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EXPERIMENTAL INVESTIGATION OF A HEAT-TRANSFER COEFFICIENT

PREISKAVE KOEFICIENTA PRENOSA TOPLOTE

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A special piece of apparatus was developed to study the cooling of hot steel surfaces using full-cone nozzles. This apparatus allowed the movement of the test sheet in a vertical direction, up and down. Experiments with different water pressures and flow rates were conducted. It was observed that the value of the average heat-transfer coefficient increased with an increase in the water pressure for all the surface-temperature range and the dependence of the heat-transfer coefficient on the water-impingement density is linear in the region of stable film boiling. A mathematical model based on a regression analysis for predicting the heat-transfer coefficient in the region of stable film boiling was developed.

Keywords: cooling, impingement density, full cone nozzles, heat-transfer coefficient

Razvita je bila posebna naprava za preučevanje ohlajanja vroče površine jekla s področjem s šobami. Ta naprava omogoča vertikalno pomikanje preizkusne pločevine dol in gor. Izvršeni so bili preizkusi z različnimi tlaki vode in hitrostmi pretokov. Opaženo je bilo, da narašča srednja vrednost koeficienta prenosa toplote z naraščanjem tlaka vode za vsa območja temperature površine in da je linearna odvisnost med koeficientom prenosa toplote in zmanjševanjem gostote vode v območju stabilne tanke plasti pri vrenju. Na osnovi regresijske analize je bil razvit matematični model za napovedovanje koeficienta prenosa toplote v območju stabilne tanke plasti pri vretju.

Ključne besede: ohlajanje, zmanjševanje gostote, področje s šobami, koeficient prenosa toplote

1 INTRODUCTION

The spray cooling of vertically moving, hot, stainless-steel sheet was studied in the Heat Transfer and Fluid Flow Laboratory. The temperature range from 900 °C to 200 °C was covered by these experiments. The experiments with different water-impingement densities were conducted. The dependence of the heat-transfer coefficient (*HTC*) on different water-impingement densities (mL) has been studied by many authors, but it is known that different nozzles and test conditions provide different results. It is also known that in the range of stable film boiling, the heat-transfer coefficient is independent of the surface temperature and that it is mostly influenced by the water-impingement density. It was shown in[1] (**Figure 1**), that the dependence of the heat-transfer coefficient on the impingement density is linear for water temperatures under 20 °C and water-impingement densities of 100–2000 kg /(m^2 min).

2 EXPERIMENTAL PROCESS

An experimental apparatus developed for the vertical moving of a hot-test, stainless-steel sheet was used in the experiments (**Figure 2**). The hot-test sheet with a thickness of 1 mm moved vertically up and down, and it was cooled by three rows of collectors with full-cone nozzles. The collectors were connected through a pump to a water tank with an adjustable water temperature. Each collector was directly connected to a manometer. The heater, which heated the test sheet to 900 °C, was on the top of the experimental apparatus. Four thermocouples of type

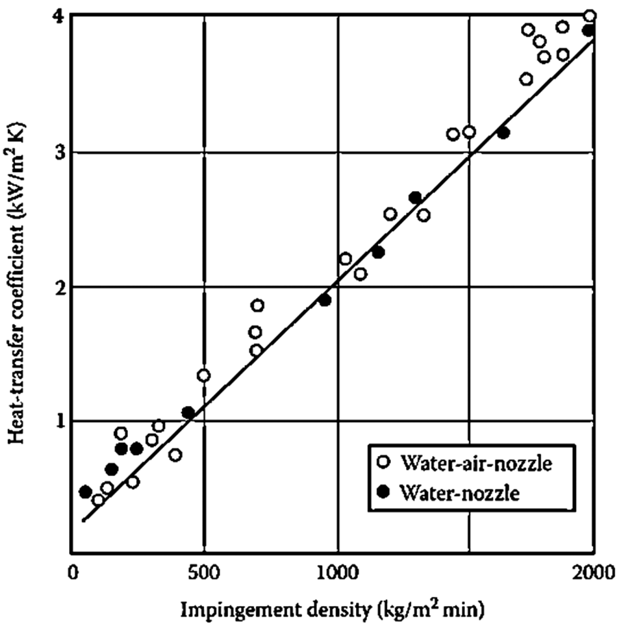

Figure 1: Heat-transfer coefficient as a function of the impingement density[1]
Slika 1: Koeficient prenosa toplote v odvisnosti od zmanjševanja gostote[1]

