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STUDY ON STIRRING BEHAVIOR OF LIQUID STEEL IN BOTTOM-BLOWING LADLE WITH IMMERSED CYLINDER

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The ladle bottom argon blowing process has an important influence on the refining liquid steel. The effects of diameters, insertion depth of immersed cylinder and bottom gas flow rate on the flow state of liquid steel and the amplitude of liquid steel surface are numerically simulated for 150t ladle. The results show that the slag entrapment of liquid steel surface can be confined by changing the diameters and insertion depths of immersed cylinder. The effects of gas flow rate, diameter and insertion depth with immersed cylinder on the flow of molten steel in the ladle were analyzed.

Key words: steel flow, ladle, bottom-blowing stirring, immersed cylinder, numerical simulation

INTRODUCTION

The ladle as the intermediate containers between steelmaking and continue casting processes is an indispensable equipment in the steel production [1,2]. It is taken as a container for transport and purification of molten steel, and also as a refining furnace in external refining [3,4]. The ladle bottom argon blowing technology is widely used as an affordable and simple refining method, which has the advantages of balancing the temperature and composition of molten steel, removing the harmful gas and inclusion, and improving the quality of liquid steel [5]. The mathematical model of ladle bottom blowing gas into the flow field of immersion cylinder liquid steel is established in this paper. By changing the diameter and depth of immersed cylinder, the influences of ladle with immersed cylinder on the molten steel flow of ladle and the slag entrapment of molten steel are analyzed. The feasibility is investigated for improving the refining efficiency and reducing the refining time.

MATHEMATICAL MODEL

The ladle injection system, belongs to a typical two-phase flow, therefore, it needs to select a multiphase flow model and turbulence model. According to the requirements, mixture model is selected [6], set phase 1 to liquid steel, phase 2 to argon, and set the diameter of bubble to 10 mm. The drag force for gas-liquid phase force is selected [7], the selection of drag coefficient is Schiller and Naumann model, the lift and virtual mass force can be ignored [8].Realizable model is selected for turbulence model. The initial conditions are: select the entrance in the initialization, the initial values of field variables should be determined by entrance conditions. The entire flow field is considered as molten steel [9,10]. Building the physical three-dimensional model and meshing with GAMBIT software, the grid is shown in Figure 1.

The original data of 150 t ladle is used in the simulation, the single-hole gas injection is adopted, the vent is set at 1/2 R of the bottom (R is the bottom radius of ladle), insert different diameter and depth of immersed cylinder from the liquid steel surface, cylinder is coaxial with the bottom blowing holes. Under the condition of different bottom blowing gas, the status of liquid steel flow and phenomenon of liquid steel surface slag entrapment are researched with and without immersed cylinder. The main parameters of prototype are shown in Table 1, and the parameters of immersed cylinder are shown in Table 2.

Figure 1 Grid generation

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Table 1 **Main parameters of prototype /mm**

Project	Top diameter	Bottom diameter	Depth	Gas flow / 1 / min^{-1}
Prototype	3 154	2 781	3 850	0-700

