M. SATERNUS, T. MERDER, J. PIEPRZYCA

ISSN 0543-5846
METABK 53(2) 205-208 (2014)
UDC – UDK 669.71:66.067:669.788:546.293:62.001.57=111

PHYSICAL MODELLING OF REMOVING HYDROGEN FROM LIQUID ALUMINIUM CONDUCTED IN URC-7000 REACTOR

Received – Prispjelo: 2013-07-26
Accepted – Prihvaćeno: 2013-10-30
Preliminary Note – Prethodno priopćenje

The research which visualizes the process of argon blowing through modelling agent in continuous URC-7000 reactor was carried out. Physical model was built according to the theory of similarity. Additionally, the measurements of modelling agent conductivity were done. As a consequence the obtained results enabled to determine the change of tracer concentration in the volume of the reactor.

Key words: aluminium, reĀning, argon, hydrogen, physical modelling.

INTRODUCTION

Today aluminium obtained electrolitycally as well as from scrap needs to be refined. It includes many metallic and nonmetallic inclusions such as sodium, calcium, borides, oxides, carbides and above all hydrogen which is particularly harmful, because it causes porosity. There are many methods for hydrogen removal from aluminium, but the most popular becomes the one based on blowing liquid metal by inert gas, especially argon. As a consequence hydrogen is picked up to the surface and additionally nonmetallic and metallic inclusions are partially removed due to flotation [1,2].

The process mentioned about is conducted in bath and continuous reactors. Also the way of gas introduction to the metal can be different. These reactors are equipped with nozzles, ceramic porous plugs or rotary impellers [3,4].

URC-7000 reactor belongs to continuous reactors in which gas in generated by two ceramic porous plugs. This reactor is commonly used in different polish cast foundries [5].

During the process of a gas blowing into the liquid metal the most important is to find the most desirable level of gas dispersion in the liquid metal. Such a liquid metal should be uniformly dispersed in the whole volume of the reactor. It can be done by trial-and-error method; however it is really expensive and not economical. Therefore, today, such a research is carried out in laboratories with the use of water models which are usually scaled down.

Modelling research (physical and numerical) is commonly used for analyzing the phenomena occurring in reactors applied in metallurgy of steel and nonferrous metals [6-8]. In modelling research of metallurgical reactors in which processes of metal mixing and homogenization occur, it is often assumed that their course is isothermal [9,10]. Of course it is some simplification of the examined system, although it is justifed technologically and does not influence fundamentally the obtained results. Then it is not necessary to take into consideration thermal effects, and the similarity of the model to the real object can be reached by geometrical and dynamic similarity.

Geometric similarity is reached by keeping compatibility of ratios of model characteristic dimensions with a real object dimensions. Dynamic similarity needs the compatibility with different forces (inert force, gravitational force, force of internal friction, force of surface tension) influencing the built system.

Physical and also numerical modelling [11,12] give the important data which allow to find more about the process of blowing the inert gas into aluminium. That is the reason why the process can be controlled and stirred in appropriate way.

EKSPERIMENTAL PROCEDURE

Research was carried out with the use of water model of URC-7000 continuous refining reactor. This model was built at 1:4 scale (see Figure 1).

The presented model simulates hydrodynamic conditions occurring in a liquid aluminium during refining process by argon blowing. According to the theory of similarity in modelling research of hydrodynamic and isothermal flows, the thermal and chemical effect cannot be considered. Thus, the similarity of water model to URC-7000 reactor is realized by geometrical, dynamic and kinetic similarity. To determine dynamic similarity the rule of equality of criterial numbers in a model and a real object was used; whereas kinetic similarity was determined by the scale methods applying modified Froude number.

