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ISSN 0543-5846
METABK 53(3) 327-330 (2014)
UDC – UDK 669.186:518.1:531.3=111

PHYSICAL MODELLING OF THE PROCESS OF MIXING LIQUID METAL IN A TUNDISH BLOWN BY GAS

Received – Prispjelo: 2013-08-26
Accepted – Prihvaćeno: 2014-01-10
Original scientific paper – Izvorni znanstveni rad

The article presents results of physical modelling of phenomena occurring during the process of blowing steel by inert gases. The aim of the research was to determine the optimal ceramic material for the porous plugs. Three different materials varying in porosity were tested. Water model of industrial tundish with nominal capacity 320 Mg was used in research. This model was made at 1:10 geometrical scale. Results of the research were presented graphically in the form of Resistance Time Distribution (RTD) curves and graphs of mixing efficiency for particular ceramic materials.

Key words: steel, physical modelling, ladle metallurgy, blowing by argon

INTRODUCTION

Modern metallurgy applies mixing of melt almost in all stages of liquid steel production. For this purpose different metallurgical apparatus are used. The process of steel mixing by oxygen introduced by the lance takes place during steel melting in oxygen converter. The movement of metal is often supported by inert gas, blown by nozzles or plugs placed in the bottom of the converter. Electric furnaces are equipped with argon plugs and oxygen lances. However, the most frequently the melt mixing is done in a ladle metallurgy.

Blowing argon into the melt is commonly used in secondary metallurgy. The important, simplest and most economical technique of ladle metallurgy is a process conducted in a steel ladle.

The process of melt mixing in a ladle in order to achieve chemical and thermal homogeneity is a complex phenomenon. There are attempts to describe it by means of characteristic sequence of physical partial processes with the simultaneous help of data coming from modelling research. Despite of the diversity of such trials the description of mixing is always made by means of characteristic behaviour and features such elements of the system as gas bubble, its movement and the structure and properties of gas-liquid column. These elements are possible to be identified using physical modelling.

Physical modelling depends on carrying out the measurements of a chosen quantity on the built model of a real object. Model should map the phenomena occurring in a real industrial process – this is realized by keeping to the rules of similarity. Such similarity is determined basing on rules contained in the field of applied mathematics called theory of similarity. It says that the geometric similarity is the basic requirement taking into account the modelling of a full size object. It means that similar ratio and characteristic linear dimensions in the model and a real object are kept. This condition is relatively easy to fulfill and consists of geometrical scale of the model. However, it does not ensure the similarity of fluid flow applied in the model to the fluid flow in a real apparatus. Hydrodynamic similarity is obtained by fulfilling the condition of equality of the dimensionless criterial numbers determined for the studied phenomena. These numbers can be determined according to the laws of dimensional analysis and they are the ratio of physical dimensions essential for the examined process. The total similarity of flows is extraordinarily hard to reach, therefore the partial similarity is often considered as sufficient. In practice the convergence of one or two most important criterial numbers for the examined case is checked.

The majority of physical models of metallurgical reactors are scaled-down models. They are built from transparent materials which enable to observe occurring phenomena. Liquid steel is then replaced by water at ambient temperature [1-4], that is why the kinematic viscosity of water is almost equal to the viscosity of liquid steel at casting temperature. The blown gas is usually air [5, 6] and sporadically nitrogen or helium [7].

EXAMINED OBJECT AND RESEARCH PROCEDURE

Research was carried out using water model built to simulate condition of the apparatus used for steel refining by argon blowing. This apparatus should cooperate with steel ladles with nominal capacity of 350 Mg. The industrial stand for steel blown by argon consists of [5]:

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- lance to introduce argon,
- installation for blowing argon from the bottom through plugs,
- two-strands apparatus to feed wire,
- apparatus to measure temperature and activity of oxygen in metal,
- apparatus to measure FeO and MnO content in slag.

Such model was made at geometrical scale $S_L = 1 : 10$. As a dominant criterion of hydrodynamic similarity the modified Froude`s criterion was determined [8]:

$$Fr_M = \frac{\rho_g \cdot v^2}{\rho_l \cdot g \cdot L} \quad (1)$$

where: ρ_g - density of gas / g · cm^{-3}, ρ_l - density of liquid / g · cm^{-3}, v- velocity of gas / cm · s^{-1}, g - gravitational acceleration / cm · s^{-2}, L - characteristic dimension / cm.

The modification of such criterion enabled to obtain the required similarity in case of diphase flows (liquid-gas). Kinetic similarity concerning the jet of gas flow in the model of steel ladle was determined using the scale method. Water was used as a modelling agent and NaCl solution as a tracer.

Figure 1 presents the scheme and main dimensions of a ladle model.

The model was equipped with specialist control and measuring apparatus. It included the microprocessor controller to steer the gas flow provided with LED display for the measured and set values.

