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A Comprehensive Study of Split-Triangular Fins under Natural Convection Field: Experimental and Numerical Investigation

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Abstract

Due to the geometry orientation, the triangular shaped fins could enhance the heat transfer rate by inducing the local flow turbulence as compared to the rectangular or circular shaped fins. Splitting the fins and placing them in such a way to create a clearance gap between those fins were an effective method to improve the heat transfer rate. This project work investigated the triangular finned heat sinks for these geometrical configurations. Studies for estimating optimal orientation of the fins were conducted The thermal operating conditions for the study was ΔT = 40°C, 60°C, 80°C and 100°C. CFD simulations were performed using ANSYS FLUENT while experimental studies were conducted for validating the numerical results. The results indicated that the triangular fin's orientation had an influence over the heat transfer rate from heat sinks. Also, the split-fins had enhanced the heat transfer rate by nearly 26% and in general the split-distance had a favorable impact on the heat transfer rate. However, the vertical offset had adverse impact beyond a certain fin offset distance in the vertical direction.

Keywords:*Natural Convection, Split Fins, CFD Analysis for Fins, Triangular Fins*

1. Introduction

Extended surfaces or fins are widely used for heat removal from high temperature heat sources such as electronic components, automobile internal combustion engines. When the fins are applied to the heat sources, the overall solid area that are available for the natural convection heat transfer increases which results in high heat transfer rate. In recent years, detailed research had been conducted in improving this heat removal process by studying the fin shapes, fin orientations, materials etc. One such way to increase the heat transfer rate was to introduce the flow turbulence surrounding the fins which would enhance the mixing between the hot and cold air. In order to create this local turbulence, various researchers had suggested geometrical changes such as inline arrangement as well as staggered arrangement and split fins.

The most commonly applied fins are of either circular or rectangular / square shapes. However, due to the orientation, the triangular shaped fins could produce local turbulence in terms of eddy formations near the fin surfaces. This would enhance the heat transfer rate from the heat source.

In order to further enhance the heat transfer rate, the concept of splitting the fins while maintaining the same fin volume was studied by Aishwarya A Patil(2016) for pin fins. A similar investigation for the triangular fins was considered for this project. The detailed problem description had been discussed in the following sections.

2. Literature Review

The research work by Aishwarya A Patil(2016) was focused on investigating the split pin-fins for natural convection heat transfer enhancement. The authors had concluded that significant heat transfer enhancement could be achieved from the split pin-fin heat sinks as compared to the solid pin fin heat sinks. MehranAhmadi(2014)had investigated the effect of interrupted fins on the natural convection heat transfer using experimental and CFD simulations. The authors had studied the fin spacing, fin interruption and their subsequent role in heat transfer enhancement. The combined physics of natural convection and mass transfer from vertically placed fin arrays that were surrounded by moist air by A. Giri (2003). The application of radial fins on horizontal circular and square cylinders was investigated by ImanJafari(2014) for the natural convection field. The authors had suggested six and eight fin arrangement rather than two and four fin arrangement for higher heat transfer rate. C.S Wang (1997) had investigated the natural convection heat transfer for an annular finned heat sink. In their analytical solution method, the superimposition of boundary layer and fully developed flow solution were applied based on the local flow physics. Avram Bar-Cohen (1983) had identified optimal fin positioning on printed circuit board. The authors had considered symmetric and asymmetric thermal channels. The optimum spacing during this study was considered as the fin spacing for which the volumetric heat dissipation rate was maximum. They had observed that the increase in the PCB card thickness resulted in optimum fin spacing. With the finite element method, H. R. Goshayeshi (2009) had analyzed natural convection heat transfer field surrounding both vertical and horizontal heated plate that were attached with fins. The authors had observed the increase in heat transfer rate when the fin spacing was increased till a certain spacing and any further increase in fin spacing resulted in reduction in heat transfer rate. The inclination angle and its impact on the heat sink's thermal performance was studied by A. A. Walunj (2014). From their study it was observed that the inclination angle had an adverse effect on the heat transfer rate. The entropy generation during the natural convection heat transfer mechanism was investigated by Hakan F Oztop(2017). Their study was conducted for various opening ratio of the duct as well as center of the opening and varying Rayleigh numbers. They had concluded that the significant entropy generation was observed near the cavity opening. Dhanunjay S Boyalakuntla(2004) had investigated the application of pin-fins for heat removal from the laptop's display panels. They had studied for various factors such as the effect of panel inclination, effect of fin spacing etc. Han-Taw Chen (2017) had conducted numerical and experimental studies for annular finned heat exchanger that was under the natural convection heat transfer field. The authors had suggested Zero-Equation turbulence model over the RNG k-ϵ model for the CFD simulations. Bhupender Kumar Bharti (2015) had applied finite element method based solution approach for predicting the natural convection heat transfer field surrounding the conical and trapezoidal fins. They conclude that the trapezoidal fins perform better than the conical fins.

