INVESTIGATION OF HEAT TRANSFER WITHIN AN ARRAY OF IMPINGING JETS WITH LOCAL EXTRACTION OF THE SPENT FLUID

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Introduction

One of the most sensitive steps during the manufacturing of high technological functional films is the drying process. The performance of organic and printed electronics (e.g. polymer solar cells, OLEDS or Li-Ion batteries) depends on the drying conditions and hence homogeneous drying under predefined conditions has to be realized. Over the last decades it has been shown that arrays of impinging jets can be used to achieve high drying rates. The disadvantage is the highly inhomogeneous distribution in the field of the exchange variables. To minimize the effects caused by interaction of neighboring jets, the spent air has to be extracted pre interaction. Since the target plate can’t be used to route the spent fluid out of the domain, the extraction realized has to be using holes in the orifice plate.

In this work, numerical investigations using the commercial solver ANSYS FLUENT® have been performed to determine the distribution of the local heat transfer coefficient at the target plate within an array of impinging jets with local extraction of the spent fluid. The presented case studies include a variation in nozzle design and array structure. Based on these studies, transient heat transfer experiments using thermochromic liquid crystals (TLCs, [1]) will be performed to investigate the most promising configurations.

Experimental

To determine the distribution of the heat transfer coefficient under an array of impinging jets, a method applying the analytical solution of the heat transport equation considering the target plate as semi-infinite is used. A schematic drawing of the test rig (under construction) is shown in Figure 1.

To match the assumptions made and to be able to evaluate the heat transfer coefficient, the semi-infinite specimen has to undergo an ideal step change of the temperature of the surrounding gas phase. Knowing the initial temperature distribution throughout the specimen T_0, the temperature of the fluid T_f and the evolution of the wall temperature T_w of the specimen as a response to the step change, Eq. 1 [2] gives the respective heat transfer coefficient, α.

$$\frac{T_w - T_0}{T_f - T_0} = 1 - \exp\left(\alpha^2 \frac{t}{\rho_w c_{p,w} \lambda_w}\right) \operatorname{erfc}\left(\alpha \sqrt{\frac{t}{\rho_w c_{p,w} \lambda_w}}\right) \tag{1}$$

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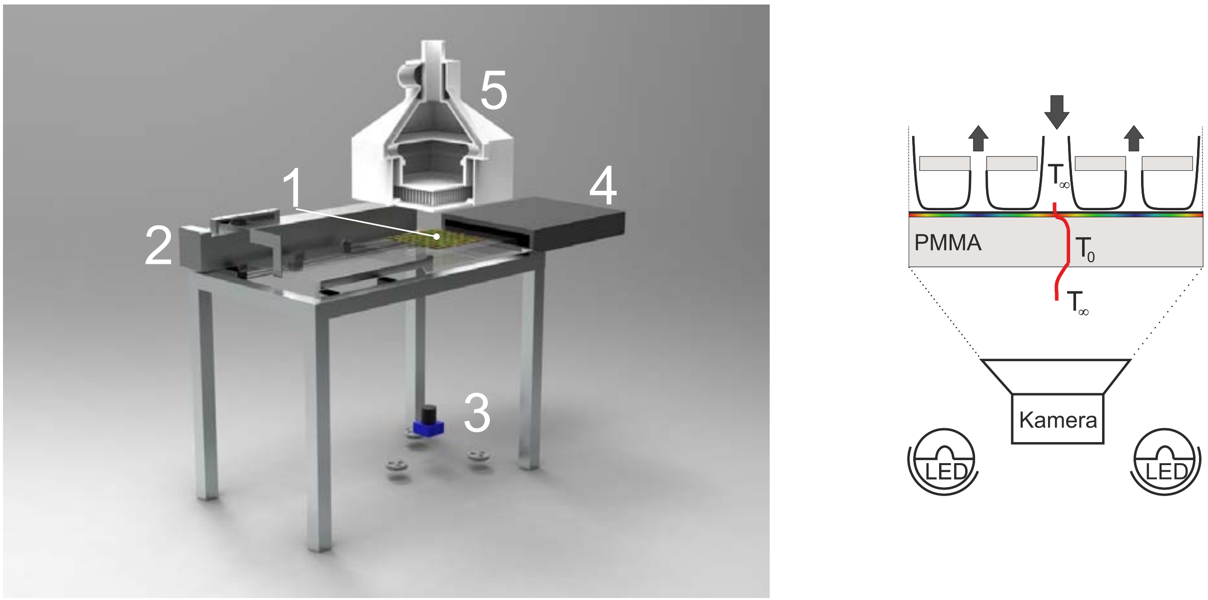

