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The Influence of Plate Fin Heat Sink Orientation under Natural Convection on Thermal Performance: An Experimental and Numerical Study

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ABSTRACT

Many electronic gadgets now require more power as a result of technological advancements, and to prolong their lifespan, they must all be kept thermally stable. To prevent electronic equipment from operating above their safe operating temperature, numerous techniques are used. Due to its low cost and dependable manner of cooling, the naturally cooled heat sink is the most used technology. The goal of the current research is to improve the thermal efficiency of less dense heat sinks by modifying their design and orientation. The aluminium heat sink utilized for the experimental and numerical investigation has the following dimensions: length 120 mm, width 100 mm, thickness 2 mm, height 40 mm, and channel width 12 mm. The cartridge-type heater received heat input ranging from 25 W, 50 W, 75 W, and 100 w. Under natural convection, the orientation was changed to 0°, 15°, 30°, 45°, 60°, and 90°. By increasing the orientation angle of the heat sink from 00 (horizontal position) for all the heat input, the Nusselt number and rate of heat transfer increases. Due to changes in the flow pattern, the vertical orientation of the heat sink was found to be transferring heat more quickly than other orientations. According to the study, plate-fin heat sinks with circular in-line notches perform thermally better than those without any notches.

1. Introduction

The ever-increasing demand for electronic devices with enhanced performance has led to a constant rise in power densities and heat generation within the systems. Efficient thermal management is imperative to ensure the reliability and longevity of these devices. Naturally cooled heat sink most commonly used technique due to its low cost and high reliability. The different types of heat sinks are used in many industries for cooling applications such as automotive radiators, air

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conditioning, LED lights, power electronics, servers, power amplifiers, and telecommunication [1-4]. The geometric optimization of the heat sink by varying the various important parameters such as fin thickness (t), fin height (h), and channel width (w) was performed by Yu *et al.,* [5]. Kim *et al.,* [6] conducted the analytical, numerical, and experimental analysis to find out closed-form correlation for thermal optimization of plate-fin heat sink under the natural convection. It was discovered that the optimal fin thickness depends on height, solid conductivity, and fluid conductivity. Kim and Kim [7] carried out an experimental study to understand the effect of cross-cuts on the thermal performance of heat sinks under the parallel flow condition. The following parameters were varied during the tests: length of cross cuts, number of cross cuts, and position of cross cuts. The experimental results showed that among all the parameters investigated the cross-cut length had more influence on thermal performance of heat sinks. Kim *et al.,* [8] carried out an optimization study for the optimization of the plate-fin heat sink by varying fin thickness in the direction of normal to fluid flow based on volume averaging theory. The thermal resistance of the variable thickness fins with water-cooled arrangement was reduced by 15% compared to the uniform thickness fin [8,9]. Sable *et al.,* [10] conducted the experimental investigation of the vertically heated plate by multiple V-fin arrays to enhance thermal performance under natural convection. The result revealed that the V-type fin array gave better heat transfer performance than the vertical fin array and 'V' fin with bottom spacing type array. Various studies related to the heat sink are found in the literature to enhance heat transfer coefficient [11-20].

Very few research papers emphasized understanding the heat transfer performance at the different orientations of the fin heat sinks. This research paper focuses mainly on studying the effect of the orientation of a less-dense fin heat sink and the circular inline notch on its thermal performance. The effect of a circular inline notch is also compared with solid fins. This study aims to examine experimentally and numerically the influence of orientation on the thermal performance of the heat sink. For the sake of the thermal performance comparison at different orientations, there is a need to use a fixed fin volume heat sink. It should be noted that the failure rate of electronic components increases exponentially with temperature and any system capable of removing more heat will increase reliability and the life of the components.

2. Experimental Setup

The experimental setup includes the following arrangements: heater, thermocouples, temperature indicators, wattmeters, fins, spacers, and Bakelite covering plates. The layout of the experimental setup is shown in the Figure 1 and Figure 2. The tests were performed on aluminium fins with spacing = 12 mm, thickness = 2 mm, fin height = 40 mm, and the number of fins = 8. The proposed array of fins was tested for different heat inputs which are as follows: 25W, 50W, 75W, and 100W. The heat input of different watts (25 W, 50 W, 75 W, and 100 W) was generated by using the two-cartridge type of rod heaters (10 mm in diameter). The heaters were placed at the center of the bottom plate of the fin heat sink array. The testing was conducted in an open environment (i.e. natural convection). The fin heat sink array was supported by the spores block at the bottom and its side to minimize the conduction and radiation losses. The K–type thermocouples were placed at various locations of the fin arrays (Figure 1) to collect the data on the temperatures.

