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Design optimization of flow control device for multi-strand tundish

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Abstract: The fluid flow phenomena in tundish have a strong influence not only on the uniform of composition and temperature of bath, but also on the separation of non-metallic inclusions, especially for the multi-strand tundish. A water model of a multi-strand tundish has been set up based on the Froude number and Reynold number similarity criteria. The effect of dam+weir and baffle on the uniform of composition and temperature of bath for different nozzles has been studied. The residence time distribution curves of the fluid flow were measured by SG800. Comparing the photos of the flow pattern in tundish, the optimum arrangement of baffle+dam was obtained. This new structure is benefit not only to uniform the temperature among different SENs (submerge entry nozzles) but also to separate the non-inclusions from the liquid steel, it can be widely used in multi-strand tundish.

Key words: tundish; fluid flow; weir + dam; baffle; water model

1 Introduction

In the continuous casting process, tundish is an intermediate vessel placed between the ladle and the mould, which is designed to supply and distribute molten steel to different continuous casting moulds. In recent years, in order to improve the cleanness of steel, a tundish as an intermediate refining vessel is used in the continuous casting process. The fluid flow phenomena in tundish have a strong influence not only on the uniform of composition and temperature but also on the separation of non-metallic inclusions [1-3], especially for the multi-strand tundish. Many investigators have studied the flow field and its effect on the residence time of the fluid flow in tundish [4, 5]. Desirable fluid flow pattern can be obtained by use of flow control devices as dam, dam+weir and baffle.

In this paper, the effect of dam, dam+weir and baffle on the fluid flow in the multi-strand tundish were studied by means of a physical model. The optimum arrangement of flow control device was also obtained.

2 Water model experiment

The system chosen for the present investigation is a six-strand billet caster tundish with dam, dam+weir and baffle as the flow modification devices. Considering that the fluid flow pattern in the tundish is dominated by inertia, gravity and viscosity, the *Re* number and *Fr* number have been used in this experiment as the similarity criteria. Therefore, a 1/3-scale model of the tundish was constructed using a transparent plexiglass. The scale factor of velocity (V) and flow rate (Q) were calculated:

Velocity scale: $V'/V = K^{1/2} = 0.577$,

Flow rate scale: $Q'/Q = K^{5/2} = 0.064$.

The molten steel was simulated by water. By calculating, both the *Re* and *Fr* numbers are invariant at any given volumetric throughout. The water model of the tundish is shown in **figure 1**.

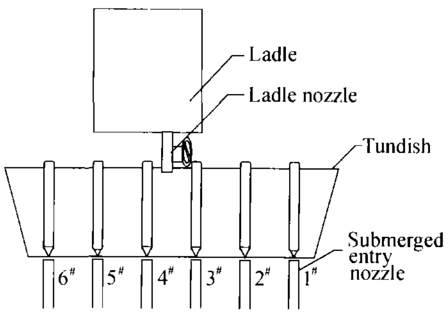

Figure 1 The experimental equipment of tundish.

In order to study the effect of the dam, weir and baffle on the fluid flow in the tundish, the residence time distribution (RTD) was measured by using a water experimental system SG800. By calculating the RTD-curve, the mean residence time (t_{mean}), dead volume fraction (φ) and the minimum residence time (t_{min}) were obtained. The expected flow pattern means that both of t_{mean} and t_{min} for the entire nozzle are increased and uniform. In order to study the flow field in detail, the flow routes from the ladle stream spot to SEN (submerge entry nozzle) in the tundish were recorded by camera. The experiment conditions are listed in **table 1**.

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Table 1 Experiment conditions

V_s / (m·min^{-1})	1.8	2.0	2.2	2.4	2.6	2.8
Q_p / (m^3·h^{-1})	2.43	2.70	2.97	3.24	3.51	3.78
Q_m / (m^3·h^{-1})	0.156	0.172	0.190	0.207	0.224	0.241

Note: V_s—casting speed; Q_p—volume flow rate of prototype; Q_m—volume flow rate of model.

