PHYSICAL MODELLING OF FLOW PATTERN IN 5-STRAND ASYMMETRICAL TUNDISH WITH BAFFLES

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Abstract

The paper is a study of the nature of steel flow in the five-strand asymmetrical tundish situated at CCM No. 1 located in Trinecke Zelezarny, a.s. The plexiglass water model is constructed in a 1:4 geometric scale to the real plant tundish and is located in the Laboratory of Physical and Numerical Modelling at the Department of Metallurgy, FMME, VSB-Technical University of Ostrava. The discussion of results is focused on the evaluation of molten steel behaviour under the conditions of two baffle-type perforated walls inserted into the tundish impact area. The baffles were placed symmetrically between the impact area and the nearest casting strands No. 3 and 4. The technological delay between the discharging of two ladles is not constant. This is why the five different variants of tundish refilling regimes were studied using the physical modelling methods. The method of permanent concentration change (Heaviside unit step) was used to describe the differences between the character of the steel flow under various conditions of the tundish refilling. KCl was used as a marker. The visualization used for a qualitative study of the nature of the steel flow in the tundish was the impulse injection (Dirac pulse) of KMnO₄ aqueous solution. The minimum residence times (τₘᵢₙ) and 0.5 dimensionless concentration achievement (τ₀.₅) were acquired from the obtained F-curves. The results gained from experiments were discussed using mathematical and statistical methods. The coefficient of variation was used for homogeneity rate interpretation of steel distribution into individual casting strands.

Keywords: steel, tundish, flow pattern, baffle, physical modelling, residence time distribution

1. PHYSICAL MODELLING OF STEEL FLOW IN THE TUNDISH AT THE DEPARTMENT OF METALLURGY

The attention of the Department of Metallurgy has for a long time been focused on the study of steel flow nature in the tundish using physical modelling. The results from physical simulations carried out on the model of CCM No. 2 and CCM No. 1 tundishes constructed from organic glass in geometric scales M₁ = 1:3 and M₂ = 1:5 were used to optimize their inner configuration. The physical modelling of two different melts intermixing in the tundish carried out on both models, have been successfully used for the improvement of control systems in terms of intermixed zones under conditions in Trinecke zelezarny. The sophisticated methodology of the experiments and the well selected system of physical modelling results transformed, into the operational experience with the verified use of similarity theory, offers the opportunity to address other fundamental technological problems. It is necessary to constantly review the existing production technology and find a solution leading to continuous improvement of the manufacturing process.
As presented in previous papers, in 2008 the Department of Metallurgy built a new water, partially automated, model of CCM No. 1 tundish, this time in the geometric scale $M_l = 1:4$ (Fig. 1).

The advantage of using water as the fluid model is its ease of accessibility, manipulability and order of magnitude match of its kinematic viscosity with liquid steel at 1600 °C.

2. THE METHODOLOGY AND CONDITIONS OF PHYSICAL MODELLING

Fig. 2 shows a schematic representation of the tundish without any impact area modification. This is a 5-strand asymmetric tundish with the position of impact place between the casting strand No. 3 (CS3) and CS4. The experimental study presented in this work was carried out on the tundish model in the geometric scale $M_l = 1:4$. The model is located in the Laboratory of Physical and Numerical Modelling at the Department of Metallurgy, FMME, VSB-Technical University of Ostrava.

The experimental tests, conducted on the tundish model of CCM No. 1, have been carried out to simulate the actual operating conditions of the steel refilling regime in the tundish during the ladle exchange. The refilling was implemented to the model conditions for the level of liquid (water) from 168, 187, 206, 224 and 243 mm to 262 mm level. It corresponds to refilling of steel into the real plant tundish from 23, 26, 29, 32 and 35 tons to 38 tons of steel.

The volumetric flow rate of liquid during refilling to the level of 262 mm was 32 l.min$^{-1}$. It conforms to the operating conditions of the steel mass flow 7 t.min$^{-1}$ into the tundish. The volumetric flow rate after reaching the level of 262 mm of liquid in the tundish was 12.4 l.min$^{-1}$, which corresponds to the operating conditions 2.7 t.min$^{-1}$ of the mass flow rate, respectively 0.7 m.min$^{-1}$ casting speed for the billet size 300 x 350 mm. The experiments were realized under isothermal conditions at the water temperature 15 °C.

