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# OPTIMIZATION OF THE STEEL FLOW IN THE TWO-STRAND TUNDISH USING DIFFERENT GEOMETRY OF IMPACT PAD

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One of the primary factors affecting the quality of continuously cast billets is the way the steel flows and mixes in the tundish of Continuous Steel Casting (CSC) machine. This is of particular importance in the case of continuous billets. The article presents the results of model tests of identifying the mechanism of liquid steel flow through a tundish under the influence of the applied arrangement of the working space. Two models of turbulence inhibitors and an impact pad with the surface of a sphere segment were used for the research. The tests were carried out with the use of the physical water model of the CSC device, and the obtained results were verified by numerical methods.

*Key words:* tundish, liquid steel flow, arrangement of working space, physical water model

## INTRODUCTION

Currently, the basic criteria for assessing the quality of continuous billets are the metallurgical purity of steel and their primary structure. These features of billets are influenced by various factors [1]. One of the most important is the flow and mixing of liquid steel in a tundish [2-5]. The process of achieving the requirement parameters of the billets is achieved, among others, by the use of flow regulators in the working space of the tundish [5-9]. Their task is to ensure the formation of appropriate proportions of active flows, i.e. turbulent flow to laminar (plug) flow with the maximum limitation of stagnant flow (dead zones). Therefore, the design of flow regulators is subject to changes and modifications along with the development of the technology of continuous casting of steel. The article presents results of model tests aimed at determining the effectiveness of three new designs of flow regulators: two modified turbulence inhibitors and an impact pad with a spherical impact surface, which is increasingly used in industry.

The results of visualization tests and the obtained RTD (Residence Time Distribution) type F curves were used for this analysis.

## EXPERIMENTAL MATERIALS AND METHODS

The research was carried out with the use of the physical model of the CSC device, which has a segment structure. The main segment was a two-strand tundish model. The model is built in accordance with the requirements of the similarity theory [10, 11]. The model is described in detail in [12]. In the authors' own research, the dominant criterion was Froude number [10].

The tundish model was made on a scale of 1 : 4 (the volume of the model is 0,130 m$^3$). Tundish bottom is 0,025 m lower in the area of the outlets. Figure 1 shows the geometry of the tundish model with the basic dimensions.

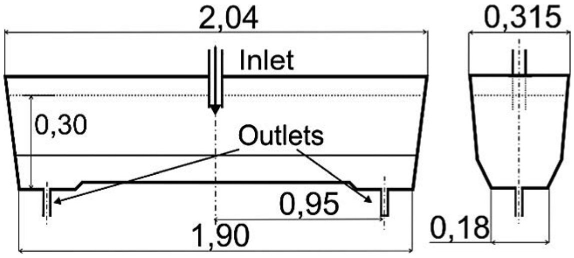

**Figure 1** Diagram of a model tundish with the most important dimensions / m

Before starting the research, an analysis of industrial tundish geometry was carried out, taking into account the possibility of using arrangement in the form of flow regulators in its working space, and a review of the literature was carried out in terms of the analyzed issue.

The next stage included the design and construction of elements for the arrangement of the working space of the tundish (the project was carried out in the SolidWorks program). Models of arrangements elements were printed using FDM (Fused Deposition Modeling) 3D printing. The use of this technique significantly shortened the total time of the preparatory work. Figure 2 shows the geometry of the designed elements of the working space arrangement.

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As mentioned above, the designed impact pad is characterized by the fact that its working surface is a segment of a sphere. The justification for this is the fact that, in contrast to the flat surface, it is less exposed to rinsing and, consequently, to the formation of exogenous non-metallic inclusions, and helps to reduce turbulence in the inlet zone of the tundish [9].

On the other hand, the designed two variants of the turbulence inhibitor differ in terms of dimensions and thus in the occupied volume of the tundish working space. However, both variants have rounded and bevelled inner edges with the basic dimensions.

The location of particular arrangement variants in the working space of the tundish model is schematically shown in Figure 3.