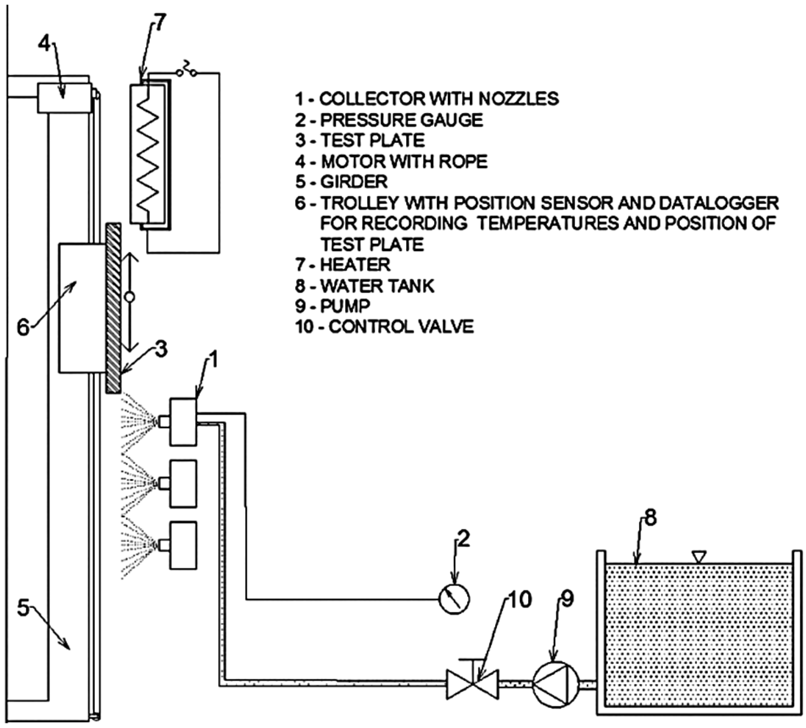

Figure 2: Experimental apparatus
Slika 2: Preizkusna naprava

K were welded on the rear side of the test sheet. The distance between the thermocouples was 20 mm (**Figure 3**). The holder of the test sheet was equipped with a position sensor and data logger, which recorded the information about the test-sheet temperature and the position. The test sheet was heated in a furnace at a temperature of 900 °C and then moved up/down under spraying nozzles until it was cooled to a temperature of 200 °C. The movement of the test sheet was conducted with a velocity of 3 m s^{-1}. The distance between the nozzles was 40 mm, while the distance between the collectors was 330 mm, and the distance from the nozzle orifice to the test sheet was 250 mm. An example of the nozzle configuration and photographs of the experiment are shown on the **Figure 4**. The experiments were made with a water temperature of 40 °C and differed only in terms of the pressures. The pressures and water-impingement densities used in experiments are shown in **Table 1**.

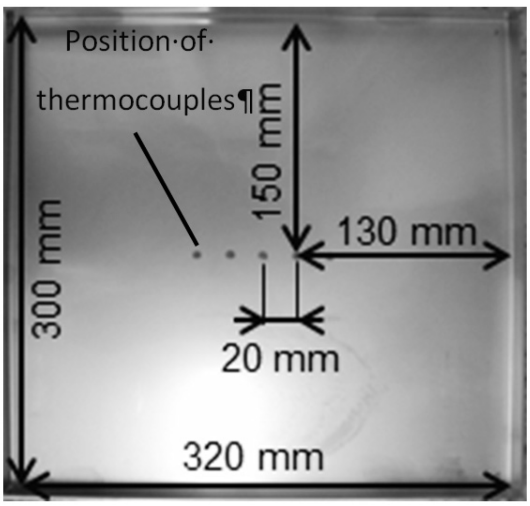

Figure 3: Rear side of the test sheet with marked positions of the thermocouples
Slika 3: Zadnja stran preizkusne pločevine z označenimi položaji termoelementov

