# Numerical study of the heat transfer characteristics of impingement cooling surface with inhomogeneous temperature distribution

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## 1 Introduction and problem formulation

An impingement cooling system is an array of jets with high velocity fluid which is made to strike a target surface. Such systems are installed in electronic devices, aero engines, heavy industry equipment and others. Many experimental and numerical investigations of arrays of impingement cooling jets directed to the flat surface with constant temperature have been performed. Many of them are focused on high Nusselt number delivery [1]. The majority of the studies are experimental ones. However many simulations of the impingement cooling systems are numerical [2]. Only a few are devoted to the problem of cooling a surface with an inhomogeneous distribution of temperature. Such situation occurs in many technical applications such as photovoltaic cells. The main goal of the numerical investigation was to examine an inline array of ten impingement jets which is heated with various heat fluxes $q_w(x)$. The impingement cooling system consists of an array of ten cylindrical impingement nozzles directed normally to the flat surface. In this study diameter $D$=0,8 mm of the jet was taken into consideration. The nozzle exit-plate distance $X/D$=8 and the nozzle pitch-diameter radio $S/D$=8 were constant for all simulations. At the first analysis the wall, the jet impinged onto was represented by the constant heat flux $q_w(x)$=5000W/$m^2$ and later on by the three decreasing linear functions $q_w(x)$.

## 2 Solution method and numerical setup

The simulations were performed using Computational Fluid Dynamics (CFD) code Ansys CFX. In the present investigation the k - $\omega$ shear stress transport (SST) turbulence model was used. SST model is recommended for such applications [3]. To validate the numerical technique and the solution procedure the comparison of numerical results of an impingement cooling system of surface with uniform temperature distribution with experimental were performed which showed satisfying agreement [4]. The numerical calculations were carried out using unstructured tetrahedral grids with 1,79 mln elements and 323119 nodes generated by the Ansys CFX mesher. The influence of the numerical grid density on the results of the heat transfer coefficient and the Nusselt number in the stagnation region was taken into consideration. As to investigate the sensitivity of the results of the numerical analysis, the Grid Convergence Index GCI was calculated [5] and it might be concluded that numerical results on the fine grid were grid independent [6].

## 3 Results and discussion

Flow of an array of ten impinging nozzles had a very complex behavior for each type of the jets and inlet flow parameters. It is a result of the deflection at the stagnation area (especially at the first jets) and because of the jet to jet interaction, which is called "fountain effect". The sudden change in the flow direction in the nozzles before striking onto the target plate resulted in the impinging jet deflection angle in the direction of the flow inside the distribution tube. This was also observed in [7]. The optimal system configuration for a given heat flux gradient $q_w(x)$ will be determined by the constant mass flow rate and the uniform Nusselt number distribution on a cooled surface. The usage of a constant heat flux$q_w$=5000W/$m^2$ resulted in the highest averaged Nusselt number $Nu$=4,59. Also it was noticeable that the line of the averaged Nusselt number decreased in the direction of the flow in the distribution tube for the heat flux function $q_w(x)$=5000-1000W/$m^2$ and $q_w(x)$=5000-0W/$m^2$. The heat flux function $q_w$=5000-25000W/$m^2$ represented most uniform values of the Nusselt number Nuo in the stagnation region for all of the jets. Presented conclusions are significant for the designers to handle with the temperature gradient on the cooled surface. Especially during the design of the photovoltaic cells or turbine cooling systems. Further investigations are presented in [8].

## References

[1] San J. Shiao W. *Effect of jet plate size and plate spacing on the stagnation Nusselt number for a confined circular air jet impinging on a flat surface*, International Journal of Heat and Mass transfer 49 pp. 3477-3486 2006.

[2] Zukowski M. *Heat transfer performance of a confined single slot jet if air impinging on a flat surface*, International Journal of Heat and Mass Transfer 57 pp 484-490 2013.

[3] Zuckerman N. Lior N. *Jet impingement heat Transfer: Physics, Correlations and Numerical Modeling*, Advanced in Heat Transfer Vol. 39 2006.

[4] Marzec K. Kucaba-Pietal A. *Applications of computer science in impingement cooling system design*, Pre-Proceed. of 9th International Conf. on Applied Mathematics Baia Mare, Romania, 2013

[5] Blonski S. 2009 PhD Thesis: *Laminar-turbulent flow analysis in micro-channels*, Polish Academy of Science, Institute of Fund. Techn. Research.

[6] Marzec K. Kucaba-Pietal A. *Heat transfer characteristic of an impingement cooling system with different nozzle geometry*, Journal of Physics Conference Series Ser. 530, 2014.

[7] Marzec K. Kucaba-Pietal A. *Numerical investigation of a heat transfer characteristics of an impingement cooling system with non-uniform temperature on a cooled surface*, Journal of Physics Conference Series Ser. 745, 2016.

[8] Marzec K. Kucaba-Pietal A. *Numerical investigation of local heat transfer distribution on surfaces with a non-uniform temperature under an array impinging jets with various nozzle shape*, International Journal of Numerical Methods in Engineering - under review.