Y. WANG, X. AI, S. LI, H. LI, H. LIU

ISSN 0543-5846
METABK 57(1-2) 51-54 (2018)
UDC – UDK 669.18.621-498:658.281.669.163:621.642.3-282.5:62.001.57.083.3=111

OPTIMIZATION OF SIX STRAND TUNDISH BASED ON INCLUSIONS MOTION

Received – Primljeno: 2017-09-24
Accepted – Prihvaćeno: 2017-11-20
Original Scientific Paper – Izvorni znanstveni rad

Inclusion transport and the influence of structural parameters of baffle holes on inclusion removal rate are discussed. The physical modeling experiments give two optimal integrated tundish structural parameters of baffle holes. From the further study of Inclusion trajectories, the tundish should be optimized in the structural parameters of baffle holes in the condition of height 300 mm, angel 30 ° and diameter 20 mm.

Key words: liquid steel, continuous casting, strand tundish, mathematical model, inclusions

INTRODUCTION

Tundish in continuous casting are important intermediate buffers between ladles and moulds. It is well known that liquid steel flow characteristics in tundishes have a large influence on the cleanness of steel [1]. In order to obtain ideal fluid flow characteristics in tundish, flow control devices, such as, weirs, dams, baffles with inclined holes and turbulence inhibitors, have been widely used in continuous casting tundish. All of them are designed to increase residence times and plug flow volume of liquid steel in tundish for enhancing inclusion removal from the molten steel. Usually, two research methods, physical modeling and mathematical simulation, are employed to optimize tundish configurations [2].

Most optimization of tundish are based on flow only [3 - 5]. Several studies [6] have been carried out for investigating flow and inclusion behavior in tundish. Tacke and Ludwig [3] and Kaufmann *et* al. [4] studied inclusion flotation based on the scalar diffusion through an isothermal 3-D turbulent flow field. Most of these studies discuss the inclusion removal mechanism in single strand slab caster tundish. The presence of more than one outlet makes the study of multi-strand tundish more important as the inclusions passing through each outlet will determine the quality of the billets coming through each strand. Zhang *et* al. [7] studied the 3-dimensional fluid flow in continuous casting tundishes with and without flow control devices with the use of random walk model to incorporate the effect of turbulent fluctuations on the particle motion. Pradeep *et* al. [8] have studied the effect of height and position of dams on inclusion removal in a Six Strand Tundish, simulated with a 3-D finite-volume computational model.

In this paper, fluid flow in a 40 tons six-strand tundish with different structural parameters of baffle holes was investigated by using physical modeling. In the experiments, residence times of fluid flow in the tundish with different configurations were measured and flow characteristics were determined from the residence time. In the mathematical simulation, governing equations for the molten steel flow and inclusions trajectories in the tundish with different baffle holes are set up and then numerically calculated to obtain final inclusion removal rate.

Physical model description

Similarity

In order to insure the fluid flowing between the model and prototype tundish for isothermal and non-reactive systems similar, geometrical and dynamic similarities must be satisfied between the two vessels [8]. In the present work, the ratio of geometrical similarity of model tundish to the prototype was chosen to be 1:2. Dynamic similarity required simultaneous equality of both turbulent Reynolds and Froude numbers, but it was impossible to keep the condition satisfied in reduced scale modeling studies. It showed that the magnitude of turbulent Reynolds number under turbulent flow range in different tundishes was very similar [6]. Therefore, Froude number between the model tundish and the prototype one was maintained to be equivalent.

Experimental apparatus

A schematic of the experimental apparatus is shown in Figure.1. Two baffles were used in this tundish configuration and each baffle had three holes which upwardly inclined to the horizontal.

Y. Wang, X. Ai, H. Li, H. Liu, University of Science and Technology Liaoning, Anshan, China
S. Li, Anshan Iron and Steel Group Corporation, Anshan, China
Corr. author: e-mail: aixingang@126.com

