# Numerical Analysis of Cooling of a Hot Plate by an Array of Submerged Microjets

Adrian Ciepliński[1, b)], Piotr Łapka[1, a)] and Michał Wasik[1, c)]

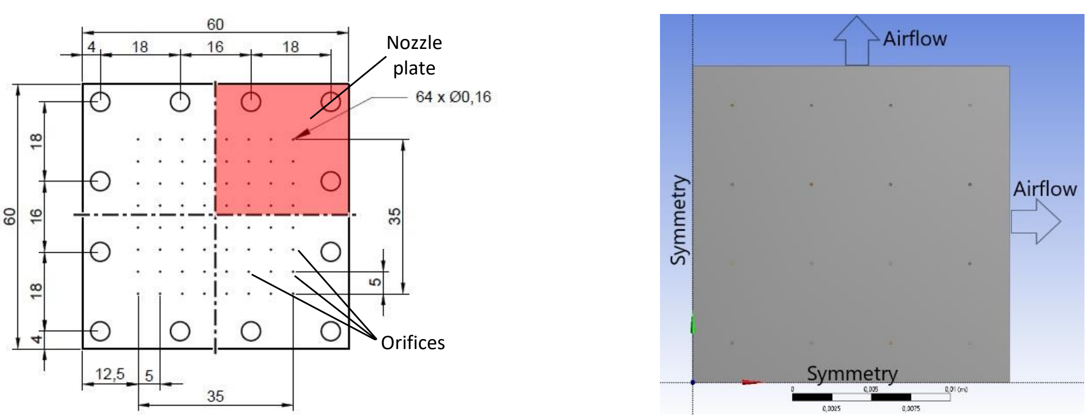
[1]*Institute of Heat Engineering, Warsaw University of Technology, 21/25 Nowowiejska St., 00-665 Warszawa, Poland*

[a)]Corresponding author: piotr.lapka@itc.pw.edu.pl
[b)]a.cieplinski@gmail.com
[c)]michal.wasik@itc.pw.edu.pl

**Abstract.** The effect of a distance between a nozzle and hot plates on flow and heat transfer characteristics was investigated numerically for an array of submerged air microjets. Considered numerical model consisted of 16 microjets, arranged in the regular array of 4×4. The compressible steady state air flow, including turbulent effects, was model applying the SST *k*-*ω* turbulence model. Numerical simulator was developed in the ANSYS Workbench environment. During analyses the jet diameter-based Reynolds number and jet pitch to jet diameter ratio were equal to $Re_d = 1100$ and $s/d = 31.25$, respectively, while the distance between the nozzle and hot plates to jet diameter ratio was set to $H/d = 3.125$, 25 and 50. In terms of heat transfer, the best distance-to-jet diameter ratio was found to be $H/d = 25$. Increase of this ratio resulted in more uniform distribution of temperature and heat transfer coefficient on the hot surface and drop in cooling performance. The effect of lateral flow on adjacent jets was the most significant for $H/d = 3.125$ and decreased with rise in this ratio.

## NUMERICAL MODEL OF AN ARRAY OF SUBMERGED MICROJETS

The considered geometry consisted of a space where the air jets which were generated in orifices were developed, impinged on the heater surface and then flow out through lateral openings – see Fig. 1. The nozzle plate consisted of 64 orifices of diameter and *x* and *y* pitches equal to $d = 0.16$ mm and $s_x = s_y = 5$ mm, respectively. It gave the jet pitch to jet diamter ratio of $s/d = 31.25$. In simulations only one fourth of the geometry presented in Fig. 1a was considered due to symmetry. The geometrical model with symmetry planes, orifices and air outlets is shown in Fig. 1b.




(a) (b)

**FIGURE 1.** *Schematic of cooling system with the jet array: (a) sketch with dimensions and highlighted area considered in the modeling, (b) top view of the geometrical model of space between the nozzle and hot plates with boundary conditions*

Dimensions of the computational domain were equal to 20×20×$H$ mm, where three heights of the space between the nozzle and hot plates were assumed, i.e., $H$ = 0.5 mm, 4 mm and 8 mm. These values corresponded to the following distance between plates to jet diameter ratios: $H/d$ = 3.125, 25 and 50, respectively.

