distributions on a log-log plot (PDF versus equivalent inclusion diameter) that fit a well-defined Lognormal distribution are related to the reoxidation of steel. What happened for sample B5 in the post agitation station and in the distributor. In runs where the PDF curves did not show a Lognormal fit, normal behavior (no reoxidation) is attributed during manufacturing operations.

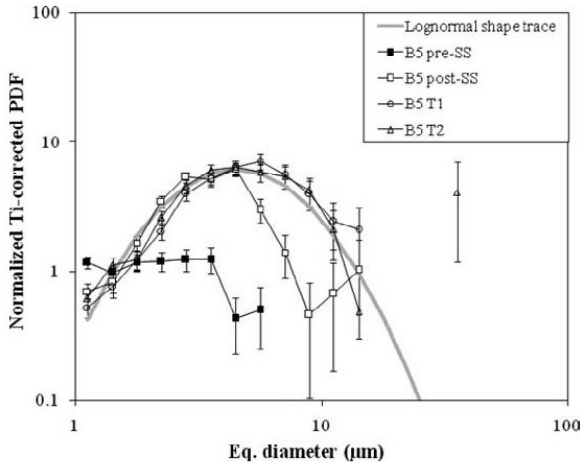


Figure 6. PDF analytics for non-metallic inclusions. Samples B5(SS- stirring station (pre: before; post: after; Tundish-T1,T2).[12,13]

In the laboratory Sasai e Mizukami [16] conducted a study using three kinds of experiments: one with oxygen gas entrainment by gas jet and the other of molten steel with gas blowing, besides another one of molten steel by plasma heating. Figure 7 shows the apparatus used in the experiment on the oxygen gas entrainment. In order to determine the oxygen gas partial pressure of gas jet blown from the nozzle in the air, an oxygen meter was buried in a flat sheet with its sensor segment. A single nozzle was set so that the gas jet from the nozzle vertically hit the center of the sensor segment. Ar gas was blown from the nozzle to the flat sheet. When argon gas was blown from the single nozzle the oxygen meter reading dropped immediately and became constant in 5 to 8 seconds. The experiment was conducted varying the flow rate of Ar gas jet between 0.01 and 0.1 $Nm^3.min^{-1}$, nozzle inside diameter between 0.4 and 1.1 cm and nozzle height between 3 and 20 cm.

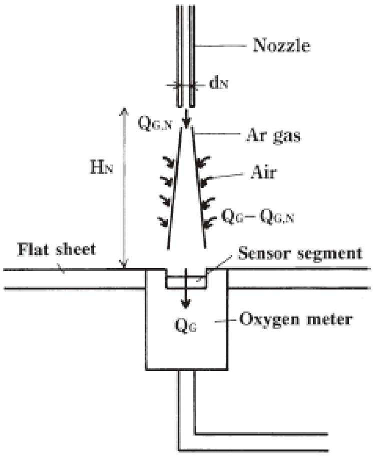


Figure 7. Scheme view of experiment apparatus to check oxygen gas entrainment by gas jets [16]

Figure 8 demonstrates the high frequency vacuum induction melting furnace used in the experiment. By introducing Ar and oxygen gases into the vacuum melting furnace, the O_2 gas partial pressure in the atmosphere was adjusted to the desired value at a total pressure of 101 kPa. Then the oxidation experiment of the molten steel was started by blowing an Ar-O_2 gas mixture having the same O_2 gas partial pressure as in the atmosphere or Ar gas from a single nozzle having an inside diameter of 0.4 cm positioned 10 cm above the molten steel surface.

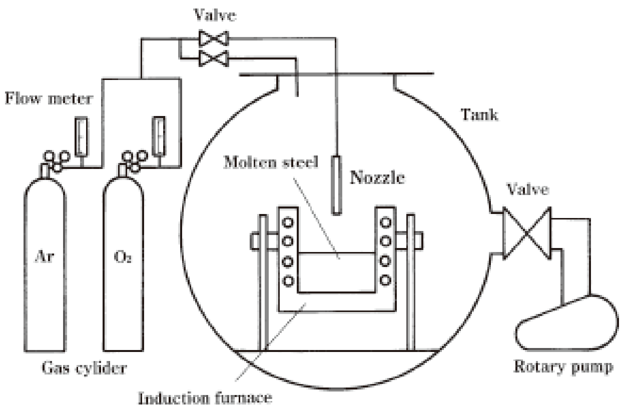


Figure 8. Schematic view of experiment apparatus to evaluate oxidation rates of molten steel with gas blowing in the induction furnace [16].

Figure 9 shows the plasma heaters in both strand sides of the second container of the H-shaped tundish.[16, 17]

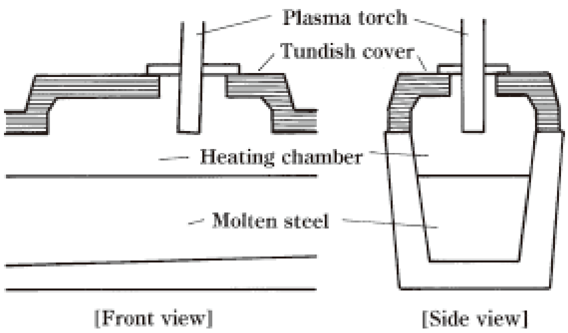


Figure 9. Schematic view of plasma heating apparatus [16].

The oxidation rates of molten steel resulting from argon gas blowing on the molten steel surface in an oxidizing atmosphere and from plasma heating in the tundish were measured and analyzed from point of view of kinetics. According to this study the following conclusions were taken in consideration:

- The oxygen partial pressure of the gas resulting from entrainment of atmosphere gas can be expressed by an equation:

$$P_{G,O2}/P_{A,O2}=1-d_N/(\beta \cdot H_N) \quad (2)$$

- The gas-phase mass transfer coefficient with gas blowing on the molten steel surface can be expressed by semi-theoretical equation:

$$k_G=1.62(\gamma \cdot D\cdot u_{G,N}\cdot d_N)0.5/r_C \quad (3)$$

- The oxidation rates of the molten steel resulting from argon gas blowing on the molten steel surface in an oxidizing atmosphere and from plasma heating in the tundish can be explained by a reaction rate model considering gas entrainment by gas blowing and the gas-phase mass transfer with gas blowing.

3 CONCLUSIONS

After further analysis of the described works used in this review it could be concluded that each process requires the best practices for tundish inertization according to their peculiarities: capacity, baffles, number of strands. However, some features could be used as a guide for the continuous casting operation process of inertization as a north, such as playing with hot or cold start and purging inert gas. This last one can be considered fundamental when taking into account steel cleanliness. Besides some variables also must be stressed such as gas flow, injection hole diameter and so on.

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