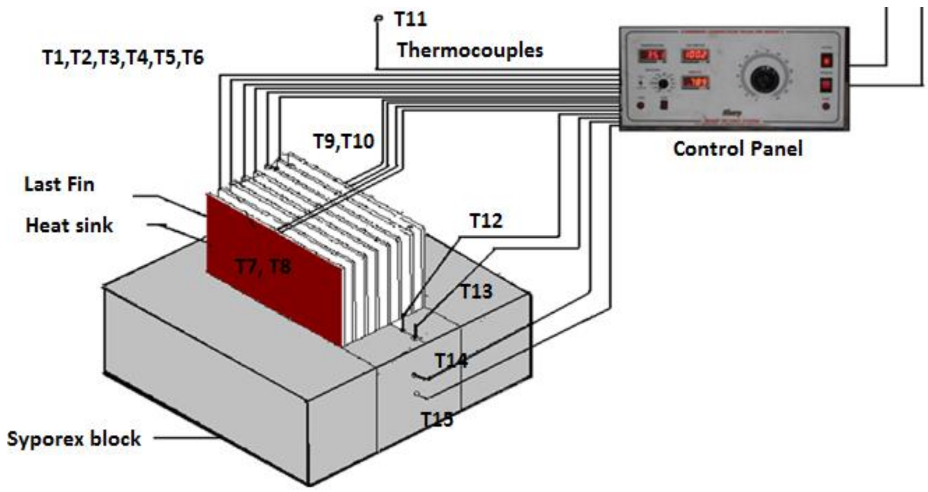


Fig. 1. Layout of experimental setup

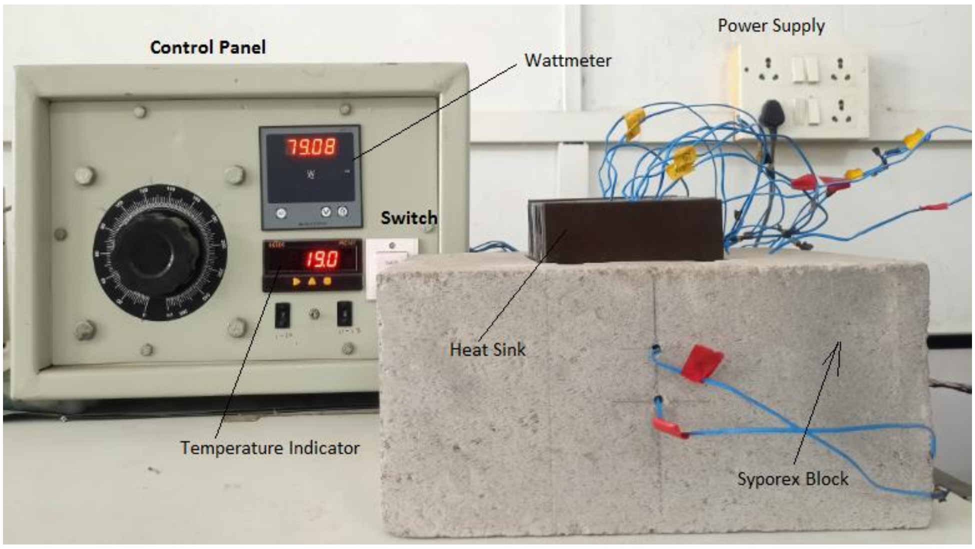


Fig. 2. Pictorial view of experimental setup

3. Calculations

The heat transfer analysis of the Solid and perforated rectangular fins was based on the following assumptions a) Steady heat conduction in the fins b) No heat generation in the fin body c) Uniform ambient temperature d) Uniform heat transfer coefficient all over the fin surface.

The rate of heat supplied to the heat sink is calculated by Eq. (1):

$$Q_t = V \cdot I \quad (1)$$

But, Q_t is also calculated by Eq. (2):

$$Q_t = Q_{cd}) + Q_{rf} + Qc \quad (2)$$

Conduction heat loss through the fin array is calculated by Eq. (3):

$$Q_{cd} = k\, A_{cd}\, [(dt/dx)\ bottom + (dt/dx)\ side] / 2 \quad (3)$$

Radiation heat loss through the fin array is calculated by Eq. (4):

$$Q_{rf} = [\varepsilon \times \sigma \times A_S \times (TS4 - T\infty4)] \quad (4)$$

Convection heat Transfer is calculated by Eq. (5):

$$Q_c = Q_t - Q_{cd} + Q_{rf} \quad (5)$$

The average heat transfer coefficient is calculated by Eq. (6):

$$ha = [\ Q_c / Ae \times (TS - T\infty)] \quad (6)$$

The average Nusselt Number is calculated by Eq. (7):

$$Nu\ a = ha\ L / k \quad (7)$$

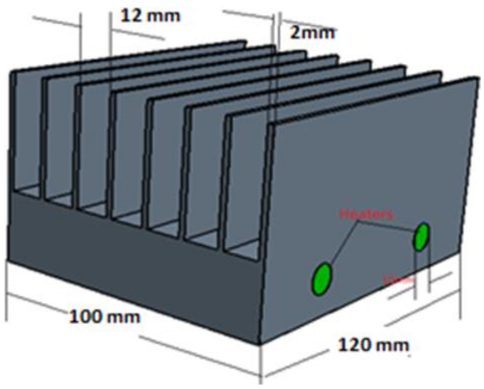
4. Computational Modelling

The current investigation employs Computational Fluid Dynamics (CFD) software, specifically Star-CCM+, to explore the thermal performance of a fin heat sink array under natural convection. The CFD analysis was used in various applications and found good agreement with the experimental results [21-48]. The primary focus lies in observing convection currents and temperature distribution across the surface of the fins. The details of the numerical setup include the creation of geometry and meshing within Star-CCM+, as depicted in Figure 3. Prism layer meshing was generated using the software. The grid independence study was conducted to test the output of the case as the average surface temperature at the center of the middle fin. It was observed that when the base size of the heater and heat sink domain was equal to 0.01, and for the air domain it was equal to 0.05 the temperature noticed was equal to 95.8 deg C at heater input equal to 50 W and zero degree orientation of the fins. When the grid base size was changed to 0.005 for the heater and heat sink domain and 0.025 for the air domain, the temperature was observed to be equal to 95.9 degrees Celcius, which was almost the same and did not change, and hence that was selected as the appropriate grid for simulation (Table 1).

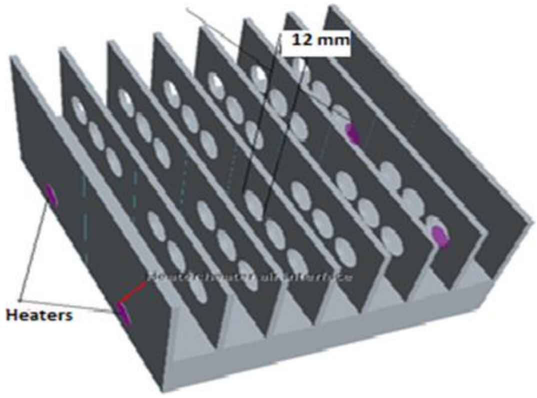
Table 1
Grid Independence study

Parameter (Base number)	Parts	No. of Cell	Nodes	Temperature at Center of Middle fin at 50 Watt 0 degree
0.02	Heat Sink	52283	66098	90
0.02	Heater	3068	8840	
0.1	Air	83958	102224	
0.01	Heat sink	354306	494039	95.8
0.01	Heater	23301	36988	
0.05	Air	322993	565617	
0.005	Heat sink	1386687	1671480	95.9
0.005	Heater	43001	48510	
0.025	Air	1253921	1600333	

