THE INFLUENCE OF POROUS PLUG TYPE ON ARGON BLOWING PROCESS

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Abstract

The most important tasks of secondary metallurgy are to accelerate the course of steel production processes and to improve its quality, at the same time limiting the amount of work, energy and sources. The basic and popularly applied treatment of secondary metallurgy is blowing the liquid steel in the ladle by inert gases. The introduction of gas into the liquid steel can be realized by differently constructed porous plugs installed in bottom of the ladle. Because there is aggressive character of the working conditions thus these plugs should be thermally and mechanically resistant, have appropriate permeability, and be able to create required amount of gas bubbles and their dispersion in the whole volume of liquid steel. Today in industry three kinds of porous plugs are used differing with construction: plugs with porous segment, crevice type and hybrid plugs.

Article presents the results of modelling research conducted with using the model of ladle with possibilities of blowing the metal bath. Research was carried out for four different types of porous plugs: two plugs crevice types with different crevice placing, plugs with porous segment and hybrid plug (crevices plus porous segment). The results of research was obtained in the form of visualization of gas bubbles creation, mechanism of gas bubbles cone creation (gaseous column) and determination of time and way of mixing the modelling liquid in the dependence on the applied type of plug.

Keywords: Porous plug, ladle, physical modeling

1. INTRODUCTION

The major advantage of applying the steel secondary metallurgy is to optimize the usage of primary metallurgical reactors for smelting the steel (oxygen converterr and electric arc furnace), as well as, efficient and effective treatment of the molten steel - in terms of their metallurgical purity, chemical composition and temperature. Basic and commonly used secondary metallurgical process is purging the liquid steel with inert gases, which main aims:

- to bring uniform temperature and chemical composition,
- to improve the fluidity of molten steel, which at the time of decreasing the casting temperature creates more favourable conditions for its solidification,
- to reduce oxygen, hydrogen and nitrogen in the steel content,
- to reduce the content of oxide and non-metallic sulphide inclusions; moreover, the surplus of refining processes favouring the reduction of macro-inclusions in metal was also found [1-4].

The introduction of gas into liquid steel is accomplished by an appropriate gas permeable plug design installed in the bottom of the steel ladle. Gas permeable plugs are porous ceramic elements demonstrating -from one side - the capability of transporting inert gas into the liquid steel, and on the other side, they form a barrier preventing from flowing out of the ladle. Due to the nature of the performed works and environmental conditions, it is expected that plugs will indicate high thermal and mechanical strength, proper gas permeability and capacity to produce large quantities of gas bubbles. In terms of technological processes, it become crucial to obtain the optimum diameter of gas bubbles, their quantity and flow rate. These parameters are decisive for effectiveness of the performed purging process. Regarding design types, plugs can be divided into three groups: porous plugs, crevice-type / slotted-type plugs (with directed porosity) and Hybrid plugs [5-7].

Porous plugs (with porous gas-permeable segment) are constructed of a variety of materials, such as magnesite, porcelainite, chamotte and corundum, having the porosity of approx. 25-40 %. Pore radius for this type of plugs depends on the fraction size being used for their manufacturing. The dimension and type of the applied fraction also affects the number of open pores through which the gas passes into the liquid metal and additionally impacts very crucial - in terms of technology - parameters, such as the diameter of bubbles being formed, their amount and velocity received when flowing out of the plug.

Crevice-type plugs (with directed porosity) are built of many slots with various cross-sections and locations, being immersed in a refractory material. In the case of these elements, gases flowing into the liquid steel (e.g. the swirl movement for plugs with spiral slots), can be controlled via adequate placement of slots.

Hybrid plugs are constructed of various cross-section and location slots with additionally mounted porous gas-permeable segment. These plugs are used at high concentrations of gases [8-10].

There is necessity to know the physical phenomena occurring during the conducted process during the design or building of new equipments used in industrial technologies as well as in modernization works of existing technologies. Very often such knowledge obtained on the theoretical analysis of the studied phenomena is not sufficient. Therefore, information carried out on the experimental way (physical and numerical modelling) has become more and more important, especially it is essential in metallurgical units [11-16].

2. RESEARCH METHODOLOGY

The research study was conducted by using a physical water model of steel ladle. The model is based on a linear scale S_L= 0.84, in accordance with requirements stated in the dynamic and kinematic similarity theory; it also satisfies the geometric similarity condition [11, 17]. The model scale close to S_L = 1 enables industrial gas permeability plugs to be installed inside it. Design of the model allows for installation of various types of gas permeable plugs. The plug is placed on 2/3 of radius from the ladle axis. At the test stand was installed additional flowmeter equipped with gas flow regulation system and a device for precise administration of marker in the gas steam. **Figure 1** shows the scheme of the test stand [11].

