INFLUENCE OF OPERATION PARAMETERS ON THE COOLING PERFORMANCE OF WATER-AIR NOZZLES

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Abstract

In the secondary cooling zone of the continuous casting process water-air nozzles are used to cool down the strand. The cooling has to be sufficient enough to ensure a certain shell thickness and finally the complete solidification of the material. Further a controlled and uniform cooling strategy is important to minimize the amount of defects in the solidified steel. For the determination of the water distribution and the cooling characteristic of water-air sprays at defined operation parameters the Nozzle Measuring Stand (NMS) at the Montanuniversitaet Leoben is used. In this work the measuring principle of the NMS is explained and the influence of several nozzle operation parameters on the cooling characteristics of two water-air nozzles is shown. In a first step the water distribution (WD) at different nozzle distances, water flows and air pressures was determined. Afterwards the heat transfer coefficient (HTC) for every parameter modification was measured. The surface start temperature for all experiments was set at 950 °C. In order to show the change in cooling intensity over the width of the spray, HTC measurements were performed at several positions. Finally the results of the experiments and possible links between the operation parameters, water distribution and HTC are discussed.

Keywords: Continuous casting, secondary cooling, nozzle measuring stand, heat transfer coefficient

1. INTRODUCTION

For the minimization of defects in the solidified steel uniform and smooth cooling of the surface is an important factor. To find an optimal cooling strategy for the secondary cooling zone of the continuous casting process it is crucial to determine the cooling characteristic of used nozzles [1].

If a hot surface is cooled by liquid water, different boiling regimes occur. The formation of these regimes is highly dependent on the surface temperature. At temperatures above the Leidenfrost point (LP) film boiling takes place where a closed layer of vapor exists between the surface and the spray. This layer works as insulation and provides a relatively low and almost temperature independent HTC. The relationship between surface temperature and HTC (and Heat Flow) is shown in **Figure 1a** in form of a boiling curve. It is important to mention that a boiling curve is only valid for a certain set up of operation parameters. The curve clearly shows the change from film boiling to transition boiling at the LP. If the surface temperature sinks below the LP the vapor layer collapses whereby the HTC is increased dramatically. Due to that for continuous casting the film boiling regime is of special interest [2-7].

The boiling curve shows a static picture of HTC over surface temperature. To include the influence of a certain casting velocity the measurement can be carried out in a dynamic way. A result of such a measurement, where a sample is moved through a spray, is demonstrated in **Figure 1b**. All further results in this work were measured in the film boiling regime using the dynamic measurement method [8].

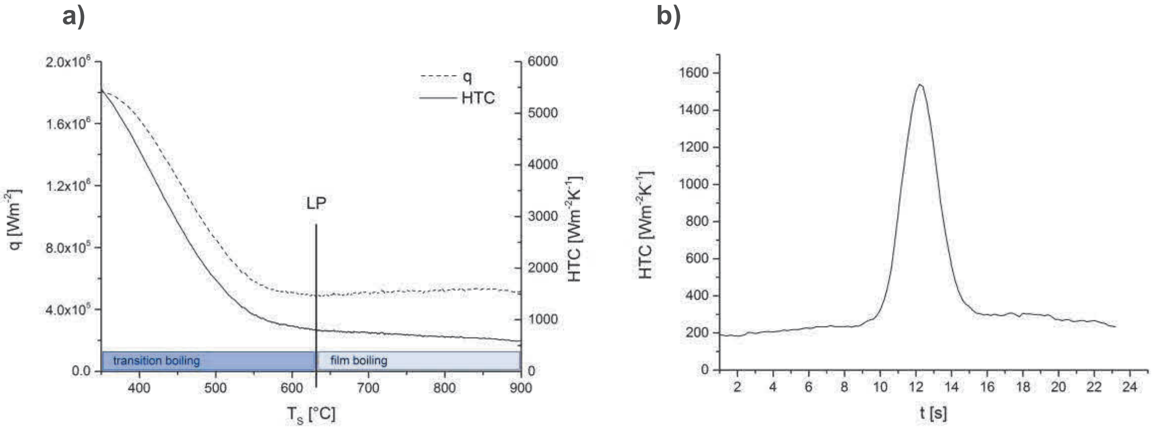
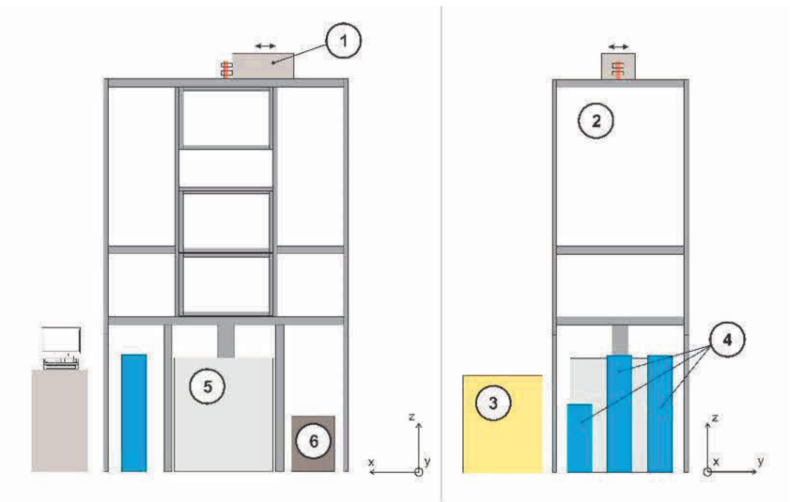


