Proceedings of 4th RIT Post Graduates Conference (RIT PG Con-18)
NOVATEUR PUBLICATIONS
JournalNX- A Multidisciplinary Peer Reviewed Journal (ISSN No:2581-4230)
April, 13th, 2018

NUMERICAL ANALYSIS OF APPLICATION OF VORTEX GENERATOR IN PERFORATED PLATE-FIN HEAT SINK

Pritam R. Hukire
Student, Department of Mechanical Engineering,
Rajarambapu Institute of Technology
Islampur, India
prhukire@gmail.com

Dr. S. M. Sawant
Faculty, Department of Mechanical Engineering
Rajarambapu Institute of Technology
Islampur, India

Mr. Vivek P. Warade
Sr.CAE Engineer
ZeusNumerix Pvt. Ltd.
Pune, India

***Abstract*—Numerousinvestigations had been attempted to enhance the heat transfer rate from the fins. Heat transfer augmentation techniques, Perforations and arrangements of fins are some of the efficient ways to enhance heat transfer. In this study, passive heat transfer augmentation combined with the perforations on fin and numerical simulations were performed for this combined system for different flow conditions characterized by Reynolds Number ranging from 5000 to 40000. The numerical outcomes were validated against the existing experimental data for the solid fin without any perforation. Further, fins with square and circular perforations were investigated for the same flow conditions. Based on the results comparison, in terms of thermal resistance, the circular perforations on the fins provide better heat transfer rate.**

Keywords—CFD, Plate fin heat sink, Vortex Generator, Fin Perforation, Forced Convection, Heat Transfer Enhancement.

I. INTRODUCTION

Cutting edge electronic gadgets are incredibly diminished to little scale making them more compact. These devices utilizes electrical energy for their operations. The effectiveness of electronic products is subjected to heat dissipation mechanism, if the heat dissipation is not sufficient then it will damage the electronic products and furthermore may lessen their life expectancy. Heat sink is commonly used to increase the heat transfer. The heat transfer rate from the fins of heat sink can be increased by various means such as having perforations on fins, using passive device and arrangements of fins like staggered etc.Passive devises are only projections in certain forms, for example, delta wings or winglet pairs. These projections act as vortex generators, which can increase the rate of heat transfer from the surface. The mechanism of these vortex generators is that they delivers longitudinal vortices in flow field that initiates turbulence, which disrupt the growth of thermal boundary layer, promote mixing of between fluid layers, and subsequently increase the heat transfer rate.The perforations in fins permits the cooling air to flow through these holes, which implies it delivers more turbulence in fluid which promotes heat transfer rate. Combination of passive device and perforated fins in heat sink has more heat transfer rate as compared to individual performances.

II. LITERATURE REVIEW

Experimental and numerical studies were performed by Hung-Yi Li, et al.[1,2]for enhancing the heat transfer rate from a plate fin heat sink and pin-fin heat sink with vortex generator. Various parameters were studied such as angle of attack of the vortex generators, the shortest distancebetween the vortex generators, the distance between each vortex generator and the heat sink, the height of the vortex generators, and the configuration of the vortex generators and their effect on performance of heat sink for different Reynold number. Their results revealed that Common-flow-up configuration causes considerable improvement in heat transfer.J.M. Wu and W.Q. Tao,[3]had studied convection heat transfer in a channel with longitudinal vortex generator. The results showed that delta winglet pair is more effective than rectangular winglet pair on heat transfer enhancement of channel. A. Pal, etal.[4]had performed computational study on coolant air flowing in heat exchanger with delta-winglet type vortex generator in common-flow-up configuration.The results revealed a significant enhancement in heat transfer because of strong swirling motion originating from vortex generator. A.A. Satam and S.Y. Bhosale.[5]analysed the flow structure and the heat transfer characteristics in a plate fin heat exchanger having built in vortex generators. They also studied the interaction between vortices and thermal boundary layer. Kai-Shing Yang, et al.[6]had performed experimental study focusing on the air side performance of heat sink under cross flow condition. They suggested that the vortex generator operated at a higher frontal velocity is more beneficial.S. Caliskan.[7] had experimentally studied heat transfer in a channel with punched triangular vortex generator and punched rectangular vortex generator. The results showed that the best heat transfer performance was obtained with punched triangular vortex ghatpenerator. Kavita H.Dhanawade, et al.[8] had experimentally studied heat transfer from heat sink with circular and square perforations on fins. Their results indicated perforated heat sink has more heat transfer than solid heat sink. PoojP.Shirjose[9]had performed numerical study of perforated heat sink considering Kavita [8]'s work as basis of her study. Triangular and elliptical perforations were studied computationally and observed that triangular perforation has more heat transfer.Raaid R Jessem.[10]had experimental study on perforation geometry variations for shapes like circle, square, triangle and hexagon. The results were compared with solid fins. Based on experimental result author concluded that triangular perforations offer better performance.M.R. Shaeri and M. Yaghoubi.[11] had worked numerically on three-dimensional array of rectangular perforated fins. Fin efficiency of perforated fin was determined and compared with solid fin. They found that considerable reduction in weight and increase in total heat transfer.

