CFD Letters 11, Issue 9 (2019) 59-68

CFD Letters

Journal homepage: www.akademiabaru.com/cfdl.html
ISSN: 2180-1363

On Numerical Investigation of Nusselt Distribution Profile of Heat Sink Using Lateral Impingement of Air Jet

Open Access

Umair Siddique[1,*], Emaad Ansari[2], Sher Afghan Khan[3], Rajesh Patil[4]

[1] Department of Mechanical Engineering, Mukesh Patel School of Technology and Management, NMIMS University, Mumbai, India
[2] Department of Mechanical Engineering, MHSSCOE, Mumbai University, Mumbai, India
[3] Department of Mechanical Engineering, IIUM, Kuala Lumpur, Malaysia
[4] Department of Mechanical Engineering, Mukesh Patel School of Technology and Management, NMIMS University, Mumbai, India

ARTICLE INFO

Article history:
Received 6 August 2019
Received in revised form 16 September 2019
Accepted 25 September 2019
Available online 30 September 2019

ABSTRACT

The looming world of electronic packaging systems and material processing industries needs a non-uniform cooling of product in order to meet the demanding challenges. Generally, impinging air jet over heat sink is used for its cooling. As far as the non-uniformity in the cooling rate is concerned, lateral geometric thickness and thermo-physical properties of target surface plays a vital role in its contribution. Study of previous research works avails immense gap in the area of characteristic heat transfer augmentation study. Looking into this, the present work takes an assignment to justify the measure of non-uniformity in the Nusselt distribution curve and its dependency on geometric thickness. Also the dependency of Reynolds number and nozzle to the target spacing in designing the Nusselt profile is observed graphically. It is seen that, after a particular critical thickness of 0.5 mm the Nusselt profile seems to be saturated and constant throughout the radial distance. Not only that, an inverse variation is observed between the magnitude of area averaged Nusselt number and non-dimensional geometric thickness (t/d). This inverse variation is applicable up till a particular critical value of a non-dimensional geometric thickness of 0.05.

Keywords:
Computation; electronic packaging; grid; heat transfer; Nusselt profile; Reynolds number; sink; turbulence; thermal conductivity

1. Introduction

Research in the field of heat transfer augmentation with the help of steady air jet impinging over the heat sink finds abundant applications in material processing industries, drying technologies and electronic packaging systems. As far as the performances of these appliances is concerned, determination of local cooling rate due to the impingement of air jet plays a bottom line role. This is regarded as one of the best attempts to replace the noisy components like fans and blowers in the cooling technologies. Cooling of these appliances in the electronic system using air jet gives comparatively higher cooling rate as that achieved by conventional cooling practices. The

* *Corresponding author.*
E-mail address: umair.siddique@nmims.edu (Umair Siddique)

advancement of cooling technology in electronic packaging systems and material processing industries recently demanded the practice of non-uniform cooling rate to be established over the heat sink. The benefit of non-uniform cooling rate in material processing industries was achieving variable metallurgical properties.

It is seen that plenty amount of research is seen to be done in the area of heat transfer augmentation by varying different injection and geometric parameters. Also the numerical analysis for the same is far accurately reported with a well-defined and recommended turbulence model. But a very least effort is observed in studying the Nusselt distribution and non-uniformity present in it. As seen from the above survey the profile is greatly affected by the thickness of the plate and its thermo-physical properties. Hence studying the local and area average heat transfer rate by varying thickness would prove out to be beneficial. For a very thin target surface, the slope of Nusselt distribution profile tends to decrease strongly with respected to the radial distance over the target surface. While for thick plates, the magnitude remains same throughout the surface. Hence the non-uniformity in Nusselt distribution profile seems to be more sensitive towards the thickness of target surface. Also the characteristic study of non-uniformity in Nu distribution profile finds abundant applications in cooling of electronic chips and material processing industries.

Above all, an adequate amount of insufficiency in the research area for determining the non-uniformity in the Nusselt distribution profile is observed. Not only that its effect with variation in geometric thickness of target plate is also studied. Umair and Nitin [1-2] carefully studied turbulence model, grid independence and non-uniformity of Nusselt profile. Present work uses same methodology and inclines present investigation towards the determination of non-uniformity occurring in the Nusselt distribution curve. This is achieved by numerically evaluating Nusselt distribution profiles for different target surface. These target surfaces are only subjected to the variation in its geometric thickness while its metallurgical properties are maintained constant. The present work also aims to investigate the dependency of Nusselt profile on the Reynolds number and nozzle to the target spacing.