Figure 1 a) Boiling curve (NMS, $V(H_2O)$ = 2.25 l / min, p(AIR) = 1.3 bar), b) Example of dynamic HTC measurement ($V(H_2O)$ = 6 l / min)

2. EXPERIMENT

Nozzle characterization with the NMS at the Chair of Ferrous Metallurgy (CoFM) in Leoben is divided in two parts, the measurement of the water distribution and the determination of the heat transfer coefficient. To investigate the influence of spray overlapping it is possible to install two nozzles, using two separate water/air supporting systems. **Figure 2** gives an overview on the NMS with all important parts.



1 - Heating & Moving unit

2 - Experimental chamber

3 - Air compressor

4 - Water pumps

5 - Water tank

6 - Induction cooling unit

7 - Measurement & Control unit

Figure 2 Components of the NMS at CoFM, Leoben

2.1. WD measurement

Figure 3 shows that for WD measurements one or two nozzles are mounted at the top of the experimental chamber in a way that the spraying direction shows downwards. A measuring grid is located on the bottom of the chamber with a defined distance to the nozzle tips (N_z). If there are two nozzles installed not only N_z but also the distance between the nozzles (N_x) has to be adjusted. The grid itself is divided into 7 cells in y-direction and 100 in x-direction where every cell measures 10x10x280 mm. During the measurement these transparent cells get filled with water by the spray [8].

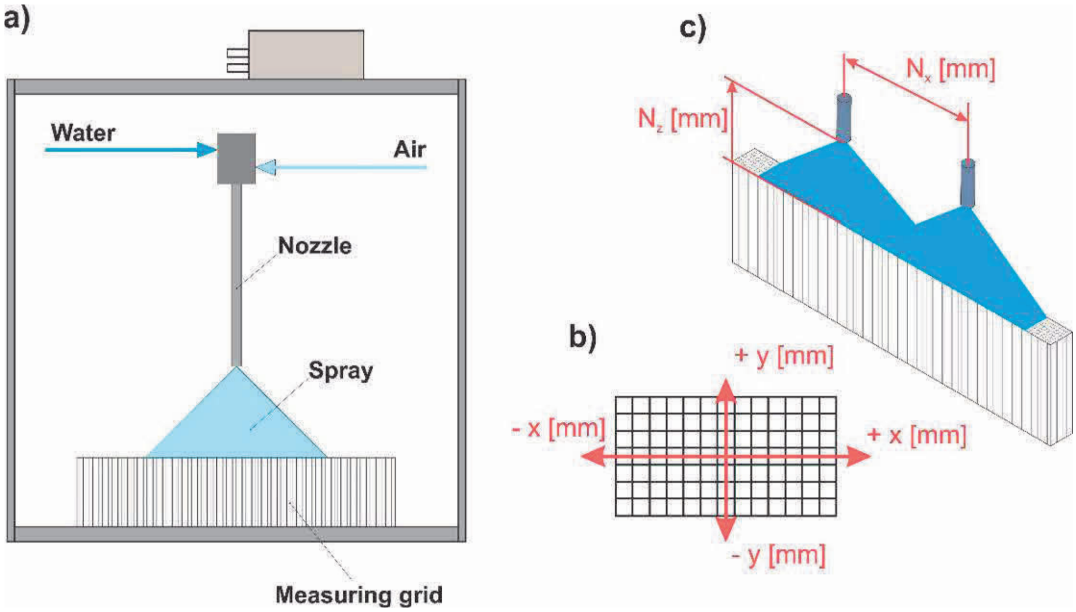


Figure 3 a) Arrangement of WD measurement, b) Sector of measurement grid, c) Nozzle distances