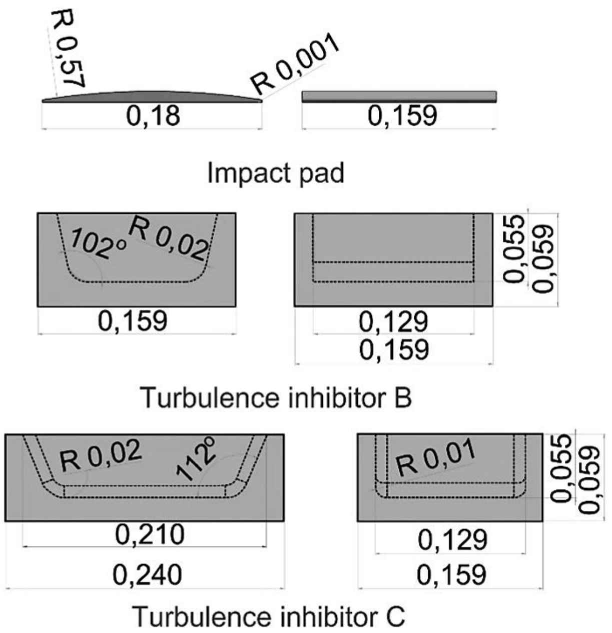

**Figure 2** Designed elements of the arrangement of model working space with dimensions / m

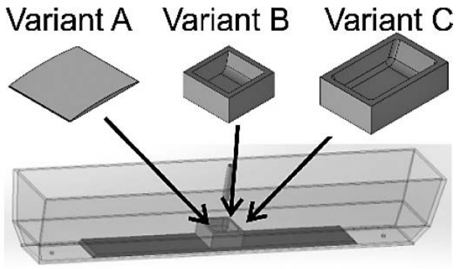

**Figure 3** Variants of the arrangement of the tundish working space analyzed in the research

The tests were carried out with the assumption that in real conditions, the cross-section of the continuous billets is 2 000 x 225 mm, with the linear casting speed $V_{cas}$ = 0,8 m/min. Therefore, the calculated water flow rate in the model was 21,6 l/min. The Heaviside method on inlet into the tundish model was used in the model tests to determine the F-type RTD curves planned in the test program and in the visualization tests. An aqueous solution of $KMnO_4$ and NaCl was used as the tracer.

The individual experiments were carried out in such a way that after reaching the assumed water level in the tundish model and stabilizing the flow in accordance with the developed similarity conditions, the clean water tank was closed and the tank with a tracer was opened. The tracer was reported throughout the measurement period.

## RESULTS AND DISCUSSION

Based on the determined RTD curves, the minimum residence time of the tracer in the model liquid was determined and the dynamics of the entire process was characterized. Figure 4 shows the developed RTD charts for individual variants of the experiment.

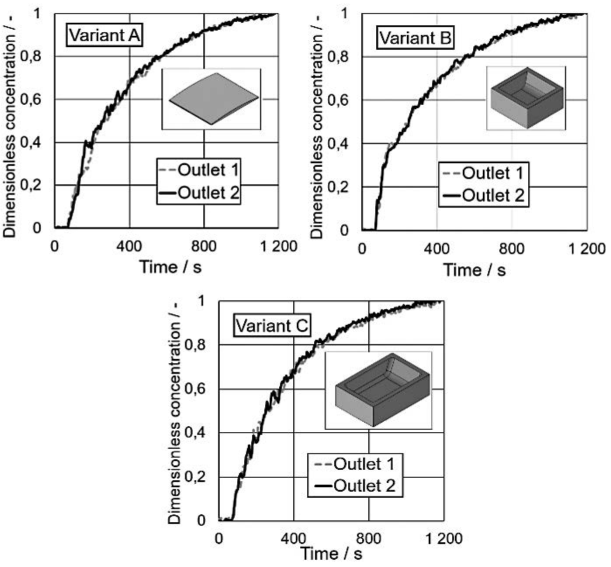

**Figure 4** RTD curves for particular variants of the experiment

When analyzing the obtained graphs (Figure 4), it should be noted that there were slight differences in the values of the minimum tundish residence time for individual variants of the experiment, ranging from 72 to 75 seconds. In the case of variant B, a certain decrease in the dynamics of mixing of the model liquid was observed in the 141 seconds of the experiment. Generally, however, the results of the research are similar and, on the basis of them, it is difficult to distinguish any of the variants as significantly different from the others.

