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Dispersive bubble wall—a new method of flow control in tundish

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Abstract: Tundish is the last refractory vessel in the steelmaking process. The fluid flow phenomena in tundish have a strong influence on the separation of non-metallic inclusions. The dispersive bubble wall (DBW) is a new method in tundish metallurgy. 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 DBW+weir on the flow pattern has been studied. The results show that this new structure of DBW+weir is beneficial not only to uniform the temperature among different submerge entry nozzles but also to separate non-metallic inclusions from liquid steel. The DBW can capture the particles of non-metallic inclusions and make them float up to the surface.

Key words: tundish; fluid flow; dispersive bubble wall; water model

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1 Introduction

In order to improve the cleanness of steel, a tundish as an intermediate refining vessel is used in the continuous casting process. Tundish is the last refractory vessel in the steelmaking process. The fluid flow phenomena in tundish have a strong influence on the separation of non-metallic inclusions [1-3]. Many investigators have studied the desirable fluid flow pattern by use of flow control devices as dam and weir [4-6]. Argon bubbling is commonly practiced in refining processes for removing non-metallic inclusions [7-8], this technique is used to achieve the homogeneity in temperature and metal composition and to remove non-metallic inclusions. So how to use the argon bubbling in tundish metallurgy is very important.

In this paper, the effect of DBW (dispersive bubble wall) and DBW+weir on the fluid flow in a multi-strand tundish were studied by means of a physical model. The optimum arrangement of DBW and weir was also obtained.

2 Water model experiment

Considering that the fluid flow pattern in 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 plexiglass. The scale of the velocity *(U)* and the flow rate (Q) were calculated as the following.

The flow rate scale: $Q_m/Q_p=K^{5/2}=0.064$;

The velocity scale: $U_m/U_p=K^{1/2}=0.577$.

The experimental parameters of the model and the prototype are listed in **table 1.** The liquid steel was simulated by water. By calculating, both *Re* and *Fr* numbers are invariant at any given volumetric throughout. The water model system, from the ladle nozzle to tundish, is shown in **figure 1.**

Table 1 Experimental conditions

$U_p/(m\cdot min^{-1})$	1.00	0.95	0.85	0.75	0.65
$Q_p/(m^3\cdot h^{-1})$	0.078	0.074	0.067	0.059	0.051
$Q_p/(m^3\cdot h^{-1})$	0.302	0.287	0.257	0.226	0.196

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

In order to study the effect of DBW and weir on the fluid flow in 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 (V_d) and the minimum residence time (t_{min}) were obtained. The expected flow pattern means that both of the mean residence time and the minimum residence time

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for all nozzles are increased and uniform.

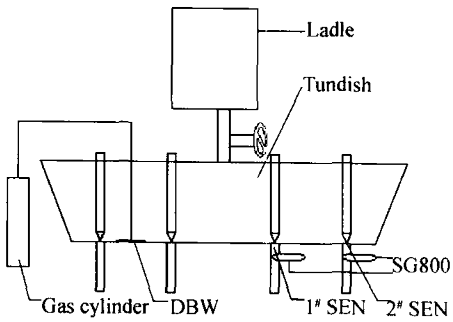

Figure 1 Experiment equipment of the tundish **(SEN:** submerged entry nozzle).

3 Results and discussion

3.1 Effect **of the original structure with DBW on the flow pattern in tundish**

In order to study the effect of the original structure with DBW on the flow pattern in tundish, some experiments were done. Figure 2 shows the structure of the tundish. The experimental results are listed in **table2.**

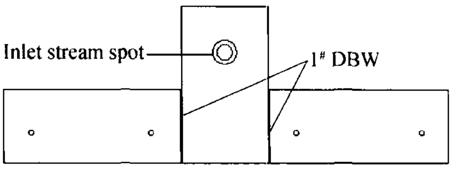

Figure 2 Original structure with DBW of the tundish.

Table 2 Effect of the original structure with DBW on the flow pattern in tundish

SEN	t_{min}/ s	t'_{min} / s	t_{mean}/ s	t'_{mean}/ s	V_d / %	V'_d / %
1#	14	21	409.2	397.1	26.7	28.9
2#	42	71	432.7	441.7	22.5	20.9
Average	28	46	421.0	419.4	24.6	24.9

Note: t'_{mean}, t'_{min} and V'_d represent the t_{min}, t_{min} and V_d in the same structure tundish without DWB.

The experimental results show that when the weir is replaced by DBW, the t_{min} values of 1# SEN and 2# SEN are all decreased. The t_{mean} values between the two nozzles become uniform, the dead volume is reduced for 1# SEN and increased for 2# SEN. The flow pattern in the tundish with 1# DBW structure does not become well when the weir is replaced by DBW. So it is necessary to optimize the structure of DBW and weir in the tundish.