Research was carried out for four different types of porous plugs: two plugs crevice types with different crevice placing, plugs with porous segment and hybrid plug (crevices type plus porous segment) (**Table 1**). There were calculated dynamic similarity conditions of gas flow in the model according to the real conditions based on modified Froude's criterion expressed by the relation [11, 18 - 20]:

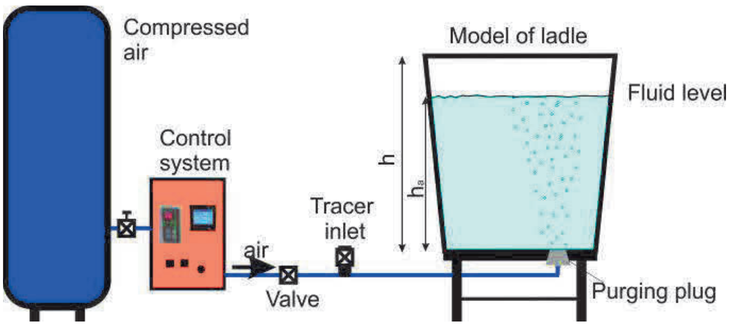


Figure 1 Scheme of the test stand

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

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

The volumetric gas flow values for real and model conditions (considering the linear scale of the model S_L = 0.84) are indicated in **Table 2**.

Table 1 Types of porous plug accepted for research

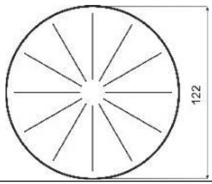
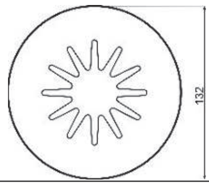
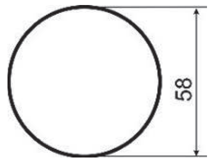
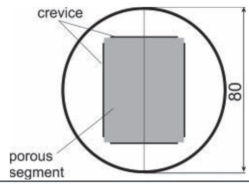
	Porous plug			
	A	B	C	D
Schematic, dimensions				
Description	Porous plug crevice type, the number of crevices - 12.	Porous plug crevice type	Porous segment	Hybrid plug (crevice plus porous segment), the number of crevices - 4.

Table 2 Volumetric flow rates accepted for testing

	Volumetric flow rate ($Nm^3 \cdot h^{-1}$)								
Model (S_L = 0.84) - air	2	3	4	5	6	7	8	9	10
Industry - argon	8.2	12.3	16.4	20.4	24.5	28.6	32.7	36.8	40.9

Experiments in the physical model of steel ladle were carried out after the required gas permeable plug was installed. The steel ladle model was filled with model liquid (water) and then the gas (air) stream, being determined on the basis of probability theory, was passed through the plug. In the research experiments, in which it was required to apply a marker as aqueous solution of $KMnO_4$, it was introduced by injection into the gas stream from a tank especially designed for this purpose.

3. RESEARCH RESULTS

The results of research was obtained in the form of visualization of gas bubbles creation, mechanism of gas bubbles cone creation (gaseous column) and determination of time and way of mixing the modelling liquid in the dependence on the applied type of plug.

3.1. Visualization of gas bubble formation

Exemplary test results are demonstrated in **Figure 2a.** On the basis of the obtained results of research tests, there can be observed significant variations in the manner of gas bubble formation in the volumetric stream of the model liquid, which depend on the type of gas permeable plug being applied. Whereas, in both cases of crevice-type plugs (variants A and B), there was observed a formation of large gas bubbles flowing out in a relatively uniform manner- from particular crevices, despite the increase in the volumetric stream of the gas flow; then in the case of a plug made of porous material (variant C), despite larger fragmentation of gas bubbles, the tendency of outflow disorders were observed. They involve accumulation of bubbles at the plug's surface and their further taking off in the form of clusters. This influences the pulsating outflow. This trend grows with an increase of the volumetric stream of the gas flow through the plug. This type of disturbances were not found in the case of blowing the bath through the Hybrid plug (variant D). In this variant, there was observed formation of relatively fine gas bubbles uniformly flowing out in the direction of the bath's surface.

