INFLUENCE OF WATER TEMPERATURE ON THE COOLING INTENSITY DURING CONTINUOUS CASTING AND HOT ROLLING

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Abstract
Two types of nozzles were tested to find out the influence of the water temperature on cooling intensity. The first type was a mist nozzle used in the secondary cooling area of a steel slab casting machine. The second type was a flat fan nozzle usually used during hot rolling and heat treatment process of rolled strips. These laboratory measurements of cooling intensity were performed in a temperature range of water temperature from 20 °C to 80 °C. A strong influence of the water temperature on cooling intensity was found. Changing the water temperature from 20 °C to 80 °C caused a change of heat transfer coefficient. For mist nozzle was found slightly increasing cooling intensity with growing water temperature. The difference was about 30 W m⁻² K⁻¹. For flat fan nozzle was found the decreasing cooling intensity with growing water temperature. The difference was about 110 W m⁻² K⁻¹. The main effect was not the change of heat transfer coefficient but the shift of Leidenfrost temperature to a lower temperature area. The change of water temperature from 20 °C to 80 °C caused the change of Leidenfrost temperature about 130 °C for both nozzles. This can be a significant change of cooling and can affect the cooling character in industrial applications.

Key Words:
Heat transfer coefficient, Leidenfrost temperature, cooling intensity, hot rolling, continuous casting, water temperature, mist nozzle, flat fan nozzle

1. INTRODUCTION
The basic influence of coolant temperature is already known from the convection equation where there is a difference between water and surface temperature multiplied by the heat transfer coefficient. This paper deals with the influence of water temperature on the heat transfer coefficient. Fig. 1 shows the typical dependence of the heat transfer coefficient on surface temperature. The change of water temperature has an influence on the shape of this curve. Cooling water temperature is usually changing during the year between 10 °C and 45 °C. The heat transfer coefficient is strongly dependent on the surface temperature (Fig. 1 on the left). The Leidenfrost effect [1] [2] started at around 470 °C (in this case). The steam layer between the droplet and surface is broken and the water wet the surface and evaporated. A huge amount of energy is used for this phase change. It is obvious to think what happen if the coolant has a different temperature.

The influence of the coolant temperature on the cooling intensity is rarely described in the literature. The research of the University of British Columbia in Canada [3] showed interesting dependences for an increasing temperature of the cooling medium. For measuring, a 7 mm thin carbon plate embedded by 16 thermocouples was used. Half of the thermocouples was positioned 1 mm under the surface. The second half was welded to the surface. The test plate was heated to the initial temperature of between 700 - 900 °C, and then positioned under the full cone nozzle. A comparison of the results (Fig. 1 on the right) showed that an area between 50 °C and 70 °C, where the cooling is effective, exists. The heat transfer coefficient reaches higher values for water temperature T_w = 50 °C than for the water temperature T_w = 70 °C. On the other hand the heat transfer coefficient differences for the water temperature 50 °C and 40°C is not
significant. These results are very interesting and showed a substantial dependence of the cooling medium temperature on the spray cooling efficiency.

![Graph](image1)

**Fig. 1 Dependence of heat transfer coefficient on the surface temperature**

In the Heat Transfer and Fluid Flow Laboratory two types of nozzles were measured. The first type was a mist nozzle used in the secondary cooling area of a steel slab casting machine. The second type was a flat fan nozzle usually used during hot rolling and heat treatment process of rolled strips. Both experiments were performed on measuring equipment developed by the laboratory (2).

2. EXPERIMENTAL EQUIPMENT AND TEST PROCEDURE

In laboratory conditions it is necessary to be as close as possible to actual cooling conditions in mills. Because of this two laboratory stands described in 2.1 and 2.2 were developed in laboratory.

2.1 Linear stand

The linear stand is a six meter long rotatable frame on which a trolley with a tested sheet (Fig. 2) is positioned. This trolley can be moved on the frame in both directions (backward and forward) through the cooling section. For cooling flat fan nozzles were used. For experiments 1.5 mm thick sheets made of austenitic steel were used. Five thermocouples were welded to the bottom side of the sheet. Measured temperatures were recomputed to surface temperatures, heat fluxes and heat transfer coefficient by the inverse task.

![FIG. 2 LINEAR STAND](image2)

Experiment procedure started by the heating of the sheet to its initial temperature (here 900°C). Then the stand is rotated into position, for example: bottom cooling, side cooling or upper cooling, and the sheet was...
moved through the cooling section by the requested velocity. The surface of the sheet was protected by the inert atmosphere during heating to prevent occurring of scales.