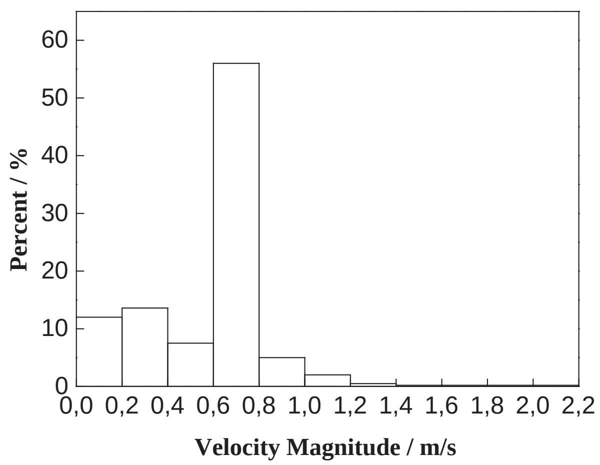
Table 2 **Parameters of cylinder /mm**

Project	Parameter		
Daimeter	560	700	788,5
Insertion depth	630	850	1 050

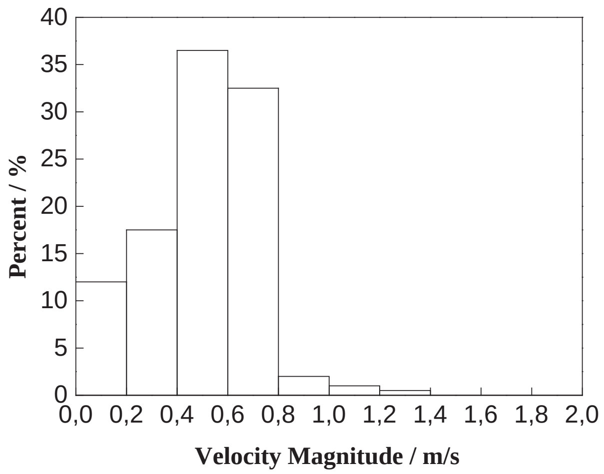
NUMERICAL SIMULATION RESULTS AND DISCUSSION

Analysis the flow of molten steel in the ladle

Figure 2 shows that the area in the ladle of middle and bottom appeared relatively vulnerable without immersed cylinder. Gas-liquid two phase velocity is larger, so the distribution of flow velocity is uneven, and the maximum speed is 1,1 m/s, while the most of the molten steel flow velocity is within 0 ~ 0,7 m/s ; After inserting the immersion cylinder, vulnerable area of the ladle bottom blowing argon is small. Steel flow velocity is uniform. Most of flow velocity distribution is at 0,2 m/s ~ 0,9 m/s, so average speed increases.



(a) Without immersed cylinder



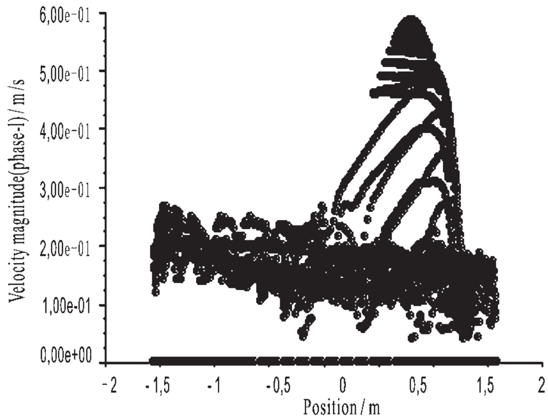
(b) Immersed cylinder

Figure 2 Speed histogram

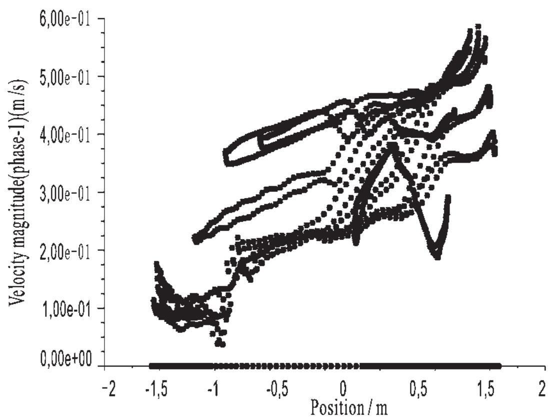
Critical blowing rate of slag

There is a mutation in the transfer process of slag/ steel interface during argon blowing and stirring in the ladle bottom. It is so called the phenomenon of slag entrapment: one phase existed in the liquid beads of another phase[10]. According to Weber number, the critical flow velocity for the slag entrapment is obtained. In numerical simulation, the speed of surface flow of molten steel surface is the main consideration, therefore, the speed 0,59 m/s can be seen as the critical speed of occurring the slag entrapment on liquid steel surface.

From Figure 3, if there is no immersed cylinder in the bottom- blowing ladle, the partial bottom blowing argon goes into the ladle, the liquid steel in the ladle forms a 3D circulating system with the axis of two-phase zone. After inserting the immersed cylinder, the liquid steel flow is driven by the bottom-blowing gas, when the gas is up to the height of cylinder, the parts of liquid steel with the bottom-blowing gas is driving into the immersed cylinder, and the gas-liquid separation is carried out on the surface of liquid steel. The flow effect of molten steel to liquid surface is violent in cylinder, under the driving force of inertia, a local small circulation flow is formed