3.2. Visualization of the mechanism of gaseous column formation

Selected research results are shown in **Figure 2b**. On the basis of the performed observations, it was stated that in the case of applying crevice-type plugs (variants A and B), the cone of gas bubbles, which is formed gradually, covers greater volume of the model liquid than in the case of using porous and Hybrid plugs (Variants

C and D). This is caused by variables being present in the nature of gas dispersion in the volume of the model liquid. For crevice-type plugs large gas bubbles are formed, which grow - due to pressure drop occurring in the model liquid on their outflow path - and finally form a cone with a large opening angle. In the case of bubbles being formed due to the gas flowing through porous and Hybrid plugs, the angle is smaller because their diameter is lower in the moment of flowing out of the plug and smaller expansion during their outflow. However, it should be noted that for variant B, the bubble cone demonstrates the trend of rotational movement, which is the consequence of slots' formation in this type of plug.

As the volumetric stream of the gas flowing through gas permeable plugs increases, an expected increase in waving of the model liquid surface was observed. At the same time, the formation of small bubbles beneath the surface of the liquid was found, which travels due to circulation of the model liquid (initially, towards walls of the ladle model, and then towards the bottom). The amount and depth of the bubbles' propagation into the depth of the steel ladle was increased, as the volumetric steam of the gas increases. As this phenomenon was observed by applying all types of gas permeable plugs, so for the Hybrid plug this phenomenon is more complex.

At high gas flow rates (exceeding 7 m^3 / h), the problem occurring for all types of plugs is a very intense waving of the model liquid surface, which together with the trend for pulsed outflow of gas bubbles (as described above) favours formation of model liquid discharges from the model of steel ladle. It should be noted, however, that when applying the Hybrid plug, the pulsation phenomenon is much lower than in the other cases.

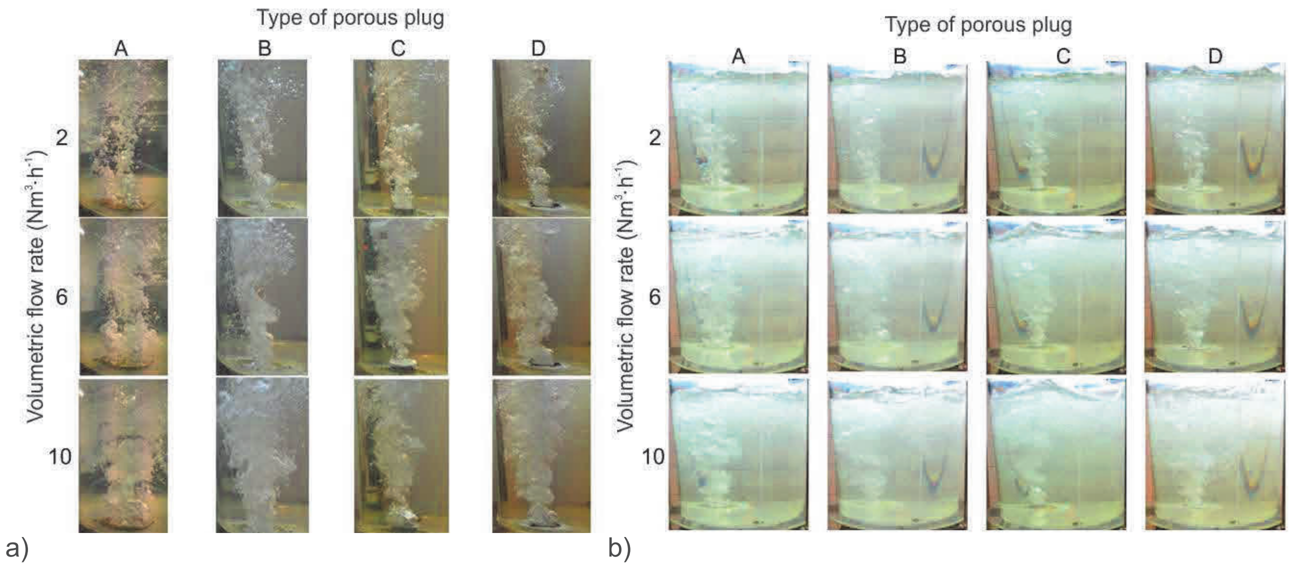


Figure 2 a) Formation of gas bubbles regarding the type of plug; b) Formation of gas column depending on the type of plug

3.3. Visualization of propagation of the model liquid in steel tundish model

Selected research results are presented in **Figure 3.** As a result of observations on propagation of the model liquid through the steel ladle model volume performed for the analysed gas permeability plugs, any disturbances in this process were observed, which differed from those being assumed. Circulation in the model liquid proceeded according to the generally known manner, as it was described in previous studies published in literature on this subject matter [2-4]. However, a crucial parameter of this process is the minimum time required for total propagation. Criterion adopted for estimating the value of this parameter was homogenization of the model liquid in terms of its colour in the entire volume of the steel ladle model. As it was expected, the minimum time required for total propagation was decreased as the volumetric pressure of gas stream increases in plugs. However, it was found that shortening the propagation time to minimum is very negligible

