Numerical Analysis of the Flow Structure in the Continuous Casting Two-strand Tundish

M. Warzecha[1], J. Jowsa[1], A. M. Hutny[1], P. Warzecha[1], T. Merder[2]
[1]Czestochowa University of Technology, Department of Metals Extraction and Recirculation, Al. Armii Krajowej 19, 42-201 Czestochowa, Poland,
[2]Silesian University of Technology, Institute of Metals Technology, Krasinskiego 8, 40-019 Katowice, Poland
*Corresponding author: warzecha@wip.pcz.pl

Abstract: The increasing requirements of steel purity (defined by the number, size, distribution and composition of non-metallic inclusions) necessitate the reduction of inclusions in the steel product. Since during production processes the inclusions are lifted by the liquid steel, therefore it is necessary to analyse the structure of liquid steel flow, which is responsible for the transport and separation of non-metallic particles.

Since the experimental research performed on real plant during normal working conditions are limited due to the high temperatures and opacity of the system, the fluid flow structure has been analysed based on the research done with mathematical modelling. To performe simulations of the fluid flow through the tundish, caluculations were done by commercial code COMSOL Multiphysics.

Keywords: numerical modeling, tundish, flow structure.

1. Introduction

Modern equipment for continuous casting of steel form, together with the steelmaking furnace and secondary metallurgy units compact and efficient manufacturing process. The growing quality requirements for metallurgical production lead to continual search for new technological solutions to eliminate the existing imperfections of continuous casting techniques. The current state of the art allows the casting of liquid steel blanks with the shape and dimensions of cross section similar to their final products, for example. tubes, bars and various profiles. However, it requires to maintain high purity of the liquid steel introduced to the mould, and here the role of the tundish is disclosed - specific reactor where next to the distribution role, a characteristic terminal sequence of metallurgy refining treatments is implemented [1]. The role of modern tundish locates it within the steelmaking cycle as the main object of which is entrusted with the final refiners tasks to maintain or improve the purity of the cast steel. Shaping the conditions of this process one can use the effects of the phenomena of spontaneous separation and flotation of non-metallic inclusions. For this purpose a different building of working space are used (baffles, dams, turbulence inhibitors) [2-5]. They cause a local increase in the intensity of turbulence flow of liquid steel, which positively influences the collision inclusions promotes their coagulation or coalescence, and thus helps the growing outflow of liquid steel inclusions and their absorption by slag phase.

In presented paper calculations were carried out for the water model of the investigated tundish, represented on a scale 1:3. Numerical calculations enable to estimate the fluid flow velocities, pahtlines and other parameters. Calculations were done for two different grids. Based on the results, the flow structure in the investigated tundish was obtained.

2. Investigated object

Two-strand tundish with a nominal capacity of 60 t was studied. The tundish is symmetrical with respect to the central cross-section (through the steel pouring gate axis). A scheme of the tundish is shown in Figure 1, while the dimensions of the commercial tundish and its model at the scale of 1:4 are given in Table 1.

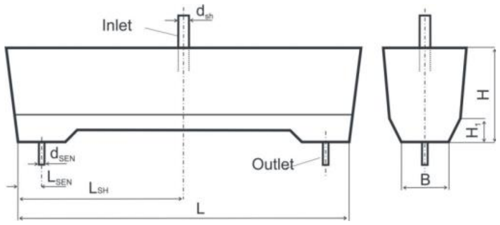

Figure 1. Scheme of the tundish shape and its size.

Table 1: Dimensions of the 60-t tundish and the water model (at the 1:4 scale)

	Symbol	Unit	Tundish	
			Scale 1:1	Water model scale 1:4
Volume of tundish at filling level H	V	m^3	8.55	0.13
Tundish length	L	m	7.600	1.900
SEN position	L_{SEN}	m	0.400	0.100
Shroud position	L_{SH}	m	3.800	0.950
Tundish width	B	m	0.720	0.180
Filling level	H	m	1.200	0.300
	H_1	m	0.440	0.110
Shroud diameter	d_{SH}	m	0.110	0.030
SEN diameter	d_{SEN}	m	0.040	0.010

3. Numerical procedures

The simulation of the liquid steel flow in the tundish during the continuous casting process is a complex hydrodynamic problem. An appropriate mathematical model (describing this process) should take into account several characteristics of such flows.

Half of the tundish was chosen for the mathematical analysis. In current study the influence of density of numerical grid on the results has been tested. Considered model contains 53 000 and 160 000 cells. Basic grid (53 Kcells) was improved by making a finer mesh in the zone of the incoming and outgoing liquid jet in order to visualize in more details the effects of velocity and turbulence gradients. The geometry of the object (tundish) was imported to the COMSOL program in the form of IGS file.

The walls are considered with no slip condition for the fluid flow. The upper surface is assumed as a free surface with zero shear stresses. The standard wall function is used to calculate the value of a node near a solid wall.

The velocity of water set at the inlet nozzle equal 1.15 m/s, and was set as a velocity inlet boundary condition. The mean vertical velocity is assumed to be uniform through the cross section and other two perpendicular velocities are assumed to be zero. Turbulence intensity at inlet is specified as 5% with turbulence length scale 0.03m. At the outlet boundary condition "Pressure" was fixed as 0 Pa.

