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THE EFFECT OF RUHRSTAHL AND HEREAEUS (RH) OPERATION ON THE MIXING OF MOLTEN STEEL

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The flow and mixing characteristics of molten steel in the RH refining process were studied. A hydraulic simulation system with the geometric similarity ratio of 1:4 was built with 210 tons of RH as the prototype. The influence of different locations of tracers and different operation processes on the mixing of molten steel in ladle was studied. The results show that the RH operation should adopt a large air blowing amount, the insertion depth of the impregnated tube should not be less than 560 mm, and the liquid level of the vacuum chamber should be kept small.

Key words: steel, RH; refining; mixing; water model

INTRODUCTION

The RH method is the most important one in the process of furnace refining [1,2]. Its main functions have been developed from single degassing equipment to vacuum degassing, vacuum decarbonization, blowing oxygen decarbonization, powder desulphurization and microalloying [3-5]. Mixing time is also an important index to measure the homogenization of molten steel [6,7]. In order to study the flow and mixing characteristics of molten steel in the RH refining process, a hydraulic model of ladle top blowing was established on the basis of similar principle [8-13]. Through simulation experiments, the influence of different positions and different operating processes on the mixing of molten steel in ladle is studied, to provide a theoretical basis for the formulation of a reasonable top blown refining process [14,15].

EXPERIMENTAL PRINCIPLE

Geometric similarity

The choice of the size ratio of the RH water model to the actual equipment can be arbitrary. Considering the experimental data processing, the similarity ratio is 1/4.

Dynamic similarity

The dynamic similarity between the RH model and the prototype is ensured by the conversion formula.

Correction of the number of Froude：

$$Fr = \frac{g \cdot L}{u^2} \cdot \frac{\rho_1 - \rho_g}{\rho_g} \tag{1}$$

with:
u - characteristic velocity;
$\rho_1 \rho_g$ - The density of liquid and gas;
L - Characteristic length.
g - gravitational acceleration

When L is the blow hole depth (H_0) and U_g is the gas outlet velocity：

$$Fr = \frac{g \cdot H_0}{u_g^2} \cdot \frac{\rho_1}{\rho_g} \tag{2}$$

The Fr of the prototype and the model is equal, we can obtain：

$$\frac{H_0''}{u_g''^2} \cdot \frac{\rho_1''}{\rho_g''} = \frac{H_0'}{u_g'^2} \cdot \frac{\rho_1'}{\rho_g'} \tag{3}$$

The relationship between the RH model compressed oxygen control meter indicator flow and the RH standard cyclic argon flow rate is

$$\dddot{Q}_0'' = \sqrt{\left(\frac{1}{\lambda}\right)^6 \cdot \left(\frac{\rho_t''}{\rho_t'}\right)^2 \cdot \frac{\rho_{g0}'}{\rho_{g0}''} \cdot \frac{\dddot{T}'}{\dddot{T}''} \cdot \frac{\ln\left(P_1'/P_2'\right)}{\ln\left(P_1''/P_2''\right)}} \cdot \dddot{Q}_0' = 0,0996\,\dddot{Q}' \tag{4}$$

EXPERIMENTAL METHOD

Experimental main equipment

In this experiment, water is used to simulate molten steel and oxygen is used to simulate the argon gas in the field. The main equipment of the experiment is shown in Figure 1.

In this experiment, a 210 tons RH-TOP vacuum refining device and a ladle are used as the prototype. Ladle depth is 4 060 mm, the upper inner diameter of ladle is 3 884, the lower inner diameter of ladle is 3 222 mm,

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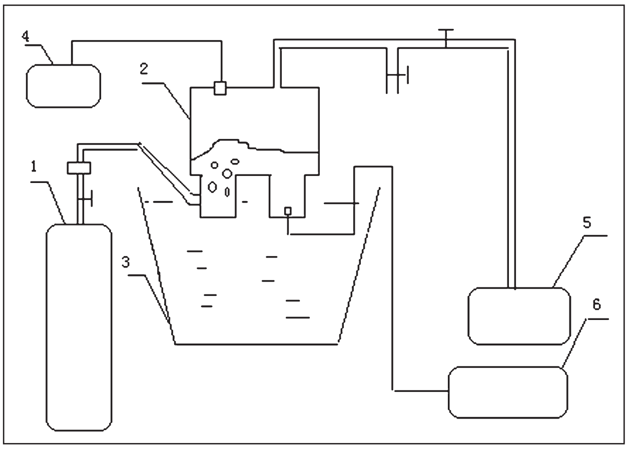

Figure 1 1 Air tank 2 Vacuum chamber model 3 Ladle model 4 Differential gauge 5 Vacuum pump 6 Velometer

the vacuum chamber diameter is 2 138 mm, the immersed tube diameter is 650 /1 294. The ratio of model to prototype geometric dimension is 1:4.