To measure the changes of modelling liquid conductivity the conductometer with the range of 0 ÷ 20 mS/cm with submersed sensors was used. All signals were directed to the multi-channel electronic register which was equipped with: 16 universal inputs (RTD, TC, mA, V), 4 two-state inputs, 16 mathematical functions, 8 outputs and colourful LCD display. The operating store

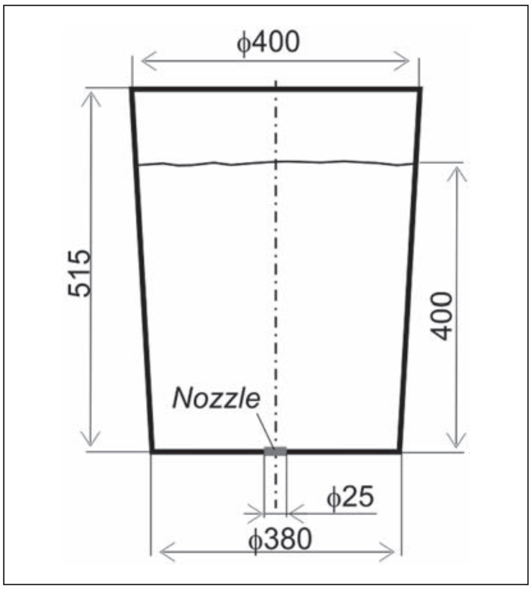

Figure 1 Scheme of the ladle model /mm

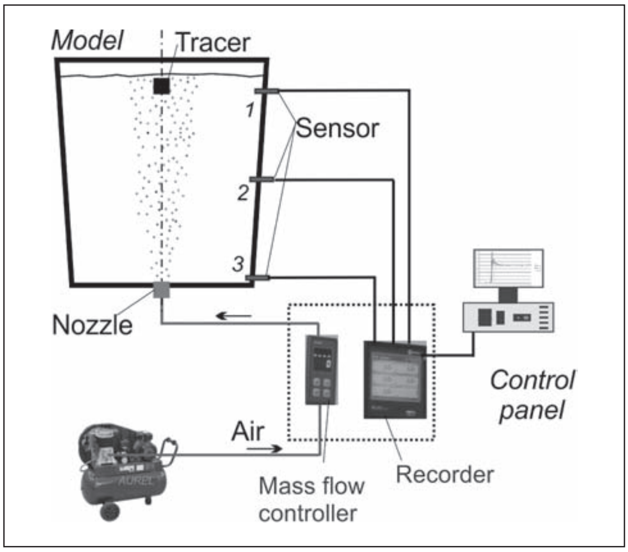

Figure 2 Scheme the test stand

was 2GB. The registered data were transmitted to the computer; where they were treated and visualized in a real time by means of dedicate software MPICRAPORT. Figure 2 shows the scheme of the test stand.

The aim of modelling research was to determine the working efficiency of three plugs of different porosity in the process of argon blowing through steel. The porous plugs were made from granular refractory materials due to applying modern technologies. The basic raw materials used to their production were corundum characterized by fire resistance under load in the range of 1860÷1900 °C or corundum mullite ($MgO \cdot Al_2O_3$) by fire resistance under load in the range of 1900÷1920 °C. Porosity of materials for porous plugs also called open porosity should stay in the range of 25 to 40 %. Radius of the capillary (wormholes) in such materials depends on the granular fraction of refractory material applied for production and can be expressed in the following form:

$$r = 0,22 \cdot R \quad (2)$$

where: R – average dimension of loose fraction of material used for plug production.

Table 1 shows model values of material parameters that can be used for porous plugs.

To identify the plugs they were marked as: A – plug with the smallest radius of wormholes, B – intermediate plug, C – plug with the highest radius of wormholes. For all those plugs the series of tests were conducted in different flow rate of inert gas. The jet of gas flow was determined basing on the real parameters of argon blow. Additionally the flow rate of gas bigger than the one applied in industry was calculated and then applied. It was done in order to know better the working efficiency of different plugs and to determine precisely their characteristics. Therefore, for every plug four different variants of test were carried out (they varied in the jet of gas flow).

Table 2 presents parameters assumed in the modelling.

First the ladle model was filled with water. Air with the determined values of jet flow was introduced into

Table 1 **Parameters of the material used for ceramic porous plugs**

Dimension of material fraction / mm	Open porosity / %
0,0 ÷ 0,5	28,2
0,5 ÷ 1,0	27,6
1,0 ÷ 3,0	25,0

Table 2 **Values of parameters used in modelling**

Variant of test	Jet of gas flow / $dm^3 \cdot min^{-1}$	
	argon	air
1	170	1,2
2	383	2,7
3	737	5,2
4	1 006	7,1

the model through the microprocessor flow controller. Tracer (water solution of NaCl) was given on the water surface. The change of electric conductivity of water was registered by means of conductometers installed in the ladle model. Water conductivity was treated as an analogy to the tracer concentration. Data obtained in such a way was stored in computer memory and then treated appropriately to obtain retention curves RTD, they characterize the hydrodynamic conditions occurring in the ladle model.

