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EFFECT OF CASTING FLOW RATE ON STEEL FLOW PHENOMENA IN TUNDISH

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Article presents results of numerical simulation of steel flow and mixing in real two strand tundish working in on of polish steelworks. In calculation different casting flow rates were tested. They were analyzed taking into account their influence on the hydrodynamic conditions occurring in reactor. AnsysFluent code was used for numerical simulation of 3D turbulent steel flow in tundish for steady and transient conditions. As a result of calculation spatial velocity fields and steel turbulence intensity were obtained. Research was complemented by residence time distribution – typical for analyzed calculated. Whereas basing on F curves the kinetic of steel mixing were estimated.

Key words: tundish, steel flow, numerical modeling, mixing time, RTD curve

INTRODUCTION

Tundish as an element of CC machine plays an important role in the technological process of steel casting. In industry many technological solutions of tundish construction are applied. They are characterized by the individual geometry, tonnage and the amount of outlets [1-7].

The purpose of using a tundish is to ensure the continuous flow of liquid steel to the mould during the exchange of the next main ladle. Additionally, tundish has become the active metallurgical unit in which many operations are made, for example the control of temperature, level of nonmetallic inclusions, or the final correction of liquid steel chemical composition. The aim of such treatment is to ensure the highest purity and quality of steel. The key factor of operation carried out in a tundish is to control the flow of liquid steel through it. So, it is really important to get to know better the structure of such a flow.

The flow of steel in working space of a tundish is usually regulated. Many different flow control devices are applied. They have significant influence on the hydrodynamic conditions of steel. Therefore, the view of a flow structure, temperature distribution and condition of steel mixing is individual for different kind of tundish. Other factors such as: the amount of steel that can be found in working space [5,8] and the steel casting flow rate [9-10] can also influence hydrodynamic conditions.

Modelling research (physical and numerical) is commonly used for analyzing (getting to know better) the phenomena occurring in reactors applied in metallurgy of steel and nonferrous metals [1-7,11-14].

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The presented results of numerical simulations apply to the analysis of steel flow and mixing in the real tundish working in polish steelworks. In calculations, different casting flow rates (commonly used in technological process) were tested. They were analyzed taking into account their influence on the hydrodynamic conditions occurring in the reactor.

As a result of calculation spatial velocity fields and steel turbulence intensity were obtained. Research was complemented by residence time distribution RTD (F and E types) – typical for analyzed cases. Basing on E curves the percentage participations of different kinds of flow occurring in a tundish were calculated. Whereas basing on F curves the kinetic of steel mixing were estimated.

EXAMINED OBJECT AND RESEARCH PROCEDURE

Tundish description

The examined object is a T type tundish designed for continuous casting of slabs intended for small cross-section rolled products. The tundish is symmetrical in relation to the lateral plane. The nominal capacity of the tundish is 7,5 Mg of liquid steel. Figure 1 presents the scheme of industrial tundish, and Table 1 shows its dimensions and basic working parameters. Table 2 includes different casting flow rates analyzed in calculations.

Numerical modelling

In the continuous casting tundish, the flow field is normally turbulent. The flow is treated as steady. The fluid is Newtonian and incompressible. Free surface of

Table 1 **Dimensions and basic working parameters of the tundish**

Parameter	Symbol	Value
Tundish length / m	L	2,30
	L_1	0,70
Tundish width / m	B	1,15
	B_1	0,60
Filling level (steady-state casting) / m	H	0,6
	H_1	0,44
Inclination of the side walls / °	α	8
Shroud diameter /m	d_{SH}	0,05
Shroud position / m	L_{SH}	0,93
SEN diameter / m	d_{SEN}	0,019
SEN position / m	L_{SEN}	0,70
Casting speed / m·min^{-1}	-	0,8 ÷ 3
Operating temperature / K	-	1 828
Density of molten steel / kg·m^3	-	7 000