Figures 5 - 7 show the visualization results for the analyzed variants. The comparison of the images obtained as a result of the experiment visualization (see Figures 5 - 7) showed significant differences in the model liquid mixing behavior under the influence of the flow regulators used. In the variant A, in which an impact pad with a surface constituting a segment of a circle was used, a typical method of shaping the flow structure of a model liquid was observed. The impact of the inflow stream on its surface, due to its shape, directed the stream in such a way that the turbulent flow zone covered about 1/3 of the tundish volume and ensured proper contact in the metal-slag phase separation

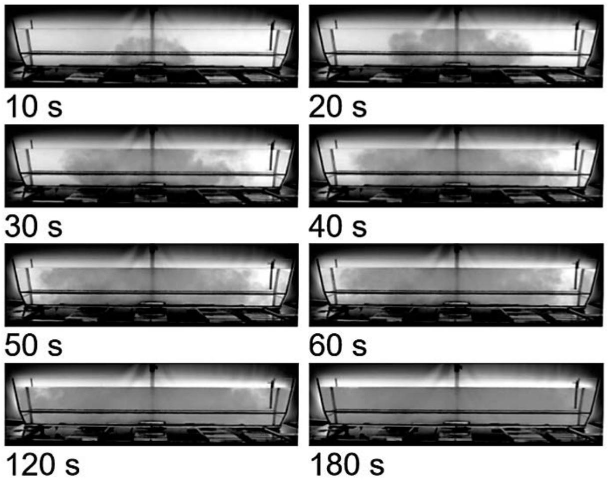

**Figure 5** Visualization of the model liquid flow, variant A

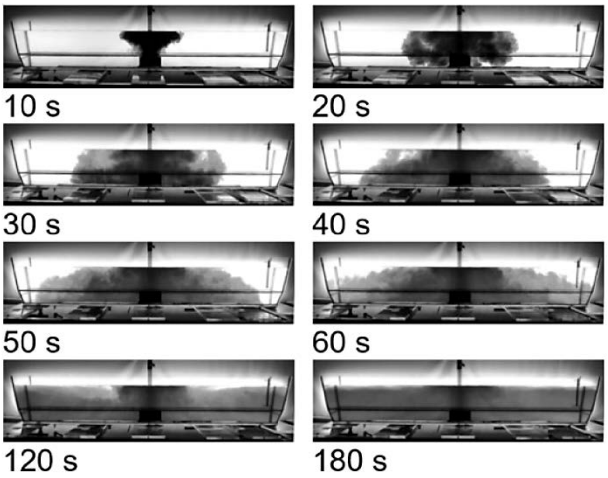

**Figure 6** Visualization of the model liquid flow, variant B

zone. No excessive undulations were observed on the surface of the model liquid. Such a shape of the flow promotes the homogenization of liquid steel in industrial conditions and the processes of taking over non-metallic inclusions by the slag. Then, a plug flow zone with a clear front was formed, which allowed to minimize the formation of unfavorable dead zones.

The mixing process was different in the other two variants, in which turbulence inhibitors were used. Particularly in variant B, a strong ascending stream was observed in the inlet tundish zone. Despite the use of rounded contact surfaces of the inlet stream with the bottom of the inhibitor, strong undulations were observed on the surface of the model liquid. The volume of the turbulent mixing zone was limited in relation to variant B. Therefore, the process of creating the plug flow zone was not satisfactorily formed due to the decrease in the kinetic energy of the model liquid stream. The flow in the lower part of the tundish and the formation of dead zones on the metal-slag interface were observed. Such a configuration of the plug flow zone prevents the proper course of the refining of liquid steel and the absorption of non-metallic inclusions by the slag.

Similar, unfavorable phenomena, although to a lesser extent, were observed in the variant C of the experiment.

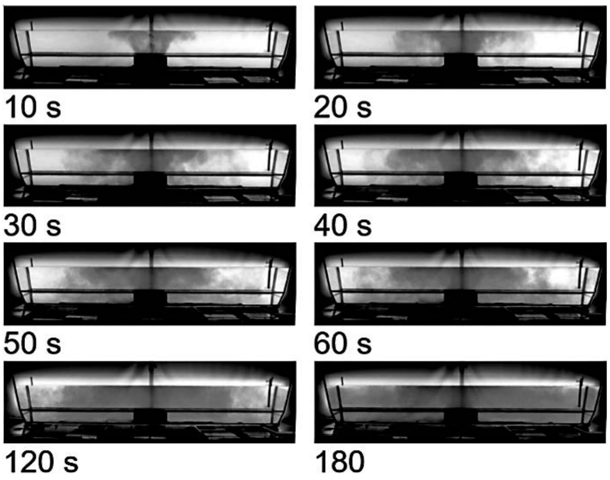

**Figure 7** Visualization of the model liquid flow, variant C

As in variant B, the proportions of the turbulent to plug flow zones are incorrect, which results in the formation of dead zones. Although their volume in the tundish workspace was somewhat limited compared to the B variant, it was significantly larger than the A variant.