A total of 15 correctly realized experiments were carried out using the method of permanent concentration change in the KCl solution under the above-mentioned conditions. In order to obtain relevant data and to achieve the possibility for further mathematical and statistical evaluation each of 5 refilling variants were modelled using three consecutive experiments. The time data obtained were transformed using the time scale into the actual plant conditions of the tundish.

The tundish model was equipped with perforated Baffle-type walls - the specific design of walls, including impact area, is marked below as Baffle1 (Fig. 3).
The so-called F-curves (transient curve) were obtained from monitoring the KCl concentration changes in the tundish output nozzles. The F-curves were then mathematically processed using a statistical indicator called the coefficient of variation (variability) - see [1,2].

The indicated minimum residence times \( \tau_{\text{min}} \) and moment of 0.5 dimensionless concentration achievement \( \tau_{0.5} \) are always expressed as a representative value derived from the three relevant experiments carried out in a consecutive manner for the individual conditions of tundish casting.

3. DISCUSSION OF BAFFLE INFLUENCE ON THE NATURE OF THE STEEL FLOW IN A TUNDISH

The minimum residence time is the significant time parameter and indicates how the nature of the steel flow is homogenous. The optimization of the steel flow in the tundish is possible due to the achievement of the highest possible value of \( \tau_{\text{min}} \) and, if the tundish has more casting strands, also these times simultaneously achieved in all casting strands (CS). Low \( \tau_{\text{min}} \) values are associated with the risk of so-called short-circuit flow.

Table 1. Minimum residence times and variability of the studied refilling variants

<table>
<thead>
<tr>
<th>Refilling Regime</th>
<th>( \tau_{\text{min}}; \text{s} )</th>
<th>Variability; %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CS1</td>
<td>CS2</td>
</tr>
<tr>
<td>23 → 38 t</td>
<td>124</td>
<td>67</td>
</tr>
<tr>
<td>26 → 38 t</td>
<td>116</td>
<td>58</td>
</tr>
<tr>
<td>29 → 38 t</td>
<td>117</td>
<td>75</td>
</tr>
<tr>
<td>32 → 38 t</td>
<td>111</td>
<td>87</td>
</tr>
<tr>
<td>35 → 38 t</td>
<td>126</td>
<td>82</td>
</tr>
<tr>
<td>Variability; %</td>
<td>5.1</td>
<td>15.5</td>
</tr>
</tbody>
</table>

Table 1 shows that the melt lasts at least one minute before reaching any casting strand. The short-circuit flow cannot rise. In terms of individual refilling regimes, it can be stated that the \( \tau_{\text{min}} \) values of steel in the tundish increase with the decreasing difference between the initial and standard operating weight particularly for casting strands symmetrical to the shroud exit (CS2-CS5). The asymmetric location of CS1 affects its significantly longer \( \tau_{\text{min}} \).
A relatively homogeneous nature of the flow direct to all casting strands (all the variability is below 50%) can be observed for all refilling regimes. The greatest variability is caused by the great difference between \( \tau_{\min} \) on CS1 and the other \( \tau_{\min} \) on CS2-CS5 in otherwise balanced refilling from 23 to 38 tons - see Fig. 4. The trend is that the uniformity of steel distribution between the individual CSs increases with decreasing levels of refilling. The minimum refilling regime, which is again an increase in the variability (21.1%), is the only exception.

When focusing on the differences between \( \tau_{\min} \) of the different refilling variants across CS (columns in Tab. 1) it is clear that no significant changes occurred from the point of view of variability. At least a change of the initial weight level affects on CS5 (variability 3.4%), and \( \tau_{\min} \) is growing with an increasing initial weight of steel. Also \( \tau_{\min} \) on the second outer CS, and sometimes on problematic CS1, is hardly affected by a difference in initial weight levels at the start of refilling and thus the time duration of intensive flow of steel into a tundish (variability 5.1%). This case promotes a rather contradictory trend - increasing the initial weight of steel leads to shorter \( \tau_{\min} \). A somewhat more influential change of refilling regime can be traced to the completion of internal casting strands CS2-CS4, which is reflected in the increasing \( \tau_{\min} \) trend with an increasing initial mass of steel at the start of refilling.