2.2 Experimental stand high temperature and low velocity cooling test

This experimental stand comprised the lift, test plate, heater and the linear driving mechanism with the nozzle (Fig. 3). 18 thermocouples were embedded into the test austenitic steel plate. They were put in holes 2 mm under the surface. The test plate was heated to its initial temperature and lifted into position. Then the bidirectional driving mechanism moved with the nozzle under the surface. A pneumatically driven deflector was between the nozzle and the surface. When moving forward the deflector was opened and the water sprayed on the surface. When moving backward the deflector was closed because of the stabilization of the temperature field on the surface. The measured temperatures were recomputed to surface temperatures, heat fluxes and heat transfer coefficient by the inverse task [4].

![Fig. 3 Experimental stand developed for testing nozzles used during continuous casting](image)

3. INFLUENCE OF WATER TEMPERATURE ON HEAT TRANSFER COEFFICIENT OF MIST NOZZLES

3.1 Experiment configuration

For these tests a couple of small mist nozzles, which are usually used for cooling in continuous casting, were used. The nozzles had a spray angle of 110° and their pitch was 430 mm. The flow rate and pressure conditions are described in Tab. 1. All tests were carried out with constant velocity of the sample 1 m/min. Each experiment was conducted with a different constant temperature, which increased by 10 °C from 20 °C to 80 °C.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Water Flow Rate [L/min]</th>
<th>Water Temperature [°C]</th>
<th>Air Flow Rate [m3/h]</th>
<th>Spray Height [mm]</th>
<th>Pitch [mm]</th>
<th>Casting Velocity [m/min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>T35 - 41</td>
<td>4.5</td>
<td>20 to 80</td>
<td>8.1</td>
<td>239</td>
<td>430</td>
<td>1</td>
</tr>
<tr>
<td>T43</td>
<td>8</td>
<td>40 °C</td>
<td>6.3</td>
<td>239</td>
<td>430</td>
<td>1</td>
</tr>
</tbody>
</table>

3.2 Results
The results shown in Fig. 4 - Fig. 6 are the average values of the heat transfer coefficient in the impacting area from -150 mm to +150 mm in the longitudinal and transversal directions. The results shown in Fig. 4 demonstrate a significant shift of the Leidenfrost temperature. Changing the water temperature from 20 °C to 80 °C causes the shift of Leidenfrost temperature of 130 °C to lower temperatures. The heat transfer gradient is almost the same for all experiments. But in the high temperature area (Fig. 5) it is possible to see that with the increasing coolant temperature the heat transfer coefficient increased. The difference is about 30 W m\(^{-2}\) K\(^{-1}\). This finding can be explained by the positive effect between the water temperature and boiling point that allows faster setting of the boiling regime with higher heat transfer rates [5].

![Fig. 4 The influence of coolant temperature to a heat transfer coefficient](image)

Surprisingly high differences in the Leidenfrost temperature were found for intensive cooling (Fig. 6) where a difference of only 20 °C in coolant temperature makes a difference of about 120 °C in the Leidenfrost temperature. In addition the cooling intensity changed in the high temperature area (above Leidenfrost temperature). In this case it was found that decreasing the coolant temperature increases heat transfer coefficient.

![Fig. 5 High temperature area](image)
4. INFLUENCE OF WATER TEMPERATURE ON HEAT TRANSFER COEFFICIENT OF FLAT FAN NOZZLES

4.1 Experiments configuration
For these tests flat fan nozzles were used. The nozzles were positioned in five rows with a pitch of 300 mm. The nozzle span in each row was 120 mm. All tests were carried out with constant velocity of the sample 0.8 m/s. Each experiment was conducted with a different constant temperature, which increased by 20 °C from 20 °C to 80 °C. (experiments T20 – T80).

4.2 Results
In Fig. 7 the dependence of the heat transfer coefficient on the surface temperature for the water temperature 20°, 40°, 60° and 80° is shown. The results (Fig. 7) showed again the shift of Leidenfrost temperature. The change of water temperature of 60°C caused the change of 130 °C of the Leidenfrost temperature. The results in the high temperature area (above Leidenfrost temperature) are compared in Fig. 8. When the water temperature increases the cooling intensity slightly decreases.
5. CONCLUSION

A high influence of water temperature on the cooling intensity was found. The main effect of this is the shift of Leidenfrost temperature to low temperatures for mist and water jet nozzles. The effect is more significant for intensive cooling. Even a temperature difference of 20 °C (between 20 °C and 40 °C) makes a significant change of the Leidenfrost temperature. This finding can explain some of the problems of cooling devices used during continuous casting and heat treatment processes in winter and summer when the temperature of cooling water varies significantly.

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LITERATURA


