OPTIMIZATION OF ARGON BLOWING CONDITIONS FOR THE STEEL HOMOGENIZATION IN A LADLE USING NUMERICAL MODELLING

Karel MICHALEK a, Markéta TKADLEČKOVÁ a, Karel GRYC a, Petr KLUS a, Zbyněk HUDZIECZEK a, Vojtěch SIKORA a, Pavel STRÁSÁK b

a) VŠB - TU Ostrava, FMMI, 17. listopadu 15/2172, Ostrava-Poruba, Czech Republic,
karel.michalek@vsb.cz, marketa.tkadleckova@vsb.cz, karel.gryc@vsb.cz, petr.klus.st1@vsb.cz,
zbynek.hudzieczek@vsb.cz, vojtech.sikora.st@vsb.cz

b) TechSoft Engineering, s.r.o, Táborská 31, 140 00 Praha 4, Czech Republic

Abstract

An essential part of the processes of secondary metallurgy occurring during liquid steel refining is blowing an inert gas into the ladle. The aim of steel production is to find such an argon flow rate and such a position of argon lance, so as to ensure thermal and chemical homogenization of steel in the ladle in the shortest time and with minimum gas consumption, while the intensity of the flow must not negatively affect the stability of the process. The optimization of argon blowing conditions for steel homogenization in the ladle can be made on the basis of the results of service tests. The use of physical and numerical modelling is much more effective as it is relatively easy to change the boundary conditions of the blowing. Traditionally, the researchers of the Department of Metallurgy, FMME, VSB-TU Ostrava solved the blowing optimization conditions by both, physical and then numerical modelling. This paper deals with calculation setting of numerical simulation of argon blowing through three-hole lance during steel homogenization in the ladle in an ANSYS FLUENT CFD programme. The calculation setting is based on the geometric definition of the modelled area, on the selection of appropriate physical models, operating parameters, physical properties of the melt and boundary conditions. Under non-stationary conditions of the calculation, the homogenization time is obtained from the monitored profiles of concentration and temperature in three planes and from selected points in the volume of the ladle. Primary results of the pre-set model of numerical simulation were correlated with the results of the parallel physical modelling performed on the physical water model of the ladle design in a geometric scale of 1:9. The aim of further research will be the verification of the steel bath homogenization character under various flow rates of gas blowing and for different positions of the three-hole lance.

Keywords: steel, ladle, numerical modelling, argon blowing, homogenization, temperature, chemical composition

1 INTRODUCTION

In particular to support the mixing of the metal melt in metallurgical vessels, gas blowing plays an important role during metal refining, thus avoiding stratification of concentration and temperature fields and increasing the speed of the homogeneous and heterogeneous chemical reactions at the same time. The blown gas is fed into the ladle volume in two basic ways. The first option is blowing “from below” through the bottom-blowing element. Some steel plants use the method of blowing “from the top” through a vertically submerged lance. Blowing an inert gas (usually argon) into the molten steel in the ladle is the most affordable and sometimes even stands as “sufficient” secondary steel processing method for obtaining the chemical and temperature homogeneity, which is done during and after applying the metallurgical technologies such as alloying, heating of steel, correction of chemical composition, etc. The research of homogenization processes during the argon blowing into steel in the ladle has been the subject of the works of many authors [2-6].

The verification of gas blowing conditions during the steel bath homogenization in the ladle can be performed using a direct service experiment. However, the process is time-consuming and very expensive. The preferred laboratory alternative is a method of modelling, both physical and numerical.
The previous works of authors of this paper [1,2] have brought considerable attention to the verification of steel homogenization conditions on the physical water model of the ladle constructed in a 1:9 scale with regard to a real operating 180-ton ladle. The main objective of modelling is the determination of the homogenization time depending on the intensity of blown gas flow and position of the three-hole lance. The method of "impulse-response" was used for physical model research on the homogenization time. The principle of this method is in the injection of the marker (tracer) substance into the fluid flowing in the reactor and evaluation of the concentration or other measurable variables of the substance through probes placed in the reactor volume. For successful and objective measurement, it is necessary to have the marker with identical properties with the carrier fluid (i.e., density, viscosity, diffusion behaviour, good mutual miscibility, etc.) and which would significantly differ in only one property. This property must be easily measurable and it must be dependent on the concentration of the marker. In the physical modelling of fluid flow, the electrical conductivity is most frequently used to for measurement. In the case of physical modelling of steel homogenization in ladle, a weak solution of KCl manifesting itself by the ion conductivity was used as a marker. The concentration change of the liquid upon the marker injection was scanned by four pairs of probes (conductivity and temperature probes).