3. Problem Statement

The project work is based on optimizing a heat sink with triangular fins. The heat sink dimensions were obtained from AishwaryaPatil (2016). In their work, the heat sink dimensions were 120 mm in width and 180 mm in height while the thickness of the heat sink was 10 mm. Their heat sink design had 16 pin-fins of diameter 30 mm and a height of 56 mm. The triangular finned heat design for this research work followed their dimensions with the heat sink plate dimension of 120 mm X 180 mm X 10 mm. The dimensions of the triangular fins were calculated by maintaining identical surface area of the pin-fins as shown in the following calculations.

- Pin fin diameter = 30 mm
- Pin fin height = 56 mm
- Total surface area of the fin = Fin lateral surface area + Fin tip surface area
- Total surface area of the fin = 8105.4 mm^2
- Total number of fins = 16

So, the total fin surface area = 16 X 8105.4 = 129684.9 mm^2

Hence, the triangular fins must be designed in such a way that the total area should be equal or less than pin-finned heat sink area.

- Triangular base size = 10 mm
- Triangular fin height = 56 mm
- Surface area of the fin = Fin lateral surface area + Fin tip surface area
- Surface area of the triangular fin = 1723.3 mm^2.
- Equivalent number of fins = 129684.9 / 1723.3 = 75

However, the number of fins as per this calculation is quite high. Among the available surface area, only 33% of the area was considered for the heat sink design calculations.

- Number of fins = 25
- Total triangular fin surface area = 25 * 1723.3 = 43082.5 mm^2.
- Ratio of the pin-fin surface area = 129684.9 / 43082.5 = 33.2%

With this design, material savings on construction was also an advantage. The following image shows the heat sink model developed in *ANSYS Design Modeler*.

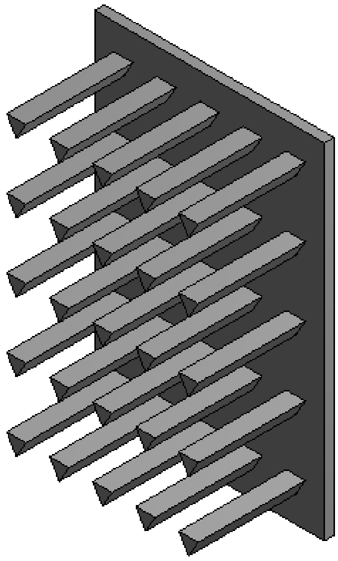


Figure 1: Triangular finned heat sink

The project work performed under three phases as explained below.

- Phase I: Determining the optimum fin orientation
- Phase II: Investigation of Split triangular fins
- Phase III: Investigation of Vertical Offset in positioning the fins

With the sharp edges on the triangular fins, local flow turbulence was expected to be generated. However, the optimum orientation of the triangular fins were analyzed in the first stage of the project. The following shows the comparison of the fin orientation.

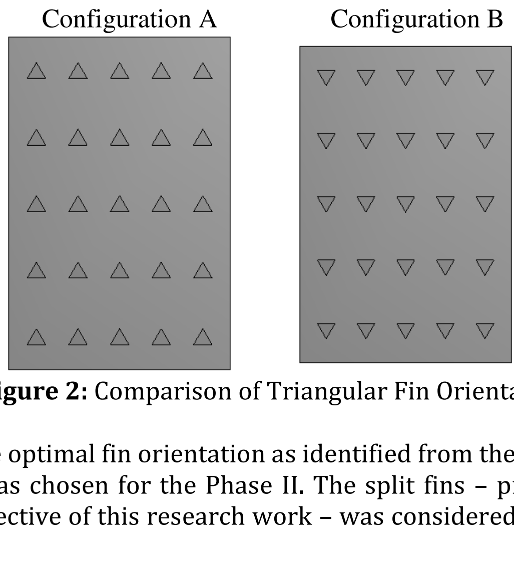


Figure 2: Comparison of Triangular Fin Orientation

The optimal fin orientation as identified from the Phase I was chosen for the Phase II. The split fins – primary objective of this research work – was considered in the next phase of the project. A variable based on the fin splitting – clearance ratio – was defined as follows.