Data acquisition and processing methods

Mixing time is a physical quantity used to describe the mixing efficiency of reactors. In this experiment, the conductivity method was used to measure the concentration change. A certain amount of tracer (saturated NaCl water solution) was added into a certain position in the model, and then the electrical conductivity of the water was continuously measured, and the change of electrical conductivity did not exceed the stability value ($C\infty$) ± 5 % (that is, selecting $Ct - Cs \leq 0,05\ C\infty$ as the standard), and the accumulated time 0,95 is the mixing time.

The data acquisition time is 3 minutes, and the data acquisition interval is 0,01 s. In order to eliminate the experimental error, 7 experimental data are repeatedly measured at each point. After removing the minimum and maximum values, the average value of the rest of the experimental data is taken as the experimental result of the measurement point.

Influence of the position of alloy addition on the mixing of molten steel

The addition time of the alloy has the certain effect on the mixing time of RH. This experiment measured the mixing time of different positions when the gas blowing volume was 1 200 NL/min, the immersion depth of the impregnated tube was 560 mm, and the vacuum chamber pressure was 100 Pa. The location of the tracer is shown in Figure 2.

The tracer is added to different positions and the mixing time is different, as shown in Figure 3. The difference of mixing time between the vacuum chamber, the rising tube, and the drop tube position is very small, and the mixing time is less than the experimental results of other positions. The vacuum chamber, the riser, and

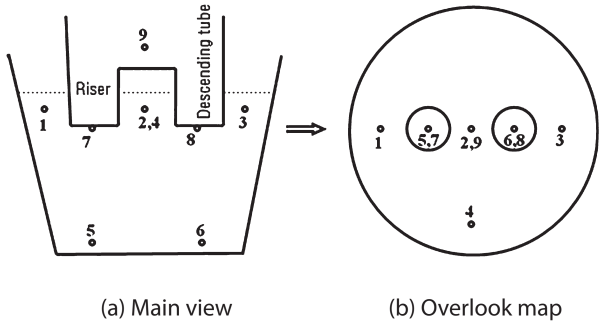

Figure 2 Tracer add position diagram

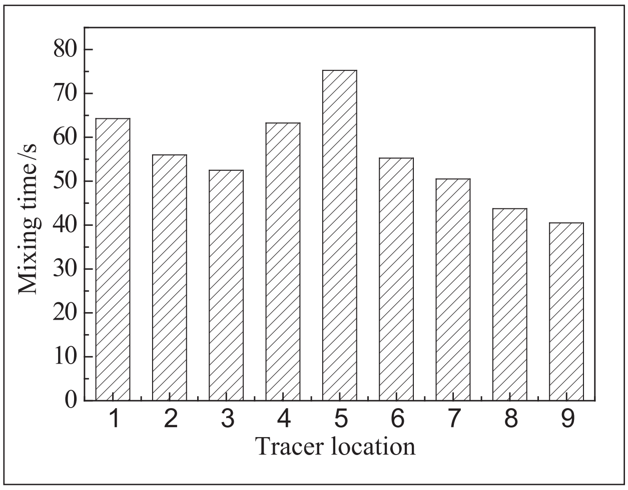

Figure 3 Mixing time of tracer at different positions when blowing volume is 1 200 NL/min

the downcomer are the active regions of the flow, and the other locations are the stagnant zones of the RH flow field. The experimental results show that the difference in mixing time is caused by the different flow fields in the RH ladle.

The degassing reaction is carried out in the vacuum chamber, and the alloy is added to the vacuum chamber. It is of practical significance to study the mixing time from the vacuum chamber, so we choose the location of the tracer as the vacuum chamber.

