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Physical modeling of the processes of metal melt movement during continuous casting

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Abstract. Studies of hydrodynamic processes in the intermediate ladle of a continuous casting machine by methods of physical low-temperature modeling was carried out. A qualitative and quantitative evaluation of efficiency of the use of various hydrodynamic elements is made using the method of studying the distribution of the liquid residence time in the unit.

1. Introduction

One of the main functions of intermediate ladle of a modern continuous casting machine is the refining of liquid metal from pre-crystallization non-metallic inclusions. The successful solution of this most important task depends to a large extent on the features of metal melt movement and mixing in the volume of intermediate ladle. Control of melt mixing processes can be carried out by installing special refractory elements (thresholds, jet strippers, partitions, etc.), the configuration and placement of which largely determines the distribution of flows in the intermediate ladle. Development of the configuration of the refractory elements in the intermediate ladle, providing favorable hydrodynamic conditions for the removal of nonmetallic inclusions, is based mainly on the results of physical and mathematical modeling [1, 2].

2. Methods of research

Investigation of hydrodynamic processes was carried out on the laboratory complex [3], including the physical model of 28-t intermediate ladle of the bloom caster at EVRAZ ZSMK JSC. Visualization of the flow of modeling fluid is done by introduction of a dye.

Estimation of the degree of homogenization and minimum residence time of the liquid portion in the volume of the intermediate ladle was carried out by conductometric analysis. Estimation of the configuration efficiency of the intermediate ladle for refining of the metallic melt from nonmetallic inclusions was carried out using the method of studying the distribution of the liquid residence time in the unit.

Physical models of refractory elements were made of organic glass and the separate components implemented by fused deposition modeling (FDM) using 3d-printing technology (figure 1), that helped to ensure the accuracy of the geometrical model parameters.

The study of the metal hydrodynamics was carried out for steel casting conditions at a speed of 0.7 m/min with the supply of metal to the intermediate ladle through a protective tube and the production of a blank with a cross section 300×360 mm.

The simulation was carried out with different designs of the intermediate ladle:

1) without refractory elements (basic option);

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2) with the installation of thresholds (figures 1a, 1b), different height (h) and the cutoff angle of the top (α) at a distance of 144 mm from the axis of the protective tube: A) h=228 mm, α=0°; B) h=228 mm, α=30°; C) h=171 mm, α=0°; D) h=171 mm, α=30°; E) h=114 mm, α=0°; F) h=114 mm, α=30°; G) h=57 mm, α=0°; H) h=57 mm, α=30°;

3) with the installation of runner pots of various heights (figure 1, c): A) 64 mm; B) 96 mm; C) 128 mm;

4) with the installation of full-profile partition plate with overflow holes directing the flow of modeling liquid to the surface at angle 30°, various configurations (figure 1, d) at a distance of 144 mm from the axis of the protective tube: A) diameter of 5 holes in the upper row 20 mm and 4 holes in the lower – 20 mm; B) diameter of 5 holes of the upper row 20 mm and 4 holes of the lower row – 32 mm; C) diameter of 5 holes of upper row 32 mm and 4 holes of lower row – 40 mm; D) diameter of 4 holes of the upper row 40 mm and 3 holes of lower row – 32 mm; E) diameter of 4 holes of the upper row 40 mm and 3 holes of lower row – 20 mm; F) diameter of 4 holes of the upper row 32 mm and 3 holes of the lower row – 20 mm.

