K. MICHALEK, K. GRYC, J. MORÁVKA

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PHYSICAL MODELLING OF BATH HOMOGENISATION IN ARGON STIRRED LADLE

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The paper presents results of bath behaviour in the ladle model investigation during its gas argon bubbling realised by one or two stir elements situated in the ladle bottom. The study was performed with use of physical modelling method on a scale model 1 to 10. Development of homogenisation processes after start of bubbling was evaluated on the basis of electrical conductivity and temperature change, which were measured at three points of the ladle volume by conductivity and temperature sensors. Executed works were realised for conditions of 180 tons steel ladles.

Key words: steel, ladles, gas argon bubbling, stir elements, physical modelling

Fizikalno modeliranje skrućivanja taline u loncu s argonskim miješanjem. Članak rad prikazuje rezultate eksperimentalnog istraživanja ponašanja taline u modelu lonca s miješanjem pomoću mjehurića argona dovedenog kroz jedan ili dva mješača na dnu lonca. Istraživanje je provedeno koristeći metodu fizikalnog modeliranja na modelu u mjerilu 1 : 10. Tijek skrućivanja (homogenizacije) nakon početka upuštanja mjehurića procjenjivan je temeljem promjena električne vodljivosti i temperature, mjerenjima pomoću senzora vodljivosti i temeprature na tri točke unutar volumena lonca. Eksperiment je proveden za uvjete lonca od 180 tona.

Ključne riječi: čelik, lonac, argonski mjehurići, mješači, fizikalno modeliranje.

INTRODUCTION

Blowing of inert gas (usually argon) into the molten steel in the ladle is the most available and sometimes adequate secondary steelmaking method for its chemical and temperature homogeneity, which is carried out during and after the metallurgical operations such as alloying, heating steel, chemical composition correction, etc.

Homogenisation processes during argon bubbling into steel in a ladle was investigated by many authors [1-5] and it brought numerous partial pieces of knowledge. Some of them are already generally accepted and are used in daily practice almost in every steelmaking shop. With some simplification it can be summarised that for the given geometry of pouring ladle there exists certain optimum axle offset of the stir element, which ensures the best results from the viewpoint of homogenisation time and rate, and last but not least it makes also possible to optimise the influence of secondary metallurgy processes on final liquid steel quality [6, 7]. In certain cases, it is possible to use bubbling through two stir elements too.

K. Michalek, K. Gryc, Faculty of Metallurgy and Materials Engineering, VŠB-TU Ostrava, Czech Republic
J. Morávka, Material & Metallurgical Research Ltd., Ostrava, Czech Republic

Usually, it is recommended to place the stirring element in the mid to two-thirds of the radius of the ladle bottom (from the centre of the ladle). This position, however, may not be optimal according to the previous data obtained from physical modelling in terms of intensification of transmission phenomena between the slag and metal, such as in case of refining by synthetic slag.

INVESTIGATED VARIANTS AND USED EXPERIMENTAL METHODOLOGIES

Executed works were realised for conditions of 180 tons steel ladles. Physically modelled experiments were aimed to obtain data about influence of argon volumetric flow rate and position of the stir element (SE) in the ladle bottom on progress of homogenisation in the ladle. The second stage was focused on evaluation of simultaneous bubbling through two stir elements in the ladle bottom in order to propose the optimum position of the second SE in the ladle bottom.

Simultaneous bubbling is used mostly in large volume ladles with higher D/H ratio (ladle diameter and height). The main effect obtained by bubbling through two SE in these ladles consists in quicker progress of homogenisation, both of concentration and temperature, and minimisation or elimination of possible dead areas in steel bath volume, where melt movement stagnates

