MODELLING RESEARCH OF HIGH GAS FLOW RATE BLOWING OF THE LIQUID STEEL IN THE LADLE UNIT

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Abstract

The application of wire scrap from tire recycling can be very important, especially when the steel is melted in induction furnace. However, in the induction furnace there is no possibility for steel decarburization because of the danger of lining erosion, and as a result unavoidable furnace failure due to liquid metal leakage. Thus, this operation can be moved outside the furnace, to the ladle. Proposals of such solution are found in literature, especially with application of blowing the liquid steel by the gas-oxygen mixture through the bottom of the ladle and the further secondary treatment in ladle furnace.

Such innovative way of decarburization of liquid steel in ladle with bottom blowing by gas-oxygen mixture was the main object of the presented research. The aim of this research, conducted on the physical model, was the preliminary identification of hydrodynamic conditions caused by the intensive mixing of modelling liquid by the gas. During such research, the mechanism of gas bubbles cone creation was observed. The following parameters are also very important: the level of gas bubbles dispersion in the modelling liquid, behavior of the modelling liquid surface as a result of flowing out gas bubbles, and the flow rate of occurring breakouts of modelling liquid, above the height of modelling liquid surface.

Keywords: Ladle, physical modeling, high intensity gas blowing, liquid steel

1. INTRODUCTION

Wire from used car tires is a valuable material in steel metallurgy [1-3], it could have high significance in the case of steel melting in the induction furnace. However, there is some limitation in its using in such kind of furnaces because of copper content. Up to now the attempts of removing copper excess are only on the laboratory scale [4]. On the industrial scale the limitation of copper content in metal bath from the charge containing cords wire is reached by diluting with other materials with small copper level. However, in the induction furnace there is no possibility for decarburization of steel because of the danger of ladle lining erosion, and as a result unavoidable furnace failure due to liquid metal leakage. Thus, this operation can be moved outside the electric furnace, to the ladle. Decarburization of liquid steel in ladle with application of blowing the liquid steel by oxygen or the gas-oxygen mixture through the bottom of the ladle and the further secondary treatment in ladle furnace is innovative solution [5]. It can be applied when low-alloy steel with low carbon content is melted, which in the future means the production of carbon steel with high mechanical and anticorrosion properties. Such type of research is conducted in the wide range, it concerns among others the innovative process of secondary steel refining in the steel production process during which different techniques of introduction gas to the melt are verified. The gaseous phase is often introduced by the bottom plugs. Some attempts were made to introduce the gas by lance placed from the top of the ladle or side terminals (e.g. in the side blown converter).

Similarly like in the case of most research concerning the innovative solution in metallurgy, to remove occurring problems, physical and numerical modelling methods are applied [6-11]. Such innovative way of decarburization of liquid steel in ladle with blowing by gas-oxygen mixture through the bottom was the main object of the presented research. The aim of this research, conducted on the physical model, was the preliminary identification of hydrodynamic conditions caused by the intensive mixing of modelling liquid by the gas. The obtained results come from one of the stages of research project concerning technology of such type. During such research it was observed the mechanism of gas bubbles cone creation. The following parameters are also very important: the level of gas bubbles dispersion in the modelling liquid, behavior of the modelling liquid surface as a result of flowing out gas bubbles, and the flow rate of occurring breakouts of modelling liquid above the height of modelling liquid surface.

2. DESCRIPTION OF THE OBJECT

Because of the assumed not so high capacity (3 Mg of steel) of the prototype of the designed ladle and not so high dimension of ladle working area, the value of linear scale of the model was considered to be similar to 1. Taking into account the laboratory condition, the forecasted costs of the model and the conducted experiments and the possibility of installing the industrial purging plugs, as an optimal value of the linear scale S_L= 0.84 was assumed. The model was built according to demands of the theory of kinematic and dynamic similarity, it also fulfilled the condition of geometrical similarity [12]. Considering the geometrical parameters of the designed model and the results of preliminary studies, the decision was made to increase the convergence of ladle model to 8 % and the height of its free side, comparing with the conventional solutions. The main aim of such treatment was to limit the negative effects of steel breakout creation with the intensive gas blowing. Model of the ladle was equipped with the modelling plug "crevices" type. This plug was placed on the 2/3 of radius from the ladle axis. In the system the additional rotameter (it gives possibility to regulate the gas flow) and the apparatus for precise tracer introduction in the gas stream were also installed. **Figure 1** shows the scheme of the test stand.