III. PROBLEM DESCRIPTION

Hung-Yi Li, et al.[1] had investigated the heat removal from plate-fin heat sink, with fin arrays, confined to a rectangular channel by the experimental as well as numerical method. The authors had studied the impact on heat transfer rate by using passive device i.e. vortex generator (VG). The authors had also studied the different parameters affecting the heat transfer rate such as the distance between the trailing edges of the VGs, the distance between VGs and heat sink, the attack angle of VGs, the height of VGs, and the configuration of VGs for different Reynolds number.

This work was considered as basis for present work. The present work extends the authors [1]research by investigating the impact by combining use of passive device and perforations on fins of heat sink. Circular and square perforations was considered for study. This investigation was carried out using the numerical approach (CFD) and the results are obtained in the form of thermal resistance. These results were compared to solid sink results.

IV. GEOMETRIC MODELLING

The sketching was done as per dimensions of heat sink and vortex generator as suggested in [1], for this modelling software SOLIDWORKS was used.

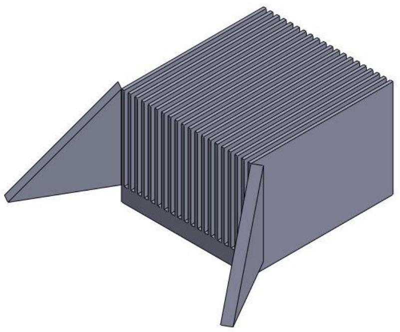

Fig. 1. Heat sink & VG

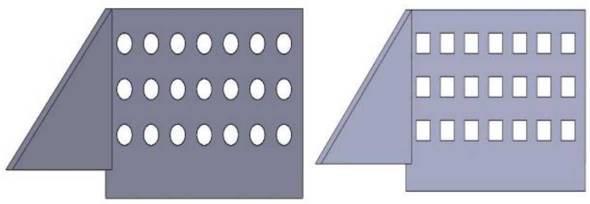

Fig. 2. Circular and Square perforations with VG

The geometry was imported to ANSYS ICEM-CFD where meshing was done, and export the mesh file to FLUENT 15.0. The heat sink consists of 20 fins along with 2 VG. The base of heat sink is 70 mm X 77 mm. The perforation size was maintained 6 mm for both configuration. The heat sink was placed in a computational domain having cross-sectional area of 200 mm X 90 mm and length of 616 mm.

V. CFD METHODOLOGY

The mesh required for the CFD simulation was created in ICEM-CFD, Mesh consist of two regions i.e. solid region and fluid region. Conduction of heat is carried out in solid region and convection of the conducted heat to the adjacent flowing fluid is carried out in fluid region. Unstructured meshing approach was selected for meshing i.e. triangular elements for surface mesh and tetrahedral elements for volume mesh.

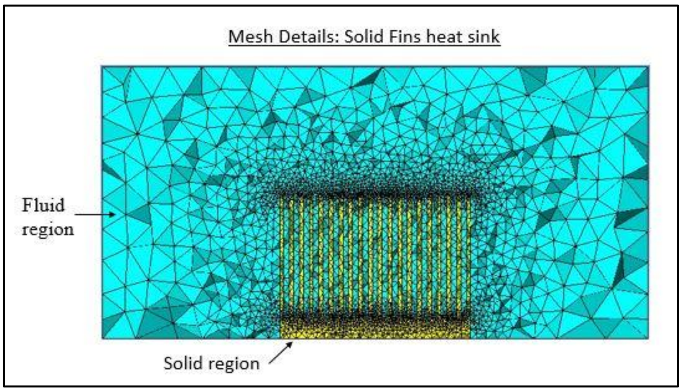

Fig. 3. Cross-sectional view of Mesh

In this study, a numerical model of the three-dimensional conjugate heat transfer for a plat-fin heat sink with vortex generators was set-up. CFD simulations were performed using ANSYS FLUENT software to investigate the fluid flow and heat transfer. In the analysis, the flow was assumed to be steady, incompressible and turbulent, hence pressure-based CFD solver was used. The RNG k-ϵ turbulence model was adopted. The fluid and solid properties in Fluent were kept constant. To discretize the convection terms in all equations the ‘first-order upwind’ scheme was used. The algorithm selected for pressure-velocity coupling was ‘SIMPLE’. The interpolation scheme used for pressure was ‘standard’. The convergence criterion for scaled residual of energy equation was chosen as $10^{-7}$and for other equations it was kept to 10^{-5}.