After a certain filling time the grid is removed and photos of cross-sections in y-direction are taken. From these pictures the water impact density (WID [$kgm^{-2}s^{-1}$]) in every cell is calculated and then merged to the complete water distribution using digital image processing [8]. An example for such a distribution is shown in **Figure 4**.

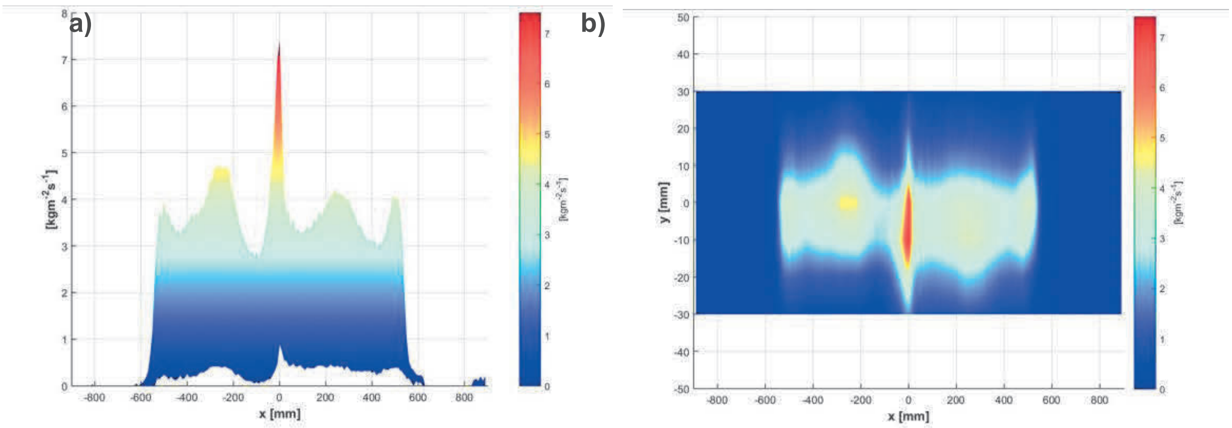


Figure 4 Example of a water distribution measured with the NMS (V(H_2O) = 4.5 l / min, p(AIR) = 1.3 bar); a) Front view, b) Top view

2.2. HTC measurement

The HTC measurement arrangement is shown in **Figure 5**. Knowing the whole water distribution, HTC measurements can be done at characteristic positions of the spray. Therefor the nozzle is turned about 180 ° so the water/air mixture can reach a sample cylinder located at the top of the chamber. Before the cylinder, made of corrosion resistant steel (1.4841), is moved through the spray it is heated up to a defined surface start temperature by inductive heating. Three thermocouples are placed inside the cylinder at different distances to the experimental sample surface. There they record the change in temperature caused by the cooling process from which the HTC can be calculated using an inverse heat conduction method. This HTC accounts the convective part as well as the part caused by radiation [8].