Table 2 **DiÃerent casting flow rates analyzed in calculations**

Case	Casting speed / m/min
A	0,8
B	1
C	1,2
D	2

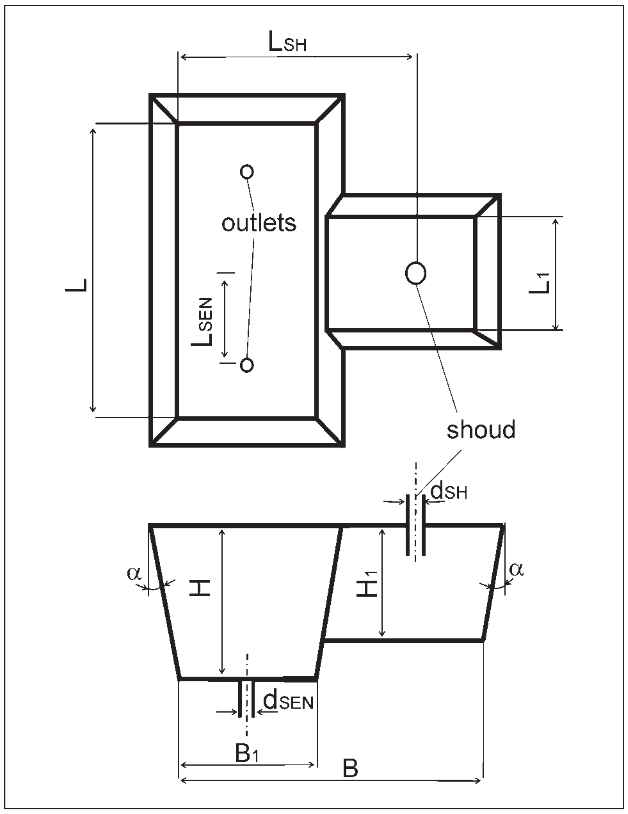

Figure 1 Scheme of industrial tundish

the liquid in the tundish was considered to be flat, and the slag depth was considered to be insignificant. With these assumptions, the flow field in the tundish was computed by solving the continuity and momentum conservation equations in the three-dimensional domain with a built in k-ε turbulence model [15] using the following boundary conditions: the walls were set to a no-slip condition, and the turbulent quantities were set from a logarithmic law wall function. A zero shear stress boundary condition was applied for the free surface of the tundish [16,17]. The velocity profiles of steel at the inlet as well as at the strand nozzles of the tundish were assumed to be uniform through cross sections, and the other two velocity components were assumed to be zero. As the considered spatial system is symmetrical to the plane passing through the pouring gate axis, this resulted in the zeroing of the first derivatives in relation to the direction of typical plane of symmetry.

The standard wall function was used to calculate the value of a node near the solid wall. In order to develop concentration characteristics (RTD) corresponding to normalized conditions, the boundary condition was applied at the pouring gate in the form of a stepwise change of concentration (C = 1). The set of governing equations were discretized using the finite volume technique in a computational domain and solved with the help of boundary conditions using a commercial computational fluid dynamics (CFD) package (AnsysFluent).

The SIMPLE numerical algorithm was used to solve those equations. During iteration, the convergence was assumed to reach a point where all the normalized residuals were smaller than 10^{-6}. Computations were carried out for transient conditions. The time intervals of recorded concentration were constant in the entire testing range, being equal to 0,05 s. The range in which continuous recording was performed was 2 500 s. The mathematical simulations were run on a INTEL CORE i7 processor computer with the CFD software.

RESULTS AND DISCUSSION

Fluid flow

Mathematical model based on the turbulent Navier-Stokesž equations allows to make numerical simulations of steel flow and mixing in the tundish. As a result of the calculations the forecasted spatial velocity fields and steel turbulence intensity were obtained. Figure 2 presents the forecasted steel movement in tundish for all analyzed cases.

These results are presented taking into account the longitudinal plane going through the tundish outlets. Distribution of steel velocity fields shows that in the inlet zone, for all analyzed cases, the favorable conditions for the free emerging of nonmetallic inclusions are observed. This situation becomes worse in the channel zone of the tundish where nonmetallic inclusions can be pulled into the tundish outlets. Areas in which the velocity is negligible are also observed, so the dead zones can appear. Generally, in the tundish two different areas can be separated: inlet area and outlet area with diversified intensity and structure of steel movement. Obtained results (Figure 2) show that the increase of casting flow rates of steel decreases areas where the dead zones can be created.