The simulations included the conduction (solid region) of heat from base plate of heat sink to fins then some amount of this conducted heat is carried away by the flowing fluid by means of convection (fluid region). This approach is generally known as conjugate heat transfer.The boundary condition give to the inlet of domain was ‘velocity-inlet’ and for the outlet it was given as ‘pressure-outlet’. The remaining surfaces – top, bottom and sides of the domain – was modelled as adiabatic, Stationary, No-Slip wall boundary conditions. The Magnitude of velocity of cooling air is based on Reynolds number.

The wall function approach was used for near wall turbulence modelling.Wall functions allow CFD models to interpret behavior near a wall without the need for a very fine mesh.

Thermal resistance of heat sink is defined as

$$R_{th} = \frac{T_{avg} - T_{\infty}}{Q} \qquad (1)$$

Where T_{avg}represents the mean surface temperature of the base plate of heat sink; T_{∞} is the temperature of cooling air, and Q is the heating power.

The Reynolds number is obtained from

$$Re = \frac{V * D}{\vartheta} \qquad (2)$$

Where V is the inlet velocity of the cooling air; D is the hydraulic diameter of test section, and ϑ is the kinematic viscosity of air at the inlet temperature.

VI. GRID INDEPENDENCE STUDY

To make sure that the results obtained from the CFD simulations were independent of the mesh size, a grid independence study was carried out. Four meshes with different mesh count was generated. A simulation for Reynolds Number = 40,000 was carried out for each of these mesh sizes.

Table I.Grid Independence Study

Mesh	Element count	Thermal resistance
Mesh – A	~1,500,000	0.13
Mesh – B	~1,700,000	0.19
Mesh – C	~2,000,000	0.20

The difference in thermal resistance between Mesh – B and more refined Mesh – C was negligible. Hence Mesh – B was selected for further simulations in order to reduce the computation time.

VII. VALIDATION

The values of thermal resistance from simulations gives the estimation of heat transfer, hence the graph of Reynolds number Vs Thermal resistance is plotted. The numerically obtained results were compared with the existing experimental data from literature[2].

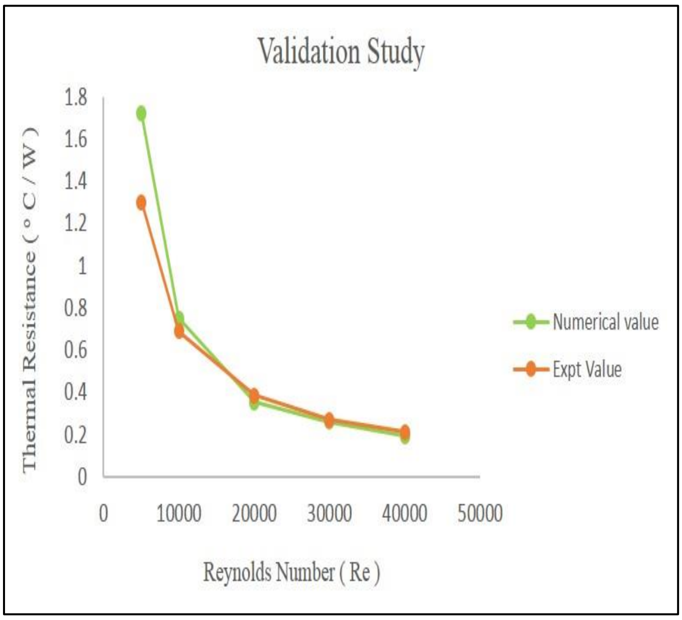

Fig. 4. Validation study graph

From the Fig. 4 it is observed that the results from CFD simulations are in great concurrence with the experimental data for higher Reynolds number.For Reynolds number 10000 and above the relative error between simulated and experimental values are below 10%. Based on these results, it can be said that the approval of CFD strategy has been accomplished.