Figure 1: Scheme of the developed test rig: Transparent target plate (PMMA) (1), pneumatic cylinder (2), camera and lighting system (3), oven (4) and nozzle system (5).

A challenging task is to determine the evolution of the wall temperature without disturbing the flow field. In the present study we use a coating of TLCs as indictor for the wall temperature. To be able to correlate a color indicated by the TLCs to a certain temperature value, a calibration is needed. A copper plate has been built with a heat sink on the one and a heat source on the other end (see Figure 2).

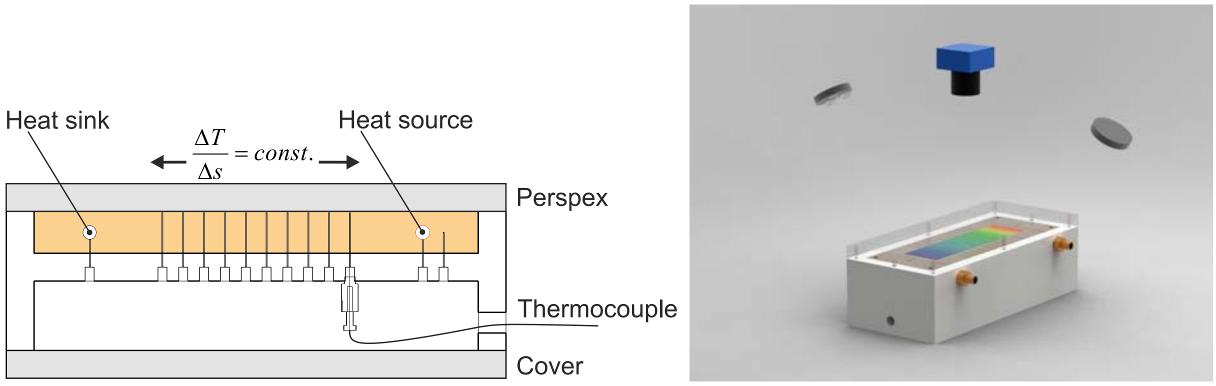

Figure 2: Schematic drawing of the TLC calibration unit: Copper plate containing heat sink and heat source to induce linear temperature gradient equipped with thermocouples.

This results in a linear temperature gradient over the copper plate. The temperature of the wall is measured at discrete positions using thermocouples close to the surface. By interpolation the distribution of the temperature of the complete surface can be resolved. Figure 3 shows the typical color play of a TLC on the surface of the copper plate and the resulting correlation between temperature and RGB intensity.