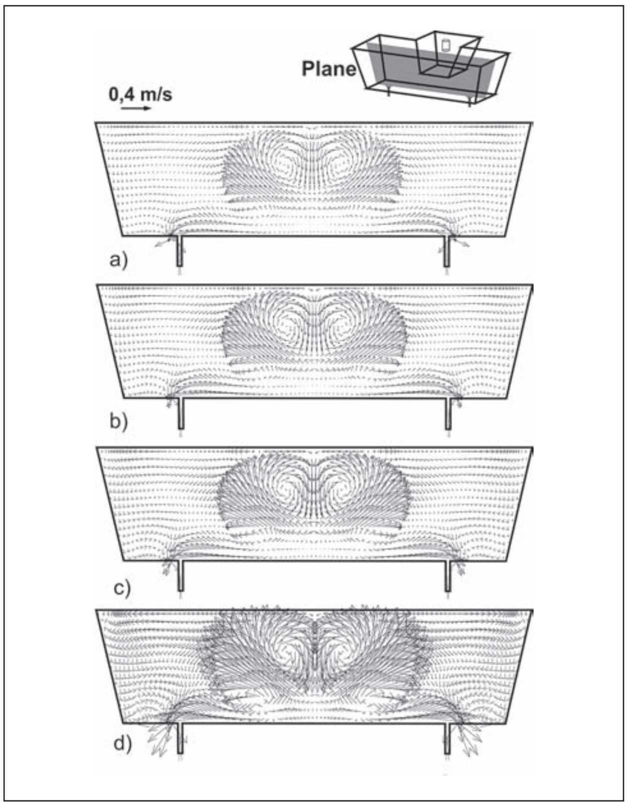

Figure 2 Forecasted fluid flow field in tundish for all analyzed cases: a) case A, b) case B, c) case C, d) case D

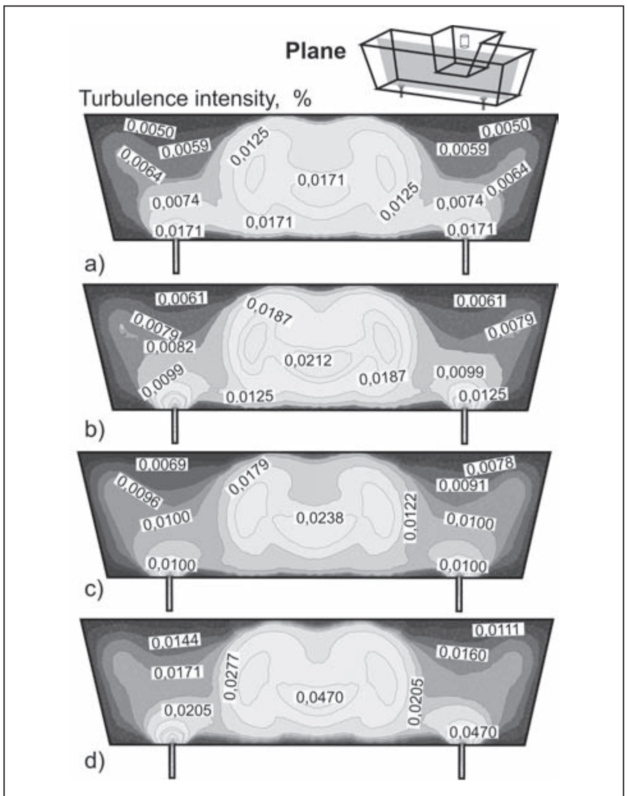

Figure 3 Isolines of steel turbulence intensity: a) case A, b) case B, c) case C, d) case D

Presented state of steel movement in analyzed variants was complemented by the characteristics of the turbulence of steel flow. Figure 3 presents the distribution of steel turbulence intensity for the examined cases.

During the analysis of these distributions, small differences can be seen in the examined cases. However, the values of turbulence intensity in the same areas of the tundish for all cases are different.

The F and E curve

Ladles and tundishes belong to continuous reactors. Therefore, the chemical effectiveness of this kind of metallurgical units can be determined basing on the ratio of reagents change or the phases homogeneity. The last one is influenced by the kind of medium taking part in the particular process. So, to estimate this effectiveness the RTD characteristics can be applied. They give information about the time a liquid spends in the reactor.

Another important parameter of the tundish is the resident time of the fluid in the tundish. The real time the fluid element remains in the tundish can be determined experimentally by measuring tracer concentration and solving an equation [17]:

$$t_{av} = \int_0^\infty C\,t\,dt \Bigg/ \int_0^\infty C\,dt \cong \frac{\sum C_{i\,sym} t_i \Delta t_i}{\sum C_{i\,sym} \Delta t_i} \tag{1}$$

RTD characteristics can be obtained experimentally or by means of numerical calculations. F and E type curves belong to the most important RTD curves [17]. To determine these curves the changes of tracer on the outlets are registered as the answer to the input signal (impulse – curves type E and stroke - curves type F) given at the inlet to the reactor.