M. Saternus, T. Merder, J. Pieprzyca: Silesian University of Technology, Department of Metallurgy, Katowice, Poland

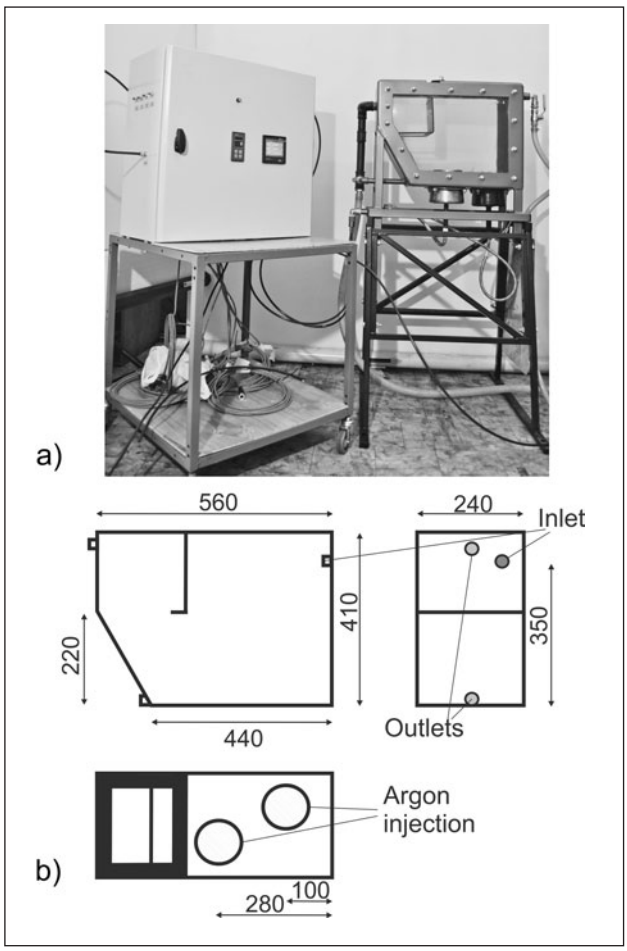

Figure 1 a) Test stand of URC-7000 physical model, b) dimensions of reAning chamber

Table 1 presents the values of Reynolds, Weber and Froude numbers for water (T = 293 K) and aluminium (T = 973 K) determined for conditions occurring in URC-7000 continuous refi ning reactor. Table 2 shows the kinetic parameters of the modelling agents calculated for the experimental conditions assumed in modelling research.

Table 1 **Value of the criterial numbers calculated for water and aluminium (URC-7000 reactor)**

Criterial number	Value for	
	water	aluminium
Reynolds number	1 905,9	4 620,0
Froude number	0,467	0,118
Weber number	0,00028	0,00028

Table 2 **The data concerning modelling variants of the flow (argon and water)**

Variant	Flow rate / $dm^3 \cdot min^{-1}$		
	argon		water
Case 1	Nozzle A	5	11
	Nozzle B	5	
Case 2	Nozzle A	10	
	Nozzle B	10	
Case 3	Nozzle A	15	
	Nozzle B	15	

Two stages of research were carried out using a water model. In the first stage the visualization of the process was made. The second stage included measurements of changing the modelling agent conductivity in the reactor – this change was a response to the impulse input function (Dirac impulse) under the infl uence of NaCl tracer. Such measurements enable to determine the change distribution of tracer concentration in the whole volume of the reactor.

The visualization of modelling agent fl ow and mixing in the reactor was done in the following way: tracer (water solution of $KMnO_4$) was introduced to the modelling liquid in the amount of 0,02 m^3 for 5 s. Tracer was given after the regulation of the modelling agent fl ow, so in that way the determined conditions of kinetic similarity of modelling agent fl ow in the reactor were not disturbed. The course of experiment was registered by a camera placed in the plane parallel to the front wall of the model.

The aim of this stage was to observe the influence of gas fl ow rate on the level of refi ning gas dispersion in the water. As a result the way of modelling agent fl ow and mixing as a function of blowing gas fl ow rate was determined.

Determination of the distribution of the tracer change in the reactor was done in the following way: when the flow of agents was stabilized according to the working out conditions of similarity, the tracer (water solution of NaCl – 20 %) was introduced to the system for 5 s. Changes of tracer concentration (represented by the change of modelling agent conductivity) were registered continuously by means of conductometer . Figure 2 shows the place in which the tracer was introduced and the location of the conductometer sensor. Research program realized in a such way enables to get information necessary to manage verifi cation of numerical model sets and analyze results obtained from this model [10,11].