3 Experiment results

3.1 Effect of the original structure on the flow pattern in tundish

In order to study the effect of the original structure on the flow pattern in the tundish, some experiments were done. The original structure tundish has no control device. The results are shown in **figure 2** and the calculation results are listed in **table 2.**

Figure 2 and table 2 shows that the dead volume fractions are much bigger in the tundish at any casting speed. It means that the real residence time of molten steel in the tundish is much shorter than the theoretical residence time, and the non-metallic inclusion has no enough time to float out from molten steel. It is disadvantageous to separate the non-metallic inclusion. So it is necessary to solve this problem

Figure 2 and table 2 also shows that the minimum residence time for 3# SEN is much shorter than that of others. It is disadvantageous not only for the separation of non-metallic inclusion but also for the temperature uniform of different SENs. So it is necessary to prolong the minimum residence time, especially for 3# SEN.

In order to solve these problems, the optimum arrangement of dam, weir and baffle were used.

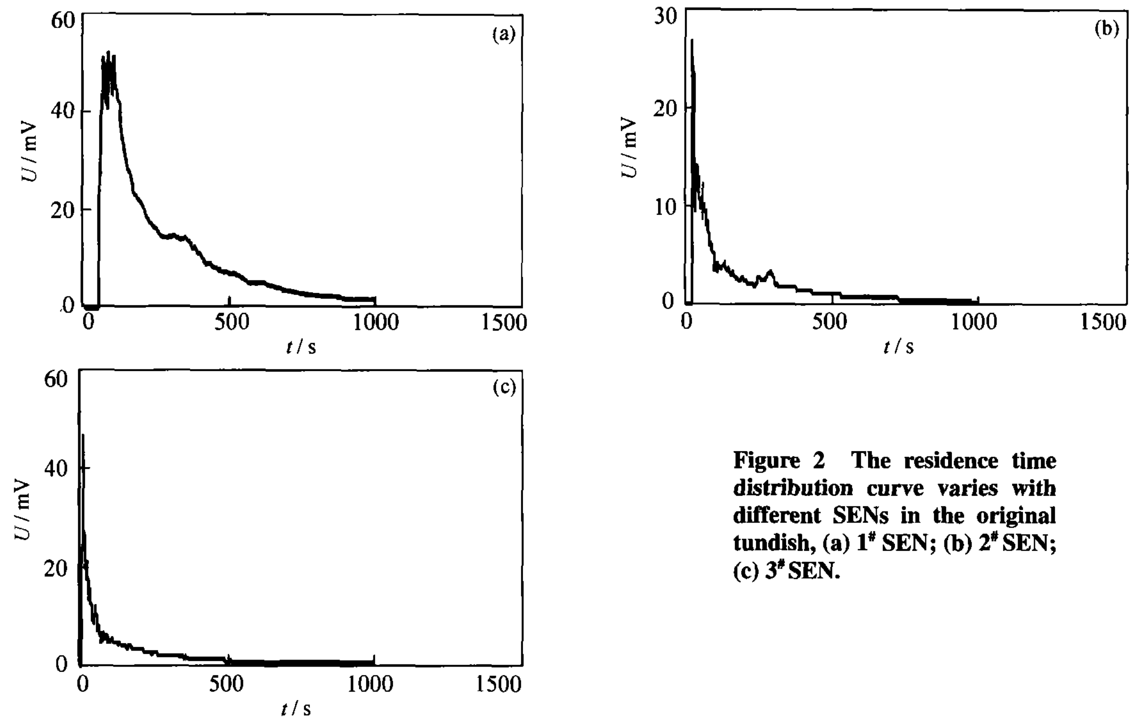

Figure 2 The residence time distribution curve varies with different SENs in the original tundish, (a) 1# SEN; (b) 2# SEN; (c) 3# SEN.