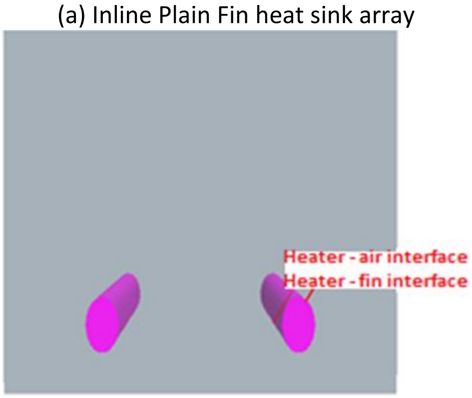
Various numerical models were utilized, including (a) Air models with coupled flow, gas-air interaction, gradient, ideal gas, laminar flow, steady-state conditions, and a 3D model; (b) Fin models featuring constant density, coupled solid energy, gradient, solid, steady, and a 3D model; and (c) Heater models with constant density, coupled solid energy, gradient, solid, steady, and a 3D model.



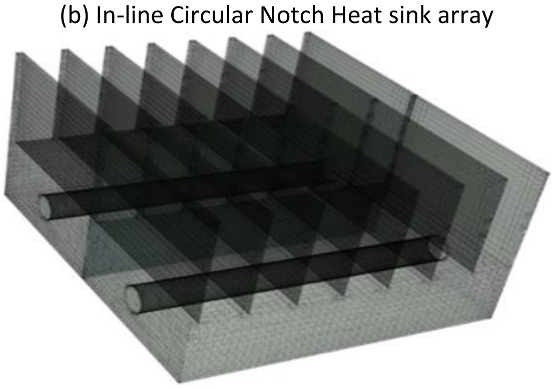
(a) Inline Plain Fin heat sink array



(b) In-line Circular Notch Heat sink array



(c) Positions of the heater in the base plate



(d) Meshing scene

Fig. 3. Details of the CFD models

5. Results and Discussion

The results and discussion section primarily showcases the experimental and numerical data, along with a comparison between the two sets of results.

5.1 Effect of Plate Fin Heat Sink Orientation

Plate fin heat sinks (without notches) underwent testing at various orientations to assess their thermal performance, with the corresponding results mentioned in Figure 4. The temperature contours and airflow patterns for different orientations (e.g., 0°, 15°, 30°, 45°, 60°, and 90°) with a 50-watt heater input are presented in Figure 4. The findings revealed that an increasing orientation angle of the fin heat sink led to improved airflow patterns, resulting in lower temperatures for the fin heat sinks. The average temperature was observed to be 372 at 0° and 363 K at 90°, indicating enhanced thermal performance at the latter orientation.