3.2 Effect **of DBW+weir on the flow pattern in tundish**

In order to get the optimum structure of DBW+weir for the multi-strand tundish, and to study the effect of DBW on the flow pattern in detail, some experiments were done. Figure 3 shows the structure of the tundish. The results are shown in **table** 3.

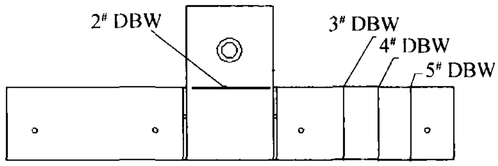

Figure 3 Structure of DBW+weir in tundish.

The experimental results show that the position of DBW is very important. Comparing with the same structure tundish without DBW for 2# DBW, the minimum residence times of 1# and 2# SENs are all decreased, the difference of 1# and 2# SENs becomes bigger. The average dead volume is also increased. So this structure is not beneficial to separate the non-metallic inclusions in tundish.

The experiments of the 3#-5# DBW structure tundish want to solve the problem that the real residence time of liquid steel in the tundish is much shorter than the theoretical one, and the minimum residence time for 1# SEN is much shorter than that of 2# SEN. The

Table 3 Effect of the DBW+weir structure on the flow pattern in tundish

DBW	SEN	t_{min} / s	t'_{min} / s	t_{mean} / s	t'_{mean} / s	V_d / %	V'_d / %
2#	1#	23.0	23.0	420.8	423.4	24.7	24.2
	2#	38.0	76.0	421.5	472.3	24.5	15.4
	Average	30.5	49.5	447.9	447.9	24.6	19.8
3#	1#	22.0	23.0	481.8	423.4	13.7	24.2
	2#	39.0	76.0	530.1	472.3	5.1	15.4
	Average	30.5	49.5	506.0	447.9	9.4	19.8
4#	1#	39.0	23.0	492.9	423.4	11.8	24.2
	2#	66.0	76.0	532.2	472.3	4.7	15.4
	Average	52.5	49.5	512.6	447.9	8.3	19.8
5#	1#	59.0	23.0	532.7	423.4	4.6	24.2
	2#	55.0	76.0	543.6	472.3	2.7	15.4
	Average	57.0	49.5	538.2	447.9	3.7	19.8

Note: t'_{mean}, t'_{min} and V'_d represent the t_{min}, t_{min} and V_d in the same structure tundish without DWB.

results show that the new structure of DBW+weir is beneficial for the flow pattern in tundish, especially for the 5# DBW's experiment, not only the minimum residence time is rapidly increased, but also the residence time is increased. So the new structure tundish is advantageous to separate non-metallic inclusions. This is because the flow route of liquid steel can be changed by the dispersive bubble wall. The DBW can cut off the bottom flow and form the upward flow. So the DBW is beneficial not only to change the flow pattern but also to remove the non-inclusion by flotation.

3.3 Effect of the DBW+T-shape weir on the flow pattern in tundish

In order to get the optimum structure of DBW+T-shape weir for the multi-strand tundish, and to study the effect of DBW+T-shape weir on the flow pattern in detail, some experiments were done. **Figure 4** shows the structure of the tundish. The results are shown in **table 4.**

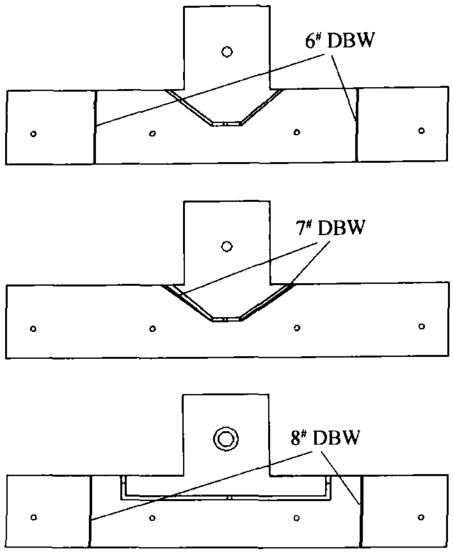

Figure 4 Structure of DBW+T-shape weir in tundish.

Table 4 Effect of the DBW+T-shape weir structure on the flow pattern in tundish

DBW	SEN	t_{min} / s	t'_{min} / s	t_{mean} / s	t'_{mean} / s	V_d / %	V'_d / %
6#	1#	21.0	23.0	418.2	453.7	25.1	18.8
	2#	31.0	26.0	482.8	400.7	13.6	28.3
	Average	26.0	24.5	450.5	427.2	19.4	23.6
7#	1#	26.0	23.0	465.2	453.7	16.7	18.8
	2#	33.0	26.0	459.3	400.7	17.8	28.3
	Average	29.5	24.5	462.3	427.2	17.3	23.6
8#	1#	16.0	64.0	467.5	466.5	16.3	16.5
	2#	31.0	35.0	340.8	345.4	39.0	38.2
	Average	23.5	49.5	404.2	406.0	27.7	27.4

Note: t'_{mean}, t'_{min} and V'_d represent the t_{min}, t_{min} and V_d in the same structure tundish without DWB.