Another analyzed characteristic time derived from the obtained F-curves was the moment of achieving 0.5 dimensionless concentrations - \( \tau_{0.5} \). The process of tundish refilling from 29, 32 and 35 tons to 38 tons has already been completed and the dynamic effect of reduced steel inflow into the tundish is limited in \( \tau_{0.5} \) times. On the other hand, the variants of the mass refilling from 23 and 26 tons of steel in the tundish to an operating weight of 38 tons is still in progress and inflow into the tundish is still very intense. Comparison of \( \tau_{0.5} \) values based on the Tab. 2 and Fig. 5 is done below.

The influence of faster steel flow dynamics into the tundish in the variants of refilling from a lower initial mass of 23 and 26 tons is evident (Fig. 5). The intensive nature of the flow mostly affects the variant where refilling starts at the lowest level (weight 26 tons, variability 16.9%). However, the intense nature of the flow does not cause the turbulence behind the perforated walls. The steel slightly directs onto the surface through perforated walls. Then, steel slowly moves down to the individual CS from the surface – it may be partly seen at the visualization process in Fig. 3.
Table 2. $\tau_{0.5}$ values and variability of the studied refilling variants

<table>
<thead>
<tr>
<th>Refilling Regime</th>
<th>$\tau_{0.5}$; s</th>
<th>Variability; %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CS1</td>
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<td>23→38 t</td>
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<td>183</td>
</tr>
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<td>29→38 t</td>
<td>281</td>
<td>238</td>
</tr>
<tr>
<td>32→38 t</td>
<td>319</td>
<td>253</td>
</tr>
<tr>
<td>35→38 t</td>
<td>323</td>
<td>258</td>
</tr>
</tbody>
</table>

While the $\tau_{0.5}$ in CS2-CS5 are very balanced - an area of intense mixing, for the newly incoming steel to get to the CS1 is much slower. Feeding with new steel during refilling from 26 tons is already slower the CS3, CS4 provides the $\tau_{0.5}$ times similar to the case of the asymmetrically placed CS1, with CS2 being an exception. The new steel supply is the most homogeneous in $\tau_{0.5}$ times during refilling from the weight of 29 tons (9.4% variability). An accelerated steel flow into the tundish is slowed down in the variants of refilling from 29, 32 and 35 tons to 38 tons, and the new steel reaches the individual CS gradually, in accordance with their distance from the shroud.

The faster flow of new steels to CS3 and CS2 than to their (relative to the position of shroud) symmetrical counterparts, the CS4 and CS5, exists probably due to denser perforations of the wall on the counter CS3, 2 and 1. It can be observed that the more a given variant is without intensive steel supply for a longer period of time, which took place during the refilling, the more it begins to form a piston character of the flow, and the new steel gets to individual CS progressively in accordance with their geometric positions and perforations of walls (variability 13.3% and 15.2%).

As Fig. 5 and Tab. 2 shows that $\tau_{0.5}$ time is far more significantly influenced by the refilling regime than $\tau_{\text{min}}$ (Fig. 4, Tab. 1). This can be demonstrated by a greater variability, particularly in CS1 and CS5 columns (12.6% and 21.5%). The difference is logical. In $\tau_{\text{min}}$ moments, ongoing intense refilling for all variants and influence of the difference in initial height levels between the individual variations is probably somewhat muted by flow dynamics.

4. CONCLUSION

The paper aimed at study of the nature of the steel flow behaviour in the tundish with Baffle type walls (configuration Baffle1). The difference in $\tau_{\text{min}}$ was observed between the different refilling regimes of ladles'
exchange on the casting stand. It was found out that the use of these type of walls prevents the short-circuit flow. Initial turbulent steel flow into the tundish changes itself behind the perforated walls to relatively homogenous downward streams spread into individual CS. The refilling regime hardly changes the nature of the steel flow during the initial stage of refilling ($\tau_{\text{min}}$) in the tundish with this inner configuration. It significantly does not restrict the positive nature of steel flow, which contains a significant operating proportion of a plug volume and supports the flotation of non-metallic inclusions after the refilling is finished – see discussion of $\tau_{0.5}$ values.

It can also be noted that the steel flow in the tundish with the Baffle1 configuration is very homogeneous in terms of all the modelled conditions of refilling in this work. Previous work [3] has also shown that the Baffle1 configuration is better than the insertion of a Turbostop-type impact place in terms of the conditions of CCM No. 1 in Trinecké zelezárny.

The next phase of research will be focused on the other modifications of the internal tundish design testing. The main objective will be to further increase the homogeneity of steel distribution between the CS, especially by $\tau_{\text{min}}$ reducing on the asymmetric CS1.

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REFERENCES