Basing on E curves the percentage fraction of different kinds of flows occurring in the tundish can be calculated: dispersed plug volume (V_{dp}), well mixed volume (V_m) and dead volume (V_d) [17] applying the following relationships:

$$V_d = 1 - \frac{\dot{V}_a}{\dot{V}} \Theta_{av} \tag{2}$$

$$V_{dp} = \frac{(\Theta_{\min} + \Theta_{peak})}{2} \tag{3}$$

$$V_m = 1 - V_d - V_{dp} \tag{4}$$

Figure 4 presents F type curves for the examined cases. The noticeable differences can be observed between curves describing the kinetics of steel mixing for the particular cases (Figure 4). To estimate the kinetics of steel mixing quantitatively the values of time interval were determined (Table 3) basing on the difference in time which is necessary to reach the tracer concentration at the level 0,2 to 0,8 of the tracer concentration C=1. The lower values of the readable interval, the better mixing conditions. Values presented in Table 3 confirmed the fact (Figure 4) that there are significant differences in Δt for particular cases. The lower value was noticed for case D, so in this case the steel mixing conditions are the best.

With the numerical modelling results, the share of each volume can be estimated. To mark these shares and

Table 3 **Kinetics of steel mixing for studied cases**

Case	Δt / s
A	558,6
B	443,4
C	369,3
D	230,1

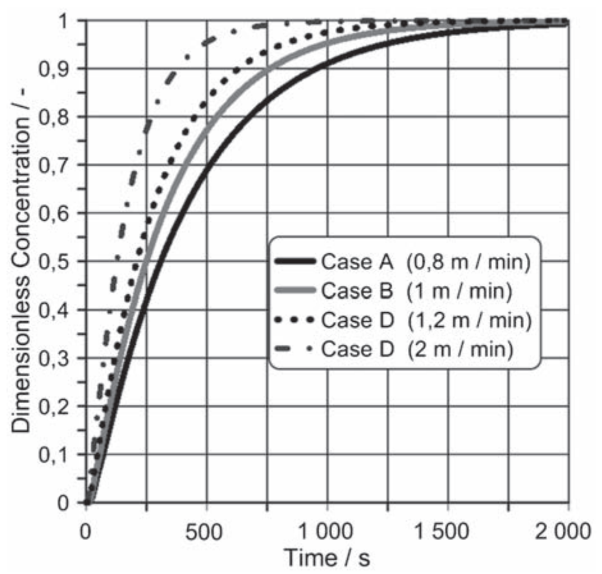

Figure 4 Curves for mixing time characteristics F types for the studied cases

calculate the average resident time for the investigated tundish, additional calculations were performed. In the present work, fractions of each volume are calculated using equations (1-4). Figure 5 presents shares calculated for all cases.

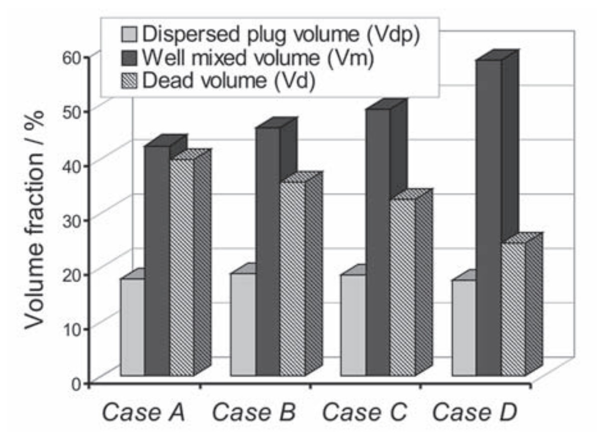

Figure 5 RTD parameters and volume fraction of flow for the studied cases

CONCLUSION

In the research the influence of steel casting flow rate on the forming process of hydrodynamic conditions in the tundish was analyzed. To obtain this, the numerical calculations were applied. Analysis of presented research results allowed to make the following conclusions:

- Carrying out modelling research based on mathematical models solving by numerical methods allows to work out the detailed characteristics of existing metallurgical units such as tundish.
- Casting flow rate has a big influence on the structure of flow and the steel turbulence intensity in the tundish. The higher casting flow rate, the lower part of dead zones in the volume of liquid steel.
- Casting flow rate considerably influences the kinetics of steel mixing in the tundish. The higher casting flow rate, the better conditions of steel mixing in tundish can be observed.
- Increasing the casting flow rate caused decreasing the percentage share of dead volume flow and in the same time increasing well mixed volume flow.

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Note: The responsible translator for English language is P. Nowak, Katowice, Poland