The next stage of the research focused on homogenization processes in the ladle carried out in the Department of Metallurgy is use of numerical modelling. This paper deals with the calculation setting of numerical simulation of homogenization processes in the ladle during argon blowing through a three-hole lance in the ANSYS FLUENT CFD. The primary results of the numerical model were compared with results of physical modelling. After validation of the numerical model setting, further research will aim to verify the nature of the steel bath homogenization for different flow rates of the blown gas and different positions of the three-hole lance.

2 PRINCIPLE OF NUMERICAL MODELLING

Generally, the whole numerical modelling procedure is divided into three stages:
1. Pre-processing – preparation of the model (which includes the geometric modelling and the computational grid generation process, definition of physical and material properties, boundary and starting conditions, definition of the physical principle of the task, time-dependent task etc.)
2. Solving – involves the computation in the solver
3. Post-processing – focuses on the processing and display of results.

2.1 Pre-processing – geometric modelling and computational grid generation process

The geometric modelling and generation process of the ladle computational grid were done in the GAMBIT pre-processor. The 180-ton casting ladle had the shape of an inverted truncated cone. The stable level of the steel bath in the ladle was 3,600 mm. The model assumed a flat shape of the liquid level without its increase due to the blowing. The modelled area is shown in Fig. 1 in green colour. [3].
The submerged argon lance (Fig. 2) was fitted with three symmetrical, (in a horizontal plane) laid holes for blowing the argon into the liquid steel. Fig. 2 also shows the inflow of argon and its equal distribution among the different lances with a diameter of 5.0 mm using the red arrows.

The submerged lance model was simplified so that the cylindrical body in the middle of the casting ladle (CL) was maintained, but the argon outlets were replaced by a series of points placed directly in the solver (Fig. 3) (i.e. directly in FLUENT). It is possible to use this simplified geometric model and method for computational grid generation of the ladle for different submergings of the three-hole lance. The size of the argon inlet area through the lance jets in the model is larger than the actual size of the hole [3].

2.2 Solving – performing the calculation

The calculation of the homogenization simulation was carried out only for one symmetrical half of the ladle. The setting of the calculation is based on the selection of appropriate physical models, operating parameters, the melt physical properties and boundary conditions. The modelling of two-phase flow of melt-argon was carried out using Discrete Phase Model (DPM). This model enables to specify and enter the location of argon blowing into the ladle directly in FLUENT. This means that the position of lance holes and argon blowing is not associated with the geometrical position already created during the geometric modelling of the ladle. The flow initiated by the argon blowing was defined as stationary, viscous and turbulent. The RNG k-ε turbulence model with a standard wall function was used. The flow was viewed as incompressible, with no heat transfer. On the surface, the friction has not been taken into account. The operational and boundary conditions were entered. The material properties of the melt were defined depending on the temperature.

The aim of the simulation was to predict the concentration homogenization; therefore it was necessary to enter the melt through two components. The material properties of both components were, with exception of density, identical. According to the initial position of components in the ladle, the components were named as follows: MELT - lower, which corresponded to the lower layer, MELT - upper, which corresponded to the upper layer. Inhomogeneity of temperature distribution and concentration in the ladle was considered the initial condition: Lower layer: The height of the layer: 3200 mm, density – 6967 kg.m⁻³, concentration 1, temperature 1500 ° C, Upper layer: The height of the layer: 400 mm, density – 6897 kg.m⁻³, concentration 0, temperature 1520 ° C. Because the density of the melt is entered depending on the temperature, the density inhomogeneity is entered by the insertion of different temperature to the lower and upper layer [3].

3 DISCUSSION OF RESULTS

Similarly to the physical modelling, the data and visualized results can be obtained using the numerical modelling. The aim of the simulation was to obtain the information about the character of flow and the course of homogenization processes in the casting ladle during the argon blowing trough the three-hole lance. The unsteady velocity, temperature and concentration fields of the melt are the results of calculation. Furthermore, the calculation result is unsteady temperature and concentration courses in selected monitoring points in three planes distanced 270, 1,890 and 3,510 mm from the bottom of the ladle.

