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Dissymmetric flow phenomenon in a multistrand tundish

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Abstract: The dissymmetric flow phenomenon exists in a symmetric multistrand tundish. It was studied by the physical simulation experiment. The fundamental flow characteristic of dissymmetry was analyzed. The asymmetry of the flow field, the temperature field, and the inclusions distribution without flow-control devices (FCDs) were compared with those with FCDs. It is proved that the asymmetry of the flow and temperature field along the outlets at the long range is more obvious. The symmetric FCDs installation has a slight effect on the dissymmetric temperature field, simultaneously, the symmetry of the average residence time and the fluid flow pattern has improved, and the fluid flow in the tundish has been more reasonable. In case of a symmetric multistrand tundish having a large volume, the influence of the dissymmetric phenomenon should be considered and the flow behaviors in the whole tundish should be studied completely.

Key words: multistrand tundish; dissymmetry; flow phenomenon; physical simulation; flow-control devices

1. Introduction

Liquid flow is the basic physical phenomenon in a tundish. Various metallurgical processes take place in the flowing steel. The flow behaviors of liquid have a significant effect on the steel cleanliness, operability and productivity. Consequently, study on the fluid flow behaviors in a tundish is the foundation of "Tundish Metallurgy".

Considering the symmetry of the internal shape of a tundish, it can be divided into two types: symmetric and dissymmetric. The half tundish is considered for study by many researchers [1-6] for studying the flow behaviors in a multistrand tundish. The methodology wherein the flow behaviors are identical in the two symmetric parts is considered. Based on the water model experiment and considering the flow field in a tundish being turbulent, the methodology is inaccuracy. When a tundish has several strands, temperature and inclusions in steel have a rather large difference along the two symmetric outlets at the exterior side. Then the flow condition in an outlet at one side cannot describe the fluid flow behaviors in other symmetric outlet accurately. An inaccurate conclusion can be drawn about the fluid flow pattern in a tundish and the inapplicable flow-control devices (FCDs) installation by this method.

The dissymmetric flow phenomenon in a multistrand tundish indicates that the composition, temperature, and inclusions in steel have a certain difference between the two symmetric parts in a tundish. The fundamentals of dissymmetric characteristic and its effect on the fluid flow behaviors have not been reported previously. Therefore, it is necessary to study the phenomenon systemically and to discover the rules of liquid flow in the multistrand tundish.

2. Theory and methods of experiment

2.1. Experimental theory

The water model experiment is based on the similarity theory, that is, the similar fluid flow pattern between the model and the prototype is based on the geometric and dynamic similarity. To geometric similarity, the prototype is a six-strand bloom tundish at a certain plant, and the scale ratio is 1:4 between the model and the prototype. To dynamic similarity, considering the flow condition in the second self-simulation area, the distribution of the velocity does not have a relation with Reynolds criterion; the Froude number is therefore considered as the similarity criterion for the model. On the other hand, the natural convection cannot be ignored as the smaller average velocity in exterior outlets when the tundish has a big volume and a long flow distance. Therefore, the natural convection should be considered, and the tundish criterion should also be satisfied [7-9].

According to Froude and tundish similarity criteria, the flow rate, velocity, and temperature difference between the model and prototype can be determined.

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The dissymmetric flow phenomenon of nonisothermal process in the multistrand tundish can be simulated.

2.2. Experimental methods

The model is made of plexiglass and the schematic of the experiment apparatus is shown in Fig. 1. From left to right, it is the 1st strand to the 6th strand in sequence.

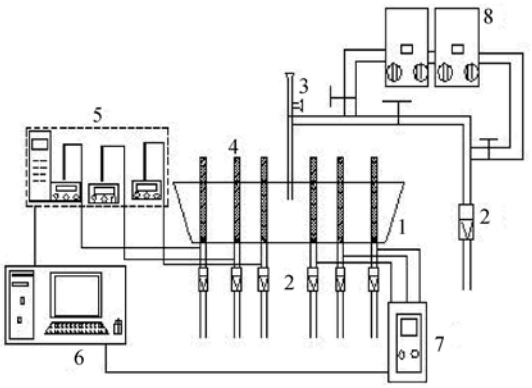

Fig. 1. Schematic of water model experiment: 1—tundish; 2—flowmeter; 3—tracer inlet; 4—stopper; 5—RTD system; 6—computer; 7—temperature collection system; 8—water heater.