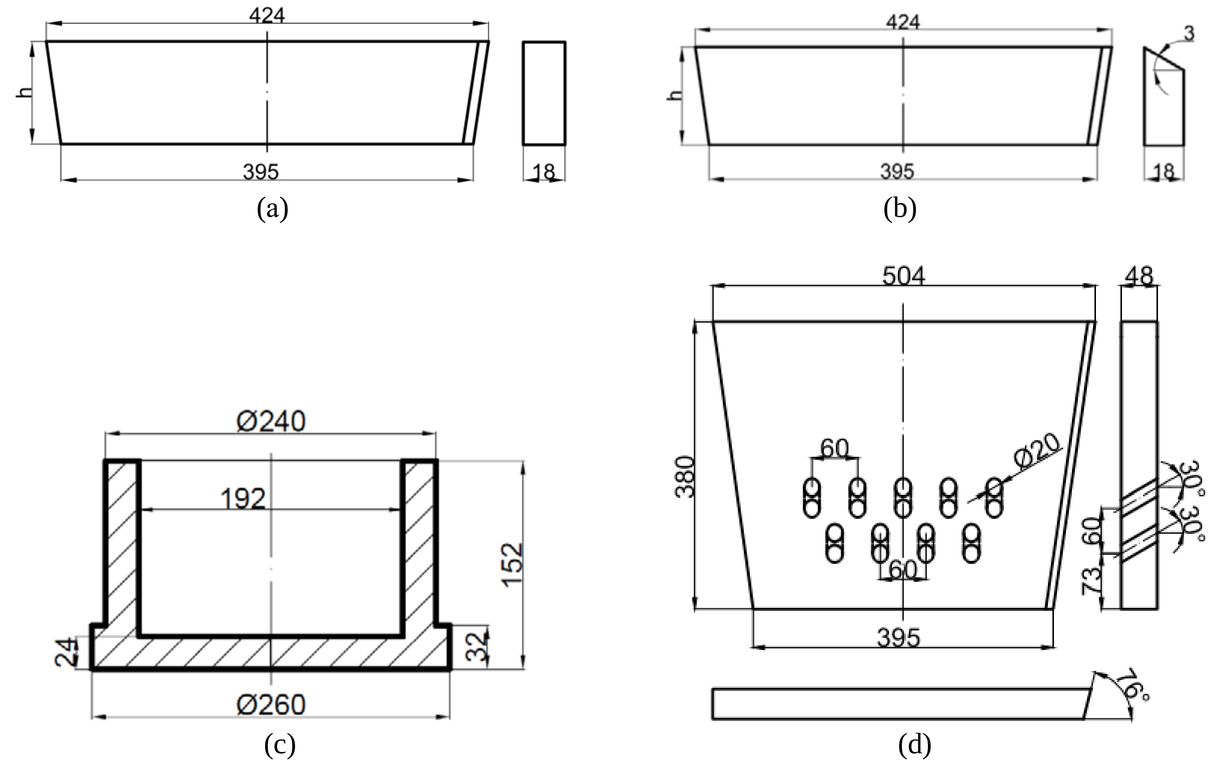

Figure 1. Models of refractory elements in the intermediate ladle: (a) a threshold with a straight top; (b) threshold with oblique top; (c) runner pot; (d) full-profile partitions.

3. Results and discussion

At the first stage, the hydrodynamic processes in the intermediate ladle of the basic design were investigated. It was found that with the basic design of the intermediate ladle, the time for reaching the central and peripheral casting cups is 4 (6) and 33 (52) seconds of the model time, respectively (figure 2, a). Here and further, the time without brackets indicates the simulation conditions, in brackets the time values correspond to the actual conditions of the metallurgical process. The flow of the central nozzles is achieved in a short time interval, forming “short” paths, which in industrial conditions results in the ingress of pre-crystallization non-metallic inclusions transported by the metal flow into the crystallizer, and further into the continuously cast billet.