VIII. OPTIMIZATION

A comparison between the circular-perforated fins and square-perforated fins were made against the solid fins i.e. without any perforation. The results are shown in following graph. Thermal performance of circular perforations was minutely higher than square perforations.

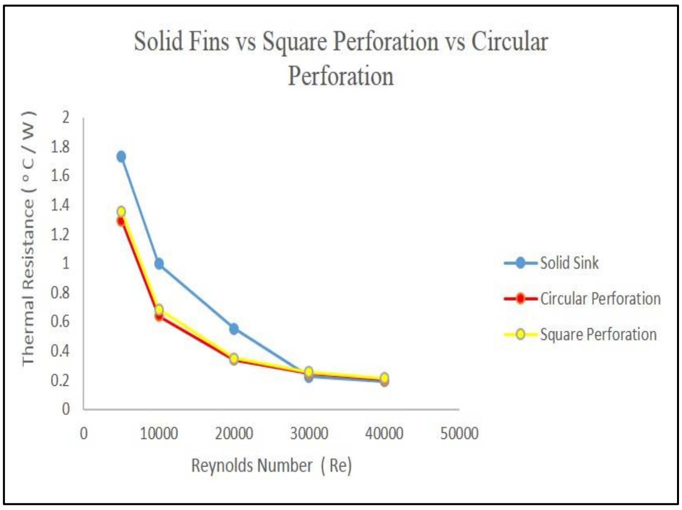

Fig. 5. Circular and square perforated fin thermal performance

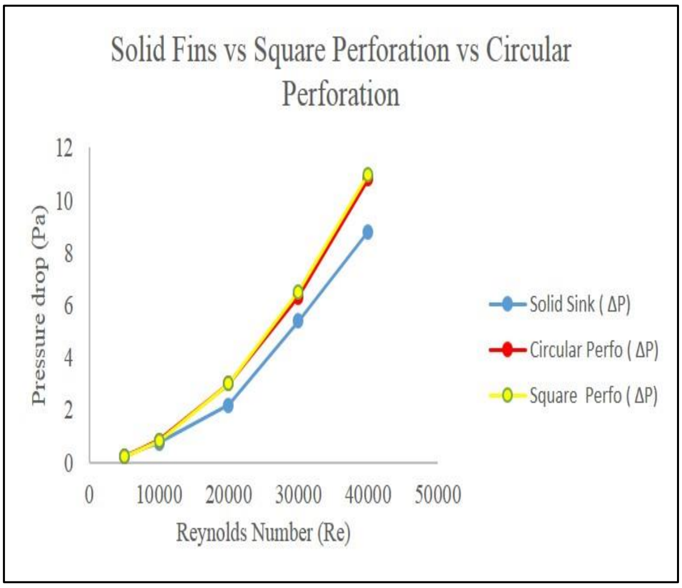

Fig. 6. Circular and square perforated fin fluid performance

From Fig.5it is clear that perforated fins with vortex generators has higher thermal performance than solid fins with vortex generators at lower Reynolds number. Hence it is an effective way to enhance heat transfer from heat sink. From Fig.6 the pressure drop for both configurations were same for lower Reynolds number but at higher values the circular perforations had minutely smaller value than square perforations.