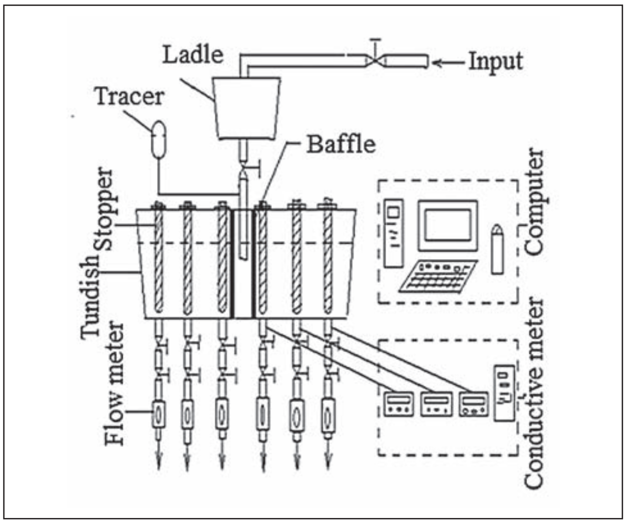

Figure 1 Schematic of physical experimental apparatus

Experimental method

A Residence Time Distribution (RTD) curve of the fluid flowing in the tundish can be obtained by stimulus-response technique to investigate the effect of different tundish configuration on the fluid flow characteristics in the tundish. After attaining steady-state flow condition, 500 ml of KCl was used as a tracer and was injected into the water stream. One conductivity probe which was connected to a conductivity meter was installed below one of the outlets of the tundish to measure the instantaneous concentration of the tracer as function of time.

From the RTD curves, residence time can be obtained for every experiment. Considering that there is fluid exchange between the fluids in the dead zone and in the active zone, the flow model proposed was employed in this work to calculate dead volume fraction, but the fractions of plug flow and well-mixed volumes were still calculated with the modified mixed model [10].

Mathematical model description

Assumptions The mathematical model is based on assumptions:

(1) Flow is assumed to be steady and incompressible. Air and gas entrainment by incoming metal stream is neglected.

(2) The surface of tundish is considered to be perfectly flat and slag depth was considered to be insignificant.

(3) The generation of inclusions in the tundish due to any erosion of refractory or by any chemical reactions was ignored.

(4) Inclusions collision and growth are neglected. [9]

Fluid flow and inclusion motion model

The continuity and Navier-Stokes equations [10] for the steady fluid flow of incompressible Newtonian fluids are used. Inclusion trajectories are calculated using a Lagrangian inclusion tracking method [1], which solves a transport equation for each inclusion as it travels through the previously calculated steady state flow field. A discrete random walk model [10] is applied to simulate the chaotic effect of the turbulent eddies on the inclusion paths.

Main dimensions of model

The geometric model of tundish and Grid Plot for flow fields are given in Figure.2.

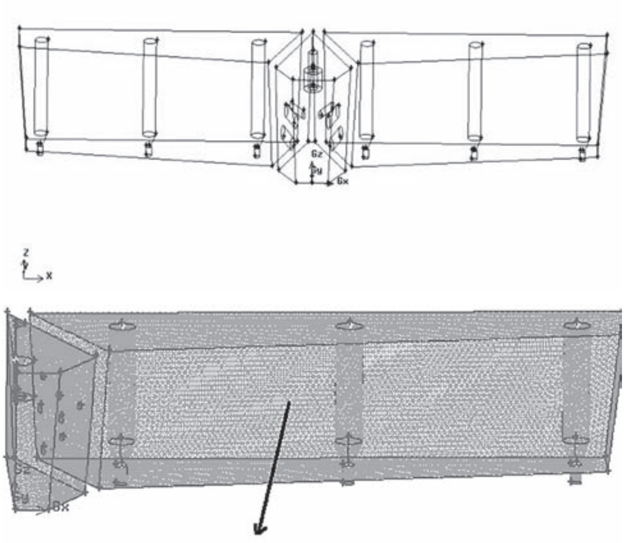

Figure 2 Geometric model and grid plot

Computational details and boundary conditions

The properties of liquid steel are given in Table1. The slag layer is set in slip wall. Shroud is set in inlet. Side walls and bottom are set in wall. Submerged entry nozzle is set in outlet. All furniture is adiabatic wall. All velocities are set to zero at the wall (no slip condition). The wall functions are employed to compute the turbulence quantities in the vicinity of walls. At the inlet, the velocity is 1,4 m/s. Turbulence intensity at inlet is specified as 2 %.

Inclusions are injected computationally distributed homogeneously over the inlet plane. Each trajectory is calculated through the flow field until the inclusion either is trapped on the plane which is 5 mm under the surface of ladle or exits the outlet [9]. In this work, the

Table 1 **Properties of liquid steel**

Property	Value
Thermal expansion coefficient / K^{-1}	$1{,}1970\times10^{-4}$
Reference density / kg/m^3	7 026,8
Reference temperature / K	1 853
Conductivity of liquid steel / W/m/K	52 535
Specific heat coefficient of steel / J/kg/K	822
Dynamic viscosity of steel / Pa.s	$5{,}3\times10^{-3}$

transport and capture of 1 000 small inclusions, with the size of 50 μm, are simulated in the tundish. Inclusions reaching the outlet are assumed to escape through it.