Clearance ratio, $\alpha = \frac{Gap\ between\ the\ fins}{Fin\ base\ dimension}$

The fin base dimension was 10 mm. As shown in the following table, four cases of $\alpha = 0.1, 0.15, 0.20\ and\ 0.25$ were considered for the study.

Table 1: Triangular Fin Split Distance Details

Configuration	Gap between the fins	Clearance ratio, α
C1	1.0 mm	0.10
C2	1.5 mm	0.15
C3	2.0 mm	0.20
C4	2.5 mm	0.25

CFD simulations were conducted for these geometrical configurations. From the obtained results, the optimum fin split distance were identified based on the heat transfer rate.

In the final phase of the project work, the impact of vertical offset in fin positions over the heat transfer rate was studied. The vertical offset was defined as the split fin positions were vertically moved. This would alter the flow profile near the fins and enhance mixing of fluid streams. A sample (Configuration D4) of the vertically offset fins had been shown below.

Four vertical offset configurations were considered. These were obtained by limiting the maximum offset to the mid position of the fin height and uniformly varying the offset distance for the configurations.

Vertical Offset Ratio, $\beta = \frac{Vertical\ offset\ ditance}{Fin\ Base\ Dimension}$

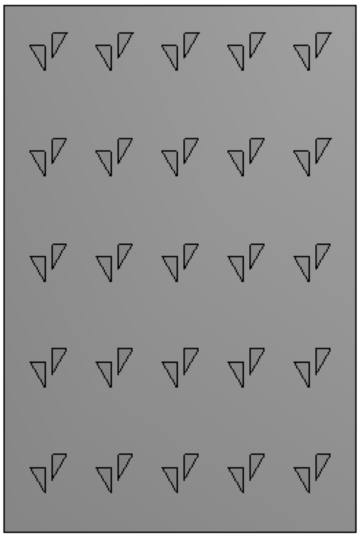


Figure 3: Split Triangular Fin with Vertical Offset

Table 2: Triangular Fin Vertical Offset Details

Configuration	Vertical offset between the fins	Clearance ratio, β
D1	1.08 mm	0.11
D2	2.16 mm	0.22
D3	3.24 mm	0.33
D4	4.32 mm	0.44

The studies were conducted for various thermal conditions to verify the performance of the heat sink over varying operating conditions that were expected in a typical electronic components. For the project work, it was characterized by thetemperature difference between the heat sink and the atmosphere.

$$\Delta T = (T_{HeatSink} - T_{\infty})$$

For this research work, four operating conditions were considered, $\Delta T = 40°C, 60°C, 80°C\ and\ 100°C$ as considered in their study by AishwaryaPatil (2016).

4. Experimental Analysis

The predictions that were obtained from the CFD simulations need to be verified for the accuracy as well as reliability. An experimental study for the identical operating conditions was conducted and the results between CFD and experiment were compared. This comparison – known as validation – of results had been discussed in Section 6. In this section, the experimental procedure for this project had been explained.

The heat sink model was placed vertically in room that had a static conditions – no movement of air – as well in isothermal condition. Heat supply was achieved with the help of dimmerstat. The voltage and current were monitored by the Voltmeter and Ammeter. The diagonally placed thermocouples on the back of the heat sink were monitored. The electrical energy was adjusted to maintain the respective thermal operating condition. At various time intervals – for every minute – the readings from thermocouples, Voltmeter and Ammeter were noted. When the variation in the readings for these between successive time intervals were negligible, it was concluded that the steady state conditions had been obtained for that thermal operating condition. This experimental methodology was repeated for all configurations.

5. Numerical Analysis

ANSYS Work Bench and its modules were utilized for this project work. The meshing for the computational volume – fluid and the solid volume – was discretized using *ANSYSMesher*. A combination of hexahedral and tetrahedral shaped elements were generated in the computational domain along with the prism layers to resolve the flow gradients near the wall surfaces. The heat sink was placed inside a room, of dimensions 1 m X 1m X 5m.