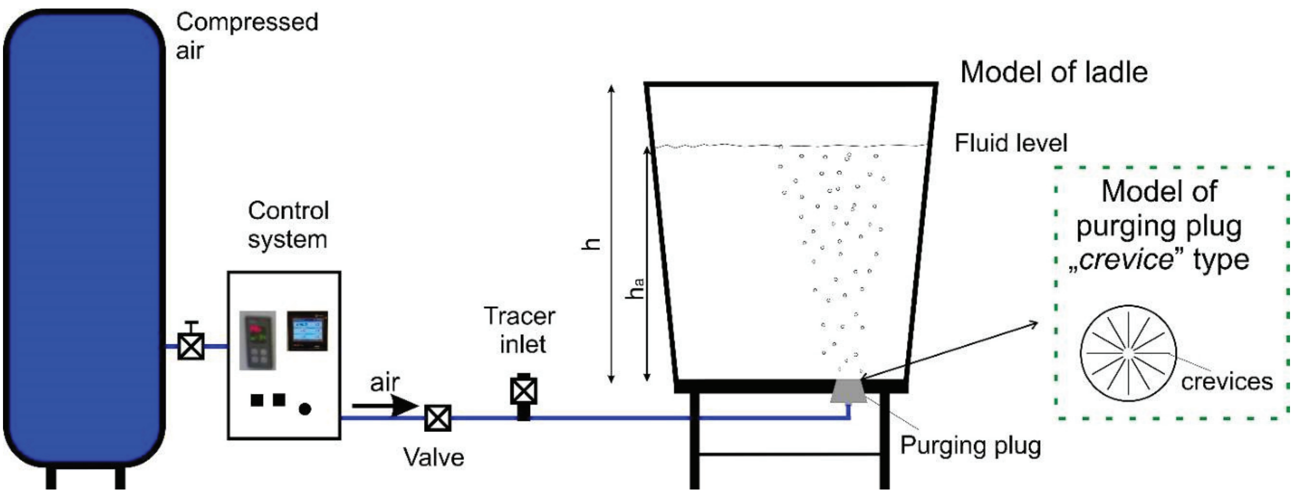

Figure 1 Scheme of the test stand

Model was built in such way that it is possible to install different kinds of purging plugs. Application in the ladle model the linear scale S_L= 0.84 similar to 1 enables also to install the original purging plug. Sensors of conductivity were also installed in the model to conduct research enabling the determination of resident time distribution (RTD). Such RTD curves are the basis for the further analysis of hydrodynamic phenomena occurring in the ladle model during blowing. Such sensors were located in the side wall of the ladle model along its height.

Basing on the conducted simulations of carbon, silicon and aluminum change in the steel melt, as a function of the added oxygen, it was determined oxygen amount necessary to get the needed level of steel decarburization.

According such guidelines, the calculation of dynamic similarity condition of gas flow in the model to the real condition was done basing on the modified Froude`s criterion in the following form [13-15]:

$$Q' = \left(\frac{c'}{c}\right)^{-\frac{1}{2}} \cdot S_L^{\frac{5}{2}} \cdot Q \quad (1)$$

where:

Q' - volumetric stream of gas flow for the water model, $m^3 \cdot s^{-1}$,
Q - volumetric stream of gas flow for the industrial reactor, $m^3 \cdot s^{-1}$,
C' - constant for the water model,
C - constant for the industrial reactor,
S_L - linear scale.

Calculated quantity of flow rate of gas in the ladle model, considering the linear scale of the model S_L = 0.84, for the air is 8.21 $Nm^3 \cdot h^{-1}$.

3. RESEARCH RESULTS

Before modelling research the series of experiments were conducted which the main aim was to verify the working efficiency of ladle model and control-measuring apparatus considering the research assumptions. After correction of small defects the experiments, which have the visualization character, were conducted. Research was carried out in series, registering its course by means of digital camera in two planes. Such research was divided into two stages. The aim of first stage was to determine the hydrodynamic conditions in the model of ladle prototype, caused by the intensive blowing of the modelling liquid by gas. In the second stage the time of tracer mixing in whole modelling liquid was determined. **Figures 2** and **3** show the exemplary research results of visualization conducted in the first stage of research.

Figure 2 Exemplary results of visualization - view in the axis of purging plug

Figure 3 Exemplary results of visualization - view from the side of the purging plug

To determine the minimal time of modeling of liquid mixing during the process of gas blowing, tracer (in the form of water solution of $KMnO_4$) was introduced to the model. The tracer was introduced together with the gas stream. **Figure 4** presents the exemplary results of those experiments.