Table 2 The minimum residence time (t_{min}) and dead volume fraction (φ) varied with the casting speed in the original structure tundish

Parameters		V_s / (m·min^{-1})					
		1.8	2.0	2.2	2.4	2.6	2.8
t_{min} / s	1#	72.0	59.7	55.0	55.0	66.7	52.0
	2#	32.0	26.7	24.0	23.0	27.0	21.5
	3#	8.7	7.0	8.0	6.7	7.0	6.3
φ / %	1#	49.1	43.7	50.1	36.7	19.2	29.3
	2#	39.1	54.7	56.3	53.0	40.1	45.2
	3#	70.7	67.8	64.2	61.5	49.9	54.8
	average	53.0	55.4	56.9	50.4	36.4	43.1

3.2 Effect of dam on the flow pattern in tundish

To study the effect of dam on the flow pattern in the tundish, some experiments were done. **Figure 3** shows the structure of the tundish. The results are shown in **table 3**.

Table 3 shows that t_{mean} and t_{min} are all increased comparing with the original structure tundish, especially for $3^{\#}$ SEN. It is because that the dam can cut off the bottom flow and form an upward flow, but the dead volume fraction is also much bigger and the minimum residence time for $3^{\#}$ SEN is much shorter than others. So the one-dam tundish design is not the optimum structure for multi-strand tundish. It is necessary to select a new structure.

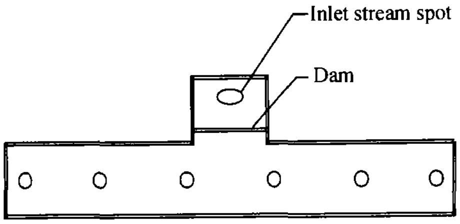

Figure 3 The structure of dam in tundish.

Table 3 Effect of the dam on the flow pattern in tundish (v_s=2.2 m/min)

Parameters	$1^{\#}$ SEN	$2^{\#}$ SEN	$3^{\#}$ SEN	average
t_{min} / s	101.3	60	30	—
φ / %	30.1	40.5	62.4	44.3

3.3 Effect of dam + weir on the flow pattern in tundish

In order to get the optimum structure for multi-strand tundish, many experiments were done. **Figure 4** shows the structure of dam + weir in the tundish. **Table 4** shows the experiment results.

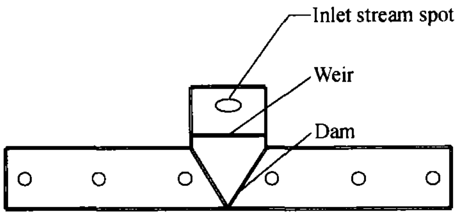

Figure 4 The structure of dam+weir in tundish.

Table 4 The effect of dam+weir structure on the flow pattern in tundish (v_s=2.2 m/min)

Parameters	$1^{\#}$ SEN	$2^{\#}$ SEN	$3^{\#}$ SEN	average
t_{min} / s	96	50	19	—
φ / %	33.0	55.4	74.1	54.2

Table 4 shows that t_{mean} and t_{min} are all increased comparing with the original structure tundish. It is because that the weir can prevent the upper recirculating flow and reduce the slag entrained. The dam can cut off the bottom flow, but the effect is not obvious for the multi-strand tundish. Table 4 also shows that the dead volume fraction is also much bigger and the minimum residence time of $3^{\#}$ SEN is much shorter than that of others. The effect of dam+weir on the flow pattern is weaker than that of the dam structure tundish.

3.4 Effect of baffle(a) + dam on the flow pattern in tundish

Figure 5 shows the new structure of baffle(a)+dam in the tundish. **Table 5** shows the experiment results. The results show that the new structure of baffle+dam is benefit for the flow pattern in the tundish. Comparing with the original structure, dam structure and weir +dam structure tundish, the minimum residence times are rapidly increased, especially for the $3^{\#}$ SEN. The mean residence time is also increased, but the minimum residence times are also obviously different among $3^{\#}$ SEN and others, so the structure of baffle was adjusted.

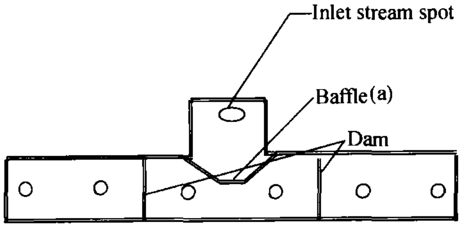

Figure 5 The structure of dam and weir in tundish.