Fig. 4 reflects the concentration course in monitoring point 2 in three planes with the flow of argon 243 l.min⁻¹ for a three-hole lance distanced 270 mm from the bottom. The homogenization of concentrations already occurs after less than 200 seconds. The decreases and subsequent increases in the concentration curves are caused by the recirculation vortices, which are formed by interaction with the blown argon. The gradual formation of recirculation vortices is clearly visible from the unsteady courses of the concentrations in the central plane of the casting ladle recorded in Fig. 5.
Fig. 4. Curves of concentrations in the monitoring point 2 in three planes, flow rate 243 l.min\(^{-1}\) for a three-hole lance at a distance of 270 mm from the bottom.

Fig. 5. Courses of the MELT-upper layer component concentrations in the selected planes for different times, flow rate 243 l.min\(^{-1}\); mean concentrations in perfect homogenization of 0.125 for a three-hole lance, at a distance of 270 mm from the bottom.

Fig. 5 shows the velocity fields of the melt flow during the homogenization process. When the vortex reaches the bottom, there is another couple of vortices in the corner of the bottom and the sidewall formed.

Fig. 6. Velocity fields of liquid melt for the argon flow rate 243 l.min\(^{-1}\) through the tree hole lance at a distance 270 mm from the bottom.

Before the initiation of the calculations with different argon flow rates and lance positions the results of the numerical modelling had been compared to the results of physical modelling. The physical model was created from Plexiglas in the geometric scale of 1:9 relative to the real 180-ton ladle (Fig. 7) [1,2]. The aforementioned physical model served to conduct a comprehensive series of experiments studying influence of the blowing (blowing intensity effect, position of the bottom blowing element or position of submerged argon lance) on the length of time of homogenization bath. The modelled flow rates were calculated on the basis of different criteria of identity of the modified Froude criterion, which includes, inter alia, the expansion of gas due to temperature.

Fig. 7. Physical model with probes for scanning changes in the concentration.
To compare the results from physical and numerical modelling, the model situation was selected with the same gas flow rate 243 l.min\(^{-1}\) and the lance position at a distance of 270 mm from the bottom of the ladle. The average time required for homogenization bath (maximum tolerated deviation was ± 5% from the established value of the dimensionless final concentration), reached a value of approximately 140 s.

The difference in homogenization time between the numerical and physical modelling is likely due to the principle of the used method and the way by which the time is counted down from the start of the experiment until its termination. While the physical model, which uses the impulse-response method mentioned in Introduction to monitor changes in the concentration, the marker is not injected into the liquid until the moment when the flow field in the ladle is stabilized; the beginning of homogenization in the numerical modelling starts from the actual moment of gas blowing (so even before the creation of steady recirculation flow in the ladle).

For this reason, the authors proceeded to adjust the setting of numerical computation conditions of homogenization, so that the computation was as close as possible to the method used for physical modelling. The method of two liquid levels in the ladle has been replaced by a step permanent change of the concentration in the ladle used in previous works of the authors [4]. To simulate the concentration changes, it was necessary to define two components: the component that constituted the initial melt in the ladle, and the component that corresponds to the melt injection marker. To distinguish the original and the newly introduced melt, the terms MELT and MELT-INJECT were used. The simulation of concentration changes was made using the Species Transport model from value 0 (MELT) to 1 (MELT-INJECT). The homogenization is modelled as time-limited process limited by the duration of marker injection into the melt. The computed time of blowing the argon into the ladle will depend on the desired degree of homogenization.

The area, shape and size of marker injection in the ladle were chosen based on the shape and method of marker injection used in the physical modelling. The injection area of the marker has had a cylindrical shape and is shown in Fig. 8.

Fig. 8. Marker injection area obtained will be a subject of further research.

4 CONCLUSION

The presented paper is devoted to the setting of the numerical simulation for the calculation of the homogenization processes occurring in a casting ladle. It will be necessary to validate the results of the simulation with the results of the parallel physical modelling. After the verification of the correct settings of the homogenization process calculation in the ladle, the calculations with different flow rates of argon and evaluation of homogenization times will be conducted. The effectiveness of homogenization simulations will depend on the initial position of the lance and the argon-blowing rate. For the numerical simulations, the initial argon-blowing rate was based on the estimation of the argon compression in a blowing element and on the nominal flow rate.
REFERENCES


[3.] STRÁSÁK, P. Numerical Modelling of liquid steel behaviour in the ladle during the argon blowing through the three hole lance. Technical report for VŠB-TU Ostrava, FMME, Department of Metallurgy, TechSoft Eng., 2009