The asymmetry of the flow field, the temperature field, and the inclusion distribution in a six-strand tundish is studied systematically. The residence time distribution (RTD) curve is obtained by the stimulate-response experiment, and the fluid flow pattern is then gained. The data collected with thermocouple are analyzed and then the temperature distribution is obtained. In the current water model, the polystyrene plastic particles were used to simulate the inclusions in steel. Inclusion trajectories were tracked by injecting the plastic particles to the inlet side of stream. Their motions were observed, and the observations were statistically averaged.

3. Dissymmetry of flow characteristic in a multistrand tundish

3.1. Asymmetry of the RTD curve, start response time of tracer, and average residence time

The RTD curves in the symmetric point of a multistrand tundish without FCDs are shown in Fig. 2. The RTD curves of the 3rd and 4th strands near the inlet stream have a better coincident. And the RTD curves of the 1st and 6th strands in the exterior outlets have a worse coincident. The differences of the start response time of the tracer between the 3rd and 4th, the 2nd and 5th, and the 1st and 6th strands are 0.5, 2, and 3 s, respectively. The distance from the outlet to the inlet stream is farther and the symmetry of RTD in the multistrand tundish is worse.

Fig. 3 shows the asymmetry of the average residence time with or without FCDs. When the symmetric FCD is installed, the differences of the average residence time of the 3rd and 4th, the 2nd and 5th, the 1st and 6th strands decrease from 8.1, 11.3, and 16.2 s to 1.5, 5.1, and 8 s, respectively. The symmetry of the average residence time for the tundish has a considerable improvement.

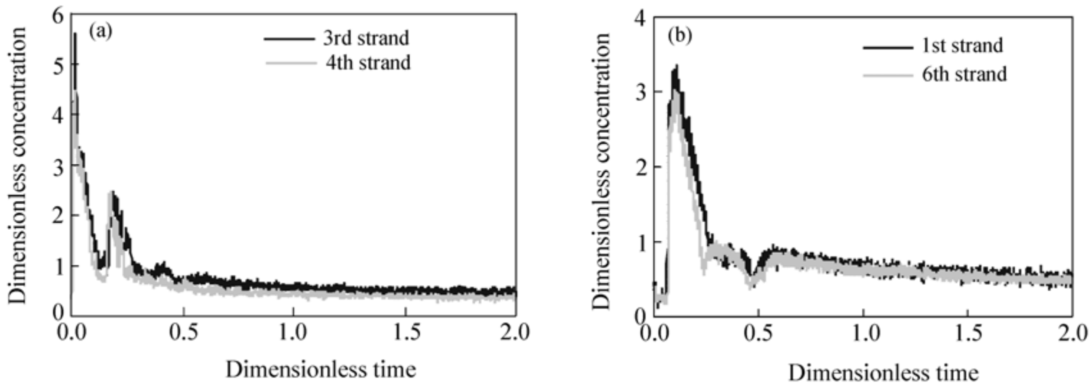

Fig. 2. RTD curves in the symmetric point of a tundish without FCDs.

The asymmetry of the fluid flow pattern in the tundish is listed in Table 1. When the appropriate FCDs have been installed, the short flow has been eliminated and the dead zone volume has been decreased. Accordingly, the volume of the piston flow and the mixing flow has been increased. Nevertheless, from the view of the absolute value, the differences of the mixing flow and dead zone volume have been decreased. The differences of the piston flow volume at the close and middle outlets have also been decreased. From the above analysis, the FCDs installation improves the asymmetry of the fluid flow pattern, and the fluid flow in the tundish has been more reasonable.

From Fig. 2, Fig. 3 and Table 1, it can be seen that the dissymmetry factors are stronger in the exterior outlets for a symmetric multistrand tundish. The flow parameters that are influenced by the dissymmetric flow on the two sides are random. When the symmetric FCDs are installed, the asymmetry of the average residence time and the fluid flow pattern are improved.