Table 5 The effect of dam and weir structure on the flow pattern in tundish (v_s=2.2 m/min)

Parameters	$1^{\#}$ SEN	$2^{\#}$ SEN	$3^{\#}$ SEN	average
t_{min} / s	40.7	44.7	23.0	—
φ / %	28.3	25.4	24.1	25.9

3.5 Effect of the structure of baffle(b) + dam on the flow pattern in tundish

Figure 6 shows the new structure of baffle(b)+dam in the tundish. **Table 6** shows the experiment results. The results show that the new structure of baffle(b)+ dam is benefit for the flow pattern in the tundish. Comparing with other structures in the tundish, not only the minimum residence times are rapidly increased, but also the mean residence time is also increased. So the new structure tundish is benefit to separate the non-metallic inclusions.

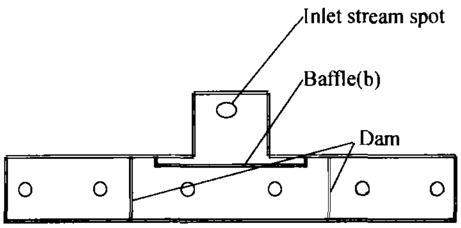

Figure 6 The structure of baffle(b)+dam in tundish.

Table 6 The effect of baffle(b)+dam structure on the flow pattern in tundish (v_s=2.2 m/min)

Parameters	$1^{\#}$ SEN	$2^{\#}$ SEN	$3^{\#}$ SEN	average
t_{min} / s	70.7	63.0	50.7	—
φ / %	11.8	15.3	38.1	21.7

3.6 The vision of the flow pattern in tundish

In order to study the effect of the new structure on the flow pattern in the tundish in detail, the flow pattern photos were recorded by camera. The experiment results are shown in **figure 7**.

Figure 7(a) shows the flow pattern of the original structure tundish. As shown in figure 7(a), the liquid stream from the ladle nozzle goes down to the bottom. After the jet strikes the bottom, it becomes a bottom flow. The bottom flow liquid flows to the nozzle and reaches to the 3# nozzle very quickly. So the minimum residence time is very shorter. It is no favorable to separate non-metallic inclusions. At the same time, the flow speed is very slower in the area above the 1# and 2# nozzle. So the mean residence time becomes smaller and the dead volume becomes larger.

Figures 7(b) and 7(c) show the flow pattern of the baffle+dam structure in the tundish. The baffle can prevent the upper recirculating flow, reduce the slag entrained and change the flow route. The dam can cut off the bottom and form an upward flow. By selecting the baffle shape and the position of hole on the baffle, the route of the fluid flow is uniform among different nozzles. So the minimum residence time and the mean residence time are all obviously increased. The new structure of baffle(b)+dam is benefit to separate non-metallic inclusions and uniform the temperature among SENs.