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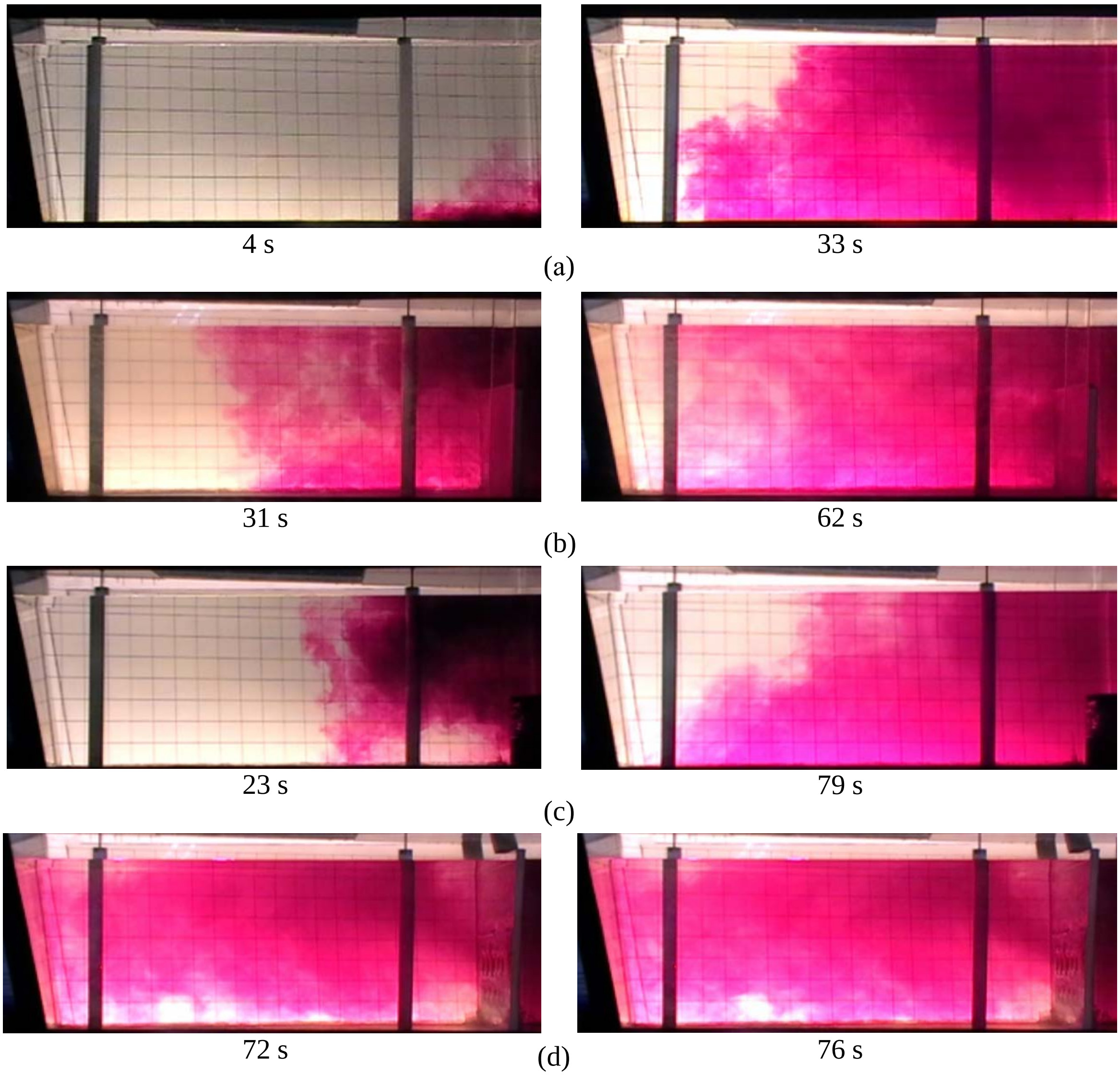

Figure 2. Hydrodynamic pattern in the intermediate ladle: (a) without hydrodynamic element; (b) using thresholds; (c) using a runner pot; (d) sing full-profile partitions.

The analysis of the data obtained by the conductometric method confirmed the minimum time for the liquid to reach the central and peripheral nozzles of the intermediate ladle – 4 (6) and 33 (52) seconds, respectively, and the uneven distribution of metal flows in the intermediate ladle of the basic configuration.

Further studies of metal hydrodynamics in the intermediate ladle were carried out using thresholds, runner pots and full-profile partitions plates of various configurations. The results of the studies at typical moments of time (reaching of nozzles) are given in figure 2.