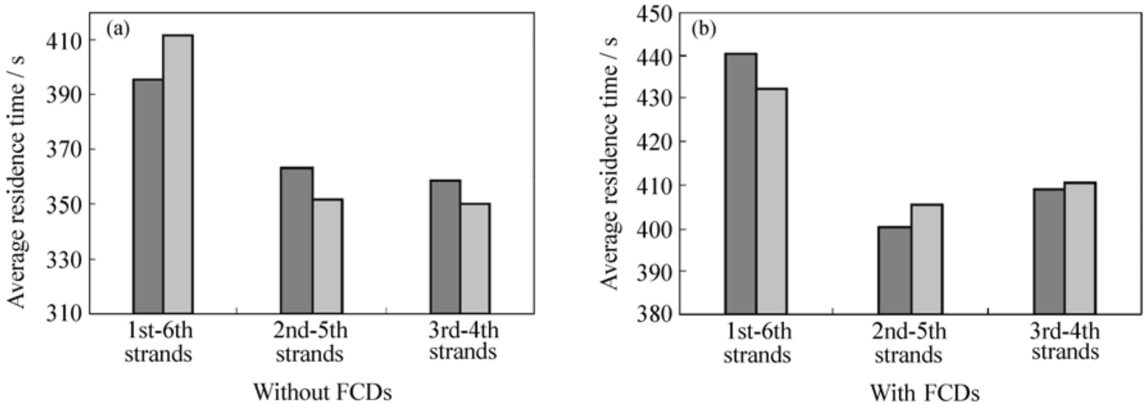

Fig. 3. Asymmetry of the average residence time for the tundish.

Table 1. Asymmetry of the fluid flow pattern in the tundish

Strand No.	Difference of mixing flow zone volume		Difference of dead zone volume		Difference of piston flow zone volume	
	Without FCDs	With FCDs	Without FCDs	With FCDs	Without FCDs	With FCDs
3rd-4th	0.0075	0.0058	0.0169	0.0037	0.0094	0.0021
2nd-5th	0.0163	0.0158	0.0235	0.0106	0.0280	0.0052
1st-6th	0.0588	0.0581	0.0370	0.0167	0.0125	0.0784

3.2. Asymmetry of temperature

The dimensionless temperature curves of the symmetric point in the tundish are shown in Fig. 4. The dimensionless temperature is the ratio of the measurement temperature to the average temperature. The dimensionless time is the ratio of the measurement time to the theoretical average residence time.