(a) Without immersed cylinder

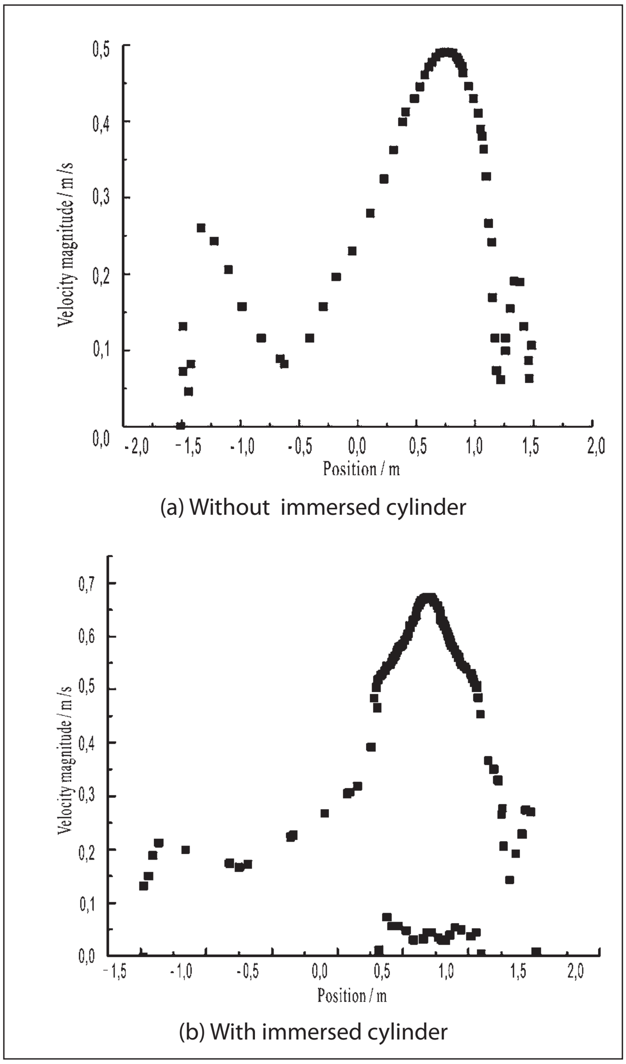


(b) With immersed cylinder

Figure 3 XY speed scatter plots of steel liquid surface along downward the cylindrical wall. The parts of gas-liquid two-phase flow form a small circulation flow in the upper part of ladle outside the cylinder, and also form a large circulation flow in the lower part of ladle to weaken the flow in the horizontal direction of ladle liquid surface outside the cylinder.

XY speed scatter plots of steel liquid surface with different lines

It can be seen from Figure 4 that the 0,65 H height is close to zero, and the circulation center of the circulating fluid is 0,6 ~ 0,7 H. With the increase of the amount of argon blowing at the bottom, the absolute velocity increases gradually, but the steel liquid circulation center in the ladle is hardly changed. With the immersed cylinder, the velocity of the turning point at the center of the ladle increases from zero to 0,15 m/s, and the circulation flow in the ladle is changed, which makes the dead rate of circulating center become lower, and promotes the mixing of steel liquid.