Table 1: Measured experiments
Tabela 1: Rezultati meritev preizkusov

Experiment	Water pressure *p*/bar	Water impingement density (kg m^{-2} s^{-1})
1	0.2	3.3
2	1.3	9.7
3	4.3	18.8
4	6	22.6

3 RESULTS

The measured temperatures were recomputed to the surface temperatures (sprayed/cooled side) for the location of the temperature sensors by the inverse task.[2] An example of the four computed surface temperatures is shown in the **Figure 5**. The heat-transfer coefficient was then computed using the inverse conduction algorithm.[3] The average heat-transfer coefficient (average value over the length of the cooling section, i.e., 660 mm) was computed for all the measured experiments. Their comparison is shown in the **Figure 6**. It is evident

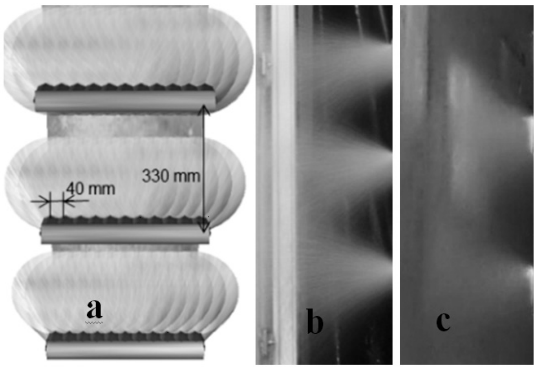

Figure 4: a) Nozzles configuration, b) spraying nozzles, c) nozzles spraying the hot test sheet
Slika 4: a) Razporeditev šob, b) razpršilne šobe, c) šobe, ki škropijo vročo preizkusno pločevino

that the average heat-transfer coefficient is increasing with the increasing water pressure (impingement density) and the Leidenfrost point increases with the increasing water-impingement density. The average heat-transfer coefficient is increasing with the decreasing of the surface temperature in the region of the film boiling. It is caused by thinning of the vapor layer. Lowering the surface temperature under the Leidenfrost temperature is connected with a change in the type of boiling. Film boiling is changed into transition boiling and this change in the type of boiling leads to a sharp increase in the heat-transfer coefficient. It was also observed that the dependence of the heat-transfer coefficient on the water-impingement density is linear in the region of stable film boiling (**Figure 7**). The first derivative of the regression functions is increasing with the lowering of the surface temperature (**Table 2**). The constant in the regression functions represents the measured natural convection and radiation. The result for a surface temperature of 900 °C is in good agreement with the result presented in[1] (**Figure 7**). The regression functions presented in the **Table 2** can be used to

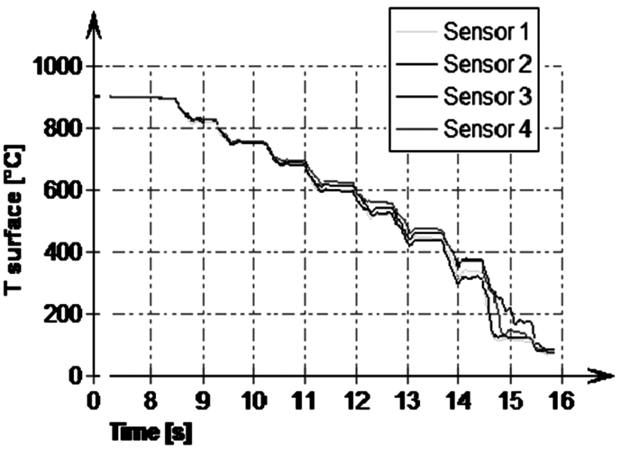

Figure 5: Example of computed surface temperature
Slika 5: Primer izračunane temperature površine