EKSPERIMENTAL RESULTS

Figure 3 shows model results of the change of water electric conductivity registered in monitoring points. The presented results of water conductivity change in the function of time depend on the concentration of NaCl water solution introduced as a tracer. Such concentration can be different in particular experiments. To compare objectively the results of experiments the measured values were transformed into dimensionless form. The following relationship was used [9,10]:

$$C_b = \frac{C_t - C_0}{C_\infty - C_0} \tag{3}$$

where: C_t, C_0, C_∞ – tracer concentration respectively in t time, at the beginning of the process and at the end of the process.

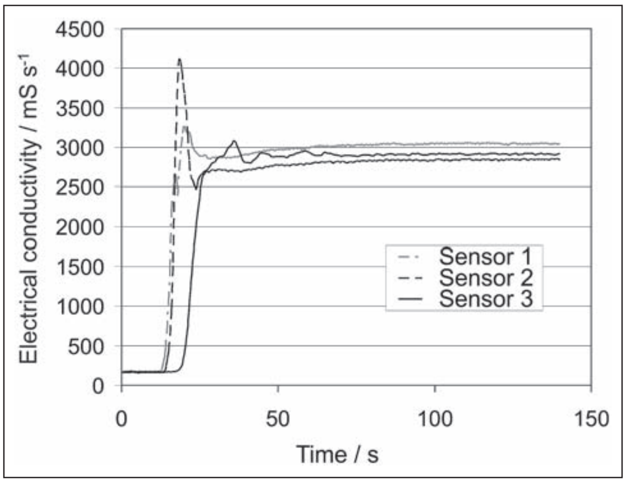

Figure 3 Example results of research

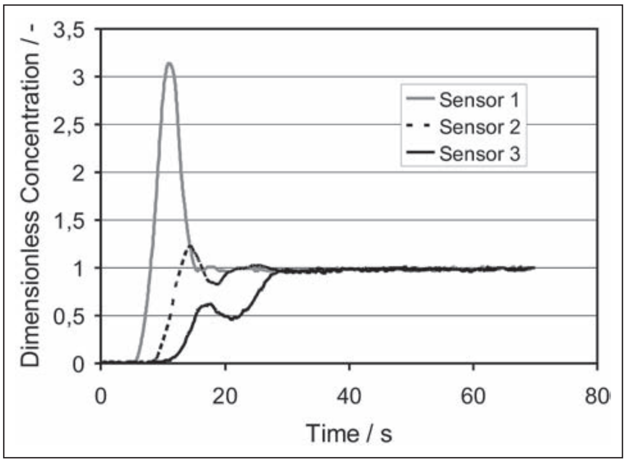

Figure 4 RTD curve for ceramic porous plug A

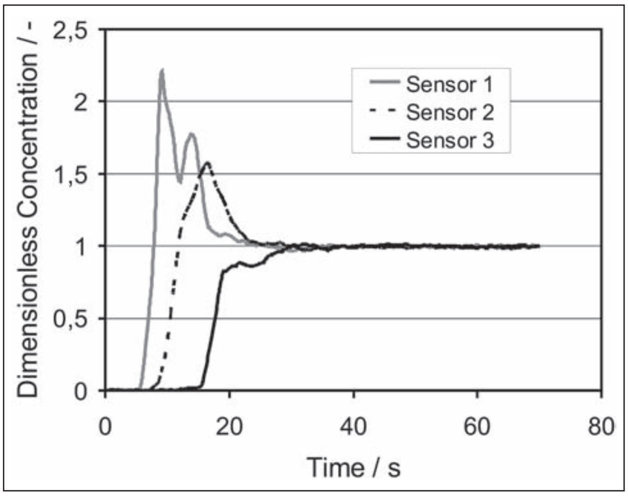

Figure 5 RTD curve for ceramic porous plug B

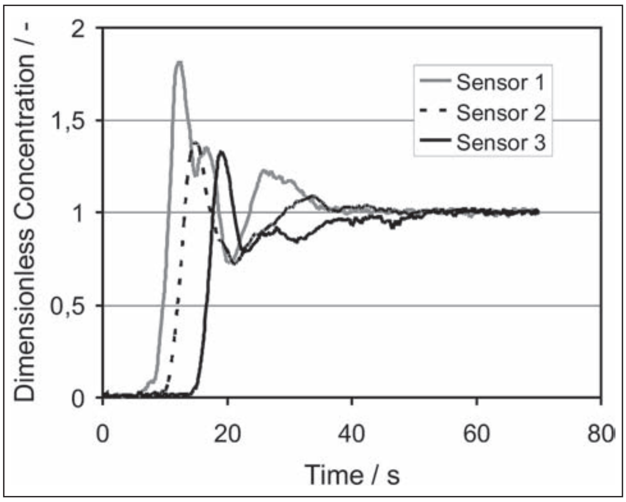

Figure 6 RTD curve for ceramic porous plug C

In this way RTD curves of resident time [11,12] for all variants of experiments were determined. Figures 4 to 6 present model results of working efficiency for particular ceramic porous plugs A, B and C respectively in the form of RTD curves for the flow rate of gas equal 2,7 dm^3/min.