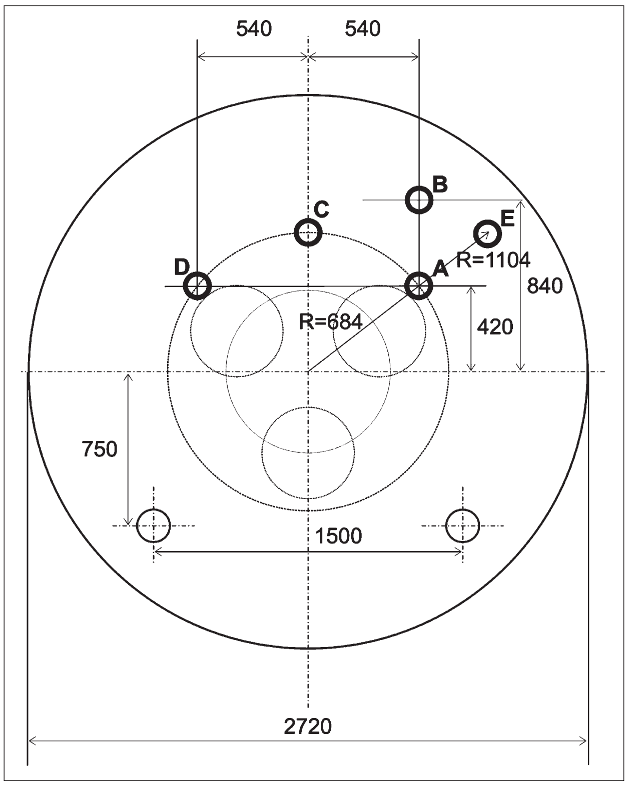


Figure 1. Positions of stir plugs in ladle bottom used for modelling study

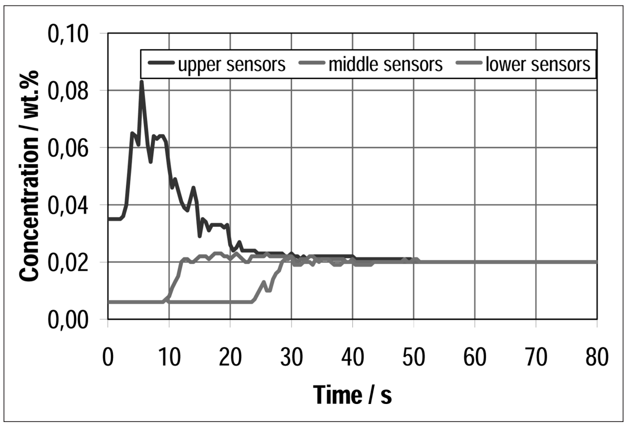


Figure 2. Typical record of tracer concentration change in three measured places of the bath in the ladle model after start of argon blowing through stir plugs

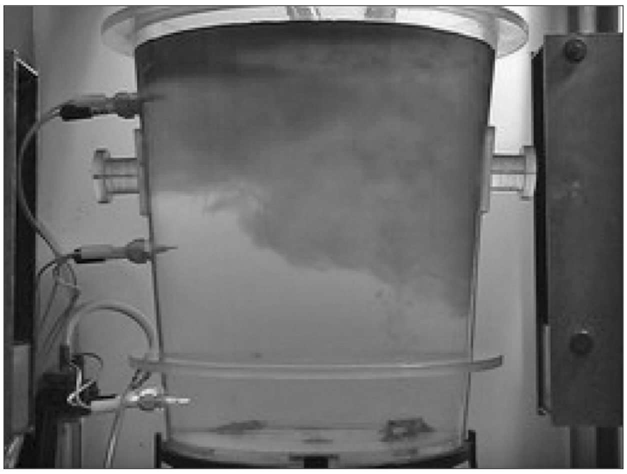


Figure 3. Red tracer visualisation (KMnO4) of homogenisation process

with all detrimental consequences for bath homogeneity. Another advantage of two SE lies in the fact that in case of failure of any one SE it is still possible to continue bubbling through the other functional SE. The Figure1 shows investigated positions of stir elements. Determination of physical similarity conditions was based on verified and used procedure published in our own previous works, e.g. in [8, 9].

While studying homogenisation processes occurring in the steel ladles blowing by argon is the chemical inhomogeneity degree of homogenized compound content in any place "A" and the time expressed by the τ dimensionless quantity

$$\overline{C}_{\mathrm{E,A},\tau} = \frac{c_{\mathrm{E,A},\tau} - c_{\mathrm{E,H}}}{c_{\mathrm{E,H}}}, \tag{1}$$

where:

$c_{\mathrm{E,A},\tau}$ - mass concentration of the compound E in the bath at point A in time τ,

$c_{\mathrm{E,H}}$ - mass concentration of the compound E corresponding to fully homogenised bath.

The value of $\overline{C}_{\mathrm{E,A},\tau}$ quantity is a function of the set of $K_{i,j}$ determining criteria and the parameters X_{A}, Y_{A}, Z_{A} determining the position of the "A" point in the bath

$$\overline{C}_{\mathrm{E,A},\tau} = \varphi(K_{i,j}; X_A; X_B; X_C), \tag{2}$$

This paper does not describe the detailed method to derive $K_{i,j}$ criteria and their survey, however, this is already contained in the previously cited works [8 - 10].