- in terms of the entire scope of the tested flow rates. Thus, by increasing the volumetric gas stream from 3 m^3 / h to 10 m^3 / h, the total propagation time decreased explicitly by approx. 12 %. By assuming that the value of the total time needed for propagation of the marker into the bath is a determinant for performance efficiency of the tested gas permeable plugs, it should be stated that the highest efficiency indicates Hybrid plug, when compared with porous and crevice-type plugs.

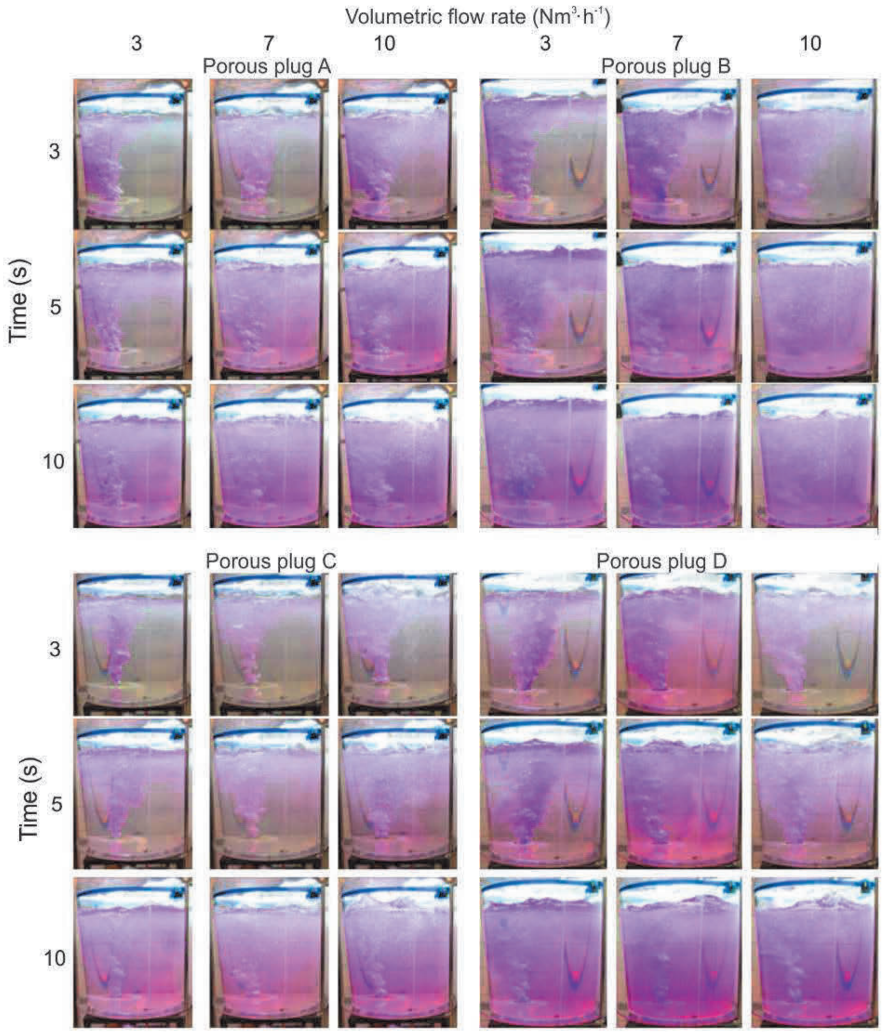


Figure 3 Visualization of propagation depending on plug type

4. CONCLUSION

Analysis of the model test results allows for drawing the following conclusions:

1) The design of gas permeable plugs significantly impacts such parameters of the argon blowing process as size and quantity of gas bubbles, the method of their dispersion in the bath and the efficiency of propagation.
2) By considering the optimal inert gas consumption, it is justified to differentiate the value of gas stream flowing through plugs in accordance to their designs. By applying Hybrid plugs, it is possible to reduce gas consumption, when comparing to other types of plugs.
3) Indication of optimal design of the plug for argon blowing is related with the need to take their price value into account. Application of very efficient, however, at the same time also very expensive Hybrid plugs is justified for melting high quality steels. In the case of processing other grades of steel, it is more favourable to use slotted plugs (crevice-type plugs) or plugs with porous core.

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