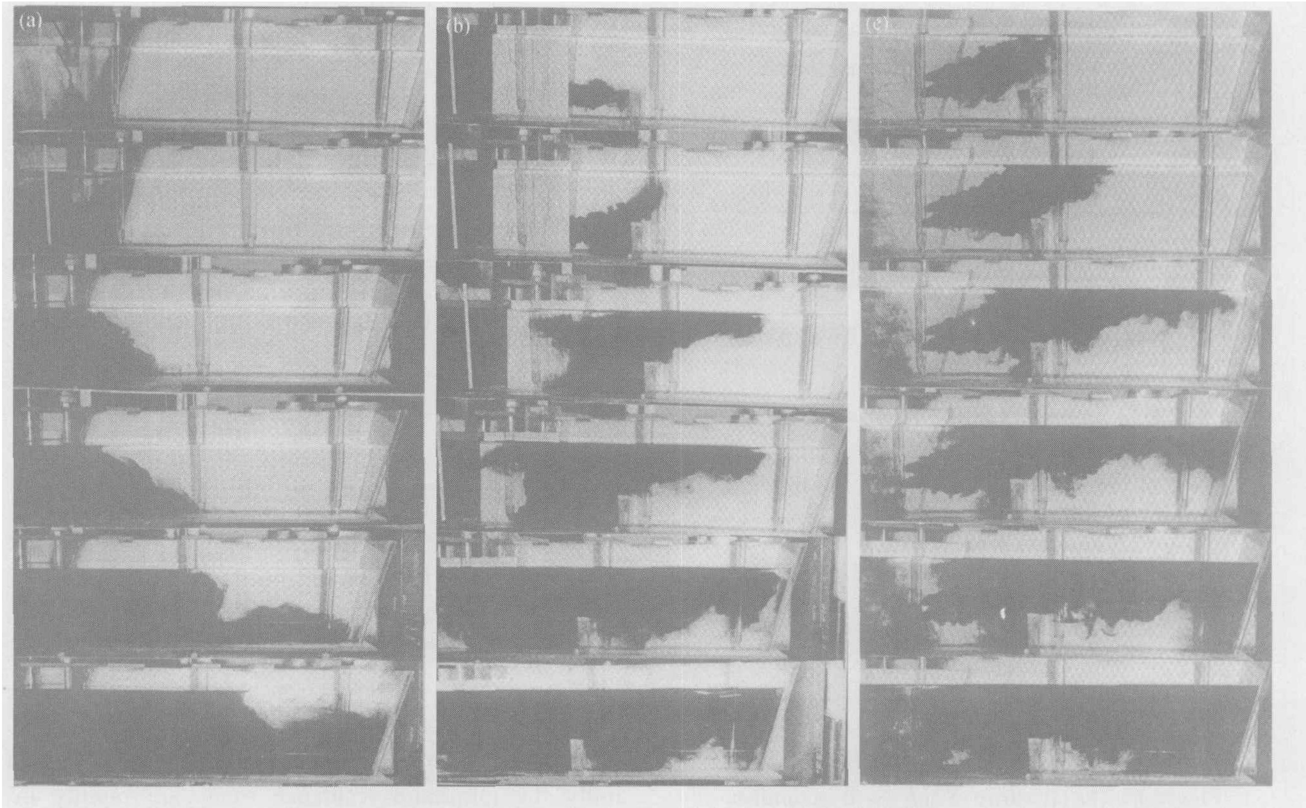

Figure 7 Photos of the flow pattern in tundish, the structure of (a)original; (b) baffle(a)+dam; (c) baffle(b)+dam.

4 Conclusions

(1) The original structure of the tundish is disadvantageous to separate non-metallic inclusions. The minimum residence time is much shorter and the mean residence time is much less. The effect of the structure of weir+dam on the flow pattern in the multi-strand tundish is not obviously.

(2) The new structure of baffle(b)+dam is benefit for the flow pattern in the multi-strand tundish. The minimum residence time and the mean residence time are all increased rapidly. The flow routes among different nozzles are also uniform. The optimum structure of the multi-strand tundish is the baffle(b)+dam.

References

[1] Y.P. Bao, W. Jiang, B.M. Xu, *et al.*, Fluid flow in tundish duo to different type arrangement of weir and dam [J], *J. Univ. Sci. Technol. Beijing*, 9(2002), No.1, p.13.

[2] A. Mclean, The turbulent tundish—contaminator or refiner, [in] *1988 Steel Conference Proceedings* [C], 71 (1988), p.3.

[3] A. Daussan, Steel purity in continuous casting tundish, [in] *1995 Steelmaking Conference Proceeding* [C], 78(1995), p.471.

[4] Manfred M. Wolf, Slab caster tundish configuration and operation, [in] *1996 Steelmaking Conference Proceedings* [C], 79(1996), p.367.

[5] D. Mazumdar, R.I.L. Guthrie, The physical and mathematical modeling of continuous casting tundish system, *ISIJ International* [J], 39(1999), No.6, p.524.