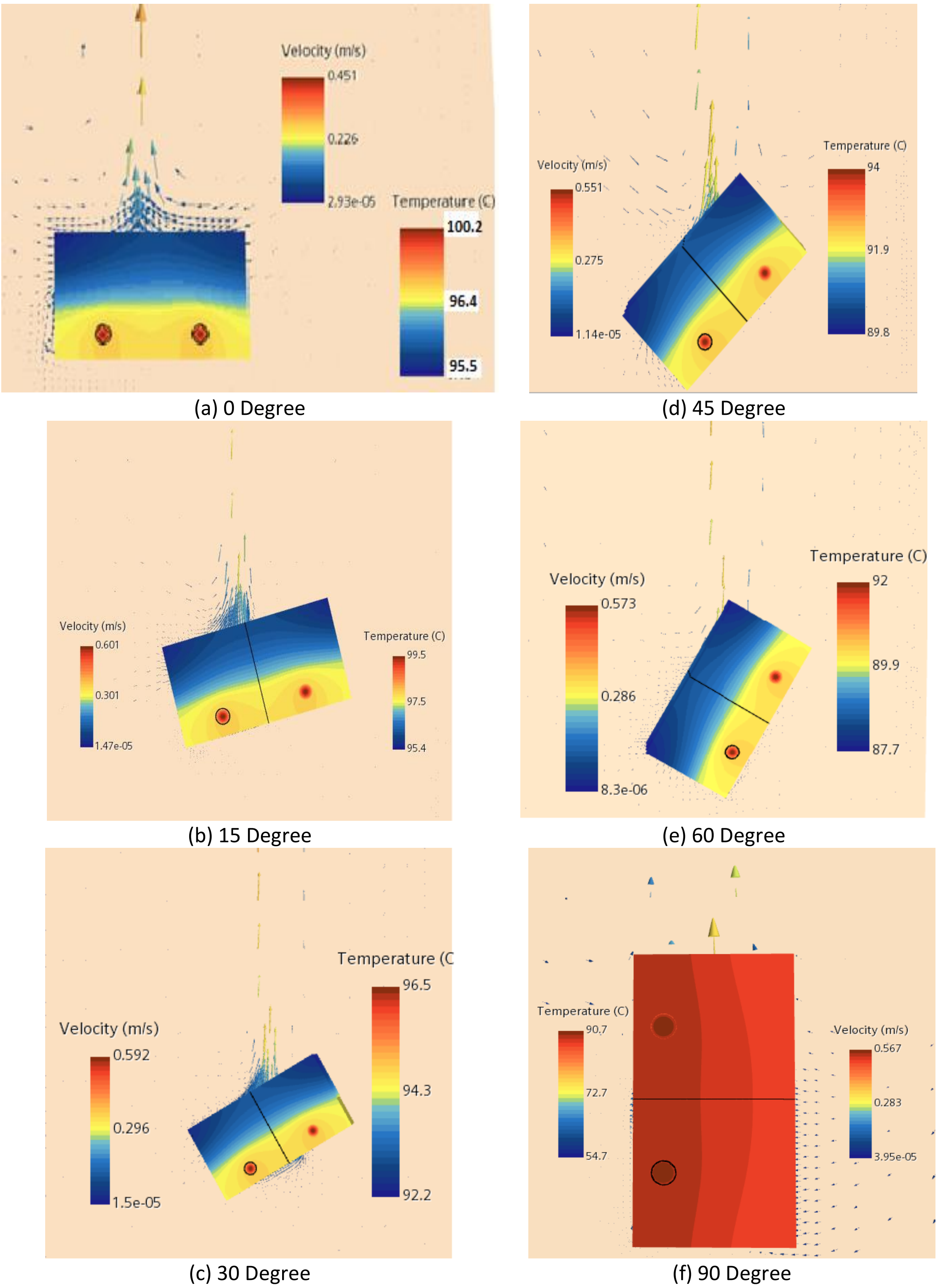


Fig. 4. CFD results for heat sink at different orientations of the plate fins and at 50 W

The heat transfer coefficient variation for different orientations of the fin heat sinks (at 50 W) is shown in Figure 5. The experimental results showed that, as the orientation of the fin heat sink was changed from horizontal 0°, 15^0, 30^0, 45^0, 60^0 to vertical 90^0 the heat transfer coefficient was found to be increasing in the ascending order of 5.42, 5.6, 5.87, 5.87, 6.16, 6.49, and 6.73 respectively. The vertical orientation of the heat sink showed the best thermal performance.

Figure 5 shows the variation of the average heat transfer coefficient with different orientations of the heat sink. The orientation angles were chosen from the horizontal to vertical position of the heat sink, where angles varied between 0 degrees to 90 degrees in a stepwise manner (a constant angle of 15 degrees was maintained during all the tests conducted). The average heat transfer coefficient was higher for higher heater inputs for all the heat sink orientations. The rate of variation of the average heat transfer coefficient was lowered as the heat input changed from 25 W to 100 W at the same orientation. The heat transfer coefficient was maximum at 90 degrees for a heater input of 100 W and its value was found to be equal to 7.2 W/m^2 K. The minimum value of the heat transfer coefficient was found to be equal to 4.2 W/m^2 K at 0-degree orientation of the heat sink and for heater input equal to 25 W (Figure 6).

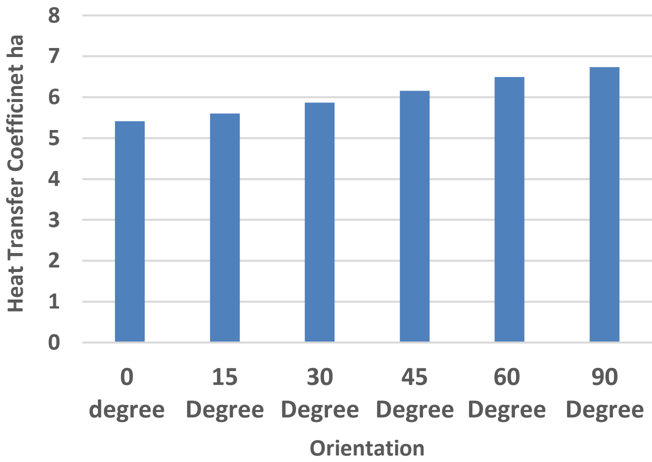


Fig. 5. The heat transfer coefficient variation for different orientations of the fin heat sinks (at 50 W)

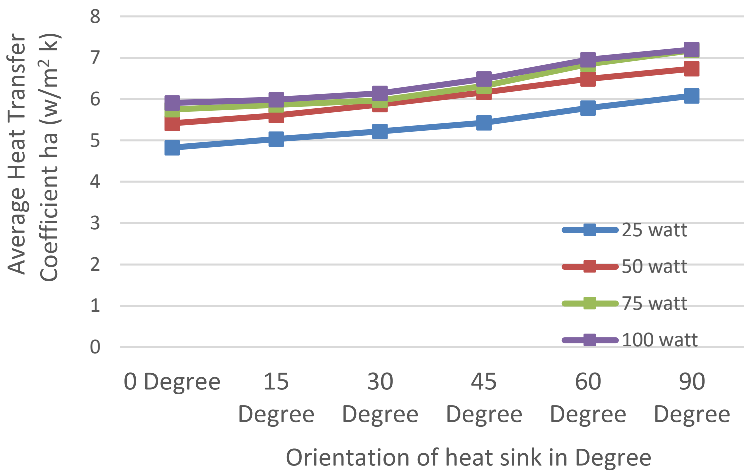


Fig. 6. Average heat transfer coefficient variation at different heater Inputs and Orientation

Experimental tests conducted were used to calculate the Nusselt numbers for different conditions of heater inputs and orientation angles. The maximum Nusselt Number (Nua) was found to be equal to 10.3 for 100 W heater input and 90-degree orientation of the heat sink. The minimum Nusselt Number (Nua) was found to be equal to 6.9 for 25 W and 0 degrees (Figure 7). The Nusselt Number was found to be increasing in ascending order as we increased the orientation angle from 0 degrees to 90 degrees at each heater input i.e., 25 w, 50 w, 75 w, 100 watts (Figure 7).