RESULTS AND DISCUSSION

Flow characters

The results of measured residence time from experiment of physical simulation are summarized in Table 2. The results show that volume fraction of dead zone is from 7,4 % (Case T11) to 16,3 % (Case T10), and the average residence time is from 552,1 s (Case T7) to 615,9 s (Case T11).

According to sum of order based on both residence time and dead flow volume, as shown in Table 2, the optimal integrated tundish structural parameters of baffle holes can be found in Case T8 and Case T11 as the top cases, in which residence time are more than 584 s, and dead flow volume are less than 12 %.

Table 2 **Results of experiment of physical simulation**

Case	Structural parameters of baffle holes			Results from residence time			
	Height / mm	Angel / °	Diameter / mm	Average residence time / s	Mixed flow Volume / %	Dead flow Volume / %	Plug flow Volume / %
T1	100	0	20	578,5	81,0	13,0	5,9
T2	100	15	40	581,6	84,5	12,2	3,2
T3	100	30	60	567,8	80,1	14,6	5,2
T4	100	45	80	565,5	77,8	14,9	7,1
T5	200	0	40	570,4	82,9	14,2	2,7
T6	200	15	20	571,1	77,1	14,0	8,7
T7	200	30	80	552,1	77,4	16,9	5,5
T8	200	45	60	584,8	82,8	12,0	5,1
T9	300	0	60	568,1	82,7	14,6	2,6
T10	300	15	80	555,9	75,6	16,3	8,1
T11	300	30	20	615,9	89,3	7,4	3,2
T12	300	45	40	575,9	80,7	13,4	5,8

Inclusion transport

In this work, the velocity vectors calculated in the tundish using a 3-D flow model with about 200 000 nodes. Inclusion trajectories are then calculated through these steady flow fields using the random walk model.

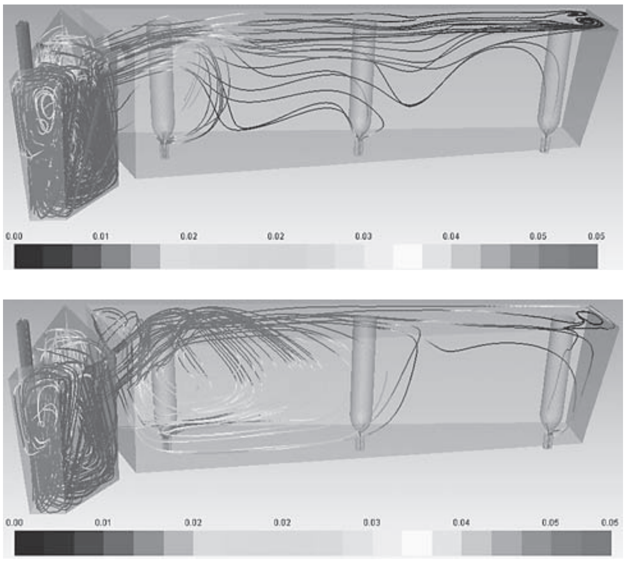

Figure 3 inclusion trajectories in case 8 and case 11

Figure 3 shows the simulated trajectories of 1 000 small inclusions, with 50 μm radius and 2 700 kg/m^3 densities, in the inlet.

Figure 3 shows the variation of the percentage removal of inclusions from each outlet with varying tundish structural parameters of baffle holes. It can be seen that the 300 mm height of the baffle holes is more advantageous than the 200 mm in the overall percentage removal of the inclusions. From near outlet to far outlet it shows decrease in the inclusion removal in the case 8 and case 11. The decrease in inclusion removal rate is more at the near outlet, than at the middle outlet and far outlet. It means that the changes of structural parameters of baffle holes succeeded to improve the rate of final inclusions remove.