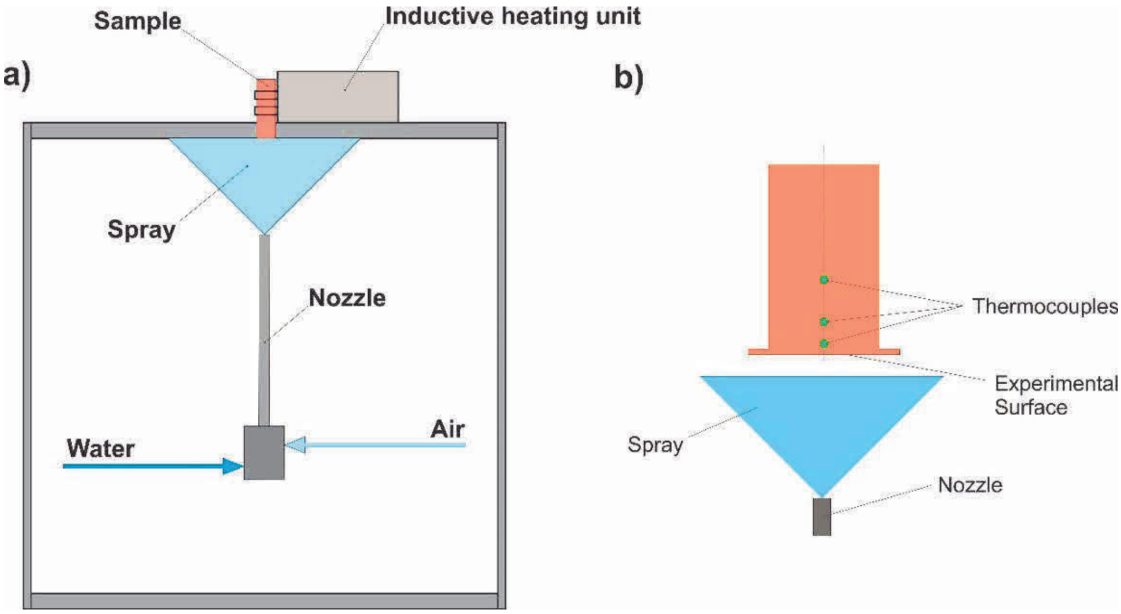


Figure 5 a) Arrangement for HTC measurement, b) Sample cylinder

3. RESULTS

To determine the influence of water flow, air pressure and nozzle distances, six different parameter set-ups were defined. The varied parameters are summarized in **Table 1**. For every set of parameters the WD and the HTC for two overlapping flat fan nozzles of the same type were measured.

Table 1 Overview on used parameter set-ups

Set-up	V(H_2O) [l / min]	p(AIR) [bar]	Nz [mm]	Nx [mm]	v [m / min]	T_{Start} [°C]
P1	4.5	1.3	205	527.6	1.3	950
P2	4.5	2.0				
P3	9.35	1.3				
P4	4.5	1.3	271	700		
P5	4.5	2.0				
P6	9.35	1.3				

To examine the change of HTC over the spray width, measurements were done at several positions which are listed in **Table 2**.

Table 2 HTC measurement positions

Nz - Nx [mm]	x-Position [mm]							
205 - 527.6	-550 +550	-500 +500	-400 +400	-300 +300	-200 +200	-100 +100	0	-
271 - 700	-700 +700	-600 +600	-500 +500	-400 +400	-300 +300	-200 +200	-100 +100	0

For a better comparison between the results four characteristic values were calculated from the gained data. For the WD these values are the maximum water impact density (WID_{max}) and the sum of water impact density

(WID_{sum}) in y-direction at defined x-Positions. Similar values are found for the HTC. The maximum heat transfer coefficient (HTC_{max}) and the heat transfer coefficient integrated over spray contact time (HTC_{int}). Examples are shown in **Figure 6**.

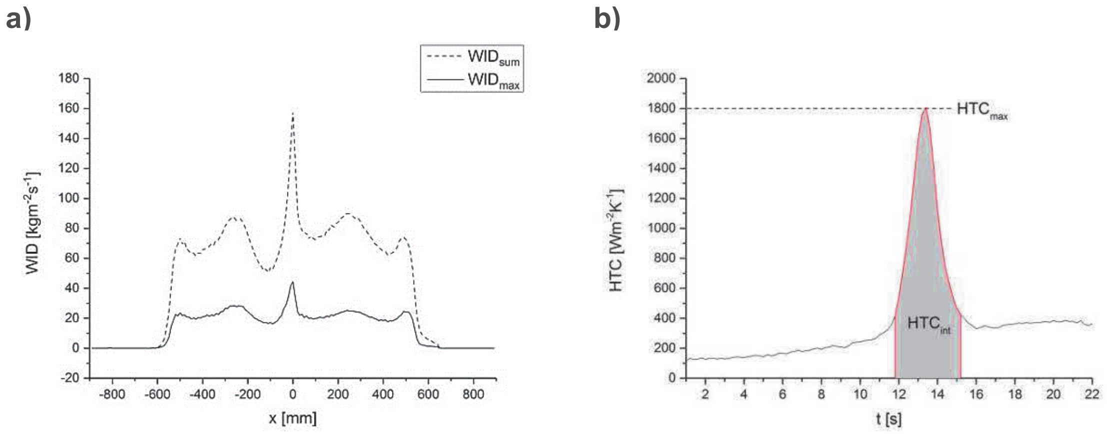


Figure 6 a) WID_{max}, WID_{sum}, b) HTC_{max}, HTC_{int}

3.1. Discussion

Figure 7 and **Figure 8** compare WID_{max} and WID_{sum} as well as HTC_{max} and HTC_{int} for all used nozzle parameters (**Table 1**) measured at the defined measurement positions (**Table 2**).