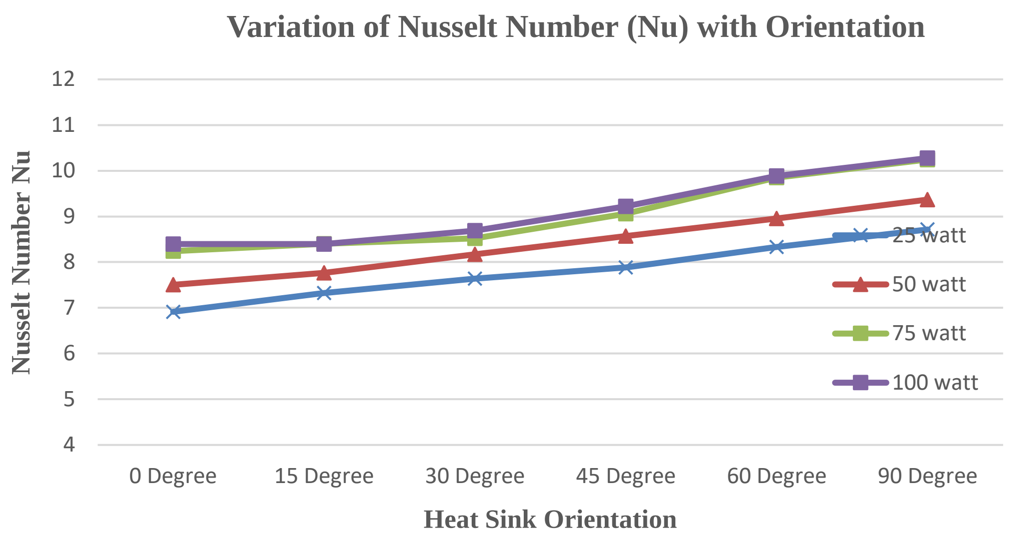


Fig. 7. Nusselt Number (Nu) variation for different orientations of the heat sinks at different heater Input

The higher thermal performance was observed at the 90-degree orientation of the heat sink for all the heater inputs. The results of the circular inline notch type of heat sink array were found to be superior compared to the results of solid/plain heat sink array for both 0-degree and 90-degree orientation (Figure 7). The heat transfer coefficient of the notch heat sink was observed to be equal to 7.8 W/m^2 K at 90-degree orientation which was more (i.e. 6.7 W/m^2 K) compared to the heat sink without notch (Figure 8).

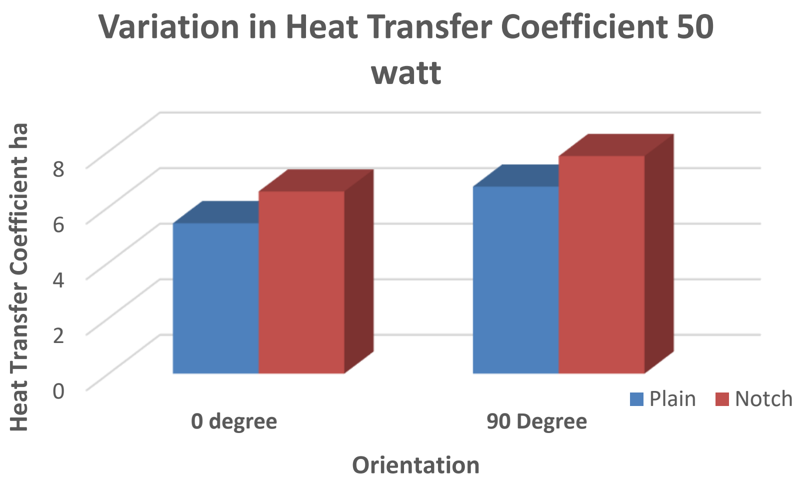
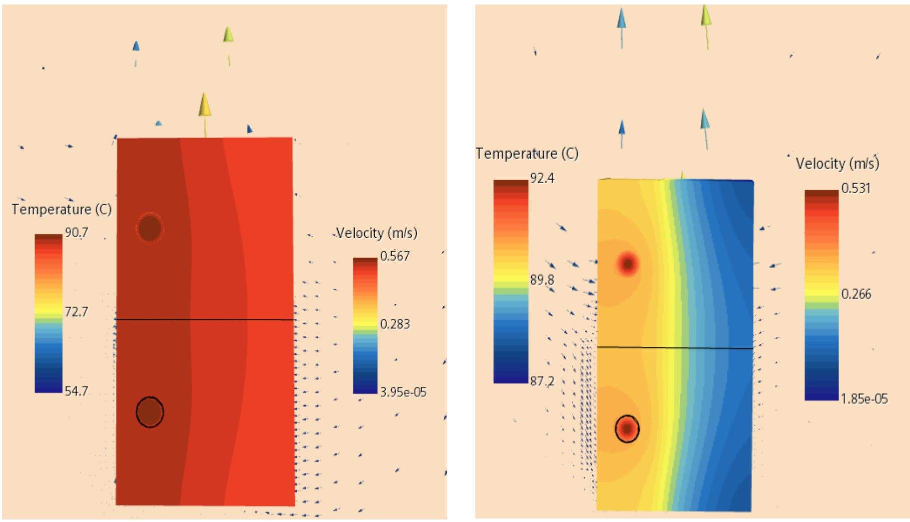


Fig. 8. The heat transfer coefficient of plain and notch type of heat sink array compared at 0 and 90 degrees

The Computational Fluid Dynamics results showed that the variation of the air velocity because of the circular inline notch fin array was higher than the plain fin array. The area of the Circular notch fin array was 15% smaller compared to the plain fin array. The notches on the fin array changed the flow pattern which resulted in increased thermal performance of the heat sink (Figure 9).

