Experimental and Numerical Simulation of Fluid Flow and Inclusion Removal in the Steel Continuous Casting Tundish

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ABSTRACT: During the steel continuous casting process, the tundish is the last metallurgical actuator in which there will be an opportunity for removal of impurities present in the melt. Therefore, improving of the fluid flow phenomena inside the tundish, including the type of fluid flow pattern, increasing of inclusion residence time in the tundish, decreasing of volume of stagnant fluid and increasing of fluid flow in the rotation, can improve the process of separation of the inclusion and absorbing them into slag and the preparation of clean steel. In the mathematical method, the FLUENT software is used and in the experimental method, by manufacturing of the glass tundish in 1:4 scale and molten flow physical simulation, the effect of applying the dam in the tundish, as well as the change in the height of the melt on the behavior of the flow has been investigated, and it has been determined that decreasing of the molten height in the tundish increases the separated inclusion from the molten and inclusion residence time in the tundish. Also, using the dam at the inlet nozzle with a tall dam on the sides of the tundish leads to the removal of the inclusion and improving the molten flow.

1. INTRODUCTION

In several studies, the flow of the molten steel in continuous-casting tundish has been simulated by experimental or mathematical modeling. In most experimental studies, simulations have been performed by the use of water at ambient temperature and under isothermal and steady-state conditions.

Mickey and Thomas [1] have provided a mathematical model for analysis of flow in a tundish with a specific geometry. They used the k-ε turbulence model to simulate the flow of molten steel and temperature variations in the tundish in both steady an unsteady state conditions and used a lagrangian particle tracking model for particle motion analysis. In this study, residence time, and density of particles of different sizes were studied.

In other studies, the effects of flow control devices on inclusion removal were investigated by mathematical and physical modeling. In these studies, turbulent flow was simulated by k-ε model. In physical simulation, reduced-scale models of tundish were used to investigate the flow behavior under various experimental conditions. [2-4]

Iran Alloy Steel Company has always struggled with the problem of filtration of inclusions from molten steel so to produce a clean high-quality product. Iran Alloy Steel Company uses a unique type of tundish, so in this study, the reduced-scale model of this tundish is modeled and then used to investigate the flow behavior and melt purification process in this particular piece of equipment. The main objective of this study is to improve the production speed as well as product quality.

2. METHODOLOGY

The physical study of flow pattern and inclusion removal in a steel continuous-casting tundish requires a model built at full or reduced scale. When using a full-scale model, the researcher has to use the Reynolds number and Froude number similitude criteria for nondimensionalization, but when using a reduced-scale model, the Froude number similitude criteria can be utilized for this purpose. Fluid velocity and discharge in a reduced-scale tundish model based on the Froude number similitude criteria are expressed with Eqs. (1) and (2) [5]:

$$U_m = \sqrt{\frac{L_m}{L_p}} \; U_p \tag{1}$$

$$Q_m = \left(\frac{L_m}{L_p}\right)^{2.5} Q_p \tag{2}$$

In this study, 1:4 scale model of the tundish was built with glass. 8-mm thick glass was used for the model's bottom and 6-mm thick glass was used for the walls. The water used for experiments was at ambient temperature and had isothermal conditions. The tundish model had a final size of 250×291×1076 mm and had one inlet nozzle and four outlets (Fig. 1).
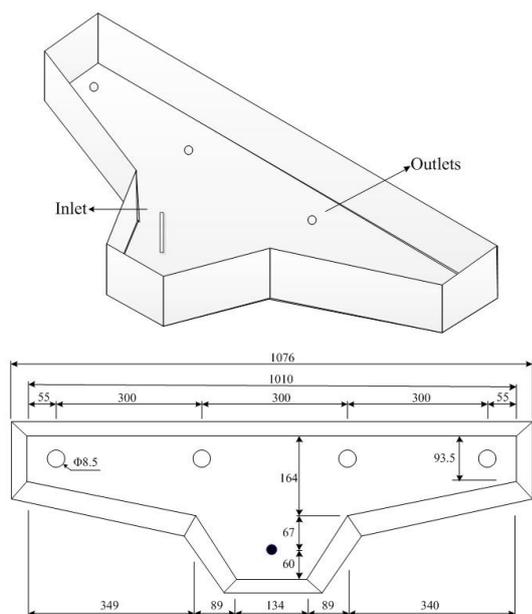
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Fig. 1. Geometry and physical dimensions of the model tundish

The flow pattern and inclusion removal were examined in two states: I) simple model (ST), II) tundish with Inlet Dam and Tall Dam (ID+TD). Furthermore, the effect of water level in the tundish with inlet dam and the tall dam was studied at four water levels of 15, 17.5, 20 and 22.5 cm.