For modeling the turbulence k-ε model was set to calculate flow of incompressible medium (water) at the ambient temperature ($\rho = 998$ kg/m^3, $\mu = 0.001 Pa \cdot s$).

The set of partial differential equations is solved with the help of the above boundary conditions numerically in a finite volume technique using the education version of the CFD software COMSOL Multiphysics.

Calculations of the velocity field and pressure were conducted in the transient state „Time Dependent Procedure" till reaching the process time t=360 s.

A criterion for convergence was set to be less than 10^{-6} on all variables and computations were carried out until the relative sum of residuals on all variables all fell bellow the fixed value.

Fig. 2 shows the view of object assumed to calculations and the calculation meshes.

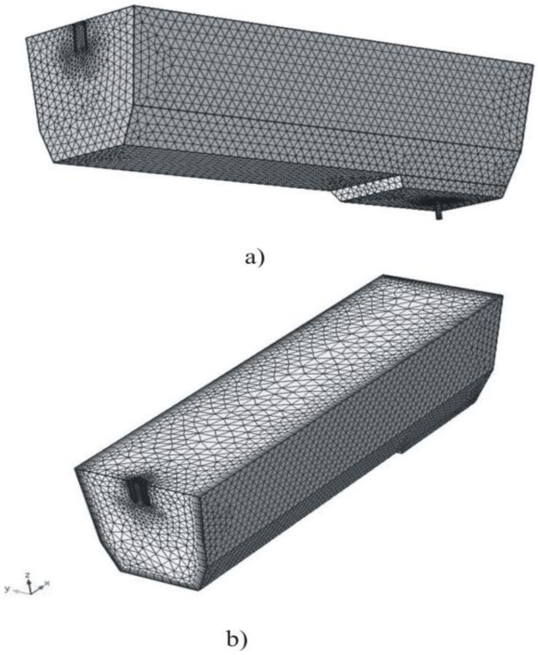

Figure 2. Computational mesh set at walls of the tundish: a) basic grid, b) finer grid.

3. Results and Discussion

Figure 3 shows vector velocity field of liquid inside the tundish obtained with numerical simulations.

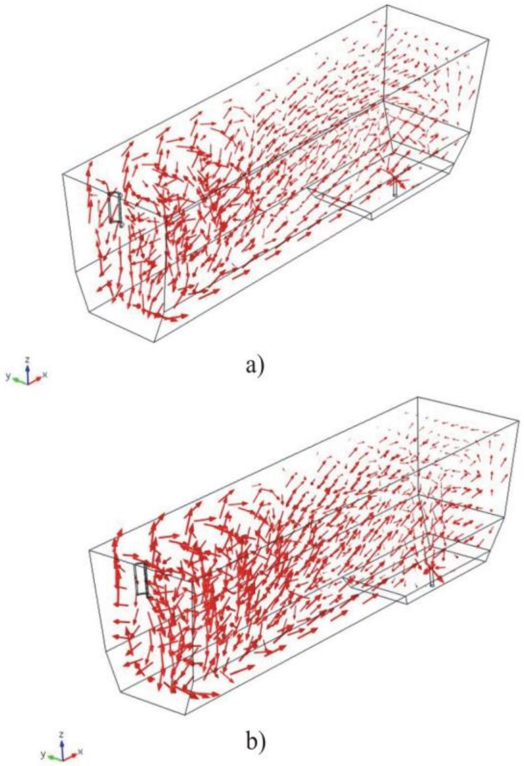

Figure 3. Velocity vectors of the fluid in the tundish: a) basic grid, b) finer grid.

From the vector velocity field analysis for the two presented cases one can noticed slight differences in the structure of the flow. Noticeable differences can be noted in the tundish inlet area. It is also seen a relatively small part of the ascending flow (in addition to the inlet area), which may not help with flowing out of non-metallic inclusions to the slag phase.

The vector velocity field of liquid (Figure 3) do not give sufficient information about the flow field in the test facility therefore additionally a distributions of the velocity field has been shown. For better analysis of the results, a characteristic cross-sections have been introduced. The first vertical cross-section passes through the tundish inlet and outlets. Other transverse cross-sections illustrates the flow in various regions of tundish. All considered cross-sections are shown in Figures 4 and 5.