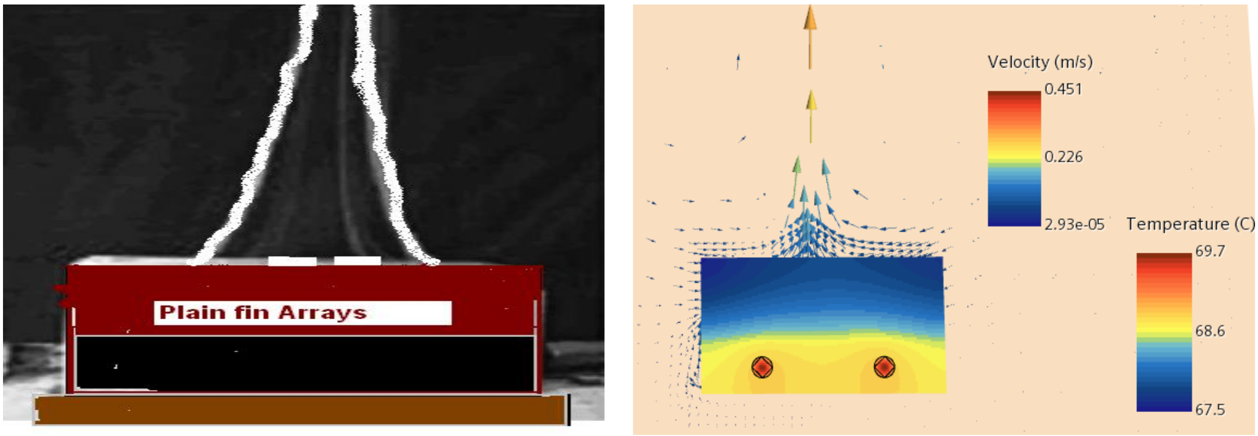


(a) 90 Degree Notch Heat sink (b) 90 Degree Plain Heat Sink

Fig. 9. CFD result of Notch heat and Plain Heat Sink at 50 Watt

5.2 Flow Pattern

The experimental flow pattern was compared with numerical results and a single chimney flow pattern developed at the Horizontal Position of the Heat sink. The experimental results for flow visualization by smoke technique at the horizontal position and CFD analysis results show a similar flow pattern. Figure 10 shows the experimental and CFD analysis results.



(a) Flow visualization by smoke technique at a horizontal position (experimental approach)

(b) Flow visualization using CFD technique at horizontal position (numerical approach)

Fig. 10. Flow Pattern Developed at Horizontal Position

6. Conclusion

The use of plate-fin heat sinks in cooling applications plays a significant role. It helps to maintain better thermal stability and reliability of electronic devices. The experimental and numerical results highlighted the following important outcomes

i. The heat transfer coefficient was found to be increasing with increasing orientation of heat sinks from 0 degrees to 90 degrees (for all the heater inputs).
ii. The heat transfer coefficient was found to be maximum at 90 degrees i.e. vertical position of the heat sink array, this happened due to changes in the flow pattern over the fin arrays.

iii. The Nusselt Number was maximum for the plain fin heat sink at the 90-degree orientation of the heat sink array and this was observed for heater input which was equal to 100 W.
iv. The minimum Nusselt number was observed at the horizontal orientation of the heat ink array(at 25 W heater input).
v. The chimney type of flow pattern was observed for the horizontal orientation of the fin array and the flow pattern changed for different orientations of the fin array.
vi. The circular inline notch type of heat sink array was found to be the best option in terms of getting the showed better performance at lower and higher orientation angles.
vii. The Chimney Flow Pattern gets developed at the horizontal position of the Heat sink

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References
[1] Charles, Roody, and Chi-Chuan Wang. "A novel heat dissipation fin design applicable for natural convection augmentation." *International Communications in Heat and Mass Transfer* 59 (2014): 24-29. https://doi.org/10.1016/j.icheatmasstransfer.2014.10.014
[2] Li, Bin, and Chan Byon. "Orientation effects on thermal performance of radial heat sinks with a concentric ring subject to natural convection." *International Journal of Heat and Mass Transfer* 90 (2015): 102-108. https://doi.org/10.1016/j.ijheatmasstransfer.2015.06.012
[3] Ahmadi, Mehran, Golnoosh Mostafavi, and Majid Bahrami. "Natural convection from rectangular interrupted fins." *International Journal of Thermal Sciences* 82 (2014): 62-71. https://doi.org/10.1016/j.ijthermalsci.2014.03.016
[4] Kumar, K., P. Vinay, and R. Siddhardha. "Thermal and Structural Analysis of Tree Shaped Fin Array." *International Journal of Engineering Research and Applications* 3, no. 6 (2013): 1054-1057.
[5] Yu, Xiaoling, Jianmei Feng, Quanke Feng, and Qiuwang Wang. "Development of a plate-pin fin heat sink and its performance comparisons with a plate fin heat sink." *Applied Thermal Engineering* 25, no. 2-3 (2005): 173-182. https://doi.org/10.1016/j.applthermaleng.2004.06.016
[6] Kim, Tae Hoon, Kyu Hyung Do, and Dong-Kwon Kim. "Closed form correlations for thermal optimization of plate-fin heat sinks under natural convection." *International Journal of Heat and Mass Transfer* 54, no. 5-6 (2011): 1210-1216. https://doi.org/10.1016/j.ijheatmasstransfer.2010.10.032
[7] Kim, Tae Young, and Sung Jin Kim. "Fluid flow and heat transfer characteristics of cross-cut heat sinks." *International Journal of Heat and Mass Transfer* 52, no. 23-24 (2009): 5358-5370. https://doi.org/10.1016/j.ijheatmasstransfer.2009.07.008
[8] Kim, Dong-Kwon, Jaehoon Jung, and Sung Jin Kim. "Thermal optimization of plate-fin heat sinks with variable fin thickness." *International Journal of Heat and Mass Transfer* 53, no. 25-26 (2010): 5988-5995. https://doi.org/10.1016/j.ijheatmasstransfer.2010.07.052
[9] Morega, Mihaela, and Adrian Bejan. "Plate fins with variable thickness and height for air-cooled electronic modules." *International Journal of Heat and Mass Transfer* 37 (1994): 433-445. https://doi.org/10.1016/0017-9310(94)90043-4
[10] Sable, M. J., S. K. Bhor, S. B. Barve, P. A. Makasare, and S. J. Jagtap. "Computational analysis for enhancement of natural convection heat transfer on a vertical heated plate by multiple V-fin array." *International Journal of Applied Engineering Research* 6, no. 13 (2011): 1617-1628.
[11] Yu, Xiaoling, Jianmei Feng, Quanke Feng, and Qiuwang Wang. "Development of a plate-pin fin heat sink and its performance comparisons with a plate fin heat sink." *Applied Thermal Engineering* 25, no. 2-3 (2005): 173-182. https://doi.org/10.1016/j.applthermaleng.2004.06.016
[12] Wang, Chi-Chuan. "A quick overview of compact air-cooled heat sinks applicable for electronic cooling-recent progress." *Inventions* 2, no. 1 (2017): 5. https://doi.org/10.3390/inventions2010005
[13] Li, Bin, Sora Jeon, and Chan Byon. "Investigation of natural convection heat transfer around a radial heat sink with a perforated ring." *International Journal of Heat and Mass Transfer* 97 (2016): 705-711. https://doi.org/10.1016/j.ijheatmasstransfer.2016.02.058
[14] Al-Sallami, Waleed, Amer Al-Damook, and H. M. Thompson. "A numerical investigation of the thermal-hydraulic characteristics of perforated plate fin heat sinks." *International Journal of Thermal Sciences* 121 (2017): 266-277. https://doi.org/10.1016/j.ijthermalsci.2017.07.022