In order to prolong the minimum residence time and reduce the dead volume, the new structure tundish of DBW+T-shape weir were studied. The results show that comparing to the same structure tundish without the 6# and 7# DBWs, the minimum residence time becomes longer, but the dead volume population becomes shorter. So this DBW structure improves the flow pattern in tundish.

The tundish with 8# DBW is a new structure tundish. The experimental result shows that the dead volume changes a little, but the minimum residence time is rapidly decreased. So this structure is not beneficial to separate non-metallic inclusions.

3.4 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 experimental results are shown in **figure 5.**

Figure 5 shows that the flow pattern of the 5# DBW+weir structure tundish. As shown in figure 5, the liquid stream from the ladle nozzle goes down to the bottom. The weir can cut off the bottom flow and form an upward flow. So the minimum residence time of the 1# SEN becomes longer. When the liquid steel flow reaches the DBW, the DBW also can cut off the bottom flow. The particles of non-metallic inclusions can be captured by gas bubbles and float up to the surface of the liquid steel. By selecting the position of weir and DBW, the route of the fluid flow is uniform between different nozzles. So the minimum residence time and the mean residence time are all obviously increased. The new structure of DBW+weir is beneficial to separate the non-metallic inclusions and uniform the temperature between SENs.

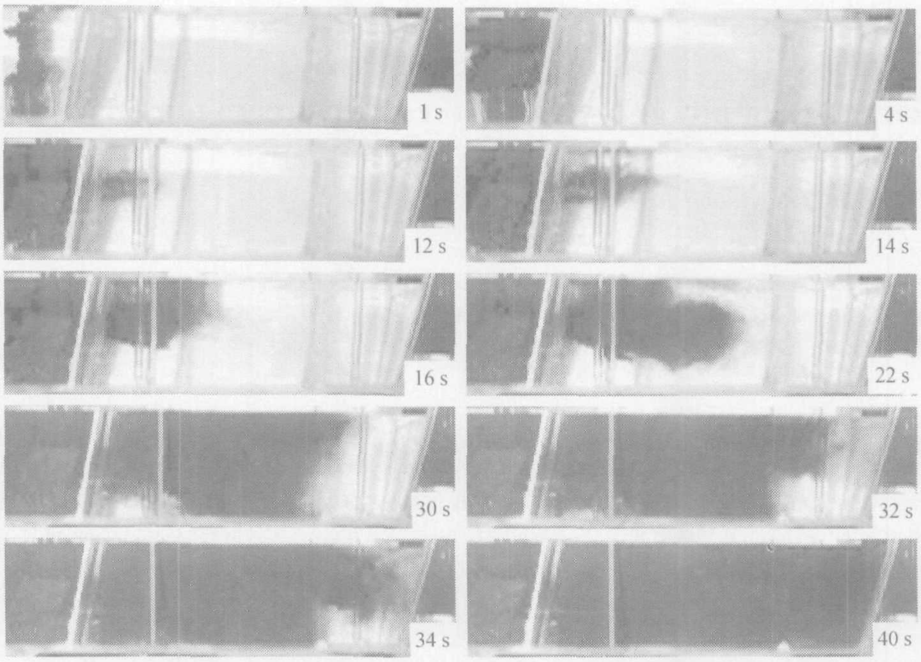

Figure 5 Photos of the flow pattern in the tundish with the structure of DBW+weir ($5^{\#}$ **DBW).**

4 Conclusions

(1) DBW is a very important method of tundish metallurgy for producing cleanness steel. DBW is beneficial not only to improve the flow pattern but also to capture the particles of non-metallic inclusions and make them float up to the surface.

(2) The new structure of $5^{\#}$ DBW+weir is beneficial 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 between different nozzles are also uniform.

(3) Comparing to the weir in tundish, DBW can prevent refractory pollution.

References

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

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

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

[4] Y.P. Bao, B.M. Xu, GL. Xu, *et al.,* Design optimization of flow control device for multi-stand tundish, *J. Univ. Sci. Technol. Beijing,* 10(2003), No.2, p.21.

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

[6] Manfred M. Wolf, Slab caster tundish configuration and operation, [in] 1*996 Steelmaking Conference Proceedings.* 79(1996), p.367.

[7] L.H. Wang, Hae-Geon Lee, and Peter Hayes, Prediction of the optimum bubble size for inclusion removal from molten steel by flotation, *ISIJ Int.,* 36(1996), p.7.

[8] L.H. Wang, Hae-Geon Lee, and Peter HAYES, A new approach to molten steel refining using fine gas bubbles, *ISIJ Int.,* 36(1996), p.17.