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APPLICATION OF HIGH FLOW RATE GAS IN THE PROCESS OF ARGON BLOWING TROUGH STEEL

The article demonstrates results of modelling research tests concerning the analysis of possibilities of blowing gas into the metal bath at high flow rates in a steel ladle with a nominal capacity of 50 Mg. Various configurations concerning of gas introduction into the steel ladle were analysed. There were considered cases of blowing into the metal bath via one, two or three purging plugs, being installed on the bottom and via additional support for blowing the gas from the top through the lance.

Results obtained from the water model of the reactor were verified with the results of numerical simulations.

Keywords: ladle, high intensity gas blowing, numerical modelling, physical modelling

1. Introduction

The process of argon treatment of steel is commonly used in the ladle metallurgy. Currently used industrial technologies allow for controlling the volumetric flow of gas at the level of several hundred litres per minute. For melting common steel and higher quality steel are most often used ladles with purging plugs non-centrally installed, however, there can be also found purging plugs located in the middle of the axis of steel ladle [1-2].

The modern steel market demands from manufactures to provide high-grade steel, commonly with very low carbon content. In the case, when utilization of vacuum devices is impossible, a possible solution seems to be application of deep argon treatment for this type of steel. Progress in design and materials used for construction of purging plugs facilitate application of new technological solutions [3-4]. Thus, it becomes possible to introduce much higher volumes of inert gas into the metal bath. However, this raises a number of new problems that require thorough research.

Selection of suitable parameters for metallurgical processes is very crucial, considering their proper and economic implementation process. Due to the fact that it is difficult to test various types of solutions under industrial conditions, for this purpose physical and numerical modelling is commonly applied [5-9]. Thus, this was the object of this research study.

2. Object of the research study

Object of the research study was a model of steel ladle (S_L = 0.2), representing an industrial ladle with a capacity of 50 Mg of liquid steel. The model is designed in accordance with the requirements of kinematic and dynamic similarity theories, satisfying as well the condition of geometric similarity [10]. It has an option to blow into the bath via one, two or three purging plugs, installed on the bottom and in addition gas could be blown through the lance from the top. The geometry and view of the model is presented in Figure 1, and dimensions are given in Table 1.

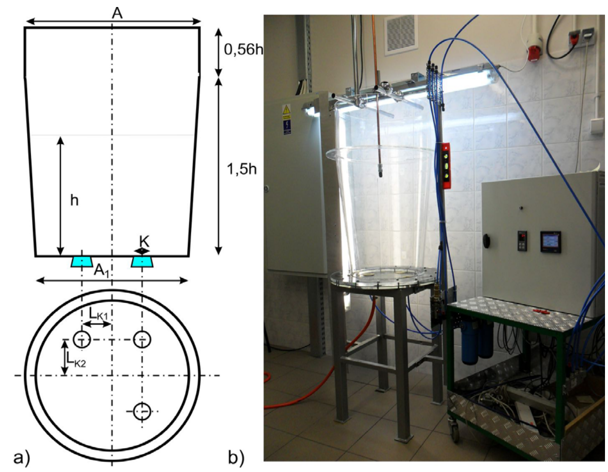

Fig. 1. a) Scheme of model, b) view of the test model

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TABLE 1

Design parameters of the ladle model (scale 1:5)

Parameter	Symbol	Unit	Value
Volume (to the liquid steel level)	V	m^3	0.057
Diameter	A	m	0.511
	A_1	m	0.386
Height	1,5h	m	0.648
Height (to the liquid steel level)	h	m	~0.44
Purging plug diameter	K	m	0.023
Purging plug position	L_{K1}	m	0.094
	L_{K2}	m	0.096

According to the guidelines, the calculation of dynamic similarity condition of (gas) argon flow in the model to the real conditions were performed on the basis of the revised Froude`s criterion in the following form [11-12]:

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

where:

Q' – volumetric stream of gas flow for the water model, $m^3 \times s^{-1}$,

Q – volumetric stream of gas flow for the industrial reactor, $m^3 \times s^{-1}$,

c' – constant for the water model,

c – constant for the industrial reactor,

S_L – linear scale.