Kirsch *et al.,* [3] performed longitudinal heat transfer augmentation on oblong pin fins and compared with cylindrical pin fin. 30% to 35% increment in heat transfer rate with use of oblong pin fin over cylindrical one was observed. Also, a very sensitive dependence of steam wise and span wise spacing on heat transfer rate for oblong pin fin was concluded. They reported the formation of weak boundary layer in case of oblong pin fins and strong boundary layer thickness in case of cylindrical fins inhibiting the heat transfer rate.

Chapman and Lee [4] performed thermal analysis on elliptical pin fin heat sink and compared it with cylindrical one. The above research was carried out in terms of flow bypass and thermal resistances. As far as cylindrical fins are concerned bypass of air takes place less as compared to that in elliptical. As result of which elliptical offers more thermal resistances as compared to cylindrical. Ames *et al.,* [5] on the other hand determined the ratio of heat transfer due to temperature gradient and that due to turbulence. Here, the number of row at which heat transfer is a maximum is well examined. Also they reported the dependency of surface angle of impingement on the heat transfer ratio and concluded the augmentation to be highest at 100 degree angle of impingement. Siw *et al.,* [6] studied the effect of detached space on heat transfer in pin fin arrays. Also, demonstrated the augmentation at H/d = 4, 3 and 2 by using thermo liquid crystal technique on bases of which Nussselt number is calculated. The area averaged Nusselt number through each rows is being evaluated which justifies the dependences of Nusselt number on local velocity. The conclusion is made, that not much difference in heat transfer rate due to detached fin is observed. Also the occurrence of secondary peak in heat transfer rate at mid row was observed. Rao *et al.,* [7] examined the experimental and numerical study of flow and heat transfer in pin fin surface staggered with dimples. They observed an improvement of 8% to 20% over the range of Reynolds number. However for the flow across the dimples located immediately downstream the pin in the channel, apparently one additional strong vortex is induced in the left and upstream half of the dimple and then injects into the wake behind the pin fin which improves the three dimensional turbulent mixing in the wake. On the hand Shi *et al.,* [8] studied the heat transfer characteristic of pin fin array by inducing some external vibration. Due to this external effect thermal boundary layer gets affected and enhancement in heat transfer rate of 90% is observed. As a result of this vortex generation takes place and heat transfer increases. There exists an optimum frequency at which the heat transfer is maximum which signifies the resonance of vibrating frequency with any one of the fundamental frequency. Lupton *et al.,* [9] demonstrated the local heat transfer characteristic for submerged miniature of 0.95mm diameter air jet impinging normally onto an ohmically heated flat plate. The effect of heat transfer rate is significantly found to be dependent on the level of confines which is observed through simulation. Also, the dependency of confinement on the diameter of jet and velocity of impingement was reported. While stagnation heat transfer was found to be initially independent of the diameter of jet, after which stagnation point heat transfer rate gets affected. Li *et al.,* [10] performed thermal analysis on plate fin heat sink undergoing cross flow forced convection in presences of shield. The results of attaching a shield show that more coolant fluid is forced to flow into the fin to fin channel and enhances the heat transfer coefficient. This is achieved at the expense of pressure drop. Also the effect of variation in fin height and width for plate type heat sink is studied. Heat transfer rate increases with increase in Reynolds number and number of shield. Ndao *et al.,* [11] performed augmentation in heat transfer using refrigerant R134a. He demonstrated the augmentation by impinging a single jet collimated refrigerant on micro pins attached to the target surface. The enhancement of 200% in heat transfer coefficient was observed. This increase was attributed to flow mixing, boundary layer disturbance and turbulence transport. Here, the dominancy of pin surface plays a vital role in achieving more heat transfer as compared with base plate, which is valid only for refrigerants. Hence, the standoff ratio for such types of impingement is defined. This is given by the ratio of area of pin surface to the area of base surface.