The results of the research with the use of the water model were verified by numerical methods of CFD (Computational Fluid Dynamics). Numerical simulations were performed using the ANSYSFluent program ver. 19.2 [13]. The description of the mathematical model used is presented in [14,15]. The initial and boundary conditions adopted for the calculations correspond to the conditions of the tests carried out on the physical (water) model. Figure 8 presents the RTD (from physical modeling and CFD) curves for the experiment variant A. There is a slight difference between the measured and calculated data for the individual curves. These differences show up in the form of curve shifts, but the growth rate of the tracer concentration is largely consistent.

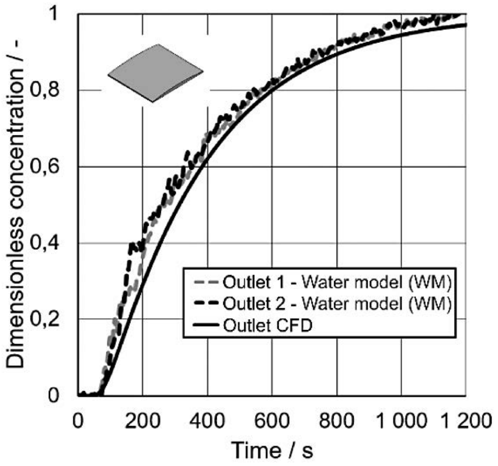

**Figure 8** Compiled RTD curves (WM and CFD) for variant A

Figure 9 presents a summary of the tracer distribution (physical modeling and CFD) in the tested tundish for the experiment variant A. On these basis, it is possible to see

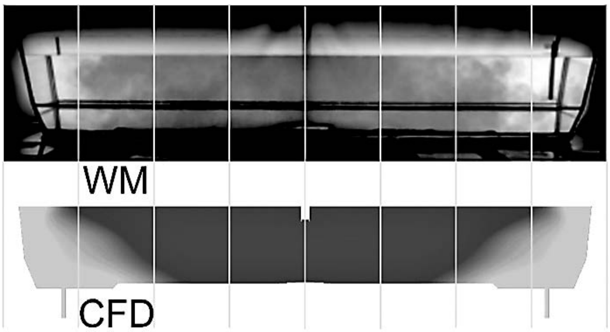

**Figure 9** Summary of tracer distribution (50 s) in the tested tundish for experiment variant A (WM and CFD)

a good qualitative compliance of the results obtained on the water model with the results of the CFD.

## CONCLUSIONS

The mechanism of liquid steel flow through the tundish of the CSC device is very complex. It is characterized by many variables. These variables have a direct impact on the expected course of the technological process of casting. Often these variables are interdependent and the improvement of one negatively affects the other. Hence, the determination of the suitability of applying changes to the liquid steel flow control system in tundish is always a compromise.

On the basis of the determined RTD curves, it is not possible to clearly distinguish any of the variants of the conducted experiments. However, visualization of the hydrodynamic phenomena occurring in the tundish model reveals important differences between them.

The obtained research results give grounds for the following conclusions:

- The best variant of the model liquid flow control through the tundish of the CSC device is variant A.
- The proportions of active flows (turbulent and plug) are the most favorable in variant A. They favor the correct course of homogenization process and refining of liquid steel.
- The tendency to create dead zones is most visible in variant B. However, in variant A it is minimal.

The results of the verification of the tests with the use of the water model using the CFD method indicate the correctness of the adopted assumptions and computational procedures necessary to describe the movement and mixing of the liquid in the tested variants. This authorizes to carry out further numerical calculations of the casting parameters that cannot be tested on the physical water model.

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**Note:** The responsible for English language is Paulina Pieprzyca