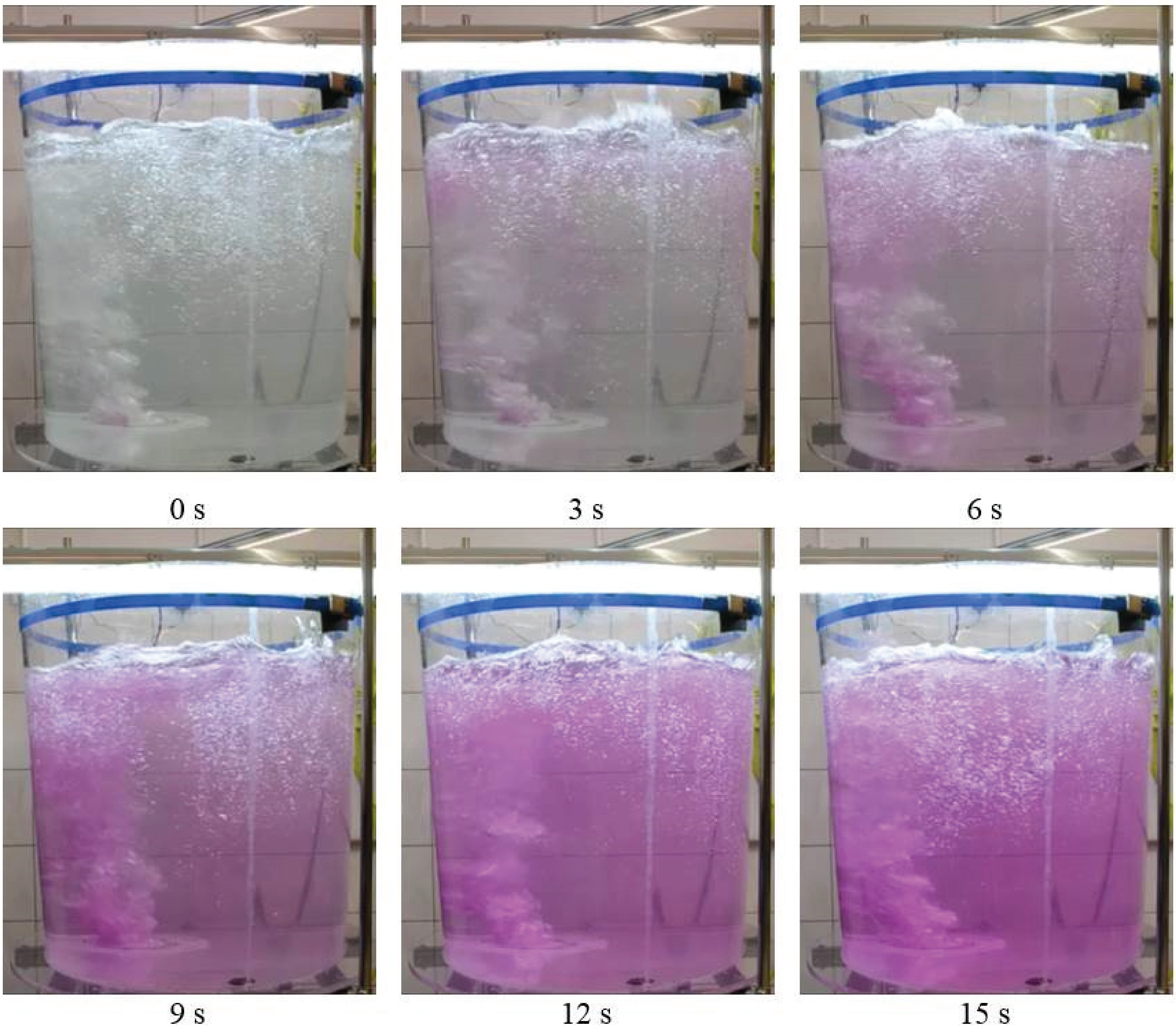

Figure 4 Exemplary research results of minimal time of tracer mixing

As a results of conducted visualization research the strong eddying of the modelling liquid surface and tendency to breakouts creation was observed. Mechanism of breakouts creation differs, however, from this one observed in prototype model. Consideration of the ladle model convergence to the bottom (8 %) revealed the decrease of tendency to create breakouts of modelling liquid. In the same time, the clear tendency of creating energy accumulation in the whole volume of modelling liquid was observed, and as a consequence there are many breakouts creation progressing periodically. The created cone of gas bubbles is strongly douching the ladle model walls - in practice that could be caused lining wearing and as a consequence secondary contamination of liquid steel. Additionally, the dispersion of gas in the whole volume of modelling liquid has unfavorable character. All that suggests that there is necessary to apply different type of purging plug or dividing the stream into two, which needs the using of the second purging plug in the bottom of the ladle model.

The main aim of presented research was to determine the minimal time of tracer mixing in the whole volume of modeling liquid, and it was indicated that the time is no longer than 15 s.

4. CONCLUSIONS

The analysis of the modeling research enables to draw the following conclusions:

- It was observed the strong eddying of the modeling liquid surface and tendency to creation of small breakouts. There is strong tendency to occur the energy accumulation in the whole volume of modelling liquid, which as a consequence gives the creation of breakouts progressing periodically.
- Cone of gas bubbles has tendency to the strong douching of ladle model walls, which as a result in practice can cause stronger wearing of the lining in that area and secondary contamination of liquid steel.
- Gas dispersion in the whole volume of modelling liquid has the unfavorable character. The created gas bubbles are growing up to big diameters, which taking into account their chemical efficiency is really unfavorable phenomenon.

It should be also mentioned that if the flow rate of gas if really high, then the small argon bubbles disappear, which absorb bubbles of CO creating during decarburization reaction. As a result, the decrease of decarburization intensity is observed. Thus, it should be considered the application of different type of purging gas or the second purging plug in the bottom of ladle and division of gas into two streams.

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