Influence of blowing volume on mixing

The mixing time of impregnated tube immersed in the depth of 400 mm, 480 mm, 560 mm, 640 mm, 720 mm and simulated blowing volume at 400 NL/min, 600 NL/min, 800 NL/min, 1 000 NL/min, 1 200 NL/min, 1 400 NL/min is measured experimentally. The results are shown in Figure 4. It can be seen that the trend of mixing time with the amount of blowing gas is basically the same under the immersion depth of different impregnation tubes, and the mixing time decreases with the increase of gas blowing amount. When blowing volume is 800 NL/min, it is the turning point of mixing time with the speed of blowing. When the gas blowing volume is less than 800 NL/min, the slope of the curve is larger and the mixing time decreases obviously. The slope of the curve is smaller when the air blowing volume is

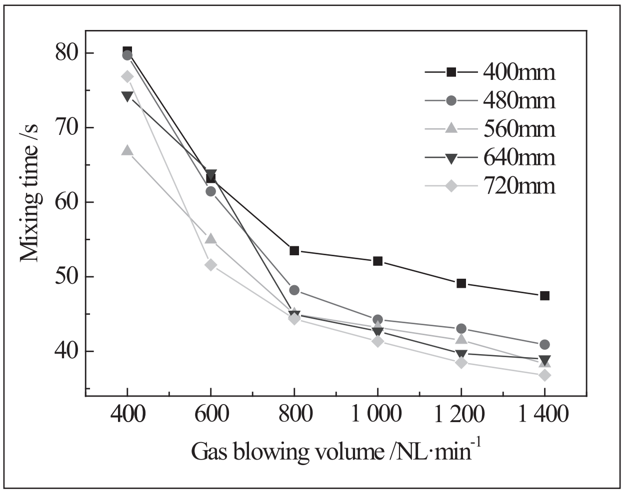

Figure 4 Effect of blowing volume on mixing time under different immersion depths

greater than 800 NL/min, and the mixing time decreases not obviously.

The increase of blowing volume is beneficial to shorten the mixing time in RH ladle. In order to facilitate mixing of molten steel in ladle, large blow volume should be adopted.

Influence of immersion depth on mixing

This experiment measured the mixing time of the simulated field blowing volume were 400 mm, 480 mm, 560 mm, 640 mm and 720 mm, the immersion depth of 400 NL/min, 600 NL/min, 800 NL/min, 1 000 NL/min, 1 200 NL/min and 1 400 NL/min. The pressure of the simulated field vacuum chamber is 100 Pa. The results of the experiment were shown in Figure 5 respectively.

As can be seen from Figure 5, when the air blowing is greater than 600 NL/min and the immersion depth of the impregnated tube is below 560 mm, the mixing time decreases significantly with the increase of the immersion depth of the impregnating tube. When the immersion depth of the impregnated tube is greater than 560 mm, the mixing time decreases with the increase of immersion depth. The mixing time is the shortest when the blowing volume is 400 NL/min and 600 NL/min, and the immersion depth is greater than 560 mm. It can be seen from the diagram that the greater the volume of blowing, the greater the mixing time decreases with the increase of immersion depth.

In order to facilitate mixing, the immersion depth of the impregnated tube should not be less than 560 mm.

Effect of pressure on mixing in RH vacuum chamber

Keeping the depth of the impregnated liquid surface unchanged and changing the level of the vacuum chamber, keeping the level of the vacuum chamber unchanged and changing the immersion depth of the impregnated tube, the influence of the pressure change of the RH vacuum chamber on the mixing of the vacuum chamber is studied in the above two cases. Experiment under the condition of air blowing at 1 200 NL/min

(1) the influence of vacuum chamber pressure on mixing in the vacuum chamber when the liquid level is constant.

The level of the vacuum chamber is kept 100 mm unchanged. The immersion depth of the impregnated tube is adjusted according to the pressure of the vacuum chamber and the mixing time under different blowing volume is measured.

From Figure 6, we can see that the mixing time increases with the increase of pressure in the vacuum chamber under the same conditions. However, the variation of the mixing time is relatively small, the maximum value is 50,3 s measured at 20 kPa, and the minimum value is 40,5 s measured at 0,1 kPa. This shows that the influence of the measurement results on the mixing time is minimal in the case of the large blowing volume, keeping the liquid level in vacuum chamber unchanged, changing the height of the vacuum chamber namely changing the depth of the immersion in the vacuum chamber. Therefore, when the height of the vacu-