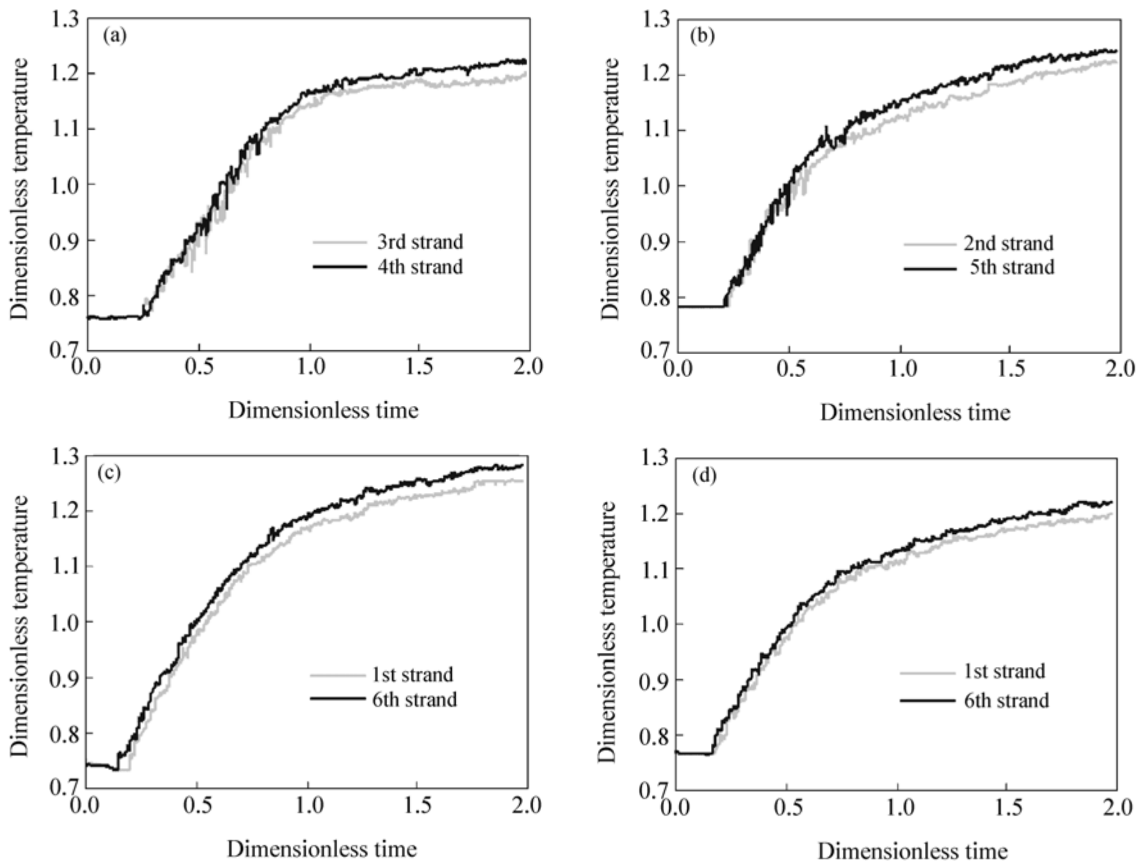

Fig. 4. Temperature curves of the symmetric points in the tundish: (a), (b), (c) at the outlet; (d) at the point of 150 mm above the outlet.

It is shown that the trend of the temperature curves at the 3rd and 4th outlets that are near the inlet stream is uniform. The temperature curves at the 2nd and 5th outlets are coincident in the previous period, and then the two curves divide. With the time increasing, the difference of the two temperature curves grows larger. The temperature curves at the 1st and 6th outlets divide in the previous period, and two separate curves then form. The dissymmetric degree of the temperature field in the tundish increases with the increase of the distance to the inlet.

In the processing of the experimental data, the average temperature difference of two symmetric strands was obtained carefully. The experiment was carried out twice repeatedly, and two temperature differences, ΔT_1 and ΔT_2, were obtained. Then, $\Delta T = \frac{|\Delta T_1| + |\Delta T_2|}{2}$ can be obtained. The ΔT value is considered as the judgement criterion. That is, if the ΔT value is bigger, the temperature difference of the two symmetric strands is larger, and the temperature field is more dissymmetric.

The dissymmetric degree of the temperature in a tundish with or without FCDs is shown Fig. 5. It is known that the symmetric FCDs installation has a slight effect on the dissymmetric temperature field. The measure position of each thermocouple of symmetric strands was changed, and the temperature curves at different heights were measured. The results are shown in Figs. 4(c)-(d) and 6. From the figures, it is clear that the temperature difference of each thermocouple of symmetric strands at different heights of the symmetric plane is smaller. The dissymmetric flow phenomenon influenced on the two symmetric region of the temperature field is random.

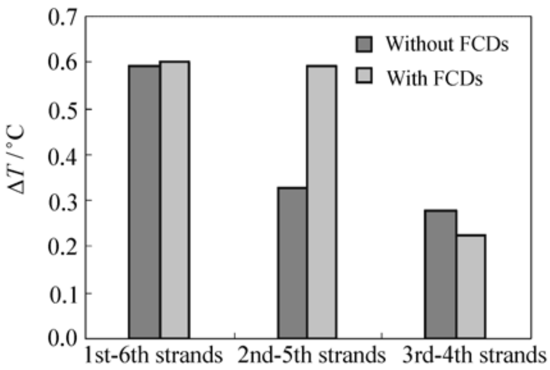

Fig. 5. Dissymmetric degree of temperature.

3.3. Asymmetry of inclusion distribution

The collected quantity of inclusions is shown in Table 2. The inclusion trajectories are dissymmetry in the tundish, and the collected quantity of inclusions is not equal at the symmetric position in the tundish. It is also caused by the dissymmetric flow phenomenon in the tundish.