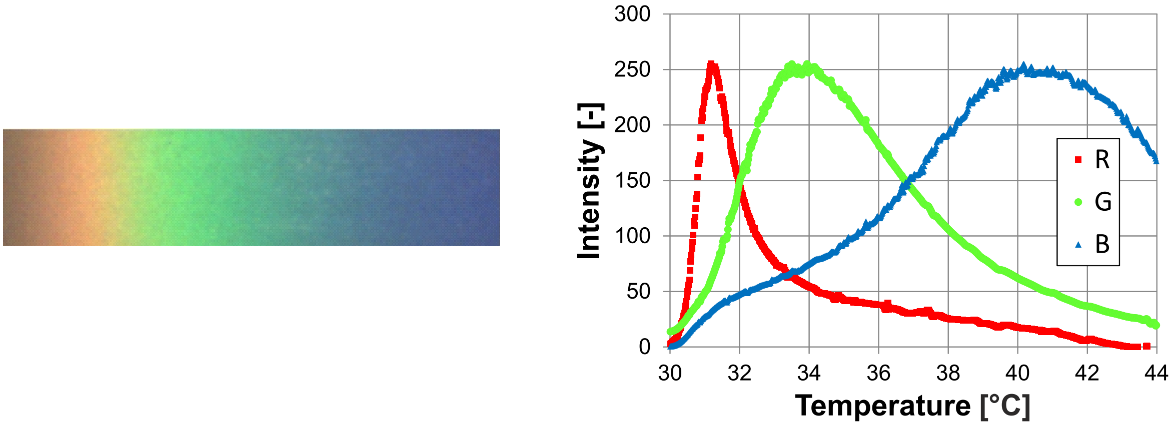

Figure 3: Color play of a thermochromic liquid crystal, left and correlation between temperature and intensity for a calibration of a TLC, right.

With the exact correlation, a CCD camera can be used to spot a certain event (e.g. peak of Green intensity) in the evolution of the wall temperature by capturing a video. A pixel of the captured picture, showing the event earlier in time must have seen a higher heat transfer coefficient compared to a pixel showing the event later. Figure 4 shows the evaluation routine schematically.

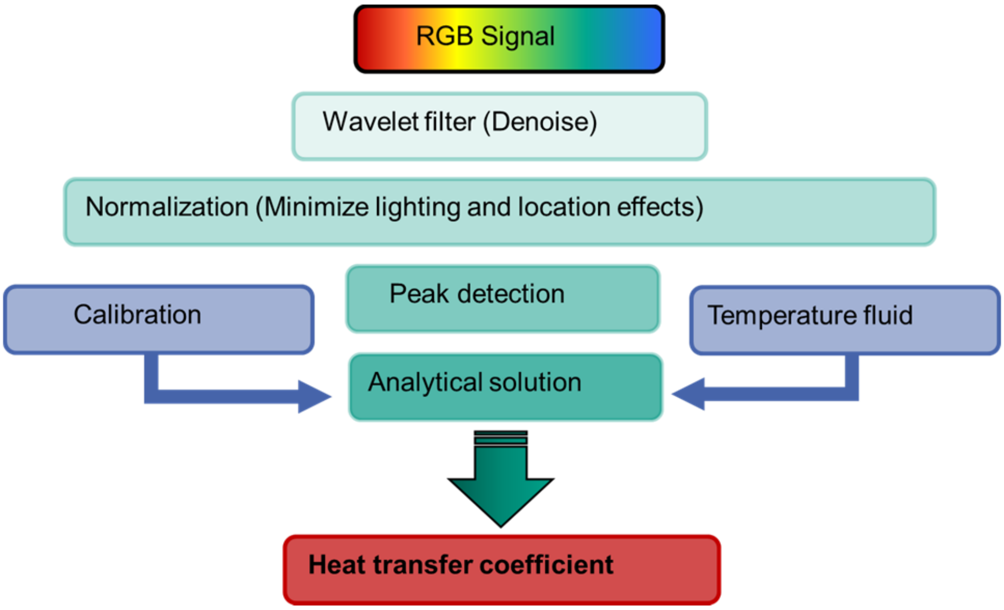

Figure 4: Scheme of the evaluation routine to determine heat transfer coefficients from transient experiments using TLCs.

Numerical

Numerical investigations of arrays of impinging jets with local extraction of the spent fluid over the orifice plate have been performed. Based on a staggered array of impinging jets without effusion holes, different configurations have been investigated. To perform the numerical calculations, the commercial solver ANSYS FLUENT$^{®}$ has been used. The boundary conditions that have been set for the basic case are visualized in Figure 5.

