COOLING SYSTEMS FOR CONTINUOUS GALVANIZING LINE

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Abstract

An experimental program was carried out to design an after pot cooling section for Continuous Galvanising Line. The cooling system should reduce an initial temperature of 550 °C down to about 50 °C for the shortest possible distance. Reference thickness of a strip is 1 to 2 mm and expected velocity for a strip 1 mm thick is about 3 m/s.

The cooling tower has a vertical configuration and the strip is moving upwards in the first cooling section. A test for the quantity of dropping water from the cooled area was done to minimise the amount of coolant which must be removed by air knives to protect the galvanising pool.

Optimal nozzles were selected in the first stage of the project. Water and mist nozzles of various footprints were tested and finally full cone water nozzles were selected to use in a cooling chamber.

A great number of laboratory cooling experiments provided a great deal of information about the cooling intensity for the following spray parameters (nozzle size, coolant pressure and flow rate, spray height, nozzle pitch, velocity of motion). These boundary conditions were used in a thermal numerical model for the computation of cooling rates in a variety of the cooled strips.

Final design achieved optimised the length of the cooling line and the production costs as well.

Key words: galvanizing line, cooling unit, heat transfer, spraying

1. SPECIFICATION OF PROJECT / INTRODUCTION

Innovative markets, such as automotive industry, pipelines or architectural building design require the development of new steel and new process. To achieve these grades in continuous annealing lines as well as in galvanizing lines, Fives Stein constantly improves and develops new technologies: Flash Cooling technology up to 75% H2, Wet Flash Cooling Technology for the cooling process. In After Pot cooling for Galvanizing lines FIVES STEIN has a long experience in air cooling system with AERIS and efficient PAD technology. The advantages of using water cooling in this section are great and Fives Stein had developed a Fog cooling unit.

A program of experiments was carried out to find an optimal design of a unit. Measurements were followed by numerical modelling of temperature field in a cooled strip.

2. EXPERIMENTAL PROGRAM

Various types of nozzles were tested during work development. The main aspects for nozzle selection were set: optimal cooling intensity, controllability, small amount of water falling to liquid galvanizing pool below the cooling unit and operation cost. Both nozzles, single and two-phase nozzle were tested with flat jet and full cone footprint (see Fig. 1).
3. STATIONARY HEAT TRANSFER TESTS

Initial selection of the nozzles started with stationary tests without any movement of the cooled surface. These tests were used for finding major characteristics of the tested nozzles. The cooling intensity and amount of water falling down along the cooled surface were measured.

3.1 Experiment description

Stationary heat transfer tests were done on a stainless steel plate (300x300 mm) with six embedded thermocouples positioned in two rows (Fig. 8). The plate was heated to an initial temperature of 650 °C, moved in the cooling position and sprayed by the nozzle, see Fig. 2. Under the test plate a vessel was positioned to catch the splashed water. The weight of the water in the vessel and temperature were recorded. The surface temperature history was evaluated by an inverse task and the heat transfer coefficients were computed.

3.2 Results

There are two outputs from the stationary experiments. The first output is the recorded water weight in the vessel and the second is the computed surface temperature history and heat transfer coefficient. The reflection of water from the cooled surface depends on the surface temperature. The quantity of water in the vessel is nonlinearly increasing as the surface temperature is decreasing; see Fig. 3. When surface temperature is higher than Leidenfrost temperature the droplet does not wet the surface. It evaporates and between the surface and the droplet a vapour layer arises which does not only allow the surface to get wet but also reflects the droplets. When the surface becomes colder then water sticks to the surface and a portion of the reflected droplets is smaller, see area Vmax in Fig. 5. A bigger amount of steam was formed at the end of the experiment when heat transfer coefficient became bigger.
Measured temperature is recomputed by the inverse task to surface temperature and to heat transfer coefficient. A typical computed HTC dependence on the surface temperature is shown in Fig. 4. With decreasing surface temperature the HTC increases because of the Leidenfrost effect. When the temperature difference between the surface and water is high enough the steam layer arises between the surface and the impinging droplet. Therefore the droplet does not wet the surface. The Leidenfrost temperature is the temperature when the vapour layer is thin enough and the droplet impacts to the surface through the layer. The pictures Fig. 4 and Fig. 5 show the Leidenfrost temperature presented by the Vmin and Tmax value.