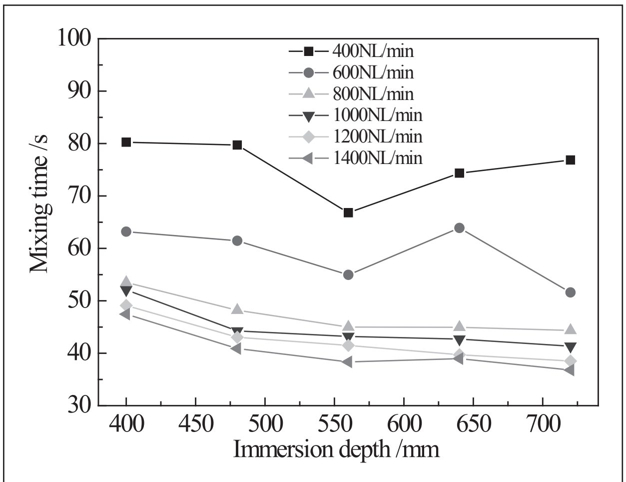

Figure 5 Effect of immersion depth on mixing time under different blowing conditions

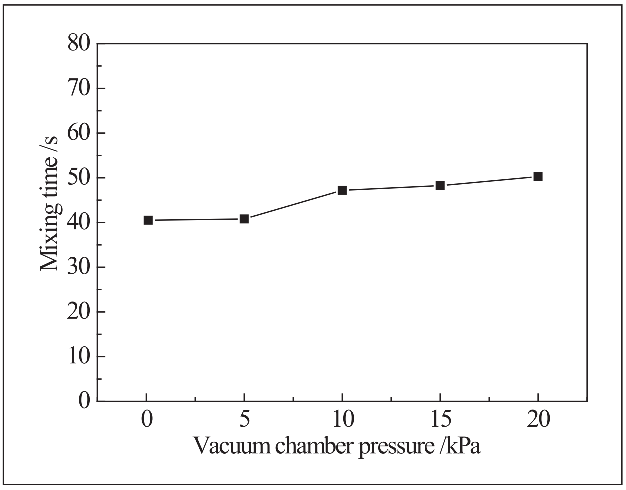

Figure 6 Mixing time under the different pressure of the vacuum chamber

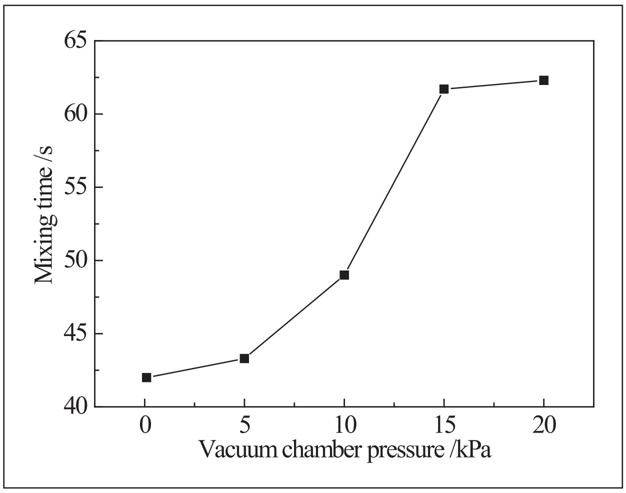

Figure 7 Mixing time under the different pressure of the vacuum chamber

um chamber is kept constant and the height of the vacuum chamber is changed (the immersion depth of the impregnated tube is changed), the effect on the measurement results of the mixing time is relatively small.

(2) the influence of vacuum chamber pressure on mixing time when immersed tube immersed in the same depth.

The mixing time of the tracer in the vacuum chamber, the immersion tube depth of 560 mm and the lift gas blowing volume 1 200 NL/min were measured. The experimental results of mixing time varying with pressure in the vacuum chamber are shown in Figure 7 respectively.

SUMMARY

Through the above experimental research, we can reach the following conclusions:

(1) The mixing time of tracer is the longest when the tracer was added between the riser and the wall of the ladle.

(2) The mixing time decreases with the increase of gas blowing amount. The increase of blowing volume is beneficial to shorten the mixing time in RH ladle.

(3) The greater the volume of blowing, the greater the mixing time decreases with the increase of immersion depth. The immersion depth of the impregnated tube should not be less than 560 mm

(4) When the depth of impregnated tube is constant, the mixing time decreases with the increase of vacuum. The influence of the measurement results on the mixing time is small.

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Note: Q. H. XIAO is responsible for English language, Liaoning, China