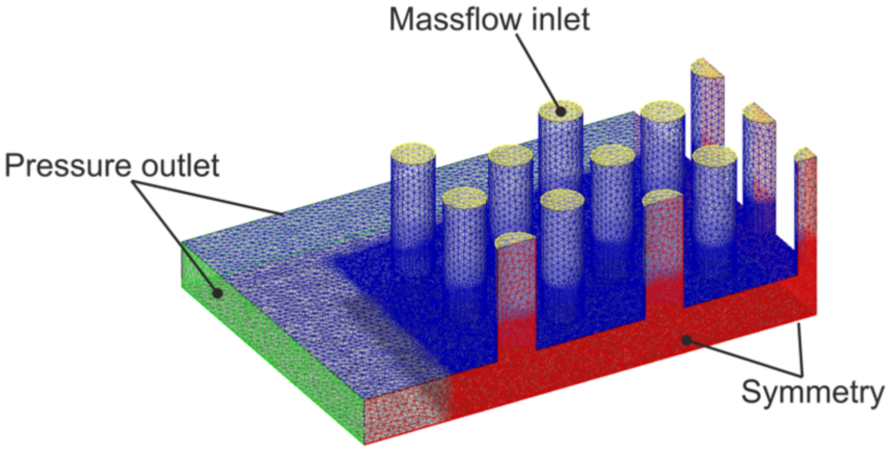

Figure 5: Boundary conditions set for the basic case (uniform and staggered array).

Mass flow inlet and pressure outlet (ambient pressure) have been combined to reach a Reynolds number of $Re = 10000$ with respect to the diameter of a nozzle. The separation distance has been set to $z/d = 1$. To model the appearing turbulence effects the $\kappa - \epsilon$ realizable model with wall enhancement implemented in FLUENT has been used [3]. Figure 6 shows the results for the basic configuration without extraction and two configurations including extraction over the orifice plate. To achieve a homogeneous distribution of the heat transfer coefficient, in a first step the interaction effects of neighboring jets have to be minimized. It can be seen that by surrounding the jets with a hexagonal pattern of extraction holes (configuration 3) unit cells can be created. In a next step the high differences of the heat transfer coefficients between the stagnation region and the transition region have to be equalized.

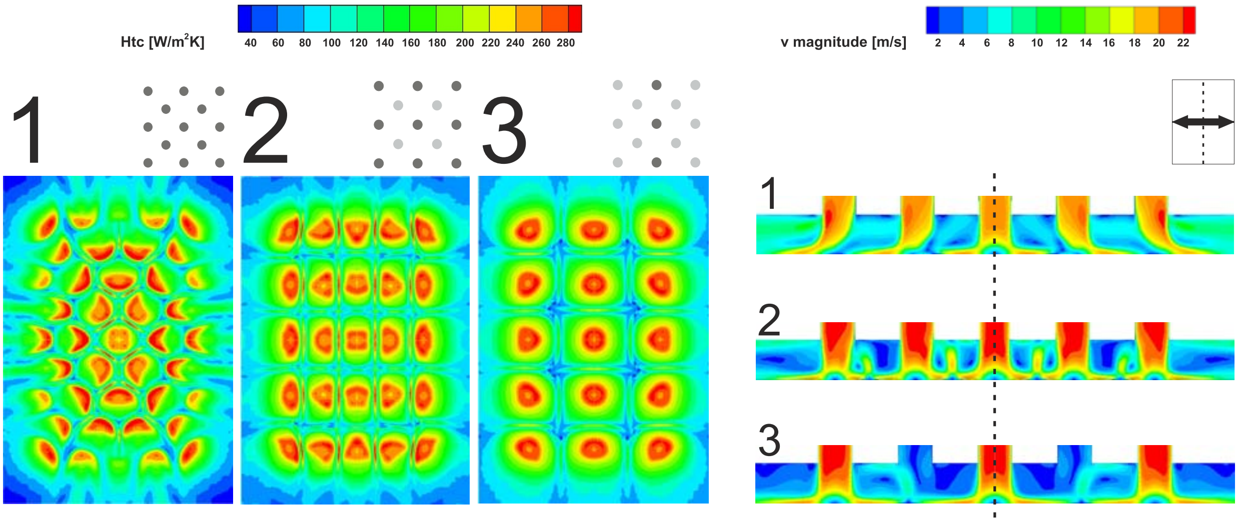

Figure 6: Heat transfer coefficients at target plate and velocity distribution at the center line predicted by the solver.

References

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