CFD simulations for this project were carried out on *ANSYS FLUENT*. The fluid motion was permitted through the bottom and top surfaces while the surrounding four surfaces were acted as wall boundary. These conditions were applied in the CFD simulations with the help of stagnant velocity inlet conditions, pressure-outlet conditions and wall boundary conditions respectively.

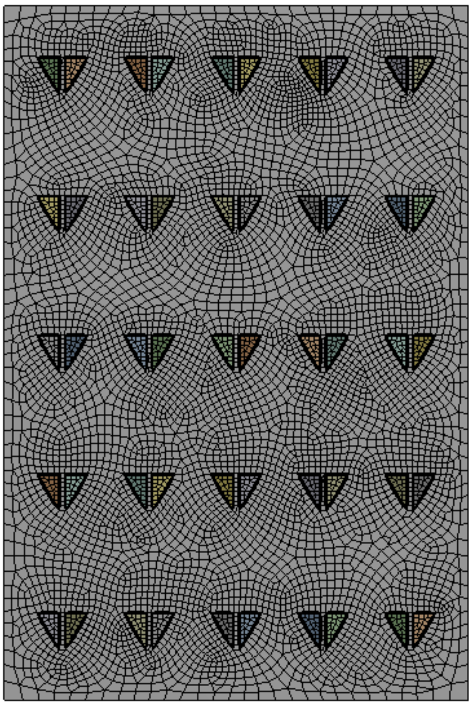


Figure 4: Meshing for the Split-Triangular Fins

The natural convection fluid motion had been modeled by activating the gravity and the fluid (Air) density was modeled using ideal-gas to account for the effects of pressure and temperature.

SIMPLE algorithm was applied to model the pressure-velocity coupling that arise for the incompressible flow physics. 3-diemensional steady-state solutions were obtained with the simulation convergence based on obtaining energy balance.

6. Validation

In order to verify the predictions from the numerical simulations, the validation – comparison between the experimental and CFD results – was considered. Based on the results obtainedfrom the CFD simulations, the orientation of Configuration B had resulted in better heat transfer rate. The experimental studies were conducted for this geometrical configuration and the heat transfer rate comparison had been shown in the graphical format in the figure 5.

As can be seen in the Figure 5, the difference in heat transfer estimation between these solution methodologies had been in the range of 7-10%. This magnitude in variationbetween the experimental and CFD simulation data was considered negligible and it was concluded the validation for the CFD simulations had been achieved.

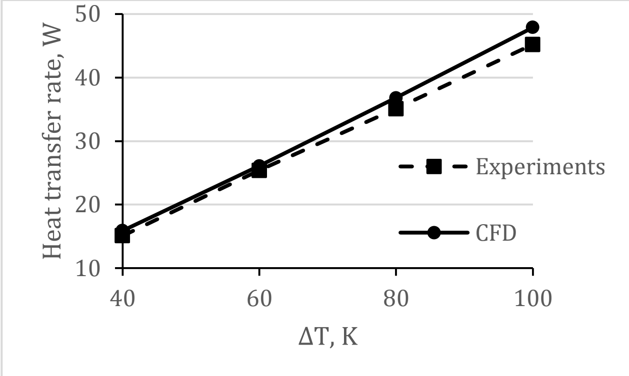


Figure 5: Results comparison between Experimental and CFD data

7. Results and Discussions

In the first phase of the work, the impact of the fin orientation was investigated by conducting the CFD simulations for Configuration A and B and the results in terms of heat transfer rate had been compared in the following table.

Table 3: Heat transfer rate comparison between Configurations A and B

ΔT, K	Configuration A	Configuration B
40	14.2	15.9
60	23.2	26.1
80	32.8	36.8
100	42.7	47.9

Heat transfer rate from the Configuration B was consistently higher (~12%) than Configuration A across all the operating conditions.