4. FULL SCALE COOLING TESTS

Full scale tests are the test where the test plate moves with the same velocity as in the plant conditions and a number of nozzles is used in the configurations which are identical to the plant conditions. The full scale tests were conducted in order to investigate the behaviour of a group of nozzles in detail. There was a set of parameters which had to be taken into account – nozzle size, feeding pressure, distance from cooled surface, nozzle pitch (vertical and horizontal). All set parameters were based on the stationary experiments. Cooling homogeneity is mainly influenced by the correct choice of the distance between the nozzles. There should be an optimal overlapping to reach a constant cooling intensity of the row of the nozzles – this was an important parameter studied.
4.1 Experimental test bench

The laboratory stand, shown in Fig. 7, was used for testing the cooling intensity of water jets from the nozzles. The test plate moves on a six meter long girder. The motor is controlled by a converter allowing the velocity of the test plate movement to be set. The test plate can rotate with the girder. Cooling can be applied to the horizontal or vertical test plate.

The test plate in the heating position is faced down and is above an electric furnace which heats the test plate to an initial temperature of the experiment. The girder with test plate rotates 90° after heating and the test plate is now in the vertical position for cooling. Along the laboratory stand the nozzles are fitted in given positions (Fig. 8). A water pump is switched on and the flow is adjusted. Flow rate conditions are stabilized. A driving mechanism moves the test plate through the sprays. The position of the test plate and the temperature of sensors are recorded. Data is transferred from the data logger into a computer for further evaluation when cooling experiment stops.

4.2 Results of heat transfer tests

4.2.1 Flow rate influence

**Tab. 1** Table of experiments for two types of full cone nozzles with different flow rate

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Velocity [m/s]</th>
<th>Water Pressure [bar]</th>
<th>Flow Rate</th>
<th>Nozzle Row Switched On (Fig. 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G16p</td>
<td>1</td>
<td>Higher</td>
<td>Higher</td>
<td>A B C D</td>
</tr>
<tr>
<td>G16</td>
<td>3</td>
<td>Higher</td>
<td>Higher</td>
<td>A B C D</td>
</tr>
<tr>
<td>M16P</td>
<td>1</td>
<td>Higher</td>
<td>Lower</td>
<td>A B C D</td>
</tr>
<tr>
<td>M16</td>
<td>3</td>
<td>Higher</td>
<td>Lower</td>
<td>A B C D</td>
</tr>
<tr>
<td>GD16P</td>
<td>1</td>
<td>Higher</td>
<td>Higher</td>
<td>A D</td>
</tr>
<tr>
<td>MD16P</td>
<td>1</td>
<td>Higher</td>
<td>Lower</td>
<td>A D</td>
</tr>
</tbody>
</table>

In **Tab. 1** the chosen configurations for two different sets of nozzles are shown. Higher flow rate nozzles were used during experiments G and lower flow rate nozzles were used during experiments M. The position of the nozzles was same for all experiments (Fig. 8). Letter D in the name of the experiment represents that the water is sprayed only by the first and last row. It is simulating the possibility of cooling intensity control.
is clear when two rows are switched off; there is still some cooling intensity (Fig. 10 – position interval - 200mm, +200mm). Fig. 9 represents computed HTC dependence on the surface temperature for smaller and bigger nozzles.