The use of thresholds (figures 1a, b) made it possible to increase the time of reaching the portions of modeling liquid of central and peripheral nozzles to 31 and 62 seconds, respectively (figure 2 b). Using thresholds with an oblique top (figure 1 b) made it possible to increase the time for reaching a portion of the modeling liquid of the nozzles on average by 2 seconds. When colliding with a threshold, the main flow loses part of the kinetic energy and is directed along the threshold to the surface of the modeling fluid, reflected from which falls to the bottom and is directed to the central nozzles, then the flow in the bottom layers is directed to the peripheral nozzles.

When installing the runner pot (figure 1 c), the time for reaching the portion of modeling liquid of the central and peripheral nozzles reaches 23 and 79 seconds, respectively (figure 2 c). An increase in the minimum residence time of the portion of modeling fluid is associated with a decrease in the flow velocity at the outlet of the runner pot volume as a result of suppressing part of the jet energy during circulation in it. When leaving the runner pot, the main flow of the modeling liquid is directed to the surface and being reflected moves to the central nozzles and then to the peripheral ones. With this flow regime, the area with active vortices decreases, the turbulence decreases and, as a consequence, the minimum time for the metal portion to remain in the intermediate ladle increases.

When installing full-profile partitions (figure 1 d), the intermediate ladle is divided into 3 chambers (a receiving chamber and 2 casting chambers). In the receiving chamber there is an active circulation of the modeling fluid, through the overflow holes the flow enters into the casting chambers (figure 3 c). The jets passing through the holes in the partitions are directed to the surface and reach it in the zone of the central part of the casting chamber between the stoppers. When the surface is reached, the conditional separation of the main flow into two parts occurs. One part moves along the surface and, reaching the end walls, rushes to the peripheral nozzles and then moves at a lower velocity in the near-bottom layers near the rear walls to the central nozzles. The other part of the main flow, reflected from the surface, is directed to the central nozzle.

Figure 3 shows the time for reaching a portion of the modeling fluid of the central and peripheral nozzles for the options under study. From the data given, it can be seen that the most rational distribution of flows is achieved when using full-profile partitions with 4 holes in the bottom row with a diameter of 20 mm and 5 holes in the upper row with a diameter of 32 mm (option 4B), while the time for reaching the central and peripheral nozzles is 72 and 76 seconds respectively, differing by 4 s, which indicates active circulation of the modeling fluid, its homogenization and the absence of “short” paths.

Analysis of the results of physical modeling obtained by the conductometric method and the method for studying the distribution of the liquid residence time in the unit allows us to conclude that the volume of stagnant zones in the intermediate ladle of the basic design is ~ 28% (figure 4), and for industrial conditions the presence of a “short” way to the central nozzles does not allow the homogenization of the metal melt in chemical composition and temperature to be fully ensured, as well as the refining of the metallic alloy from nonmetallic inclusions, and the use of additional refractory elements is required to organize the movement of metal flows, to increase the minimum residence time of a portion of metal in the volume of the intermediate ladle and create zones of active melt circulation and reduce the volume of stagnant zones.