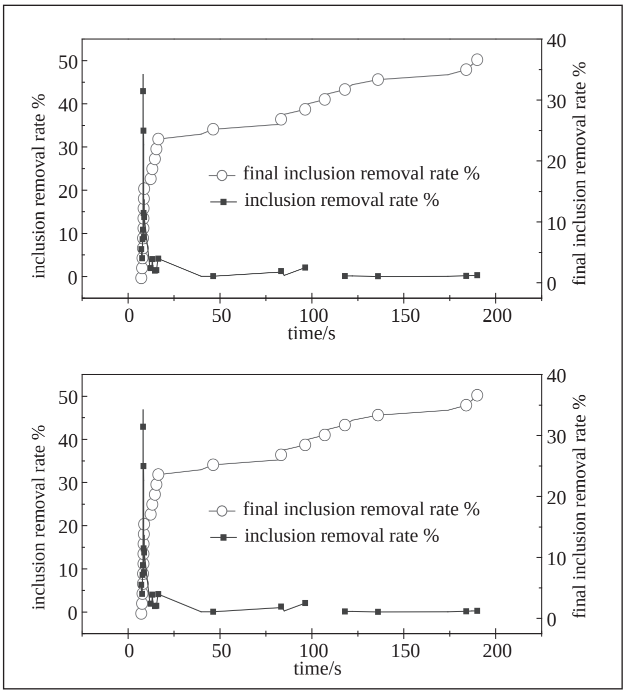

Figure 4 comparison of inclusion removal fraction in case 8 and case 11

Further, it can be seen that the percentage of removal inclusions is different among the three outlets in the case 8 and case 11. The number of inclusions coming through the near outlet is the highest and the lowest through the far. However, the billets coming out from the casting mold connected to these outlets are supposed to have similar distribution of inclusions, which is the important objective of the steelmaker. The case 11 which has minimum variation of inclusion distribution (inclusions coming out through the outlets) will be more ideal than case 8.

Inclusions have more chance of flotation to slag–steel interface in case11 than the case8, which is especially important for producing high quality steel. Figure.4 shows the inclusion remove fractions for different structural parameters of baffle holes. These results show that the influence of baffle holes on final inclusion removal rate is rather complex. The final inclusion removal rate adds up to 37,4 % at the time of 50 s in case 11, while 25,2 % in case 8. When it comes to the time of 200 s, final inclusion removal rate is the largest about 52,85 %. Yet the final inclusion removal rate is 48,78 % in case 8.

SUMMARY

Results of experiment of physical simulation showed that the currently applied six strand tundish parameters should be modified to optimize flow field of molten steel. And the optimal integrated tundish structural parameters of baffle holes can be found in Case T8(height 200 mm, angel 45 ° and diameter 60 mm) and Case T11(height 300 mm, angel 30 ° and diameter 20 mm) as the top 2 cases, in which residence time are more than 584 s, and dead flow volume are less than 12 %. From the study using fluid flow and inclusion transport together, the six strand tundish should be optimized in the structural parameters of baffle holes in the condition of height 300 mm, angel 30 ° and diameter 20 mm.

REFERENCES

[1] B.G. Thomas, Q. Yuan, L. Zhang, B. Zhao, S.P, Vanka, 2004 NSF Design, Service, Manufacturing and Industrial Innovation Research Conf., Dallas, Texas, January, 2004, 5.

[2] Morales,R. D., López-Ramírez, S., Palafox-Ramos, J., Zacharias, D.. Mathematical simulation of effects of flow control devices and buoyancy forces on molten steel flow and evolution of output temperature in tundish. Ironmaking Steelmaking 28(2001), 33.

[3] Tacke, K., Ludwig, J. C. Steel flow and inclusion separation in continuous casting tundishes. Steel Research 58(1987), 262.

[4] Kaufmann, B., Niedermayr, A., Sattler, H., Preuer, A.. Separation of nonmetallic particles in tundishes. Steel Research 64(1993). 203.

[5] Robert, A., Mazumdar, D.. Physical and mathematical modeling of flow and residence time distributions in different tundish designs. Steel Research 72(2001), 97.

[6] Sinha, A. K., Sahai, Y.. Mathematical modeling of inclusion transport and removal in continuous casting tundishes. Isij International 33(1993), 556.

[7] Jha, P. K., Rao, P. S.. Effect of height and position of dams on inclusion removal in a six strand tundish. Transactions of the Iron Steel Institute of Japan 48(2008), 154.

[8] Jha, P. K., Dash, S. K., Kumar, S.. Fluid flow and mixing in a six strand billet caster tundish. Isij International 41(2001), 1437.

[9] Jha, P. K., Rao, P. S.. Effect of height and position of dams on inclusion removal in a six strand tundish. Transactions of the Iron Steel Institute of Japan 48(2008), 154.

[10] Miki, Y., Thomas, B. G.. Modeling of inclusion removal in tundish. Metallurgical Materials Transactions B 30(1999), 639.

Note: The responsible for England language is Qinghe Xiao, Liaoning, China.