Khan *et al.,* [12] analysed threaded spikes numerically and found that it has no side effects on flow field and is efficient in base pressure control of bodies. Khan *et al.,* [13] created a semi-circular grooved cavity and concluded that it is a very effective passive control mechanism for base pressure regulations. Pathan *et al.,* [14] studied the effect of variations in base pressure on internal and external suddenly expanded flows and found that similar flow field is formed in internal and external expansion. Pathan *et al.,* [15] researched on the effectiveness of nozzle pressure ratio (NPR) and evaluated that with better NPR, base pressure gets reduced. Muhammed *et al.,* [16] focussed on the flow field around a non-circular cylinder and conclude that the pressure drag coefficient are in the range of 1 to 1.42. Convergent-divergent nozzle were studied for different area ratios by Khan *et al.,* [17]. It was found that area ratio plays an important role in base pressure distribution. Japar *et al.,* [18-19] used secondary channel for enhancing heat transfer in microchannel heat sink. They also analysed the performance of nanofluid in microchannel. Mohd et al. [20] conducted numerical and experimental studies to study the hydrothermal performance of a newly designed hybrid micro channel heat sink having optimum secondary channel geometry parameter. Abubakar et al. used a magnetite-hydro peroxide Nano fluid in rectangular microchannel heat sink to study heat transfer enhancement.

The determination of local heat transfer coefficient becomes mandatory for the purpose of measuring the degree of non-uniformity in the cooling rate. For the benefit and feasibility in the study and development of empirical correlations, a non-dimensional parameter representing heat transfer is mandatory to be introduced. Nusselt number is the non-dimensional parameter used to represent the heat transfer rate in the present study. The plot of Nu against r (radial distance) of target surface truly justifies that the cooling rate is non-uniform. For the determination of cooling rate, experimental as well as numerical analysis is extensively carried out. For experimental study the basic setup comprises of an air impinging nozzle and a target surface. Constant heating is ensured at the bottom side of the target surface, while the other side is exposed to air jet. It is true that the effort required in performing the experiment is enormous, since the temperature of target surface is initially in a transient state. Hence numerical analysis is recommended.

2. Experimental Setup

The basic experimental setup for studying the heat transfer rate through aluminum plate (10 cm × 10 cm) includes a blower of capacity 0.05 m^3/s which pumps the fresh ambient air into a cylindrical chamber called air plenum. This is 150 mm × 150 mm in cross section and 1 m long containing many vertically aligned hollow tubes which helps in making the air streamlined. This research is limited to a nozzle of diameter 16 mm. Electric heater provides constant heat flux throughout the surface. DAQ ensures the recording of temperature using four K-type of thermocouples mounted diagonally over the base at r/d of 0.4375, 1.375, 2.3125 and 3.25. Hot wire anemometer (CA-1224) is used to measure the velocity of jet near to the heat sink surface. Figure 1 shows the assembled layout of the current experimental setup.

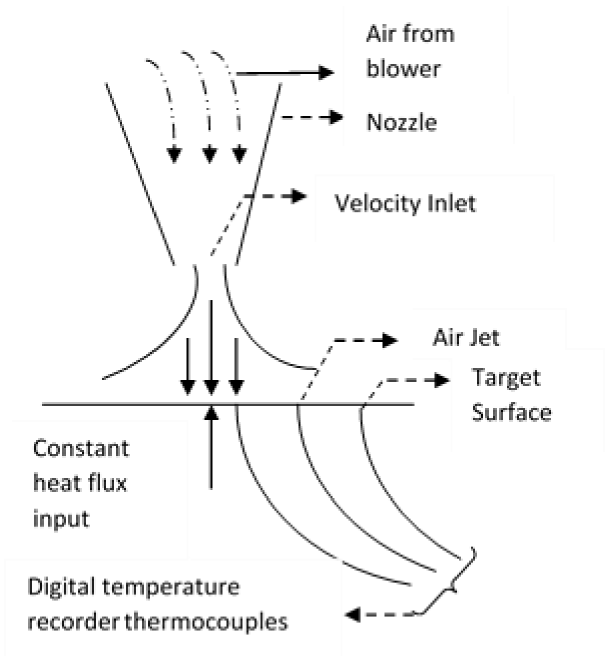

Fig. 1. Schematic layout of experimental setup

3. Grid Independence Study

It is but obvious that the magnitude of heat transfer rate will depend upon the mesh quality and density of grid in the computational domain. Hence setting the result which is independent of the grid size is a prime task. In order to compare the deviation occurring in the Nusselt profile with use of various grid sizes, area averaged Nusselt numbers are calculated for different grid size. During the process of meshing, the edge size containing nozzle – target spacing (L1) and base length of the target surface (L2) is subjected to variation in the number of division and growth rate. Number of divisions on the edges L1 and L2 are varied from 300 to 550 and 125 to 400 respectively (Figure 2). The comparison of area averaged Nusselt number with its preceding value defines the most accurate grid size. The corresponding mesh defining the best result consists of 550 × 400 numbers of divisions over edges L1 and L2 respectively.