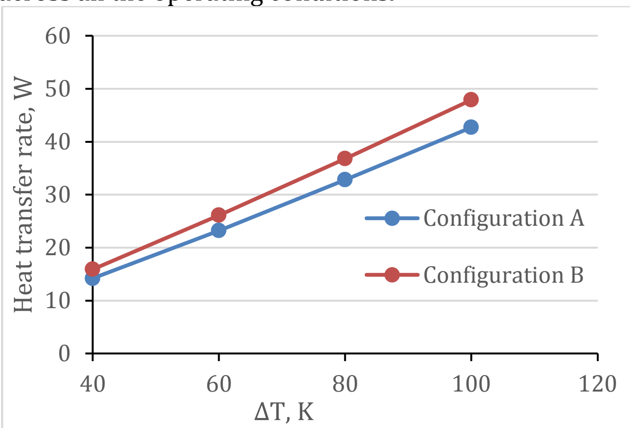


Figure 6: Heat transfer rate comparison between Configuration A and B

A section plane at the middle of the fin height was constructed in the CFD-Post, the post-processing software. The scalars such as temperature and velocity were plotted as colors to study the results.

Configuration A	Configuration B

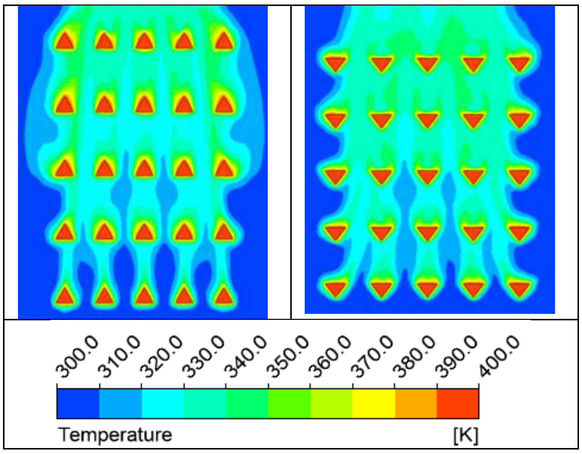


Figure 7: Temperature contours comparison for ΔT = 100°C

In the temperature contours on Figure 7, it could be observed that the temperature profile at the first row was significantly different between the configurations A and B. The sharp edges for Configuration B resulted in better fluid motion as could be seen in the velocity contours in Figure 8.
The tip vortex generated for the Configuration B resulted in relatively higher flow velocity as compared to the Configuration A. This was evident from the velocity contours near the fourth and fifth row fins in Figure 8.
Based on these results, the fin orientation on Configuration B had been considered as optimum and further investigation on this project work had been based on this configuration.

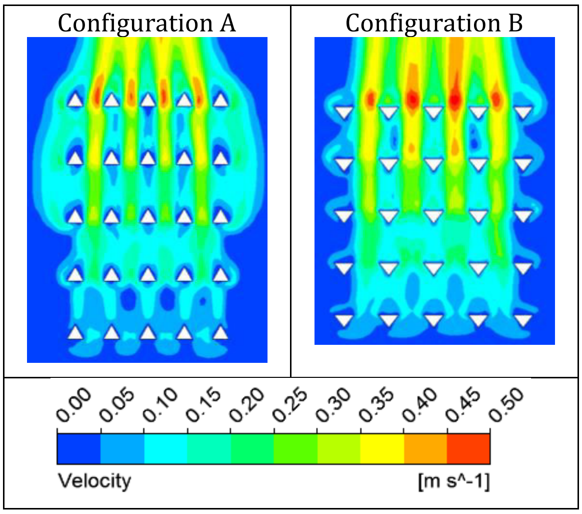


Figure 8: Velocity contours comparison for ΔT = 100°C

In the next phase of the work, the impact of fin splitting on the heat transfer characteristics was studied. From the following table, it was evident that the heat transfer rate was increased with the increase in fin splitting distance. The results were also compared in a graph in Figure 9.

Table 4: Heat transfer rate comparison between Split-fin configurations

ΔT, K	Configuration C1	Configuration C2	Configuration C3	Configuration C4
40	13.2	12.4	17.9	19
60	19.4	20.1	30.1	32.1
80	22.5	23.9	43.3	46.1
100	41.3	39.8	57.7	60.6