3. RESULTS AND DISCUSSION

In the inclusion removal experiments conducted with water levels of 15, 17.5, 20, and 22.5cm are weighted, respectively, 1.33, 1.55, 1.8, and 2 grams of perlite and then mixed it with water. The inclusion-water mixture was then injected at the inlet.

In this study, residence time was determined by the use of saturated salt solution (NaCl). For this purpose, 50 cc of saturated salt solution with a concentration of 200 gr/L was injected for 5 seconds at the inlet and then using the HORIBA EC meter, the concentration of water from the farthest outlet to the inlet nozzle was measured at different time intervals.

According to the Residence Time Distribution (RTD) curve of the simple tundish, in this tundish, the minimum residence time of the injected saturated salt solution is short, and concentration suddenly increases at the outlet. Information of the RTD curves of the simple tundish and the tundishes with ID+TD (Table 1) shows that using dam has decreased the volume of stagnant fluid and increased the $R_{p/d}$ and $R_{pm/d}$ ratios. In comparing with simple tundish, the stagnant fluid volume was decreased to 77.3% in the tundish with dam.

Table 1: Experimental results of RTD in different tundishes

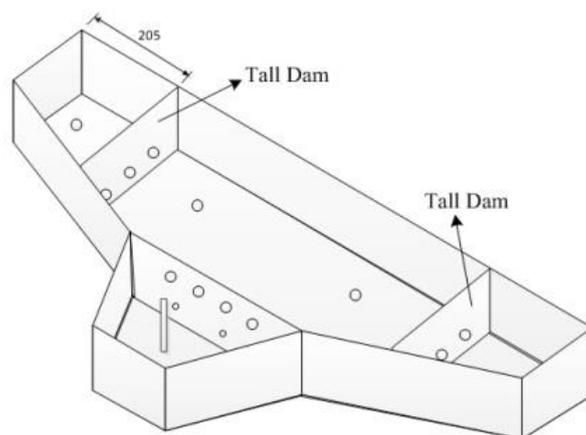| tundish	t_{min} (s)	t_{max} (s)	t_s (s)	V_d (m³)	V_p (m³)	V_m (m³)	$R_{p/d}$	$R_{pm/d}$
simple	28	40	334	0.22	0.10	0.68	0.45	3.54
ID+TD	78	385	334	0.05	0.69	0.26	13.8	19

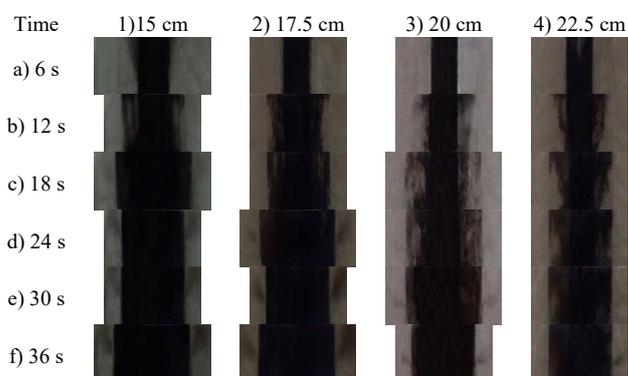**Fig. 2. Geometry of the tundish with inlet dam and tall dam**

Fig. 3. Ink flow patterns in tundish with ID and TD in different water heights

Fig. 3 shows the flow pattern in tundish with dam after injection of the ink for different water levels and at different time intervals. It can be seen that in all cases, the ink moves around the tundish top and near the water surface simultaneously downward in a circular motion. But with lower water levels, the ink moves faster toward and into the outlet and the upward circular motion is reduced.

4. CONCLUSION

The results obtained from water and numerical modeling of the steel continuous casting tundish and the investigations of the flow pattern, residence time distribution curves, and removal of inclusions of different sizes in a simple tundish and tundish with dam are summarized as follows:

1- Presence of a dam, improves the flow pattern and causes the flow path to approach the melt surface, and this contributes to the filtration of inclusions in the form of top slag.

2- Changing the water level in the tundish dam show no effect on the flow pattern and only alters the flow speed. Examination of the shooting images of injecting ink shows that the tundish with higher water level has a lower movement speed.

3- The tundish with a dam with a higher water level exhibits a better inclusion removal performance and has a

lower inclusion pass rate. Also, by increasing the diameter of the inclusions, the rate of absorption into the slag increases and the amount of inclusion going out of the tundish decreases. As percentage of outgoing inclusion from the tundish at water height of 22.5 cm compared with height of 15 cm decreased for diameter of 63 and 595 μm to 12% and 29.4%, respectively.

4- Consequently, using a dam at the tundish inlet and tall dam and increasing the liquid level in the tundish improve the flow behavior in this reactor and its ability to filter inclusions and provide clean steel.

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