Ladle model in length scale M_{L} = 1:10 was used for experimental model research. Argon flow rate measurement was realised by precise mass flowmeter with automatic regulation. Scale factor of volumetric flow rate M_{Qv} = 0,00576 was determined from the modified Froude's criterion, which respects also influence of blown argon expansion due to increase of its temperature caused by passage through a liquid phase. Volumetric flow rate of argon in the model Q_{v}' = 1,4 l/min then corresponds to the argon flow rate of basic operational case Q_{v} = 243 l/min. Time scale factor was calculated to be M_{τ} = 0,3162. Argon bubbling in the model was realised by stir element design, which was a model equivalent of the real element for industrial conditions.

Development of homogenisation processes after start of bubbling was evaluated on the basis of electrical conductivity and temperature change, which were measured at three points of the ladle volume by conductivity and temperature sensors.

Typical record of homogenisation process and the record of the tracer change measured in three areas of the bath in the ladle model is shown in the Figure 2.

The two types of visualisation methods were used for fluid flow pattern qualitative study. The first visualisation method was based on injection of violet contrast substance ($KMnO_4$) – see Figure 3.

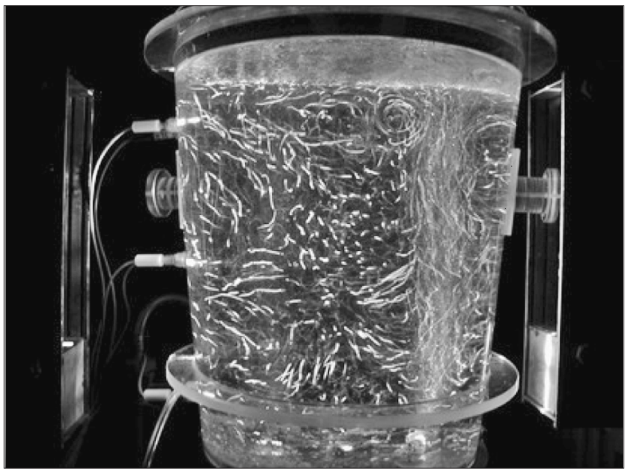


Figure 4. The long exposition time photograph from the reflex tracer visualisation

In the case of the second visualisation method, the so called light knife generated by the system of power light source was used for long exposition time photograph of moving reflection tracers (Figure 4).

OBTAINED RESULTS

Using of one stir element

The basic idea of the homogenised processes pattern using one stirring element in the position "A" can be obtained from the Figure 5.

For purposes of industrial interpretation, the homogeneity times measured on the model were re-calculated with use of already determined volumetric flow rate and time scale factors (M_{Qv}, M_{τ}) to industrial conditions of the above mentioned 180 tons steel ladles. These values were processed graphically and interlaid by regression function of the type $\tau_H = a \times Q_v^{\,b}$ – see the Figure 6.

The graph shows visible decrease of homogenisation time values τ_H with increase of argon volumetric flow rate. This decrease is not too significant and homogenisation time values vary between 100 to 150 s in the area above 400 l/min. Contrary to that, the homogenisation time values steeply increase and they achieve up to 350 s in dependence on position of the SE in the flow rate area below 100 l/min and especially 50 l/min.

From the viewpoint of homogenisation times, the course of curves also indicates that there are no distinct differences between bubbling through SE at positions A, B and E. The position A (and possibly C, D) can be regarded as the most favourable position of the SE, because it had somewhat shorter homogenisation times (approx. by 10 to 15 %) in comparison with the positions B and E.

Use of two stir elements

Physical modelling was then used for investigation of stir elements combinations AB, AC, AD and AE.

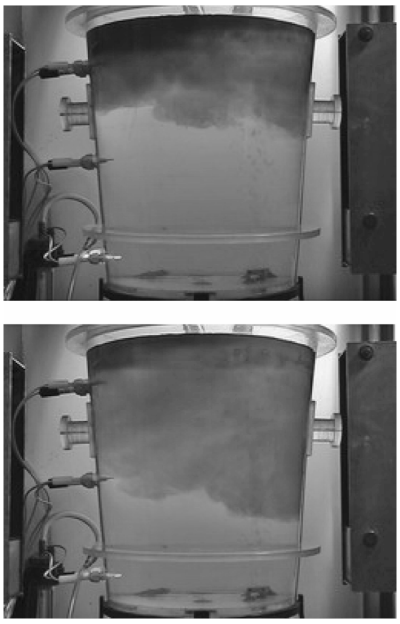
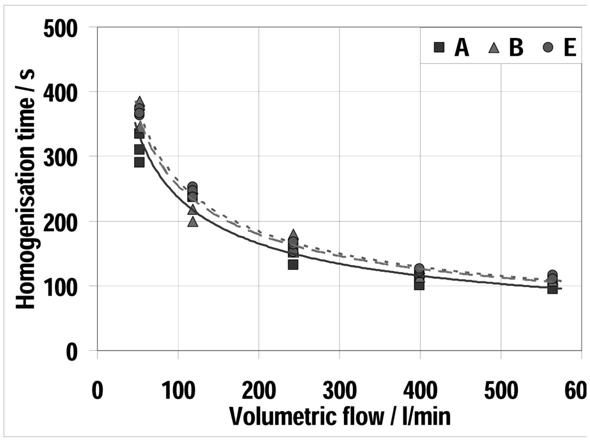


