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NUMERICAL SIMULATING OF FLUID FLOW AND HEAT TRANSFER IN STEEL LADLES DURING CASTING

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ABSTRACT
This paper presents a three-dimensional numerical model simulating fluid flow and heat transfer in 105 tones steel ladles during the casting process. The model was developed by implementation to a computational fluid dynamics (CFD) simulation package. The results of the simulations have been compared to those given in the reference literature and to those resulting from experiments.

KEY WORDS:
Numerical simulation, steel ladle, fluid flow, heat transfer, CFD.

1. SIMULATIONS CONDITIONS

According to the data to be found in the reference literature, the hydrodynamics of the fluid alloy in the casting ladle during the casting process has been studied by means of 2-D, symmetric - axial simulations of a ladle with the central tapping [3] and by means of 3-D symmetric - axial simulations of an eccentric tapping ladle [4]. The results of such simulations have been compared to those obtained by means of physical models using water [7], or by temperature measurements [1, 2, 3, 5].

Considering these aspects, we simulated the hydrodynamics of the fluid alloy in the 105-t ladle used by S.C. Mittal Steel S.A. Hunedoara, during the casting process by means of CFD-3D model.

At first, a geometrical sketch of the ladle was made (fig.1), starting from the configuration and geometrical dimensions of the industrial casting ladle. As it can be noticed, in order to simplify the modelling, we neglected the fact that the ladle has a conical shape, it being considered cylindrical.

In order to achieve a closest simulation of the hydrodynamics and temperature of the fluid alloy in the ladle during taping, we considered it necessary to take into consideration the fact that the metal bath in the ladle is thermally stratified at the moment of tapping. The consideration given above is mandatory, as in the secondary refining station (LF), the metal bath is homogeneous from the thermal point of view, but during the ladle transportation from the LF station to the tundish a thermal stratification of the metal bath takes place because of natural convection.

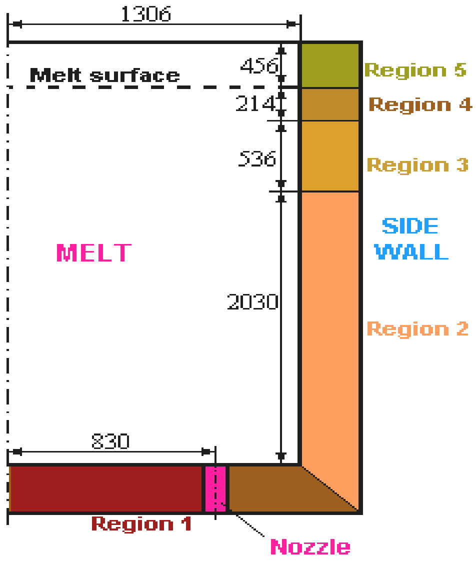

Fig.2. The geometry of the ladle used in the CFD-3D simulation

Considering this, the simulation will be done in two stages: the first will simulate the 10 minute-station of the ladle, when the metal bath will be thermally stratified, and the second will simulate the ladle emptying during the casting process.

The emptying stage also involves two periods:

- the first period, which lasts about 3 minutes, represents the filling of the 15t tundish;
- the second period, which lasts about 40 minutes, corresponds to the normal casting rate.

According to the reference information and also considering the practice of continuous casting (TC) at S.C. Mittal Steel S.A. Hunedoara, in the simulations we considered constant casting flow rates of 77,8 kg/s for the first period of emptying, respectively 36,1 kg/s for the second period.

Using two custom softwares, we simulated the hydrodynamics and the temperature of the fluid alloy in the ladle during the period of its emptying.

2. RESULTS OF NUMERICAL SIMULATIONS

After having simulated the thermal stratification of the metal bath, for a 10 minute period of stationing, we obtained the rate field (fig.2) and the distribution of temperature (fig.3). These data shall be further used as initial conditions in the stage of ladle emptying.