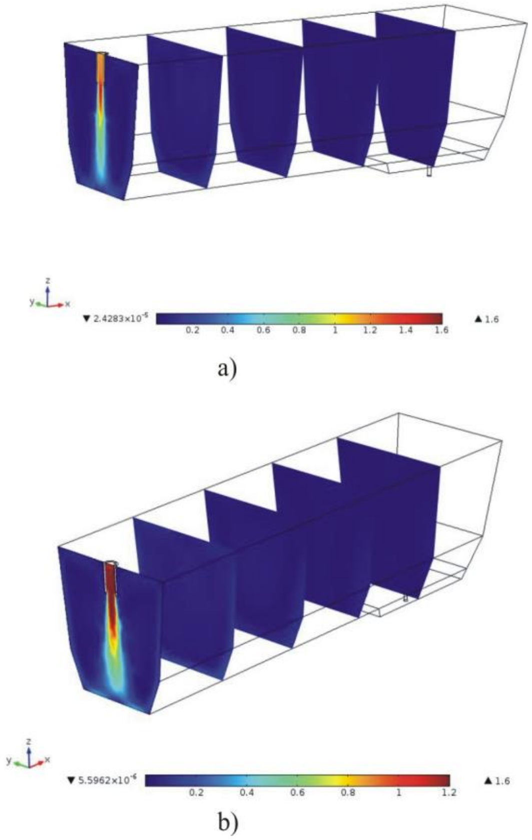

Figure 4. Velocity fields in the tundish: a) basic grid, b) finer grid.

The analysis of the velocity field in particular areas inside the tundish presented on the cross-sections (Fig. 4) shows that higher velocities are obtained in the area of tundish inlet. For the basic grid test case a higher limit velocity is obtained for the same initial and boundary conditions.

Other areas in the tundish have a relatively small velocities not exceeding 0.2 m/s.

Similar conclusions can be drawn from the observations of the velocity distribution and streamline on the cross-section along the object (Figure 5).

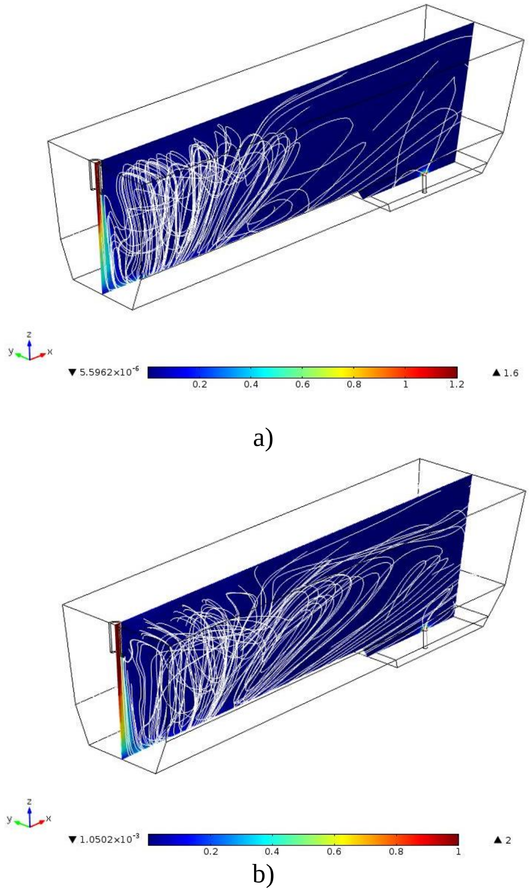

Figure 5. Velocity fields and streamline in the tundish: a) basic grid, b) finer grid.

The results of numerical simulations presented in Figures 3 - 5 show the flow of liquid in the investigated tundish which does not allow for an objective analysis of the structure of its flow. Nevertheless, the analysis clearly shows that differences are present for both used meshes, this is particularly evident for the maximum liquid velocities inside the tundish. To evaluate the selection of an optimum computational mesh one should conduct a more detailed numerical analysis and verify the results of measurements carried out by laser techniques such as PIV or LDA.

4. Conclusions

The use of numerical modeling techniques of liquid flow in the tundish is an effective way to replace costly and difficult measurements carried out in industrial conditions. Numerical simulations could help to determine the flow conditions inside the investigated tundish and then optimize its shape and construction.

Analysis of the velocity field distributions of the liquid inside the tundish are an important source of knowledge about the conditions of steel casting. However, these characteristics do not involve outright which computational grid is optimal. To evaluate the selection of an optimum computational grid one should conduct a more detailed numerical analysis and verify the results with experimental measurements of the water model. More detailed answers on these issues can be achieved by using the macroscopic characteristics such as RTD (E and F curves).

5. References

1. Y. Sahai, T. Emi, Melt flow characterization in continuous casting tundishes, *ISIJ Int.*, **36**, 667-672 (1996)
2. T. Merder, M. Warzecha**,** Optimization of a six strand CC tundish: industrial measurements and numerical investigation of the tundish modifications, *Metallurgical and Materials Transactions B*, **43**, 856-868 (2012)
3. S. Joo, R.I.L. Guthrie**,** Inclusion behavior and heat transfer phenomena in steelmaking tundish operations Part 2, *Metallurgical and Materials Transactions B*, **24**, 767-777 (1993)
4. A. Tripathi, Numerical investigation of electro-magnetic flow control phenomena in a tundish, *ISIJ Int.*, **52**, 447-456 (2012)
5. A. Espanio-Zarate, R.D. Morales, A. Najera, M.J. Macias-Hernandez, A. Sandoval-Ramos, Fluid flow and mechanisms of momentum transfer in a six-strand tundish, *Metallurgical and Materials Transactions B*, **41**, 962-975 (2010)

6. Acknowledgements

The scientific work was funded by NCN, project No 2013/09/B/ST8/00143.