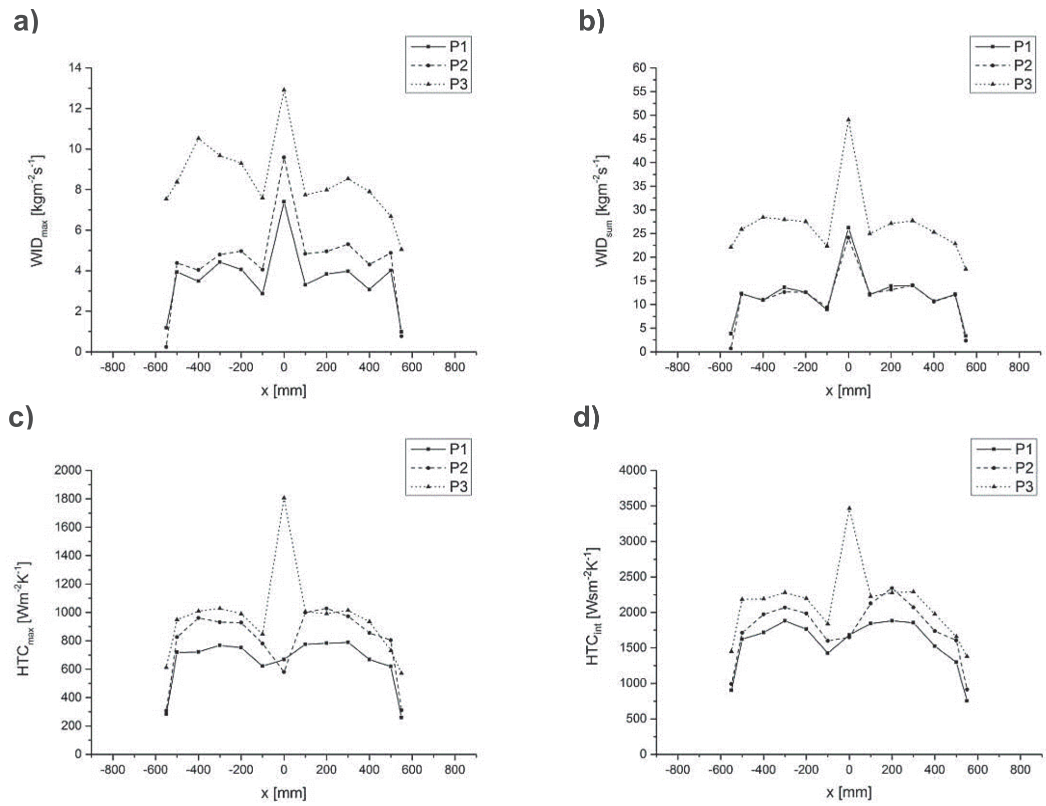


Figure 7 a) WID_{max}, b) WID_{sum}, c) HTC_{max}, d) HTC_{int} at measurement positions using parameter set-ups P1, P2 and P3