EKSPERIMENTAL RESULTS

Figures 3 to 5 show registered results of the research for the examined flow rates of refining gas.

During visualization research it was possible to state the quick course of tracer homogenization in the modelling agent. It caused some diffi culties in analyzing the examined hydrodynamic phenomena occurring in the reactor model. Therefore, the obtained fi lm materials were treated appropriately by the special computer program to elongate the time of sequence. As a results slowing down the modelling agent and in the same time slowing down the gas bubbles coming up to the surface could be obtained.

Analysis of such prepared material enabled to observe many characteristic phenomena. In Case 1 (see Figure 3) tracer fl uently moved from a zone A ceramic porous plug infl uence to B ceramic porous plug infl uence. No swirls and any tracer concentration inside the

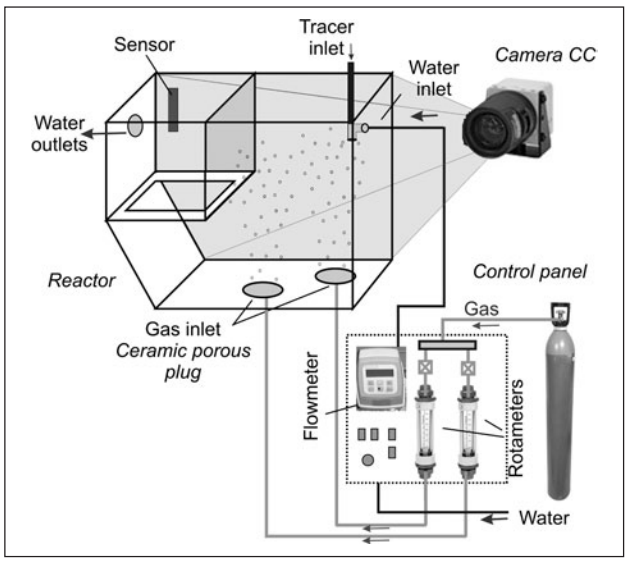

Figure 2 Scheme the test stand

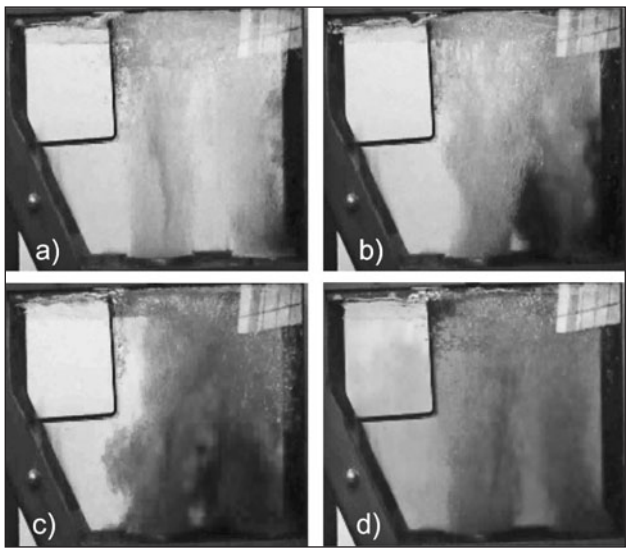

Figure 4 Distribution of the tracer for the flow rate of reÃning gas equal 10 $dm^3 \cdot min^{-1}$ after the time: a) 1 s, b) 2 s, c) 3 s, d) 8 s

streams of gas bubbles were observed. Such course of experiments can be justified by the low level of gas dispersion in a liquid phase and also the low velocity of gas bubbles coming up to the surface. This fact is a cause for a long residence time of the tracer in the reactor. To sum up, the homogenization of modelling agent runs uniformly in the areas of both ceramic porous plugs; however low kinetics of this process can make its efficiency unsatisfactory.

In Case 2 (see Figure 4) similar way of tracer distribution in modelling agent was observed, it means parallel transfer in the range of both ceramic porous plugs. Taking into account the efficiency of the process the kinetic conditions are better comparing to the Case 1. Also in Case 2 no essential swirls or tracer concentration inside the streams of gas bubbles were observed.