4.2.2 The Pressure Influence

The measurements were done for three pressure levels. In Tab. 2 is a setup of the experiments.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Velocity [m/s]</th>
<th>Water Pressure [bar]</th>
<th>Flow Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>G8</td>
<td>3</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>G12</td>
<td>3</td>
<td>Medium</td>
<td>Higher</td>
</tr>
<tr>
<td>G16</td>
<td>3</td>
<td>Higher</td>
<td>Higher</td>
</tr>
<tr>
<td>M8</td>
<td>3</td>
<td>Lower</td>
<td>Lower</td>
</tr>
<tr>
<td>M12</td>
<td>3</td>
<td>Medium</td>
<td>Lower</td>
</tr>
<tr>
<td>M16</td>
<td>3</td>
<td>Higher</td>
<td>Lower</td>
</tr>
</tbody>
</table>

The results are shown in Fig 11. The most important observation is that the smaller nozzle shows a very small sensitivity to the coolant pressure. It seems that cooling intensity for this nozzle is almost saturated.

5 NUMERICAL MODEL

One dimensional numerical model was used for simulation of the cooling unit. Temperature drops for various configurations of the nozzles and spray parameters were tested to design an optimal cooling unit. Control of the unit by setting the pressures and by switching off/on nozzle bars was studied. The model uses the boundary conditions obtained from the measurements. Fig. 12 shows an example of cooling strip thickness of 1mm, moving velocity 3 m/s in a cooling section six meters long. A combination of the bigger nozzles (initial 3 m) and the smaller nozzles (end 3 m) was used in this design. A good comparison of temperature histories for identical conditions when using only the smaller nozzles is shown in Fig. 13. It is obvious that cooling intensity is not sufficient and final temperature after running a six meter long cooling section is too high.
The influence of the thicknesses of the strip at temperature field is shown by comparison of Fig. 13 and 14. The first one is for a thickness of 1 mm and the second one for a thickness of 2 mm. It is considered that the thicker strip moves with a velocity of 1 m/s. Smaller full cone nozzles operating at a higher pressure and a water temperature of 40°C are used in both cases. Switching on and off the rows of the nozzles can be used for controlling the unit. Fig. 15 shows a situation when the cooling done by smaller nozzles is interrupted. Two rows of the nozzles are ON and two rows are OFF. It should be stressed that even in the area which is not directly sprayed a relatively high intensity of cooling can be found because of water flowing outside the direct impingement area (see Fig. 10).

6. CONCLUSION

Within this study, thanks to the skill of the Heat Transfer and Fluid Flow Laboratory of the Brno University, FIVES STEIN had developed the technology fog cooling applied to cooling tower in CGL. A complementary study of a SAS based on the use of air knife was carried out, see Fig. 16. This SAS is water droplets tight, to be fully confident about using of this technology for After Pot cooling in CGL. The combination of the experimental work with numerical modelling was successfully used in the design of the cooling unit in a galvanizing line. Intensity of the cooling is significantly temperature dependent. This feature is valid for all of the tested nozzles. The numerical model takes into account a real dependence of heat transfer coefficient on the surface temperature. The combination of the lower higher flow rate nozzles is optimal for the design of the cooling section. Spacing of the nozzles was tested and the optimal nozzle pitch was found. A staggered arrangement of the nozzles in bars was chosen. Influence of the velocity on heat transfer was found and considered in the design. A low controllability for the smaller full cone nozzles was found by changing the coolant pressure. The Cooling intensity was saturated and changes in heat transfer coefficient between higher and lower pressure obtained were small.

The numerical models showed the cooling intensity and the temperature field for a number of the cooling configurations. A significant influence of the velocity of the cooled strip (cooling time) was found. The numerical models showed the ability of the cooling system to cool the strip moving by a velocity of 3 m/s at the total length of 6 meters. Numerical simulation showed that the cooling system working at a higher pressure with the bigger nozzles is possible providing a sufficient cooling intensity even for the strip 1 mm thick at a velocity of 5 m/s and 6 meters long cooling section.

ACKNOWLEDGEMENT

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