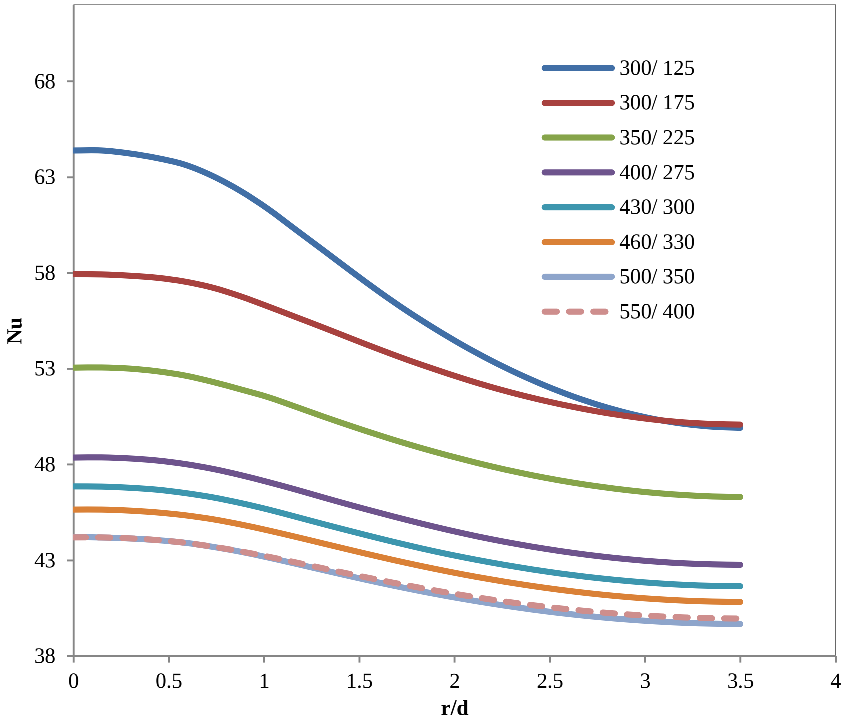

Fig. 2. Nusselt profile at different grid sizes

4. Turbulence Modelling and its Validation

The ANSYS CFX solver makes use of continuity equation (Eq. 1) and momentum equation (Eq. 2) along with energy equations for accurately predicting the heat transfer phenomenon.

$$\frac{\partial \rho}{\partial t} + \nabla(\rho.\vec{v}) = S_m \tag{1}$$

$$\frac{\partial \vec{v}}{\partial t} + \nabla(\rho.\vec{v}.\vec{v}) = -\Delta p + \Delta\bar{\bar{\tau}} + \rho.\vec{g} + \vec{f} \tag{2}$$

The prediction of flow profile due to pressure gradient and onset transition of Reynolds number is well predicted using SST turbulence model (Eq. 3 and Eq. 4). The term $(1 - F_t)$ incorporates the fluctuation in distribution of k-Epsilon and k-Omega models in far wall and near wall regions respectively.

$$\frac{\partial\,(\rho K)}{\partial t} + \frac{\partial\,(\rho U_j K)}{\partial x_j} = \frac{\partial}{\partial x_j}\left\{[\,\mu + \sigma_k\,\mu_t\,]\,\frac{\partial K}{\partial x_j}\right\} + P_k - \beta\rho K\omega \tag{3}$$

$$\frac{\partial\,(\rho\omega)}{\partial t} + \frac{\partial\,(\rho U_j \omega)}{\partial x_j} = \frac{\partial}{\partial x_j}\left\{\left[\,\mu + \frac{\mu_t}{\sigma_\omega}\right]\frac{\partial \omega}{\partial x_j}\right\} + 2(1 - F_t)\rho\,\frac{1}{\rho_{\omega 2}}\,\frac{\partial K}{\partial x_j}\,\frac{\partial \omega}{\partial x_j} + \alpha_3\,\frac{\omega}{K}\,P_k - \beta\omega\rho^2 \tag{4}$$

Intermediacy and onset transition present in the water jet. This intermediacy is well predicted by turbulence production (P_k) and dissipation (E_k) terms present in Gamma model (Eq. 5). Also, the local onset transition is predicted by differential of Reynolds number present in Theta model (Eq. 6).