[15] Altaf, Khurram, Adeel Tariq, Syed Waqar Ahmad, Ghulam Hussain, T. A. H. Ratlamwala, and Hafız Muhammad Ali. "Thermal and hydraulic analysis of slotted plate fins heat sinks using numerical and experimental techniques." *Case Studies in Thermal Engineering* 35 (2022): 102109. https://doi.org/10.1016/j.csite.2022.102109
[16] Jeon, Daechan, and Chan Byon. "Thermal performance of plate fin heat sinks with dual-height fins subject to natural convection." *International Journal of Heat and Mass Transfer* 113 (2017): 1086-1092. https://doi.org/10.1016/j.ijheatmasstransfer.2017.06.031
[17] Sertkaya, Ahmet Ali, Mukaddes Ozdemir, and Eyüb Canli. "Effects of pin fin height, spacing and orientation to natural convection heat transfer for inline pin fin and plate heat sinks by experimental investigation." *International Journal of Heat and Mass Transfer* 177 (2021): 121527. https://doi.org/10.1016/j.ijheatmasstransfer.2021.121527
[18] Joseph, Aju, Amal Dev C. George, K. Aneesh, Fibin Shafi, Jijo Joseph, and A. Arunraj. "Heat Transfer Enhancement Perforations: A Review." *International Journal of Innovative Research in Science, Engineering and Technology* 6, no. 1 (2017): 263-272.
[19] Ehteshum, Mehedi, Mohammad Ali, Md Quamrul Islam, and Muhsia Tabassum. "Thermal and hydraulic performance analysis of rectangular fin arrays with perforation size and number." *Procedia Engineering* 105 (2015): 184-191. https://doi.org/10.1016/j.proeng.2015.05.054
[20] Kim, Dong-Kwon. "Thermal optimization of plate-fin heat sinks with fins of variable thickness under natural convection." *International Journal of Heat and Mass Transfer* 55, no. 4 (2012): 752-761. https://doi.org/10.1016/j.ijheatmasstransfer.2011.10.034
[21] 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.
[22] Pathan, Khizar Ahmed, Syed Ashfaq, Prakash S. Dabeer, and Sher Afgan Khan. "Analysis of parameters affecting thrust and base pressure in suddenly expanded flow from nozzle." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 64, no. 1 (2019): 1-18.
[23] Pathan, Khizar Ahmed, Prakash S. Dabeer, and Sher Afghan Khan. "Influence of expansion level on base pressure and reattachment length." *CFD Letters* 11, no. 5 (2019): 22-36.
[24] Pathan, Khizar A., Prakash S. Dabeer, and Sher A. Khan. "Enlarge duct length optimization for suddenly expanded flows." *Advances in Aircraft and Spacecraft Science* 7, no. 3 (2020): 203-214.
[25] Pathan, Khizar Ahmed, Prakash S. Dabeer, and Sher Afghan Khan. "Optimization of area ratio and thrust in suddenly expanded flow at supersonic Mach numbers." *Case Studies in Thermal Engineering* 12 (2018): 696-700. https://doi.org/10.1016/j.csite.2018.09.006
[26] Pathan, Khizar Ahmed, Sher Afghan Khan, and P. S. Dabeer. "CFD analysis of effect of flow and geometry parameters on thrust force created by flow from nozzle." In *2017 2nd International Conference for Convergence in Technology (I2CT)*, pp. 1121-1125. IEEE, 2017. https://doi.org/10.1109/I2CT.2017.8226302
[27] Pathan, Khizar Ahmed, Sher Afghan Khan, and P. S. Dabeer. "CFD analysis of effect of area ratio on suddenly expanded flows." In *2017 2nd International Conference for Convergence in Technology (I2CT)*, pp. 1192-1198. IEEE, 2017. https://doi.org/10.1109/I2CT.2017.8226315
[28] Pathan, Khizar Ahmed, Sher Afghan Khan, and P. S. Dabeer. "CFD analysis of effect of Mach number, area ratio and nozzle pressure ratio on velocity for suddenly expanded flows." In *2017 2nd International Conference for Convergence in Technology (I2CT)*, pp. 1104-1110. IEEE, 2017. https://doi.org/10.1109/I2CT.2017.8226299
[29] Sajali, Muhammad Fahmi Mohd, Abdul Aabid, Sher Afghan Khan, Fharukh Ahmed Ghasi Mehaboobali, and Erwin Sulaeman. "Numerical investigation of flow field of a non-circular cylinder." *CFD Letters* 11, no. 5 (2021): 37-49.
[30] Khan, Sher Afghan, Mohammed Asadullah, G. M. Fharukh Ahmed, Ahmed Jalaluddeen, and Maughal Ahmed Ali Baig. "Passive control of base drag in compressible subsonic flow using multiple cavity." *International Journal of Mechanical and Production Engineering Research and Development* 8, no. 4 (2018): 39-44. https://doi.org/10.24247/ijmperdaug20185
[31] Khan, Sher Afghan, Mohammed Asadullah, and Jafar Sadhiq. "Passive control of base drag employing dimple in subsonic suddenly expanded flow." *International Journal of Mechanical and Mechatronics Engineering IJMME-IJENS* 18, no. 03 (2018): 69-74.
[32] Khan, Ambareen, Parvathy Rajendran, and Junior Sarjit Singh Sidhu. "Passive control of base pressure: a review." *Applied Sciences* 11, no. 3 (2021): 1334. https://doi.org/10.3390/app11031334
[33] Khan, Ambareen, Parvathy Rajendran, Junior Sarjit Singh Sidhu, S. Thanigaiarasu, Vijayanandh Raja, and Qasem Al-Mdallal. "Convolutional neural network modeling and response surface analysis of compressible flow at sonic and supersonic Mach numbers." *Alexandria Engineering Journal* 65 (2023): 997-1029. https://doi.org/10.1016/j.aej.2022.10.006
[34] Pathan, Khizar Ahmed, Prakash S. Dabeer, and Sher Afghan Khan. "Effect of nozzle pressure ratio and control jets location to control base pressure in suddenly expanded flows." *Journal of Applied Fluid Mechanics* 12, no. 4 (2019): 1127-1135. https://doi.org/10.29252/jafm.12.04.29495