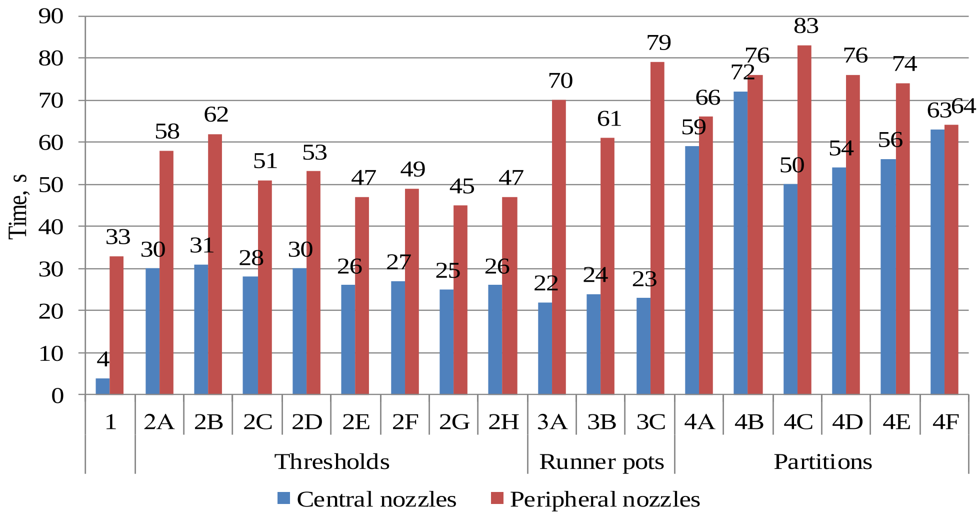

Figure 3. Minimum time for the modeling liquid flow to reach the nozzles using different models of refractory elements.

An increase in the height of threshold models to 228 mm contributed to an increase in the time for the portion of the modeling liquid to reach the nozzles (figure 3) and to reduce the volume of stagnant zones to 23% (figure 4).

The use of a runner pot allowed the time to reach a portion of the modeling liquid of the central and peripheral nozzles to be increased. In this case, an increase in the height of the runner pot model to 128 mm helps to reduce the volume of stagnant zones to 25% (figure 4). However, the effectiveness of the runner pot is of a short duration.

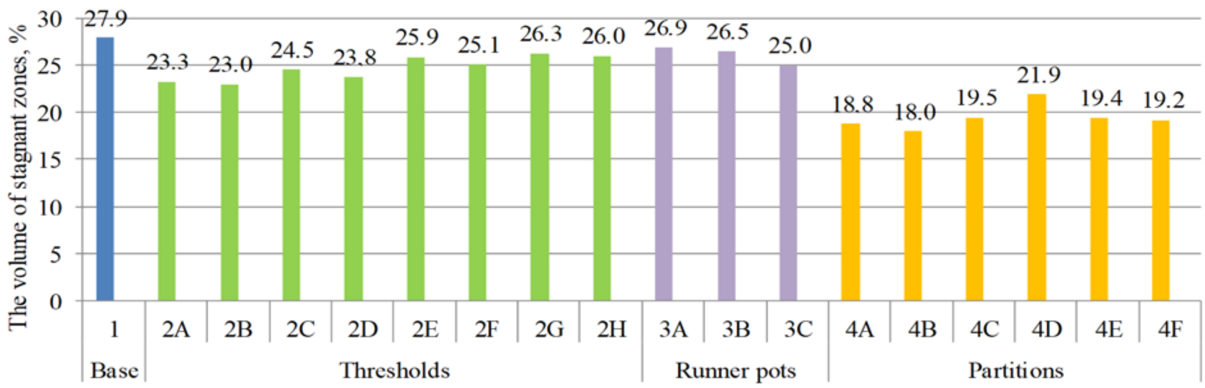

Figure 4. The volume of stagnant zones in the intermediate ladle using different models of refractory elements, %.

According to the results of physical modeling, it was established that the best results are achieved with the use of full-profile partitions with 2 rows of holes – 20 mm in diameter for the lower row (4 holes) and 32 mm for the upper row (5 holes), in this case the flow of modeling liquid goes to the surface, creating a closed loop of circulation, covering almost the entire volume of the intermediate ladle (figure 2, d). The volume of stagnant zones is 18% (figure 4).

4. Conclusion

As a result of the modeling it was established that the most favorable hydrodynamic conditions are achieved when using full-profile partitions. At the same time, the receiving chamber acts as a runner pot, metal circulates in a closed zone, actively mixing, which promotes the enlargement of nonmetallic inclusions. Getting through the overflow openings into the filling chambers, the metal flow goes to the metal-assimilating slag interface and moves near the surface, which facilitates the refining of the melt. The use of partitions with 2 rows of holes with diameter of (50) mm for the lower row and (80) mm for the upper row makes it possible to reach the central and peripheral streams almost simultaneously – (121) sec. and (126) sec. for central and peripheral flows, respectively.

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