Figure 2 presents designation of purging plugs being installed on the bottom of the model and location of the lance in different variants of experiments P6 to P10.

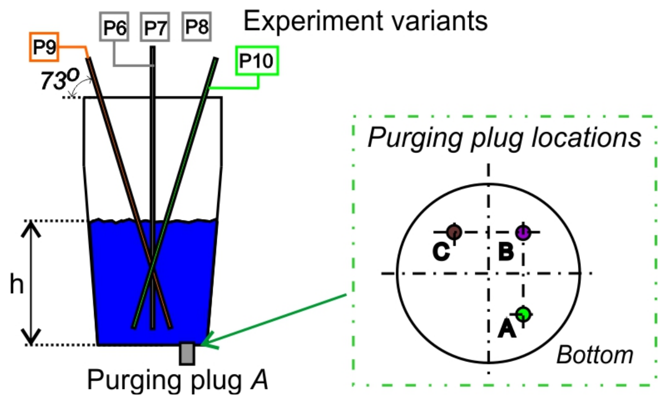

Fig. 2. Different variants of gas introduction for purging plugs and lance

Individual variants of the experimental tests were designated, depending on the configuration method for inserting the gas into the modelled ladle (Table 2).

The course of research tests was registered with cameras arranged in two planes (Fig. 3). Research tests performed is such a way allowed for complete identification of the process of forming gas bubbles, their dispersion into the volume of the model liquid, formation of bubble column, sustaining the mirror surface and the time required for complete mixing the marker in the modelled ladle. For each variant, a series of research tests were performed, each having three experimental trails.

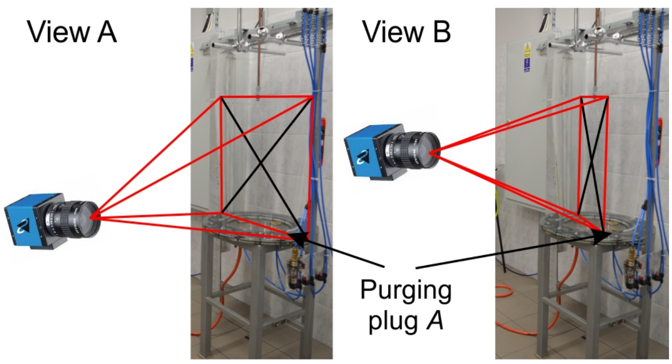

Fig. 3. Position of the measuring planes

TABLE 2

The assumed blowing process parameters of bath stirring under industrial conditions and their values computed for testing conditions on water mode

Experiment variant	Method for gas introducing	Indastry scale 1:1	Model scale 1:5
		The intensity of gas	
		$[m^3/h]$	$[m^3/h]$
P1	purging plug A	40	0.27
P2	purging plug A	70	0.47
P3	purging plug A	35	0.23
	purging plug C	35	0.23
P4	purging plug A	35	0.23
	purging plug B	35	0.23
P5	purging plug A	23.3	0.16
	purging plug B	23.3	0.16
	purging plug C	23.3	0.16
P6	purging plug A	40	0.27
	lance	30	0.2
P7	purging plug A	20	0.13
	lance	50	0.34
P8	purging plug A	20	0.13
	lance	70	0.47
P9	purging plug A	20	0.13
	lance	70	0.47
P10	purging plug A	20	0.13
	lance	70	0.47

3. Results and discussion

Figure 4 demonstrates exemplary research test results showing the mechanism of forming the cone shape bubble gas column and the degree of their dispersion within the modelled fluid for the considered test variant.