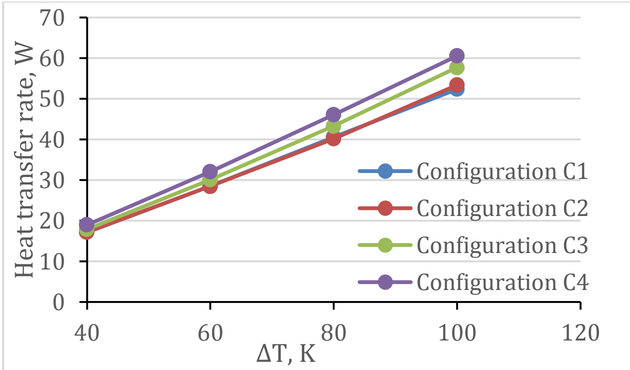


Figure 9: Heat transfer rate comparison between Split-fin configurations

Between the Configuration C1 and C2, there wasn't significant changes in heat transfer rate. However, further increase in the fin splitting resulted in significant improvement in heat transfer rate.

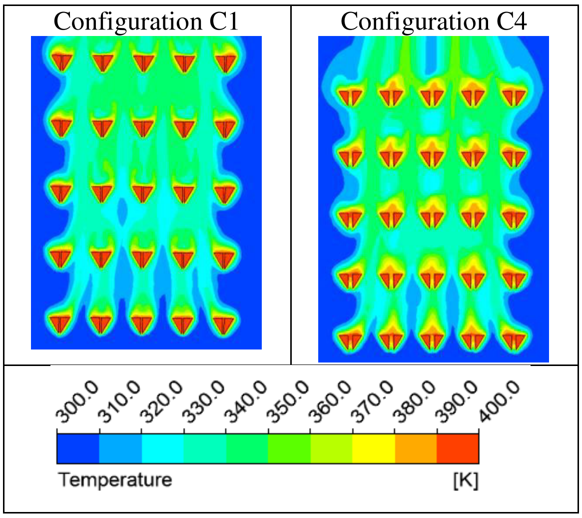
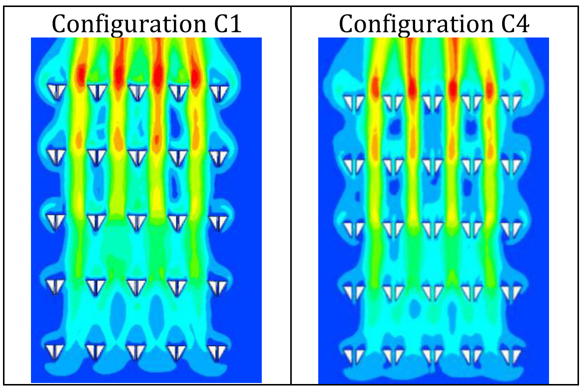


Figure 10: Temperature contours comparison for ΔT = 100°C



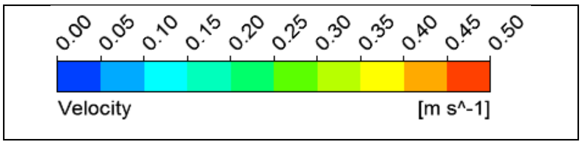


Figure 11: Velocity contours comparison for ΔT = 100°C

Among these four geometric configurations, Configuration C4 had provided higher heat transfer rate and was considered for further investigations in this project work.
Among the vertically offset heat sinks, the heat transfer rate was reducing as the offset distance was increased. The difference between the Configuration D1 and other configurations were significant as could be seen from Figure 11. Though there wasn't much difference in heat transfer characteristics among Configuration D2, D3 and D4.

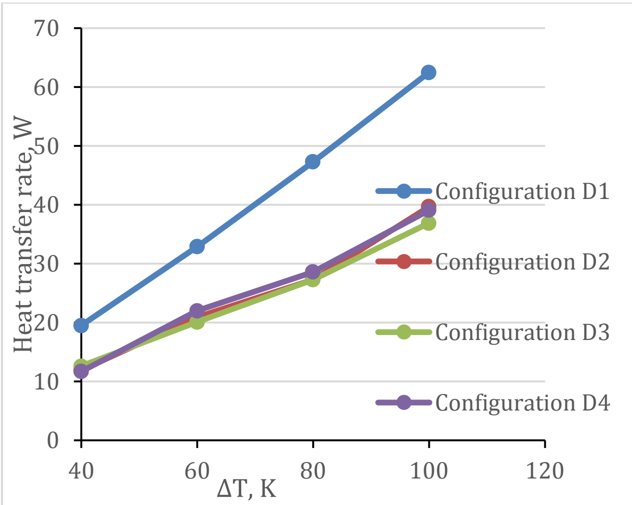
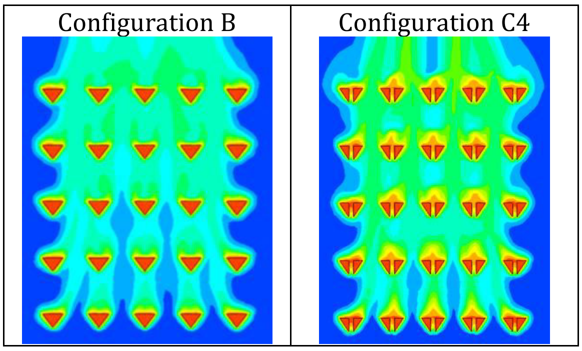