In Case 3 (see Figure 5), where the flow rate of refining gas is the highest, the unfavourable phenomenon of blocking the tracer by gas bubbles (generated by A ceramic porous plug) ascending in the modelling agent was seen. High level of gas bubbles dispersion and also high speed create a gaseous curtain. This make difficult to transfer the tracer into the influence zone of gas bubbles generated by B ceramic porous plug. Thus, efficiency of B plug work is limited. The creation of swirls and tracer concentrations inside the streams of gas bubbles in the area of A as well as B ceramic porous plug was also observed.

Basing on the above, it can be stated that case 2 is the optimal solution taking into consideration hydrodynamic conditions of the examined process and its efficiency.

Figure 6 presents the characteristics of dispersion occurring in the process of argon blowing through modelling agent in dependence of a flow rate of the refining gas.

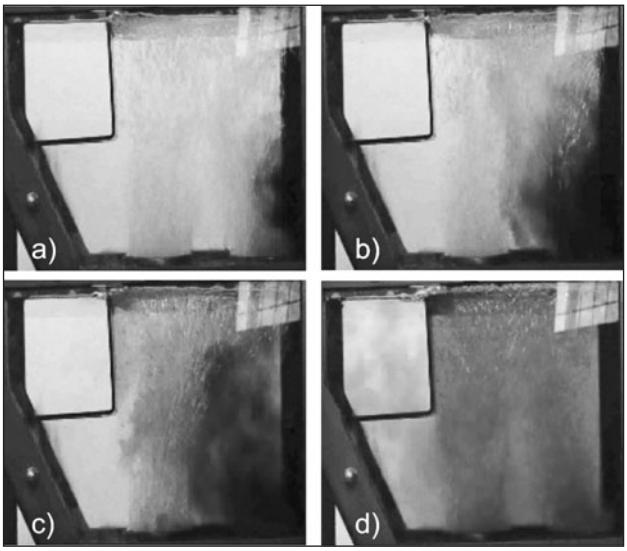

Figure 3 Distribution of the tracer for the flow rate of reÃning gas equal 5 $dm^3 \cdot min^{-1}$ after the time: a) 1 s, b) 2 s, c) 3 s, d) 8 s

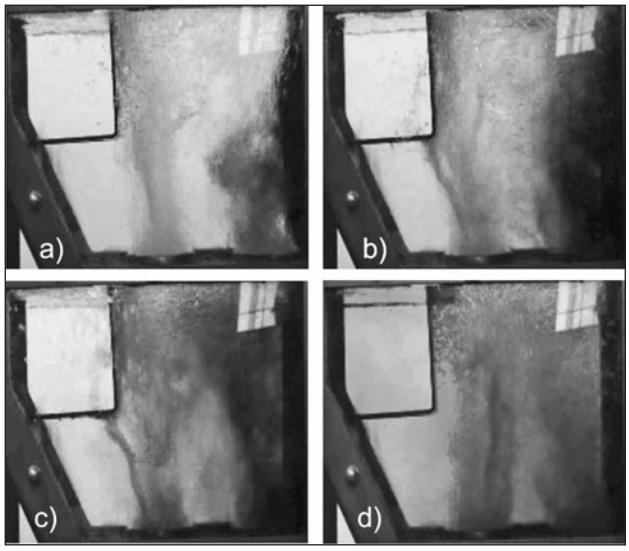

Figure 5 Distribution of the tracer for the flow rate of reÃning gas equal 15 $dm^3 \cdot min^{-1}$ after the time: a) 1 s, b) 2 s, c) 3 s, d) 8 s