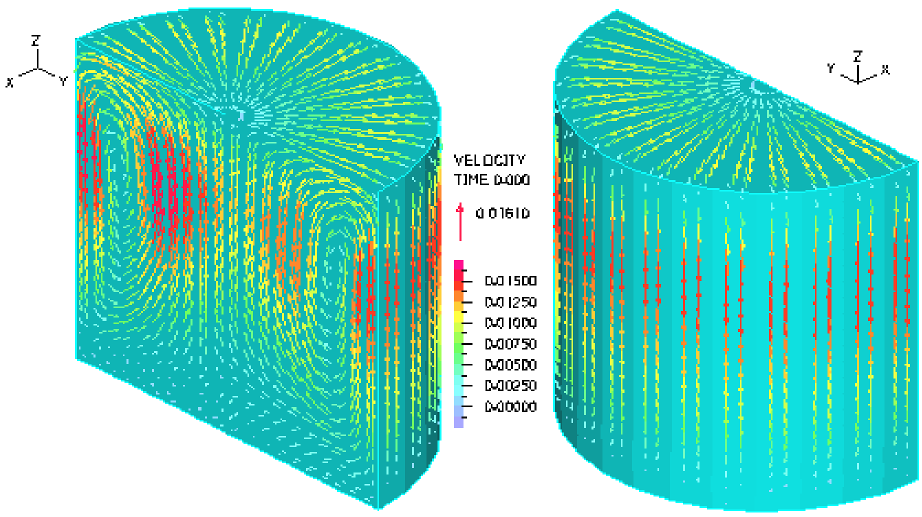

Fig.2. The rate field after 10 minutes of thermal stratification simulation

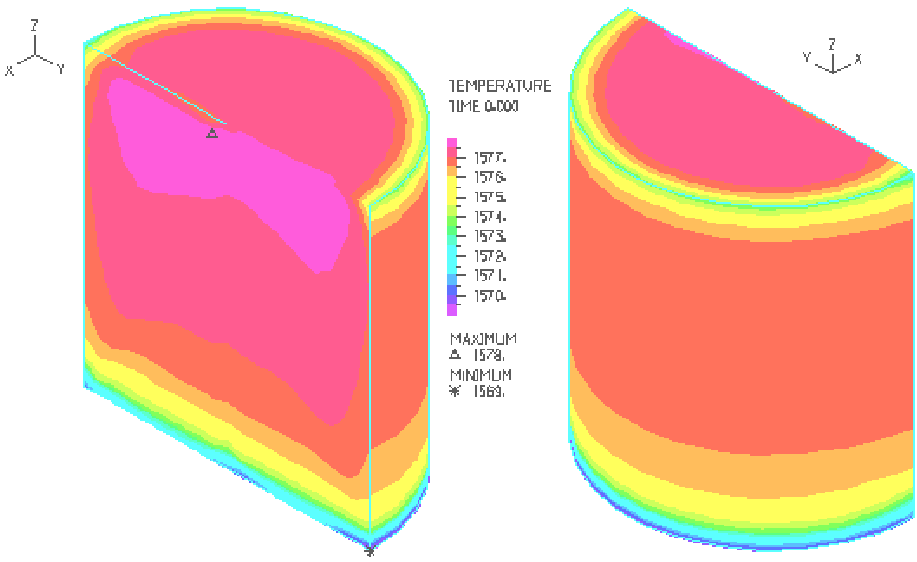

Fig.3. The rate field after 10 minutes of thermal stratification simulation

Further on, we gave the results of the simulations after 10 and 25 minutes from the opening of the tap.

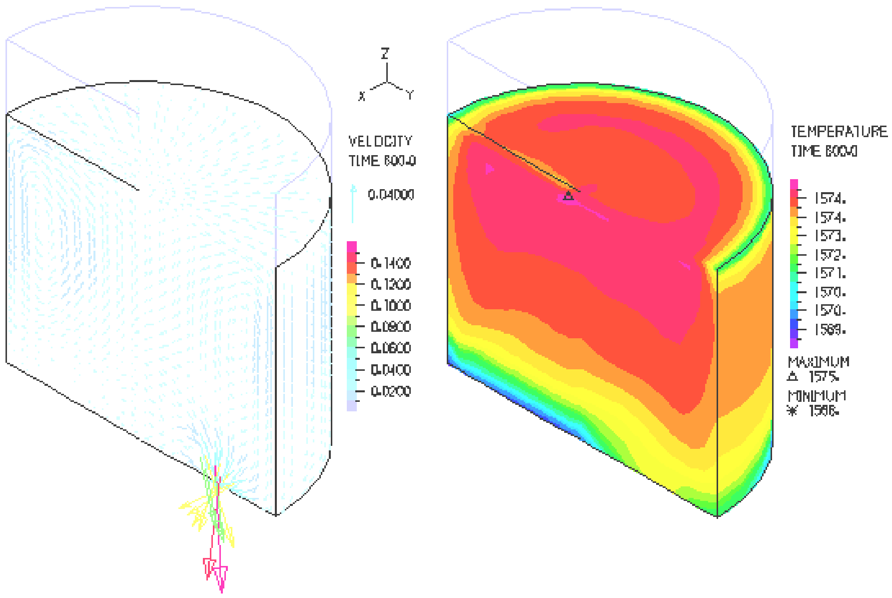

Fig.4. The field of rates and temperatures of the metal bath after 10 minutes from the opening of the tap

3. ANALYSIS OF THE SIMULATION RESULTS

Figure 4 gives the field of rates and the distribution of temperature in the metal bath after 10 minutes from the opening of the tap. One can notice that the movement of the alloy in the ladle is further due to the phenomenon of natural convection, the rate field having the same profile as in the initial stage (fig.2).