Figure 12: Heat transfer rate comparisons between the Vertical-Offset configurations

In the following Table 5, the heat transfer rate comparison among the optimal configuration from each phase of this study had been provided. With the introduction fin-split (Configuration C4), the heat transfer rate was increased nearly 26% as compared Configuration B for the operating condition of ΔT = 100°C.



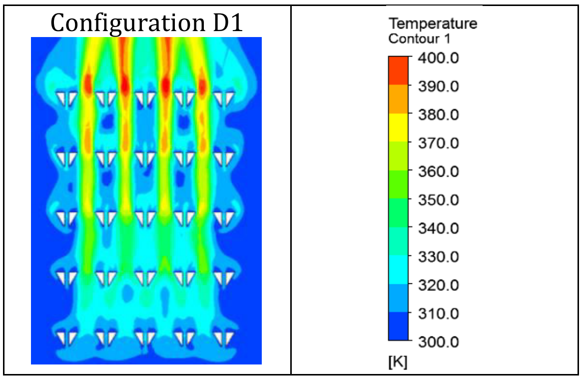


Figure 13: Temperature contour comparison

However, the vertical offset (Configuration D1) resulted in only 3% increase in heat transfer enhancement as compared to the Configuration C4 for the same thermal operating conditions.

Table 5: Heat Transfer Comparison

ΔT, K	Configuration B	Configuration C4	Configuration D1
40	15.9	19	19.5
60	26.1	32.1	32.9
80	36.8	46.1	47.3
100	47.9	60.6	62.5

Temperature contour comparison between these configurations had been shown in Figure 12.

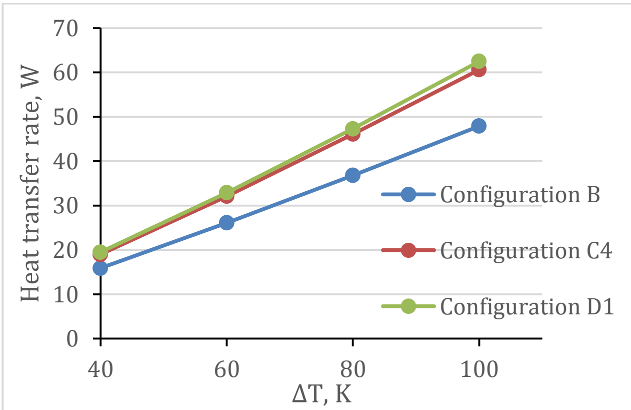


Figure 14: Heat transfer rate comparison

8. Conclusions:

Based on the results obtained, the following conclusions were identified from this project.

- The orientation of the Solid triangular fins (Configuration A and Configuration B) had significant impact on the natural convection heat transfer rate.
- Heat transfer rate from the Configuration B was consistently higher (~12%) than Configuration A across all the operating conditions. This was attributed to the tip vortex generated for the Configuration B resulted in relatively higher flow velocity as compared to the Configuration A.
- The introduction of fin-splitting resulted in significant heat transfer enhancement. However,

for the lower fin-splitting heat sink configurations A and B, the increase in heat transfer rate was minimal. As the split distance was further increased (Configuration C and D), the high heat transfer enhancement was observed.

- The vertical offset of the fins had an adverse impact on the heat transfer rate apart from Configuration D1. With the increase in the vertical offset, the heat transfer rate was reduced.
- Overall, the split-fin configuration provided 26% heat transfer enhancement while the offset-fin configuration provided 30.5% as compared to the base model (solid fins, Configuration B).

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