Basing on the presented graphs the minimal times of total mixing of the modelling liquid in the volume of

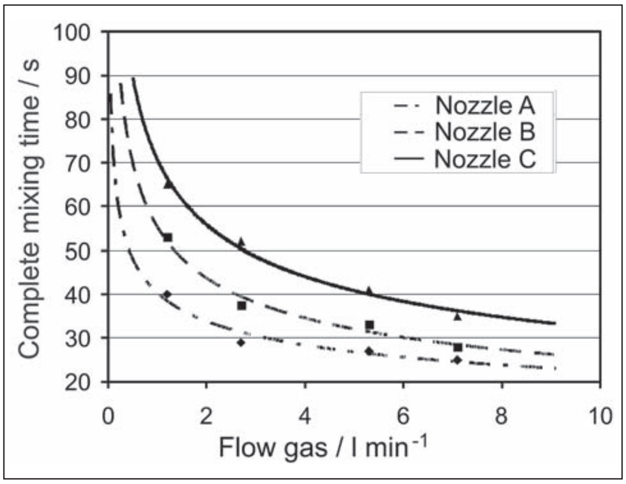

Figure 7 Working characteristics of studied ceramic porous plus

ladle model were determined. The point of total mixing was defined in the moment of reaching value 1 in all curves of the dimensionless tracer concentration. Having such data the characteristic of working efficiency of studied ceramic porous plugs were determined graphically. Figure 7 presents the obtained results.

The equations of the function of total mixing and coefficient R^2 were determined for particular curves characterizing the working efficiency of ceramic porous plugs. Table 3 presents such equations.

Table 3 **Equation of mixing function and values of R^2**

Plugs	Equation of function	R^2
A	$y = 65{,}223x^{-0{,}3116}$	$R^2 = 0{,}9412$
B	$y = 59{,}071x^{-0{,}3436}$	$R^2 = 0{,}9378$
C	$y = 49{,}829x^{-0{,}3685}$	$R^2 = 0{,}9025$

CONCLUSION

Conducted research shows that it is essential to change the conditions of argon blowing through steel if applying different ceramic porous plugs – these conditions depend on the plugs porosity. To conduct research in industrial conditions it is really difficult and expensive, at the same time the obtained results could not be satisfactory. Physical modelling enables to get information that could be applied in real apparatus with relatively lower cost. Research conducted by this method showed that the ceramic porous plug A has the best properties because the steel mixing time is shorter comparing with time of applying plugs B and C. In steelmaking practice it can be stated that the consumption of gas and energy will decrease, so it will bring economic benefits.

REFERENCES

[1] P. E. Anagbo, J.˝K. Brimacombe: Metal. and Mater. Trans. B, 21B (1990), 637-648.
[2] M. C. Diaz, S. V. Komarov, M. Sano: ISIJ International, 37 (1997) 1, 1-8.
[3] J. Mietz, S. Schneider, F. Oeters: Steel Research, 62 (1991) 1, 1-9.
[4] C. Kamata, K. Ito: ISIJ International, 35 (1995) 7, 859-865.
[5] M. Iguchi, Y. Terauchi, S. I. Yokoya: Metal. and Mater. Trans. B, 29B (1998), 1219-1225.
[6] M. Iguchi, H. Kawabata, Y. Ito, K. Nakajima, Z. Morita: ISIJ International, 34 (1994) 12, 980-985.
[7] M. Iguchi, T. Nakatani, H. Tokunaga: Metal. Trans. B, 28B (1997), 417-423.
[8] C.-J. Su; J.-M. Chou; S.-H. Liu: Materials Transactions, 50 (2009) 6, 1502-1509.
[9] T. Merder, J. Pieprzyca: Metalurgija, 50 (2011) 4, 223–226.
[10] J. Pieprzyca: Metalurgija, 52 (2013) 2, 157-160.
[11] M. Warzecha, T. Merder: Metalurgija, 52 (2013) 2, 153–156.
[12] K. Michalek, J. Morávka, K. Gryc: Metalurgija, 48 (2009) 4, 219–222.

Note: The responsible translator for English language is M. Kingsford, Katowice, Poland