Computational meshes were prepared by sweeping surface meshes in the direction perpendicular to the nozzle and heater surfaces. As the most sensitive regions of the flow are outlets of jets and jet impingement areas, meshes were refined in these regions. To generate better meshes in flow sensitive regions, sizing of elements inside the cylinders embracing jets was decreased. Grids for $H$ = 0.5, 4 and 8 mm consisted of approximately 37.22, 36.75 and 43.23 million of elements, respectively. The steady state and compressible air flow was assumed in the space between the nozzle and hot plates. Therefore, the $k$-$\omega$ turbulence model was applied which is considered among other models to predict the most accurate results for the jet impingement phenomenon. At first for each orifice velocity, turbulence and temperature profiles were generated for jet diameter-based Reynolds number of $Re_d$ = 1100. Then these profiles were applied in main simulations of fluid flow in the domain between the nozzle and heater plates with variable $H/d$ ratio.

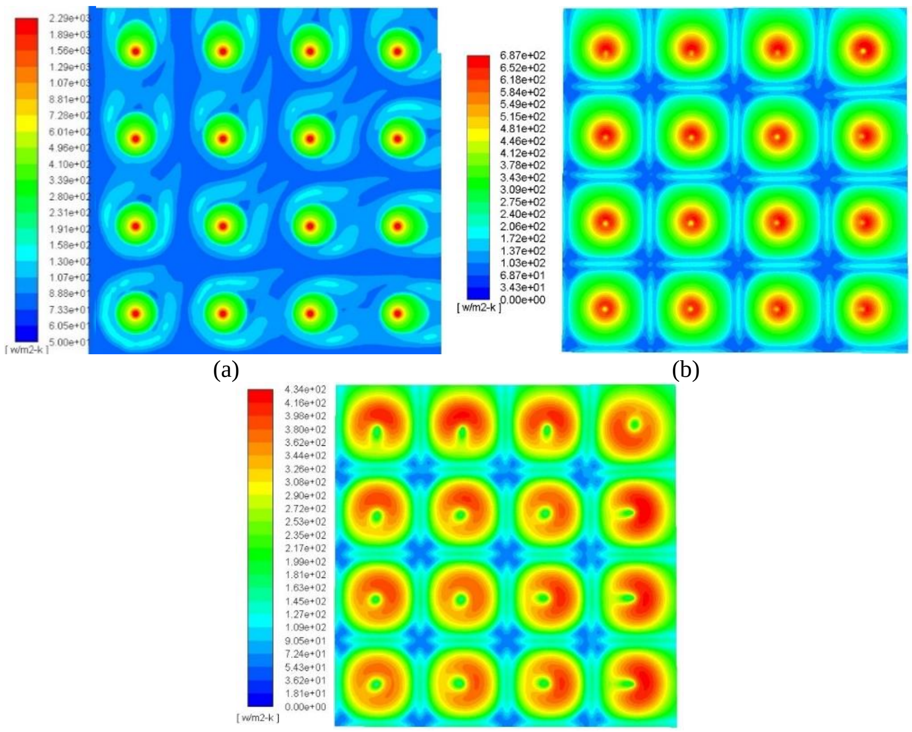



**FIGURE 2.** *HTC at the heater surface for Re = 1100 and for: (a) H/d = 3.125, (b) H/d = 25 and (c) H/d = 50*

## RESULTS

Figure 2 presents distributions of heat transfer coefficient (HTC) at the hot plate for three values of the distance between plates to jet diameter ratio. Bottom left corners of Fig. 2a, b and c refer to the center of the heater, whereas top and right edges to air outlets. The impingement and stagnation zones are clearly visible – see red and blue colored areas, respectively in Fig. 2. In these regions the highest and lowest values of HTC are observed, respectively. If the jet height $H$ was increased, the maximum value of HTC falls. However, increase of the jet height resulted in enlargement of the area with high value of HTC. In terms of heat transfer, the best distance between plates to jet diameter ratio was found to be $H/d$ = 25. For this value the highest average HTC at the heated surface was observed and average temperature of the heater plate was the lowest. The influence of lateral air flow is also clearly visible and was the most significant for the ratio of $H/d$ = 3.125. With increase in the distance between plates this effect decreased.

## ACKNOWLEDGMENTS

This work has received funding from the Faculty of Power and Aeronautical Engineering of Warsaw University of Technology in the framework of statutory activity.