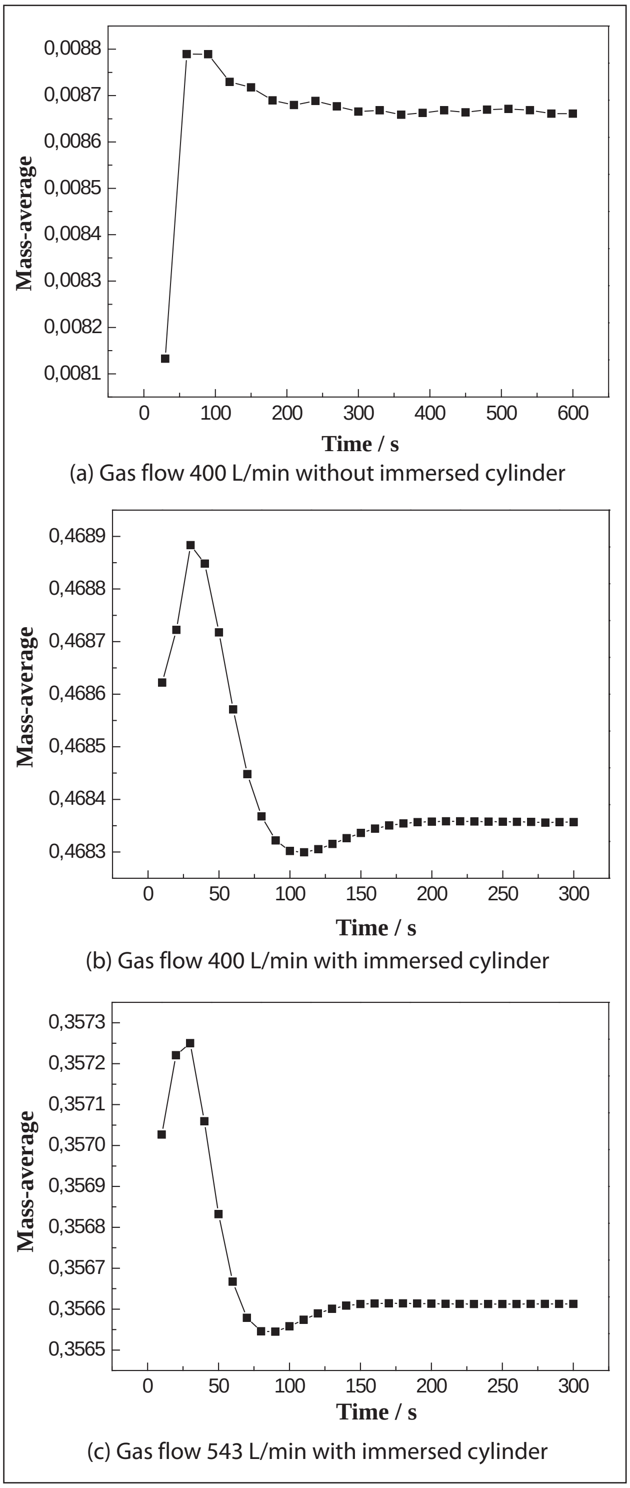


(a) Without immersed cylinder

(b) With immersed cylinder

Figure 4 XY scatterplot speed of 0,65 H

Gas flow influence on mixing time



(a) Gas flow 400 L/min without immersed cylinder

(b) Gas flow 400 L/min with immersed cylinder

(c) Gas flow 543 L/min with immersed cylinder

Figure 5 The mass-average changing with time at critical gas flow rate

It can be seen from figure 5 (a) and (b) that without immersed cylinder the uniform mixing time is 300 seconds; with inserting the immersed cylinder the uniform mixing time is about 200 s. It can be seen from figure (c) that with the immersed cylinder at critical volume slag gas blowing rate, the uniform mixing time is about 150 s. It can be concluded that the insertion of the immersed cylinder increases the critical volume slag air flow, and shortens the mixing time.

CONCLUSIONS

Without immersed cylinder, with the increasing of gas flow, liquid steel surface horizontal velocity increases. After inserting immersed cylinder, forming a cyclic flow inside and outside of cylinder, horizontal direction liquid flow on the surface of the cylinder outer ladle decreases, so as to improve the bottom blowing critical slag volume.

Large disadvantaged areas in the middle and lower ladle emerges without immersed cylinder. The speed of gas-liquid two-phase region is large, so the flow velocity distribution is uniform. With immersed cylinder, the weak area in circulation center decreases, steel flow velocity is more uniform.

The main factors affecting the liquid steel stirring are the diameter of cylinder, the insertion depth and the gas flow of ladle bottom blowing. With the increase of bottom blowing gas flow, the amplitude of molten steel is increased. The fluctuation of liquid steel can be effectively inhibited by inserting the immersed cylinder, and the fluctuation of steel liquid surface is decreased by changing the diameter of immersed cylinder and the insertion depth. If there is no immersed cylinder, the critical bottom gas flow rate of slag entrapment is 400 $l \times min^{-1}$, after inserting the immersed cylinder with the diameter of 788.5 mm and the depth of 630mm, the critical bottom gas flow rate of slag entrapment is 678 $l \times min^{-1}$.

By inserting the immersed cylinder, the critical volume slag blowing gas can be improved, the mixing time shorten, and the smelting effect is strengthened.

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