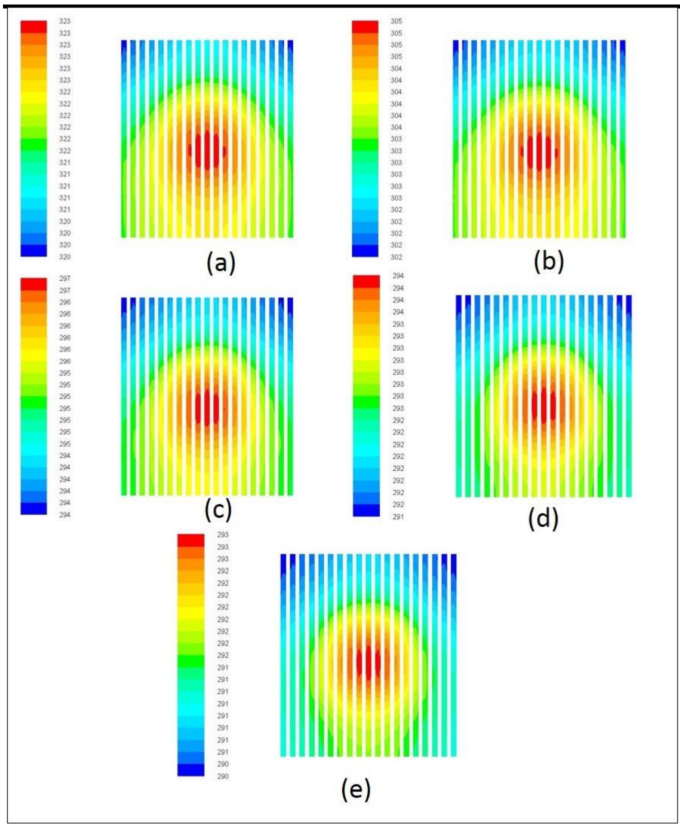

Fig. 7 Contours of surface temperature of base plate of heat sink at various Reynolds number: (a) Re = 5000, (b) Re =10000, (c) Re =20000, (d) Re = 30000, and (e) Re =40000.

Fig. 7 demonstrates the surface temperature distribution of the base plate of heat sink with vortex generator and circular perforations. The figure depicts that the temperature reduces from the center to the outside of the heat sink. Also the temperature was lower at the front of heat sink this is because vortex generators makes cooling air to accelerate by reducing the area. Also the temperature at the back side of heat sink was reducing as the Reynolds number increases.

IX. CONCLUSION

A good co-relation between experimental and numerical simulation had been observed for the estimation of thermal resistance. Based on this, further optimization studies had carried out. The result of these studies could be relied upon CFD methods. Among the different shapes of perforations, Circular configuration provides better thermal performance. The square configuration's performance was also near to the circular configuration. Due to vortex generators a wake region is produced behind heat sink this lead to the pressure drop of flowing fluid. Due to this pressure drop the power required for the blower to operate also increases. Both the configurations has same pressure drop. Circular configuration has slight lesser pressure drop for 40000 Reynolds number, hence circular configuration is better choice.

REFERENCES

[1] Hung-Yi Li, Wan-Rong Liao, Tian-Yang Li and Yan-Zuo Chang, "Application of vortex generators to heat transfer enhancement of a pin-fin heat sink," International Journal of Heat and Mass Transfer, vol. 112, pp.940-949, May 2017.

[2] Hung-Yi Li, Ci-Lei Chen, Shung-Ming Chao and Gu-Fan Liang, "Enhancing heat transfer in a plate-fin heat sink using delta winglet vortex generators," International Journal of Heat and Mass Transfer, vol. 67, pp. 666-677, August 2013.

[3] J.M. Wu & W.Q. Tao, "Numerical study on laminar convection heat transfer in a channel with longitudinal vortex generator. Part B: Parametric study of major influence factors," International Journal of Heat and Mass Transfer, vol. 51, pp. 3683–3692, May2008.

[4] A.Pal , D. Bandyopadhyay , G. Biswas & V. Eswaran, "Enhancement of Heat Transfer Using Delta-Winglet Type Vortex Generators with a Common-Flow-up Arrangement," An International Journal of Computation and Methodology, vol.61:12, pp. 912-928, July 2012.

[5] A. A. Satam& S.Y. Bhosale, "Experimental Investigation of Delta Wing Vortex Generators on a Flat Plate," International Engineering Research Journal, vol. 2, pp.798-802, November 2015.

[6] Kai-Shing Yang , Shu-Lin Li , IngYoun Chen , Kuo-Hsiang Chien , Robert Hu & Chi-ChuanWanga, "An experimental investigation of air cooling thermal module using various enhancements at low Reynolds number region," International Journal of Heat and Mass Transfer, vol. 53, pp. 5675–5681, September 2010.

[7] S. Caliskan, "Experimental investigation of heat transfer in a channel with new winglet-type vortex generator," International Journal of Heat and Mass Transfer, vol.78, pp.604-614, July 2014.

[8] Kavita H. Dhanawade, Vivek K. Sunnapwar&Hanamant S. Dhanawade, "Thermal Analysis of Square and Circular Perforated Fin Arrays by Forced Convection," International Journal of Current Engineering and Technology,vol.2,pp.110-114, February 2014.

[9] Pooja P. Shirjose, "Numerical investigation of elliptical and triangularperforated fins under forced convection," International Journal of Scientific Research Engineering & Technology, vol.5,pp.232-235, April 2016.

[10] Raaid R. Jassem, "effect the form of perforation on the heat transfer in the perforated fins,"Academic Research International,vol.4,pp.198-207, May2013.

[11] M.R. Shaeri& M. Yaghoubi, "Thermal enhancement from heat sinks by using perforated fins," Energy Conversion and Management, vol. 50,pp.1264–1270, February 2009.