Figure 5. Behaviour of concentration and density bath inhomogeneity in ladle model after start of blowing at times of 15 and 40 s - volumetric flow Qv´ = 0,34 l/min (Qv = 59 l/min)

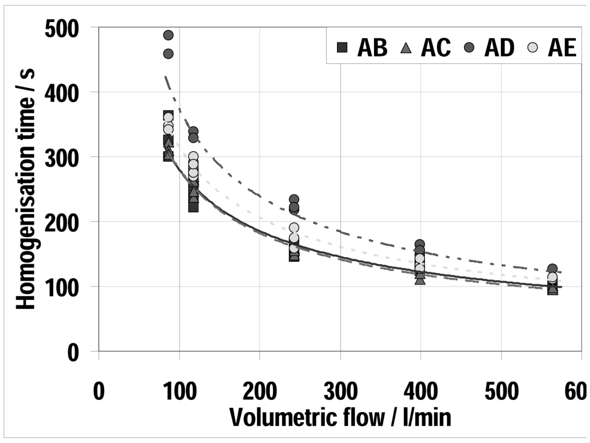


A :	$y = 2557{,}7\ x^{-0{,}5168}$
	$R^2 = 0{,}9662$
B :	$y = 2647{,}8\ x^{-0{,}5085}$
	$R^2 = 0{,}9698$
E :	$y = 2773{,}1\ x^{-0{,}5122}$
	$R^2 = 0{,}99$

Figure 6. Influence of argon volumetric flow rate Qv on the achieved homogenisation times tH for three positions of stir elements in the ladle bottom marked A, B and E. The table contains obtained regression functions and their determination coefficients for individually modelled variants

Physical modelling results are summarised in the Figure 7.

Combinations AB and AC are practically identical from the viewpoint of the obtained homogeneity times. The combination AE is less favourable, as it had longer



AB :	$y = 4381{,}4\ x^{-0{,}5971}$
	$R^2 = 0{,}9666$
AC :	$y = 4966{,}9\ x^{-0{,}6245}$
	$R^2 = 0{,}989$
AD :	$y = 7223{,}5\ x^{-0{,}6437}$
	$R^2 = 0{,}9284$
AE :	$y = 5251{,}6\ x^{-0{,}6115}$
	$R^2 = 0{,}9857$

Figure 7. Influence of argon volumetric flow rate Q_v on the achieved homogenisation times t_H for four combinations of stir elements position marked AB, AC, AD and AE. The table contains the obtained regression functions and their determination coefficients for individually modelled variants

homogenisation times than variants AB and AC. Surprisingly the worst was the variant AD, in which location of the SE in position D where the y axis was axially symmetrical to the position A. This combination had the longest homogenisation times in full volumetric flows range. It represents increase of time by 30 to 40 % in comparison with combinations AB or AC.

Explanation of this apparent anomaly can be found in flow character or in formation of two recirculation zones in the pouring ladle, directions of which are opposite to each other. In this way, the speed components of flowing mutually significantly influence or even eliminate each other with negative impact on components and heat transfer. Homogenisation process, both of concentration and temperature, slows down, and obtaining of homogenous stabilised bath requires longer bubbling and thus bigger blown argon volume, which can cause even greater drop in temperature.

CONCLUSION

Physical modelling method was used for model investigation of influence of argon bubbling through a stir element or two stir elements situated in the ladle bottom in the course of homogenisation processes in a bath. The best results were obtained in variants with simultaneous bubbling through the SE in positions A and B or A and C (Figure 7). On the other hand, the longest homogenisation times were obtained in the simultaneous bubbling variant with location of the SE in positions A and D, which can be explained by creation of two re-circulation zones in pouring ladle with important mutual influencing and elimination of components transfer rate.

In the second part of the described model study (see the paper "Mathematical Identification of Bath Homogenisation in Argon Stirred Ladle"), the results of experimental investigation were processed by mathematical models.

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Note: The responsible translator for English language is B. Škandera, Czech Republic.