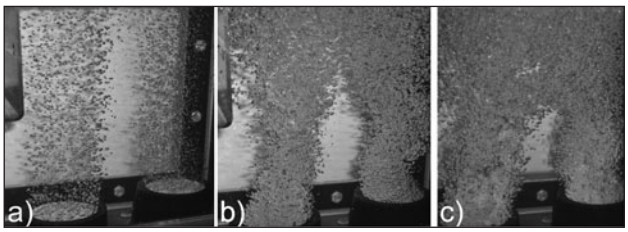

Figure 6 Characteristics of dispersion occurring in the process of argon blowing through water in the dependence of the flow rate of reAning gas: a) 5 $dm^3 \cdot min^{-1}$, b) 10 $dm^3 \cdot min^{-1}$, c) 15 $dm^3 \cdot min^{-1}$

For the flow rate of refining gas equal 5 $dm^3 \cdot min^{-1}$ (see Figure 6a) the minimal dispersion was observed. The single gas bubbles raised up to the surface of the reactor, the gas bubble dispersion was seen only in the area of gas bubble generation, near nozzles – there was no mixing in the whole volume of the reactor . For the flow rate of refining gas equal 10 $dm^3 \cdot min^{-1}$ (see Figure 6b) the intimate dispersion was observed. Single gas bubbles raised up to the upper part of the reactor , mixing of the gas bubbles with liquid was good – only near the wall sides and in the bottom parts of reactor there was no dispersion. For the flow rate of refining gas equal 15 $dm^3 \cdot min^{-1}$ (see Figure 6c) the uniform dispersion was observed. Both single gas bubbles and chains of bubbles were raised up to the reactor surface. Gas bubbles were well mixed with the liquid, only in the bottom part of the reactor (near the nozzles) there was a lack of dispersion, swirls on the liquid surface made gas bubbles mix with the liquid in the upper part of the reactor; however there is a danger that removed hydrogen could be introduced again into the liquid metal.

Figure 7 shows the curve characterizing the change of tracer concentration during the process for the studied cases. To compare obtained characteristics for three examined cases, it they were transformed into the dimensionless form using the relationships described in detail in work [13].

The characteristics presented in Figure 7 confirmed the observation made on water model. Curve for Case 2 is characterized by the shortest time of tracer homogenization in the modelling liquid.

The obtained characteristics will be also used for direct verification of results obtained from numerical simulations.

CONCLUSIONS

Modelling, both physical and also numerical, has become one of the most efficient tools used to get information about the processes occurring in industry [14]. Physical modelling enables to find out more about the phenomena that took place in the real conditions. It also gives possibilities to choose the optimal parameters of the process and in the same time control the process.

The most important parameter when blowing argon through liquid aluminium is a flow rate of refining gas.

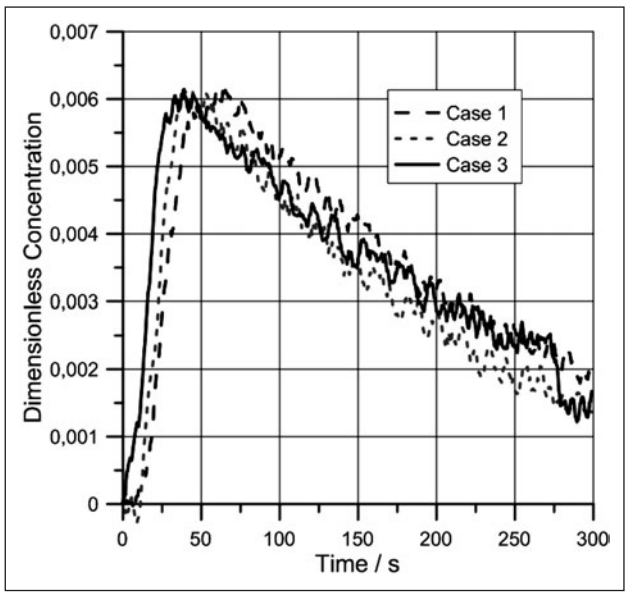

Figure 7 Characteristics of time residence for studied cases

In the research it was found that for the built model this flow rate should be between 10 to 15 $dm^3 \cdot min^{-1}$, but not more. Then the uniform dispersion of gas bubbles can be observed in the whole volume of reactor . There is also no danger of creating undesirable chains of gas bubbles which in consequence can lead to swirls that could cause, especially in the upper part of reactor (near the surface), removed hydrogen go back into the liquid metal.

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