In P1 and P2 test variants, gas has been injected into the modelled liquid by a single purging plug installed on the bottom of the modelled ladle. These variants differed with the value of gas flow through the purging plugs (Table 2). It was observed an expected phenomenon in which the size of bubbles was

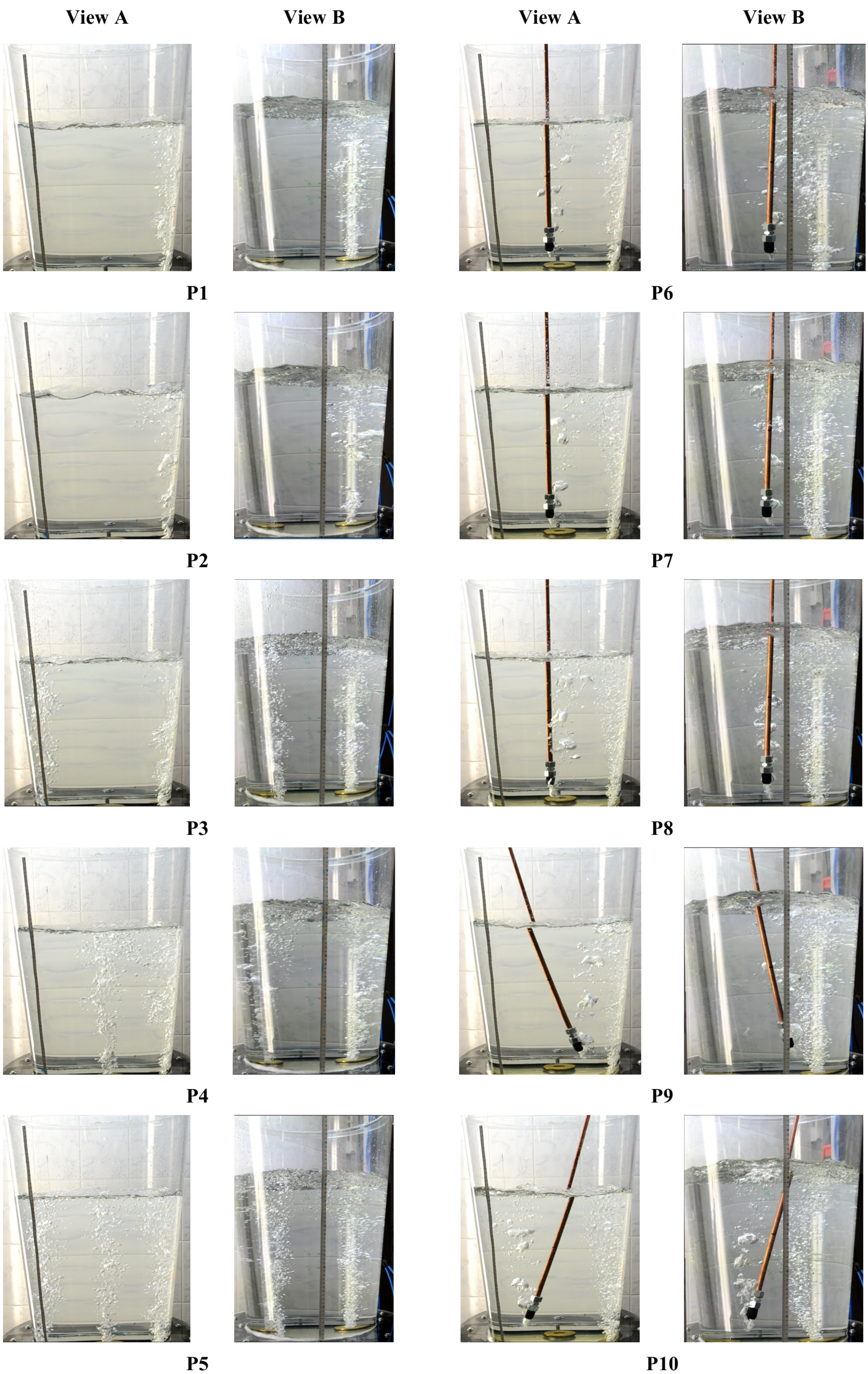

Fig. 4. The mechanism of grow of conical shape bubble gas column and the degree of their dispersion in modelled liquid for the analysed test variants

increasing in the model liquid as the volume of gas flow rate was growing. For P1 variant, the bubble column consists of relatively fine gas bubbles flowing uniformly toward the liquid free surface. In the case of P2 variant, the bubbles are significantly enlarged, which causes formation of irregular column, significantly deteriorating the degree of gas dispersion in the volume of the model liquid.