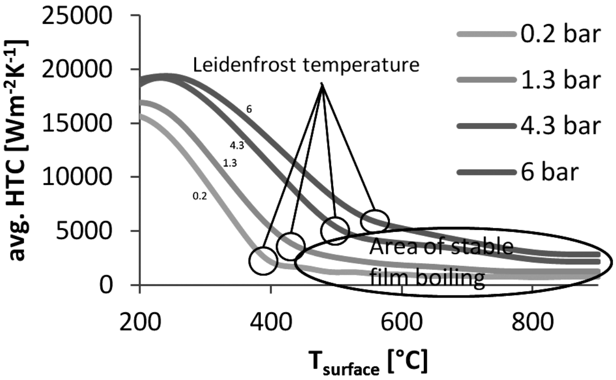

Figure 6: Comparison of experiments
Slika 6: Primerjava preizkusov

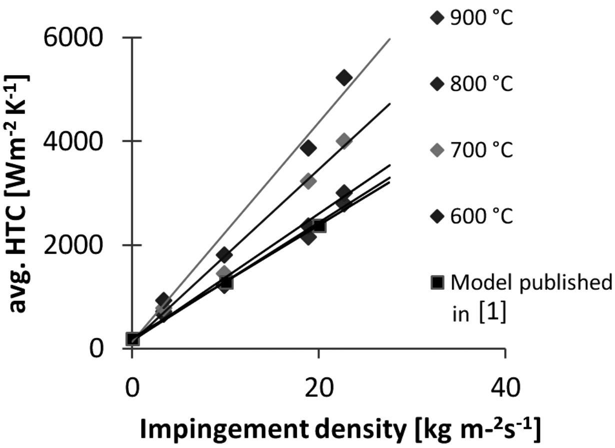

Figure 7: Regression functions for predicting *HTC*
Slika 7: Regresijske odvisnosti za napovedovanje *HTC*

extrapolate or interpolate the average heat-transfer coefficient for different water-impingement densities in the region of stable film boiling. This model can only be used for predicting the heat-transfer coefficient for parameters (type of nozzles, water temperature, configuration of nozzles, etc.) that were used in the experiments from which the regression analysis was made.

Table 2: Regression functions
Tabela 2: Regresijske funkcije

Surface temperature, *T*/°C	Regression function
600	*HTC* = 212 mL +128
700	*HTC* = 166 mL +138
800	*HTC* = 123 mL +149
900	*HTC* = 113 mL +159

4 CONCLUSION

Experiments with horizontally oriented nozzles and vertically moving hot sheet were conducted. Different water-impingement densities were tested. It was observed that the heat-transfer coefficient increases with an increasing water-impingement density at all the surface temperatures and the Leidenfrost point increases with an increasing water-impingement density. The dependence of the heat-transfer coefficient on the water-impingement density is linear in the film boiling regime. The functions for predicting the average heat-transfer coefficient in the surface temperature range from 600 °C to 900 °C were determined.

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5 REFERENCES

[1] R. Jeschar, U. Reiners, R. Scholz, Heat transfer during water and water-air spray cooling in the secondary cooling zone of continuous casting plants, Proceeding of the 69th Steelmaking Conference, Washington, 69 (**1986**), 551–521

[2] M. Pohanka, K. A. Woodbury, A Downhill, Simplex method for computation of interfacial heat transfer coefficients in alloy casting, Inverse Problems in Engineering, 11 (**2003**), 409–424

[3] M. Raudensky, Heat Transfer Coefficient Estimation by Inverse Conduction Algorithm, International Journal of Numerical Methods for Heat and Fluid Flow, 3 (**1993**) 3, 257–266