$$\frac{\partial\,(\rho\gamma)}{\partial t} + \frac{\partial\,(\rho U_j\gamma)}{\partial x_j} = \frac{\partial}{\partial x_j}\left\{\left[\mu + \frac{\mu_t}{\rho}\right]\frac{\partial\gamma}{\partial x_j}\right\} + P_k - E_\gamma \quad (5)$$

$$\frac{\partial\,(\rho Re_{\theta t})}{\partial t} + \frac{\partial\,(\rho U Re_{\theta t})}{\partial x_j} = \frac{\partial}{\partial x_j}\left\{\sigma_{\theta t}(\mu + \mu_t)\,\frac{\partial Re_\theta}{\partial x_j}\right\} + P_{\theta t} \quad (6)$$

Figure 3 shows the Nusselt profile at Re = 6000 and Z/d = 4 for different turbulent models. The models are validated with experimental results. The local Nusselt magnitude at various r/d ratios evaluated using SST + Gamma-Theta turbulence model is the nearest to experimental values. Thus, SST + Gamma-Theta model predicts the most accurate results among the different turbulence models.

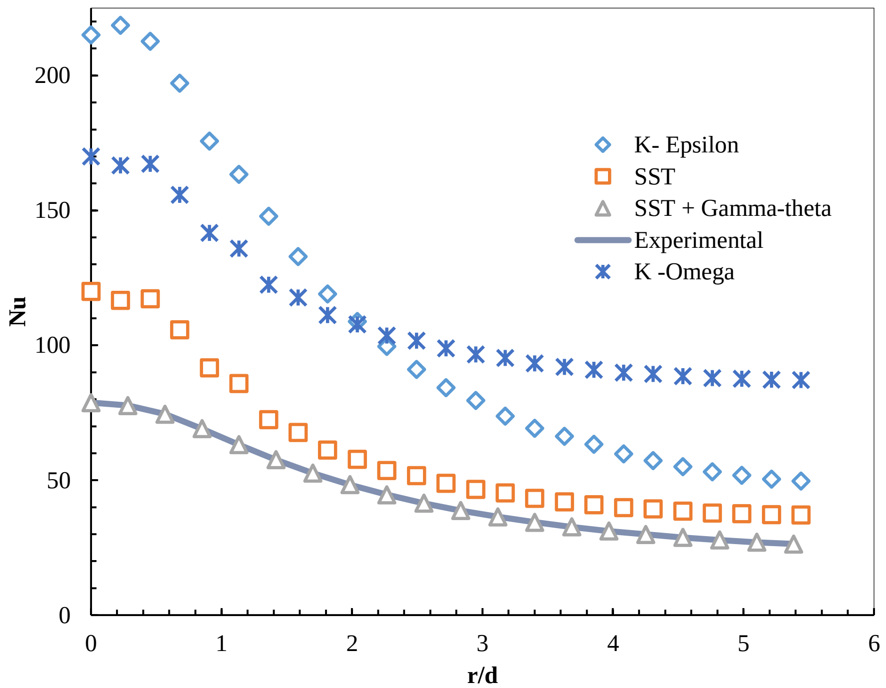

Fig. 3. Nusselt profile for different turbulence model at Z/d=4, Re=6000

5. Results and Discussion

As seen from the above survey, implementation of numerical simulation proves far beneficial over the experimental studies. For the purpose of understanding the effect of Nusselt distribution profile over the geometric thickness, simulations are being carried out at various impinging velocities and nozzle - target spacing. The present study incorporates a non-dimensional parameter which is defined as the ratio of geometric thickness to the diameter of impinging nozzle. This is done in order to promote the non-dimensional empirical correlation for local Nusselt number. Also, the critical value of the non-dimensional parameter beyond which the Nusselt distribution becomes a non-localized quantity is also justified.

The present work inclines the effort in determining the degree of non-uniformity in the Nusselt distribution profile. Various profiles for different thickness of target surface are being computed at different Reynolds number. In order to study the effect of impinging parameter over the Nusselt profile, simulation is being carried out at fixed nozzle-target (Z/d = 4). Figure 4 demonstrates the variation in local Nu values at Z/d = 4 and Re number of 5000, 10,000 and 15,000.