In P3, P4 and P5 variants it was applied a multi-point method of injecting the gas into the volume of the model liquid. This was implemented by mounting two or three purging plugs on the bottom of the steel ladle.

In P3 variant two purging plugs were placed in the diameter of the steel ladle model. The main aim was to exclude unfavourable, taking into account the work – purpose phenomena occurring in the P1 and P2 variants, while intensifying the beneficial effects, at the same time. Thus, the nature of the obtained bubble columns in the volume of the model liquid was similar as in the P1 variant; and at the same time it was possible to introduce a sufficient volume of the gas into the bath, without the risk of adverse growth of gas bubbles. This has improved the degree of dispersion of the gas in the volume of the model liquid.

In P4 variant two purging plugs were also used, however, they were installed on the bottom chord of the modelled steel ladle, which crossed its radius in the middle of the right angle. The aim of this action was to increase the entropy of the system unit, and thus, to increase its efficiency. In terms of the quality of the formation of bubble columns and dispersion of the gas in the volume of the model liquid, no remarkable differences were discovered between this and P3 variant.

In P5 variant gas was injected by three purging plugs. This variant, from the point of view of the analysed phenomena, the best satisfies the assumed expectations. This variant has a fundamental drawback, while application of such solution in industrial conditions can be very hard.

The subsequent stage of the research study included experimental tests with application of purging plug configuration and gas lance placed vertically in the axis of the model of steel ladle. Particular variants, namely P6, P7 and P8, of these experimental tests differed in the method of division of gas flow between these two design elements of the model (Table 2). On the basis of observations on the formation of the surface of purging plug and flowing away toward the liquid surface of the model bubble column and its interaction with gas bubbles discharged from the lance, it was stated that the share of total volume of the gas flow being introduced into the bath via a purging plug should not exceed the value of 40% in relation to its share in the gas lance. This is raised upon the too excessive growth of gas bubbles, being observed in P6 variant, which flow away from purging plug, as well as caused by a low dependence of bubbles flowing out of the lance on the dispersion of gas in the metal bath. The situation varies in the case of applying the second configuration for P7 and P8 variants. The structure of the bubble column is being developed properly and the flow of gas bubbles coming from the lance has a beneficial effect on its dispersion within the volume of the model liquid.

In the next phase of the research concerning variants P9 and P10, the gas was blown into the bath via purging plug and gas lance being introduced at a predetermined angle. In P9 in the direction of bubble column and in P10 in opposite direction to the bubble column. In terms of the degree of dispersion of the gas being blown in the volume of the model liquid, it was stated that the most favourable solution is P10 variant.

4. Validation with CFD tests

Numerical research tests were carried out in a water-air model, which enabled direct confrontation with results of experimental tests performed on a physical model of the analysed device. As in the case of experimental tests carried out in laboratory, also in computations, presence of slag covering the metal was excluded.

Simulations were performed with the use of Discreet Phase Model (DPM) [13,14] and therefore, it was assumed that the water level is a flat free surface – stationary wall with zero shear stresses ($\tau xy = \tau xz = \tau yz = 0$). Furthermore, it was assumed that the air flows out from the entire surface of the purging plug, at a specified mass flow rate (Q_m), generating bubbles with a fixed diameter. Consequently, the bubbles are floating in the model fluid, and then they leave the system after reaching the liquid free surface. A contact of bubbles with other walls of the object causes their reflection. For the wall and bottom of the ladle the stationary wall boundary condition ($u = v = w = 0$) was adopted.

Numerical simulations were carried out with Computational Fluid Dynamics (CFD) Software – ANSYS Fluent – version for educational purposes [15].