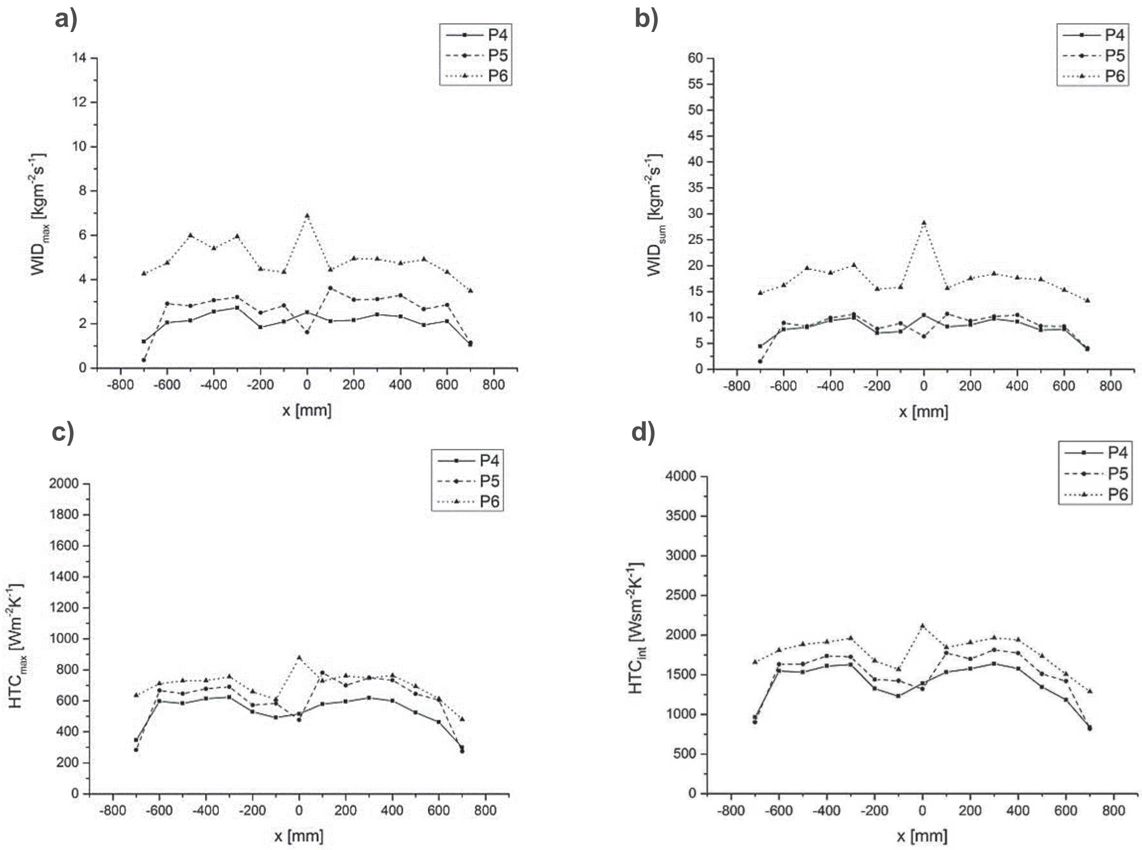


Figure 8 a) WID_{max}, b) WID_{sum}, c) HTC_{max}, d) HTC_{int} at measurement positions using parameter set-ups P4, P5 and P6

<u>Change of V(H_2O):</u>

The performed measurements show that if the volumetric water flow is increased from 4.5 l / min to 9.35 l / min, WID_{max} and WID_{sum} at all positions are increased too. Beside this an increase of V(H_2O) also results in a higher HTC_{max} and HTC_{int}.

<u>Change of p(AIR):</u>

While an increase of air pressure from 1.3 bar to 2 bar results in a higher WID_{max}, WID_{sum} does not show a significant change. In terms of HTC both values, HTC_{max} and HTC_{int}, get increased probably by a higher spray impact pressure.

<u>Change of N_z-N_x:</u>

If the nozzle distance is enlarged from 205-527.6 mm to 271-700 mm the characteristic values for the WD and the HTC are decreased. At the same time the spray gets wider and so the area of water impingement gets increased. It is also shown that with an increase of N_z-N_x all curves get smoother; local minima and local maxima are less marked.

<u>Area of overlapping (x = 0 mm):</u>

An important point to mention is the area of overlapping. It is clearly shown that the interaction of two sprays results in a maximum of WID_{max} and WID_{sum} except in case of parameter set-up P5, where a local minimum is formed. Concerning the HTC, only P3 and P6 show a maximum in HTC_{max} and HTC_{int} at x = 0 mm.

4. CONCLUSION

The performed experiments confirm a high dependence of water distribution and heat transfer coefficient from nozzle operation parameters like water flow, air pressure and nozzle distances. Especially the area of overlapping is highly influenced by a change of these parameters. The found results underline the importance of nozzle characterization using an experimental set up like the NMS at Montanuniversitaet Leoben.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the funding support of K1-MET GmbH, metallurgical competence center. The research program of the K1-MET competence center is supported by COMET (Competence Center for Excellent Technologies), the Austrian program for competence centers. COMET is funded by the Federal Ministry for Transport, Innovation and Technology, the Federal Ministry for Science, Research and Economy, the provinces of Upper Austria, Tyrol and Styria as well as the Styrian Business Promotion Agency (SFG).

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