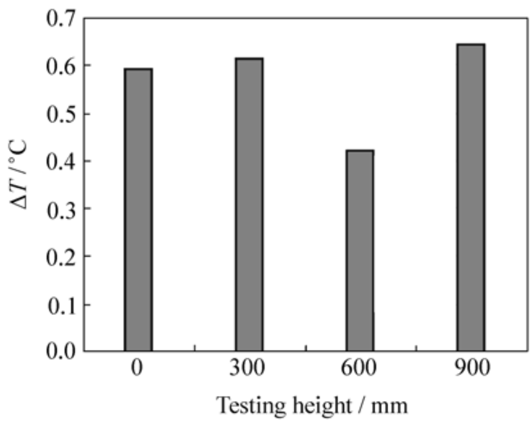

Fig. 6. Dissymmetric degree of temperature of the 2nd and 5th strands at different heights.

Table 2. Collected quantity of inclusions in the tundish

Stand No.	1	2	3	4	5	6
Without FCDs	1	1	6	5	3	0
With FCDs	1	1	1	2	1	0

4. Results and discussion

4.1. Results of dissymmetric flow phenomenon

The flow pattern of the 1st and 6th strands when the symmetric FCDs were installed is listed in Table 3. The flow pattern near the outlets at the long range is distributed dissymmetrically very much because the tundish has a big volume and a long flow distance. From Table 3, it is evident that the volume deviations of the mixing flow zone, dead zone, and piston flow zone between the 1st and 6th strands are 1.7%, 18.4%, and 28.1%, respectively. The viewpoint that the fluid flow is symmetry at the 1st and 6th strands is inaccurate because the flow pattern has so large deviation at the symmetric strand regions. When the flow phenomenon are studied and the FCDs are chosen in a tundish, especially the tundish has a large volume and several strands, the dissymmetry of flow phenomenon should be considered.

4.2. Reason of dissymmetric flow phenomenon

It is sure that the dissymmetric flow phenomenon exists in a symmetric multistrand tundish. The essential reason is that the fluid flow is turbulent in a tundish. The turbulent flow is a kind of movement, which is complex, unsteady, chaotic, and has eddies [10]. In turbulent flow, the trajectory of any particular fluid micella is random. The flow parameters such as velocity and pressure at each point are described in terms of averages. The instantaneous velocity is given by the time-averaged and by the fluctuation velocity.

Table 3. Flow pattern of the 1st and 6th strands

Flow pattern	Volume		Volume difference of the 1st and 6th strands	Average volume of the 1st and 6th strands	Deviation
	1st strand	6th strand			
Mixing flow zone	0.5323	0.6104	0.0781	0.57135	13.7%
Dead zone	0.0823	0.0990	0.0167	0.09065	18.4%
Piston flow zone	0.3854	0.2906	0.0948	0.33800	28.1%

While studying the flow in the symmetric multistrand tundish, most researchers have considered that the flow behaviors in the symmetric two parts are uniform. The turbulent flow is a kind of chaotic movement, and the velocity at each point changes with time and space randomly. The fluctuation velocity in a certain direction may be intensified, and the flow becomes unsteady somewhere. The fluctuation velocities are sometimes positive, sometimes negative, so the fluid flow in the symmetric two parts is not same. Especially at the region beyond a long range, the fluid flow at one side cannot accurately reflect the flow at the other. Consequently, the flow behaviors in the symmetric half tundish cannot accurately reflect the whole tundish. The dissymmetry of flow phenomenon must be considered in the tundish metallurgy study.

5. Conclusions

(1) The dissymmetric flow phenomenon in a symmetric multistrand tundish was observed in the physical simulation experiment. The important reason is that the fluid flow is turbulent in the tundish.

(2) In the symmetric multistrand tundish, the dissymmetric flow phenomenon, which influenced the distribution of the temperature field and flow parameters, is random. The distance to the inlet stream is farther, the flow field is more dissymmetric.

(3) The symmetric FCDs installation has a slight effect on the dissymmetric temperature field in the multistrand tundish, simultaneously the asymmetry of the average residence time and the fluid flow pattern is improved, and the fluid flow in the tundish is more reasonable.

(4) To a symmetric multistrand tundish having a large volume, it should be considered that the influence of the dissymmetric flow phenomenon and the flow behaviors in the whole tundish should be studied completely.

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