Two test cases: P1 and P2 were subject to numerical analysis, for which the gas flow rates were: 0.27 and 0.47 m^3/h, respectively. Figures 5 and 6 demonstrate comparison of the phenomena on raising bubble column for the water model and the numerical model, for both of the analysed air flow rates. For more distinctive comparison, a scale was applied on the figures, where the value of 1 represents nominal filling of the model, equal to 440 mm.

By comparing the obtained results of numerical simulations with results for the water model, a broad convergence could be observed in raising bubble column for both air flow rates. Thus, it can be concluded that the performed research tests are mapping the actual processes.

5. Conclusion

On the basis of the performed research results, the following conclusions were drawn:

- For test parameters of the blowing process, implementing gas into bath using single purging plug installed at the bottom of the ladle is the least favourable option.
- In case where such solution needs to be applied, it is required to move the purging plug by approx. 10 percent from the

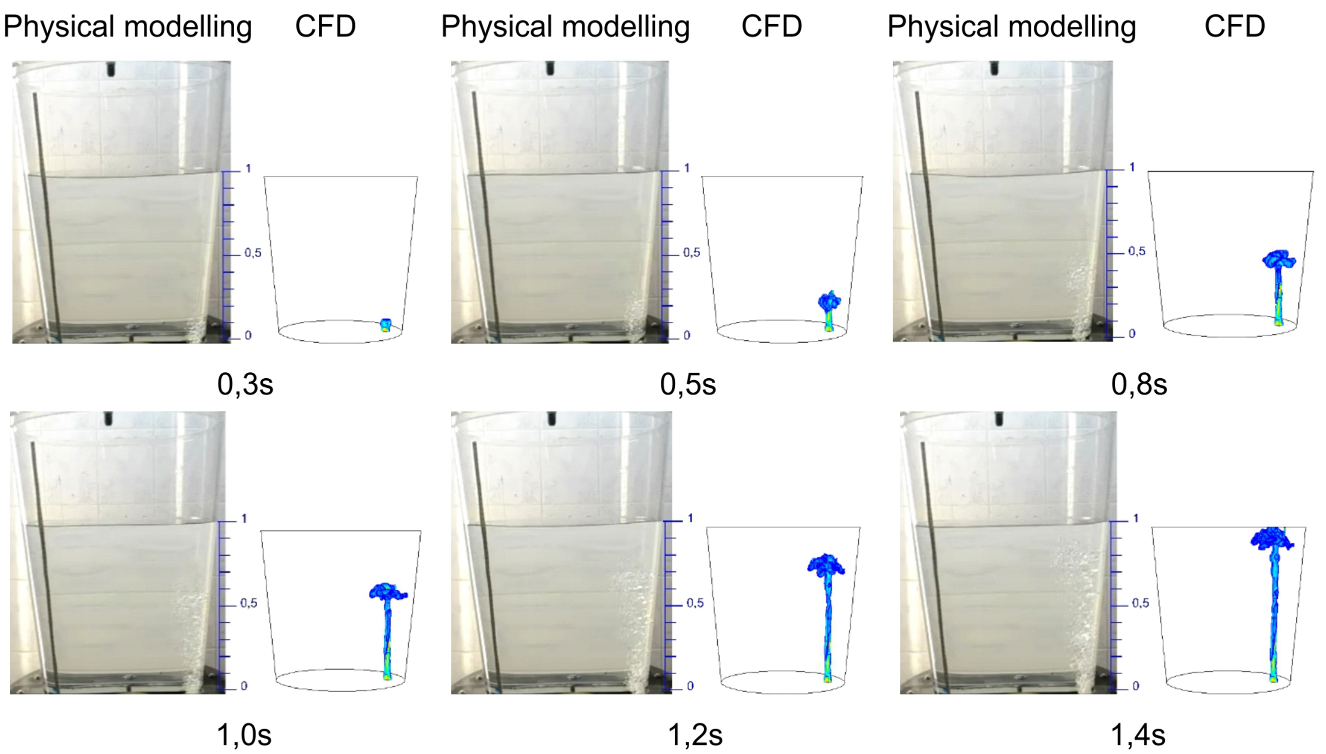

Fig. 5. Comparison of numerical simulation results with experimental data, research test N^{o}P1