[35] Pathan, Khizar, Prakash Dabeer, and K. H. A. N. Sher. "An investigation of effect of control jets location and blowing pressure ratio to control base pressure in suddenly expanded flows." *Journal of Thermal Engineering* 6, no. 2 (2019): 15-23. https://doi.org/10.18186/thermal.726106
[36] Pathan, Khizar Ahmed, Prakash S. Dabeer, and Sher Afghan Khan. "An investigation to control base pressure in suddenly expanded flows." *International Review of Aerospace Engineering* 11, no. 4 (2018): 162-169. https://doi.org/10.15866/irease.v11i4.14675
[37] Shamitha, Shamitha, Asha Crasta, Khizar Ahmed Pathan, and Sher Afghan Khan. "Numerical simulation of surface pressure of a wedge at supersonic Mach numbers and application of design of experiments." *Journal of Advanced Research in Applied Mechanics* 101, no. 1 (2023): 1-18. https://doi.org/10.37934/aram.101.1.118
[38] Shamitha, Shamitha, Asha Crasta, Khizar Ahmed Pathan, and Sher Afghan Khan. "Analytical and Numerical Simulation of Surface Pressure of an Oscillating Wedge at Hypersonic Mach Numbers and Application of Taguchi's Method." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 30, no. 1 (2023): 15-30. https://doi.org/10.37934/araset.30.1.1530
[39] Shaikh, Javed S., Krishna Kumar, Khizar A. Pathan, and Sher A. Khan. "Analytical and computational analysis of pressure at the nose of a 2D wedge in high speed flow." *Advances in Aircraft and Spacecraft Science* 9, no. 2 (2022): 119-130.
[40] Shaikh, Javed S., Krishna Kumar, Khizar A. Pathan, and Sher A. Khan. "Computational Analysis of Surface Pressure Distribution over a 2D Wedge in the Supersonic and Hypersonic Flow Regimes." *Fluid Dynamics & Materials Processing* 19, no. 6 (2023). https://doi.org/10.32604/fdmp.2023.025113
[41] Shaikh, Javed Shoukat, Khizar Ahmed Pathan, Krishna Kumar, and Sher Afghan Khan. "Effectiveness of Cone Angle on Surface Pressure Distribution along Slant Length of a Cone at Hypersonic Mach Numbers." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 104, no. 1 (2023): 185-203. https://doi.org/10.37934/arfmts.104.1.185203
[42] Khan, Sher Afghan, Abdul Aabid, and C. Ahamed Saleel. "CFD simulation with analytical and theoretical validation of different flow parameters for the wedge at supersonic Mach number." *International Journal of Mechanical and Mechatronics Engineering* 19, no. 1 (2019): 170-177.
[43] Shaikh, Sohel Khalil, Khizar Ahmed Pathan, Zakir Ilahi Chaudhary, B. G. Marlpalle, and Sher Afghan Khan. "An Investigation of Three-Way Catalytic Converter for Various Inlet Cone Angles Using CFD." *CFD Letters* 12, no. 9 (2020): 76-90. https://doi.org/10.37934/cfdl.12.9.7690
[44] Shaikh, Sohel Khalil, Khizar Ahmed Pathan, Zakir Ilahi Chaudhary, and Sher Afghan Khan. "CFD analysis of an automobile catalytic converter to obtain flow uniformity and to minimize pressure drop across the monolith." *CFD Letters* 12, no. 9 (2020): 116-128. https://doi.org/10.37934/cfdl.12.9.116128
[45] Khan, Sher Afghan, M. A. Fatepurwala, K. N. Pathan, P. S. Dabeer, and Maughal Ahmed Ali Baig. "CFD analysis of human powered submarine to minimize drag." *International Journal of Mechanical and Production Engineering Research and Development* 8, no. 3 (2018): 1057-1066. https://doi.org/10.24247/ijmperdjun2018111
[46] Pathan, Khizar A., Sher A. Khan, N. A. Shaikh, Arsalan A. Pathan, and Shahnawaz A. Khan. "An investigation of boat-tail helmet to reduce drag." *Advances in Aircraft and Spacecraft Science* 8, no. 3 (2021): 239-250.
[47] Pathan, Khizar Ahmed, Zakir Ilahi Chaudhary, Ajaj Rashid Attar, Sher Afghan Khan, and Ambareen Khan. "Optimization of Nozzle Design for Weight Reduction using Variable Wall Thickness." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 112, no. 2 (2023): 86-101. https://doi.org/10.37934/arfmts.112.2.86101
[48] Khalil, Shaikh Sohel Mohd, Rai Sujit Nath Sahai, Nitin Parashram Gulhane, Khizar Ahmed Pathan, Ajaj Rashid Attar, and Sher Afghan Khan. "Experimental Investigation of Local Nusselt Profile Dissemination to Augment Heat Transfer under Air Jet Infringements for Industrial Applications." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 112, no. 2 (2023): 161-173. https://doi.org/10.37934/arfmts.112.2.161173