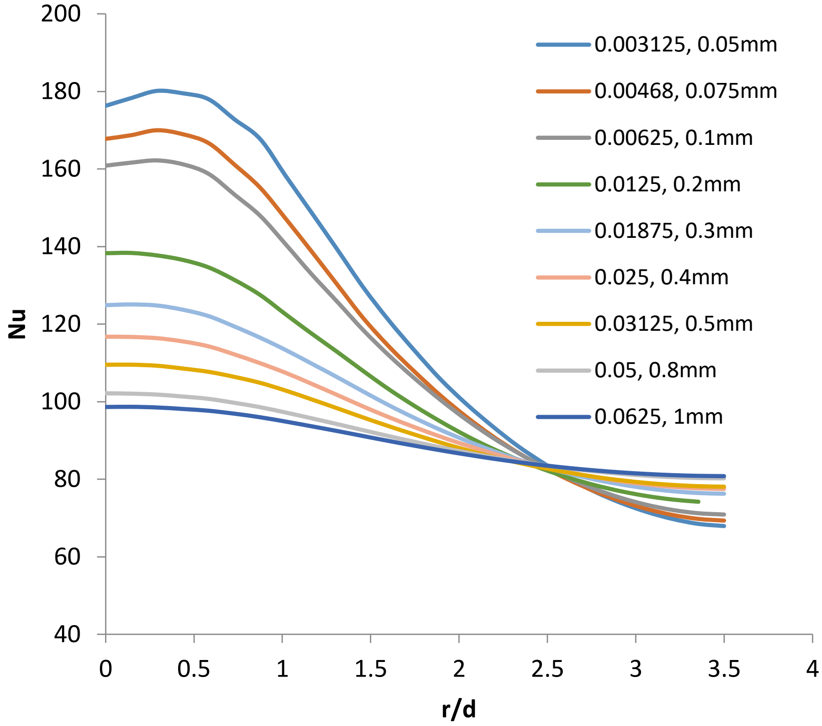

Fig. 4. Justifies the dependency of local Nusselt profile for different thickness of flat surface on Reynolds number Z/d = 4, Re = 15000

As observed from Figure 4, with increase in the magnitude of Reynolds number, tangible amount of increment in local Nusselt magnitude is observed. It is also noted that after a particular critical thickness (0.8 mm – 1 mm) of target surface, the Nusselt distribution curves almost coincides. This justifies the existences of weak thermal resistance. The corresponding characteristic thickness evaluated at this critical value of geometric thickness rounds to 0.05.

The present study is also motivated towards determining the effect of potential core of impinging air jet over the Nusselt distribution profile. This is achieved by subjecting the present computational geometry to variable nozzle-target spacing. Looking into the magnitude of penetrating momentum and base area of target surface, Nusselt distribution profiles are being evaluated at Z/d = 2, 4 and 6. While the impinging velocity is maintained constant (Re = 5000). Figure 5 demonstrates the variation in local Nusselt magnitude for different thickness of target surfaces. From the nature of profile, it is concluded that with increase in nozzle-target spacing, the Nusselt distribution profile gain more uniformity and smoothness (Figure 5). At higher nozzle-target spacing, flat plate of thickness 0.8 mm and 1 mm resembles the same profile. This justifies the independency of geometric thickness over the Nusselt distribution profile. Whereas the corresponding characteristic thickness at which this independency occurs is evaluated to be 0.05. Above all the local Nusselt magnitude is found to be strongly depended over the thickness, provided the characteristic thickness falls below the approximate value of 0.05.