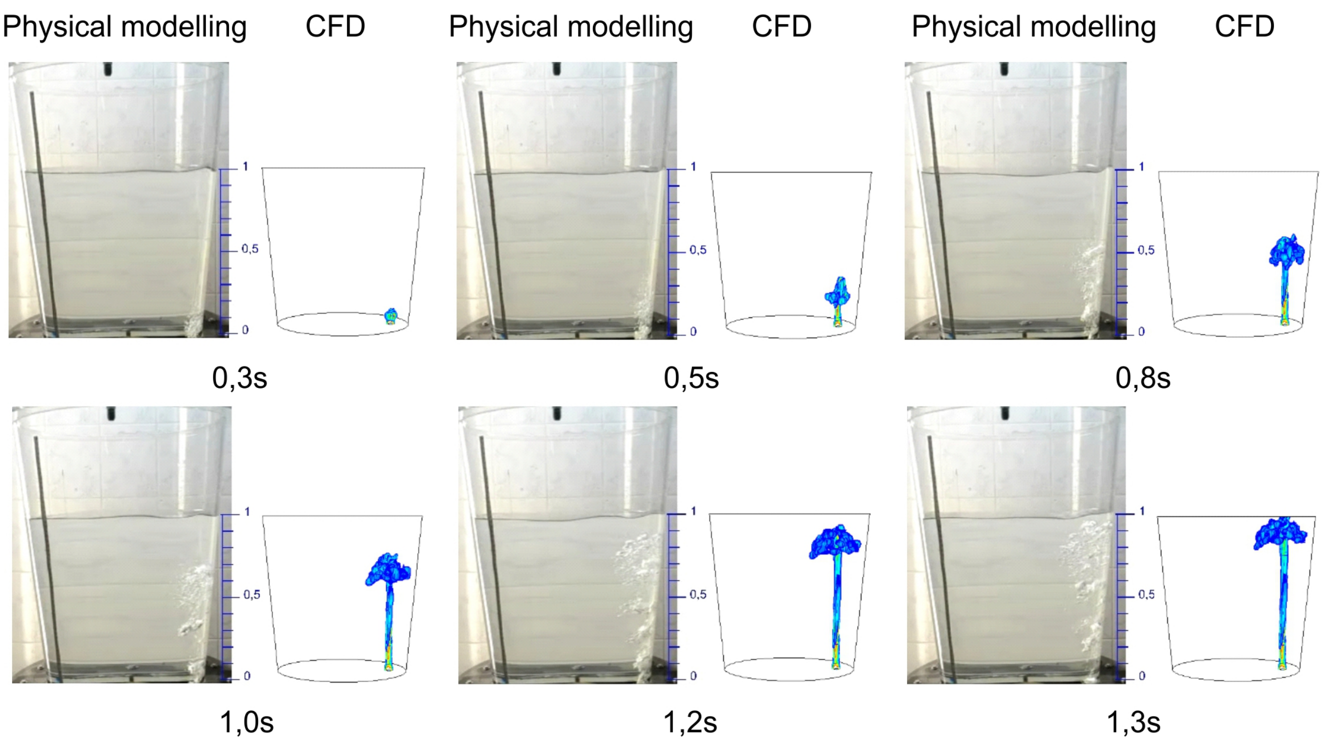

Fig. 6. Comparison of numerical simulation results with experimental data, research test N^o P2

ladle axis location, in order to reduce very negative impacts of bubble column on the refractory lining in this zone.

- Improvement of hydrodynamic conditions can also be achieved by facilitating the metal bath blowing process by using gas lance injected vertically, whereby in this case proper distribution of volumetric flow of the gas between the fitting and the lance is required. It was stated that share in the filling should not exceed 40%.
- Optimal option for introducing the gas into liquid metal is to use two purging plugs located on a chord of the ladle bottom crossing the radius in the middle section, at the right angle.

Acknowledgements

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