Continuing the analysis of the rate field evolution, one can notice that it starts being influenced increasingly by the fact that a movement of the alloy arises from its flowing out through the tap. After about 25 minutes from the opening of the tap (fig.5), this movement starts to prevail over the one due to natural convection.

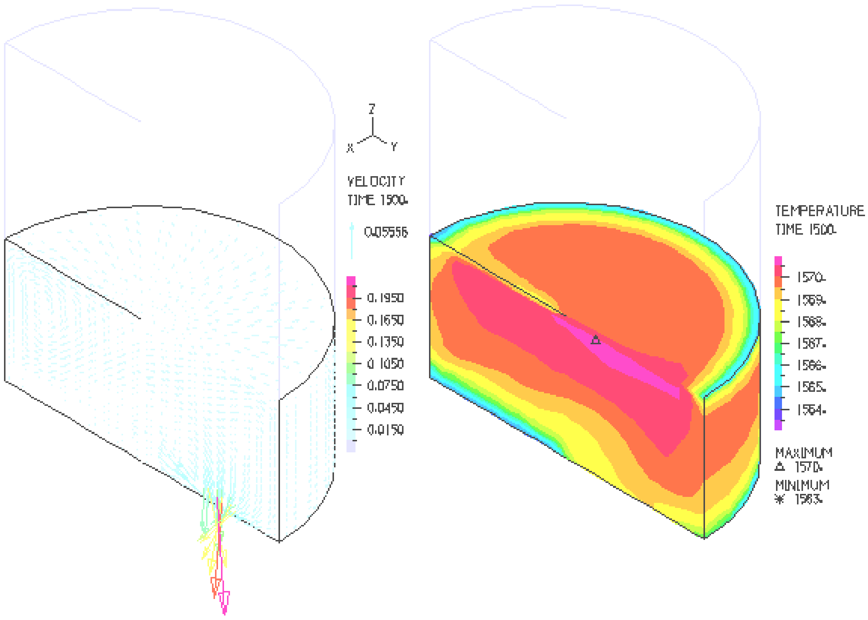

Fig.5. The field of rates and temperatures of the metal bath after 25 minutes from the opening of the tap

This tendency is also revealed by the evolution of the temperature field inside the metal bath. Thus, at the beginning of tapping, the phenomenon of thermal stratification is still present because the metal bath keeps losing heat to the environment and natural convection is still present. In the latter half of the tapping period (after about 25 minutes from the opening of the tap), because of the low level of the metal bath in the ladle, the heat lost to the exterior is diminished and the phenomenon of thermal stratification comes to an end. At the same time, the movement of the fluid alloy through the tap determines the mixing of the metal bath, which leads to diminishing the thermal stratification already existent.

One very important result to be noticed when simulating the hydrodynamics and temperature of the fluid alloy from the ladle during its emptying is the fact that we know the temperature of the fluid alloy at the knots of the domain of analysis, corresponding to the entrance of the ladle tap. Taking into consideration the fact that, on leaving the tap, the alloy flows through a protection ceramic tube, up to the tundish of the continuous casting machine, and the loss of heat to the walls of this ceramic tube is very low (corresponding to a decrease of under 0,1 ^{0}C of the temperature of the fluid alloy [6]), we can consider that this is the temperature at which the fluid alloy enters the tundish and we shall further call it *the temperature of the alloy flow.*

As we have mentioned, the temperature of the alloy flow into the tundish is particularly important for the control of the temperature into the tundish. Figure 6, shows the time-variation of the fluid alloy temperature on entering the tap, obtained by means of numerical simulation (continuous line) all along the period of ladle emptying.

As one can notice from figure 6, at the beginning this temperature is increasing, up to a maximum value, after which it stays constant up to the end of the first stage of emptying (of about 3 minutes), corresponding to the filling of the tundish, after which it starts decreasing. In the second stage of emptying, the temperature decreases almost linearly, up to the final, when the decrease is more abrupt, up to the minimum temperature.

The results of the simulations have been compared to those given in the reference literature and to those resulting from experiments. Thus, figure 7 shows, for the sake of comparison, the temperature of the fluid alloy, as resulting from [7], by simulation of emptying a ladle of the same capacity (105 t), done by means of the same CFD-3D model, but using as domain of analysis the whole volume of the metal bath.