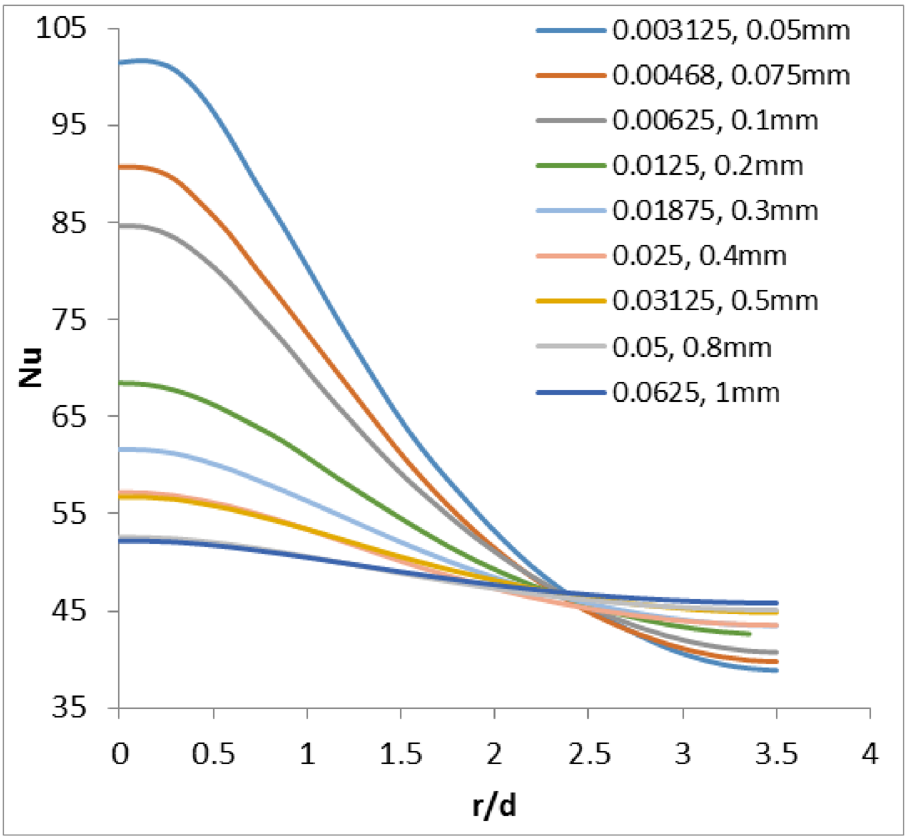

Fig. 5. Justifies the dependency of local Nusselt profile for different thickness of flat surface on Nozzle-target spacing Z/d = 6, Re = 5000.

6. Conclusion

A very careful study of present graphical results justifies the geometric thickness of target surface to be one of the strong parameters in deciding the nature of Nusselt profile. This strong dependency is valid up till a particular critical thickness. Beyond which this critical value, geometric thickness of target surface becomes a weak function of local Nusselt profile. The corresponding characteristic thickness beyond which the Nusselt profile becomes non-localized is evaluated to be 0.05. This happens due to heat conduction resistance above the characteristic thickness value becoming uniform and constant. On the other hand for the target surface possessing the characteristic thickness well below the critical value (0.05), heat conduction resistance are localized and increases away from the stagnation region. Hence the local phenomenon of heat transfer augmentation study proves to be far different for the target surface possessing characteristic thickness less than its threshold value. In the present study the corresponding characteristic thickness evaluated carries a magnitude of 0.05. The plot of local Nusselt profile at different Reynolds number and nozzle-target spacing signifies an equivalent contribution in inducing the non-uniformity in Nusselt magnitude. Hence it can be concluded that the non-uniformity in Nusselt profile is equally contributed due to the potential length and penetrating momentum of impinging air jet. This is valid for the target-nozzle geometric combination carrying a characteristic thickness below 0.05. Below this value the cooling rate proves to be well characterized. However, the saturation condition in local Nusselt profile takes place at the cost of destruction in potential core (length) of impinging jet. Beyond this optimal length of potential core, the outside air well interrupts the impinging penetrating momentum. As a result of this anomaly the local heat transfer rate becomes independent of radial distance. In spite of this, the current work leaves behind a gap for determining the exact materialistic reason responsible for variation in local thermal resistance. This study needs to be carried out within the critical limit of characteristic thickness.

References

[1] Siddique Mohd Umair and Nitin Parashram Gulhane. "On Numerical Investigation of Heat Transfer Augmentation through Pin Fin Heat sink by Laterally Impinging Air Jet.'' *Procedia Engineering* 157 (2016): 89 – 97.

[2] Siddique Mohd Umair and Nitin Parashram Gulhane. "On Numerical Investigation of Non-Dimensional Constant Representing the Occurrence of Secondary Peaks in the Nusselt Distribution Curves." *International Journal of Engineering* 29(10) (2016): 1431 – 1440.

[3] Kathryn L. Kirsch, Jason K. Ostanek and Karen A. "Comparision of Pin surface Heat Transfer in Array of Oblong and Cylindrical Pin Fins." *Journal of Turbomachinery* 136 (2014): 041015-1-10.

[4] Christopher L. Chapman, Seri Lee and Bill L. Schmidt. ''Thermal Performance of Elliptical Pin Fin Heat Sink.'' In *Proceedings of 1994 IEEE/CHMT 10th Semiconductor Thermal Measurement and Management Symposium*, (1994): 24-31.

[5] Ames, F. E., L. A. Dvorak, and M. J. Morrow. "Turbulent augmentation of internal convection over pins in staggered-pin fin arrays." *Journal of turbomachinery* 127, no. 1 (2005): 183-190.

[6] Siw, Sin Chien, Minking K. Chyu, Tom I-P. Shih, and Mary Anne Alvin. "Effects of pin detached space on heat transfer and pin-fin arrays." *Journal of Heat Transfer,* 134, no. 8 (2012): 081902.

[7] Rao, Yu, Chaoyi Wan, and Shusheng Zang. "An experimental and numerical study of flow and heat transfer in channels with pin fin-dimple combined arrays of different configurations." *Journal of Heat Transfer* 134, no. 12 (2012): 121901.

[8] Shi, Junxiang, Jingwen Hu, Steven R. Schafer, and Chung-Lung CL Chen. "Numerical study of heat transfer enhancement of channel via vortex-induced vibration." *Applied Thermal Engineering* 70, no. 1 (2014): 838-845.

[9] Lupton, T.L., Murray, D.B. and Robinson, A.J. (2008). *The effect of varying confinement levels on the heat transfer to a miniature impinging air jet*. Eurotherm, Eindhoven, Netherlands.

[10] Li, Hung-Yi, Go-Long Tsai, Ming-Hung Chiang, and Jhih-Ye Lin. "Effect of a shield on the hydraulic and thermal performance of a plate-fin heat sink." *International Communications in Heat and Mass Transfer* 36, no. 3 (2009): 233-240.

[11] Ndao, Sidy, Hee Joon Lee, Yoav Peles, and Michael K. Jensen. "Heat transfer enhancement from micro pin fins subjected to an impinging jet." *International Journal of Heat and Mass Transfer* 55, no. 1-3 (2012): 413-421.

[12] Khan Sher Afghan, A. Alrobaian, Mohammed Asadullah, Aswin, "Threaded spikes for bluff body base flow control." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 53, no.2 (2019): 194-203.

[13] Khan Sher Afghan, Abdulrahman Abdullah Al Robaian, Mohammed Asadullah, and Abdul Mohsin Khan. "Grooved Cavity as a Passive Controller behind Backward Facing Step." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 53, no. 2 (2019): 185–193.

[14] Pathan, Khizar Ahmed, Prakash S. Dabeer, and Sher Afghan Khan. "Investigation of Base Pressure Variations in Internal and External Suddenly Expanded Flows using CFD analysis." *CFD Letters* 11, no.4 (2019): 32-40.

[15] Pathan, Khizar Ahmed, Prakash S. Dabeer, and Sher Afghan Khan. "Influence of Expansion Level on Base Pressure and Reattachment Length", *CFD Letters* 11, Issue 5 (2019): 22-36.

[16] Muhammad Fahmi Bin Mohd Sajali, Abdul Aabid, Sher Afghan Khan, Fharukh Ahmed G M, and Erwin Sulaeman, "Numerical Investigation of Flow Field of a Non-Circular Cylinder", *CFD Letters* 11, Issue 5 (2019) 37-49.

[17] Sher Afghan Khan, Abdul Aabid, and Fharukh Ahmed Mehaboobali Ghasi, Abdulrahman Abdullah Al-Robaian, and Ali Sulaiman Alsagri, "Analysis of Area Ratio in a CD Nozzle with Suddenly Expanded Duct using CFD Method", *CFD Letters* 11, no. 5 (2019): 61-71.

[18] Wan Mohd Arif Aziz Japar, Nor Azwadi Che Sidik, and Shabudin Mat. "A comprehensive study on heat transfer enhancement in microchannel heat sink with secondary channel." *International Communications in Heat and Mass Transfer* 99 (2018): 62-81.

[19] Wan Mohd Arif Aziz Japar, Nor Azwadi Che Sidik, Siti Rahmah Aid, Yutaka Asako, and Tan Lit Ken. "A Comprehensive Review on Numerical and Experimental Study of Nanofluid Performance in Microchannel Heatsink (MCHS)." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 45, no.1 (2018): 165-176.

[20] Mohd, Wan. Arif Aziz Japar, Nor AzwadiCheSidik, and M'hamedBeriache," Hydrothermal Performance in a New Designed Hybrid Micro channel Heat Sink with Optimum Secondary Channel Geometry Parameter: Numerical and Experimental Studies." *Journal of Advanced Research Design* 54, no. 1. (2019): 13-27.

[21] Abubakar, S., CS Nor Azwadi, and A. Ahmad. "The use of Fe3O4-H2O4 nanofluid for heat transfer enhancement in rectangular microchannel heatsink." *J. Adv. Res. Mater. Sci.* 23 (2016): 15-24.