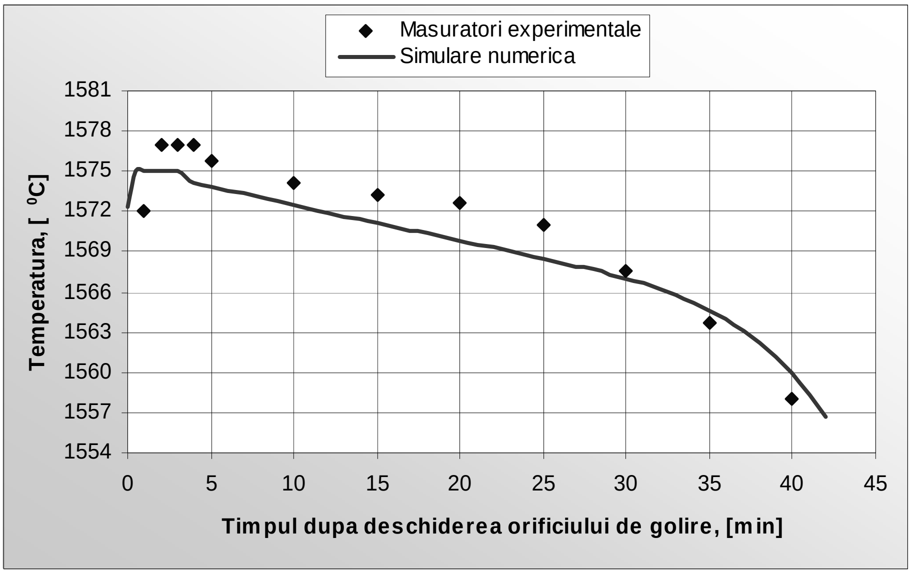

Fig.6. The temperature variation of the fluid alloy on entering the ladle tap

Comparing the two figures (fig.6 and fig.7) one can notice that the curves representing the temperature variation of the fluid alloy flow along the period of ladle emptying, have the same shape, namely there is an increase at the beginning, up to a maximum value and, after a short period of time, (corresponding to the filling of the tundish of the continuous casting machine) this temperature stays constant, to further decrease almost linearly almost until the end of the emptying period, when the decrease is more abrupt. The differences between the values of the alloy flow in the two cases result from the fact that in the two simulations the initial conditions were different.

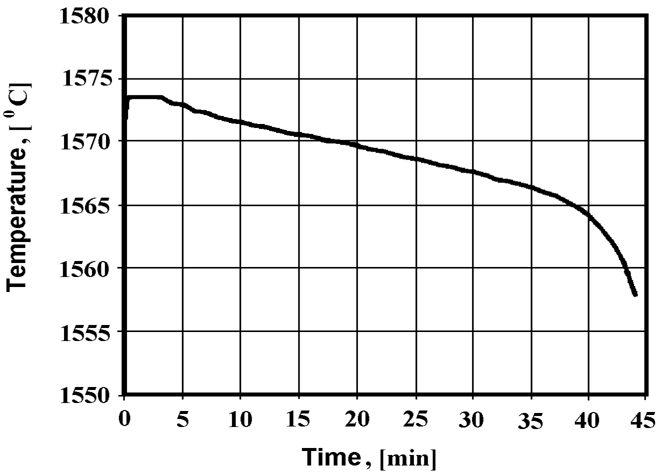

Fig.7. The variation of the temperature of fluid alloy flow during the emptying of the ladle [7].

We also carried out temperature measurements for two ladles containing alloys of the same quality (the same steel grade), the graphical results being given in figure 12 (points). Comparing these results to the ones obtained by numerical simulation (fig.6) one can notice they are consistent.

We can therefore say that the CFD-3D model, developed for the study of the hydrodynamics and temperature of the fluid alloy in the ladle during the stage of its emptying is valid from the point of view of results obtained.

4. CONCLUSIONS

The results obtained by modeling and simulating the hydrodynamics and temperature of the fluid alloy in the ladle during its emptying stage can lead to the following conclusions:

- at the beginning of the emptying period, the phenomenon of thermal stratification is still present, as the metal bath keeps losing heat to the environment by natural convection. In the second period of emptying (after about 25 minutes from the opening of the tap), because of the fact the level of the metal bath in the ladle is low, the amount of heat lost to the environment diminishes, and the phenomenon of thermal stratification halts. At the same time, the movement of the fluid alloy due to its flowing out through the tap triggers a mixing process of the metal bath, which leads to the diminishing of the existent stratification.
- once we know the variation of the alloy flow temperature into the ladle, we can take technological steps in the sense of increasing, respectively decreasing the temperature inside the tundish in order to range it within the limits required by the continuous casting technology.

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