CFD Analysis Of Pin-Fin Heat Sink Used In Electronic Devices

K. Subahan, E. Siva Reddy, R. Meenakshi Reddy

Abstract— Faster high heat dissipation plays a vital role in many of the engineering applications. The phenomenon of the simultaneous heat exchange due to convection and radiation is one of the ways to dissipate heat in most of the applications such as heat sinks where are widely used. Plate Pin-fin heat sinks obtain higher heat transfer rate, lower pressure drop and low thermal resistance than the finned or unfinned channel heat sink. Copper and Aluminium are the materials especially used rather than brass and iron. The utilization of pins in the heat sink increases the heat transfer area to reach the extreme rate of heat loss in a restricted space. In expanding the width of the heat sink the higher heat dissipation happens rather increasing the height of the heat sink and furthermore design parameters also affect thermal resistance, by considering these are as fundamental parameters the extended surfaces as pin-fin heat sink is retrieved to another Rhombus shaped pin-fin heat sink with various alignments and contrasted and Rhombus pyramid structure.

Index Terms— Computational Fluid Dynamics (CFD), Pin-Fins, Heat Sink, Rhombus Prism, Rhombus pyramid, Thermal Analysis.

NOMENCLATURE

A	-	Area (m^2)
ρ	-	Density (Kg/m^3)
C_p	-	Specific heat (J/Kg-K)
Q	-	Heat load (W)
P	-	Pressure (N/mm^2)
V	-	Volume (m^3)
K	-	Thermal conductivity (W/m ^oK)
R	-	Thermal resistance (K/W)
h	-	Heat transfer co-efficient (W/m^2 ^oK)
ΔP	-	Pressure drop over the heat sink (Pa)
µ	-	Absolute viscosity of the fluid (Kg/m-s)
v	-	Kinematic viscosity of the fluid (m^2/s)
ΔT	-	Temperature difference (^oC or ^oK)

1 INTRODUCTION

THE performance levels of electronic frameworks, for example, PCs and electronic devices are expanding foremost quickly meanwhile controlling the thermal related issues of the heat sources has been a challenge. Heat is generated when an electric current flows through a resistive element, where these resistive elements depend on the flow of electric current and perform various functions accordingly. The heat dissipation is one of the most critical aspects to be considered so as to keep up the continuous operation. Normally Aluminium (Al) plates are sufficient to dissipate heat from heat sinks as a part of convection i.e., heat transferred from fins to ambient air, when the heat loads are smaller. According to the recent studies, copper (Cu) plates have been replaced as the best conductor to improve the heat transfer rate over the heat sink from the heat source [1]. In this way, larger extended surfaces namely new type of conductive heat sinks, and more coolant stream are keys to decreasing the problem areas. The present dissipates approximately 70 W maximum meanwhile this number will increase in the future. According to the heat removal proficiency of the established heat sink the temperatures at the surface of the heat sink and surrounding ranges from 10 ^oC to 35 ^oC [2]. It has been the point of the electronic industries to lessen the power densities of the electronic segments to diminish the working temperatures. However, there is a persistent increment in the heat they disperse just as a gigantic interest for them in electronic frameworks. Along these lines, cooling innovation has consistently been and will be a fundamental and inescapable advance in appropriate working and unwavering quality of the electronic segments. Additional effective cooling loads are required in order to keep electronic devices at low temperatures (T<K) [3]. Dynamic cooling and latent cooling are the two basic techniques deal with heat removal. The heat is removed by using a cooling liquid which passes through and over the surroundings of the electronic segments to ingest their fumes of heat is called dynamic cooling [4, 5]. Then again, inactive cooling profits by radiation and free convection heat transfer rate is created and heat transferred to nature. Clearly, dynamic cooling has the higher estimation of heat transfer rate, yet it requires more prominent vitality utilization since fans or siphons are utilized to convey the cooling liquid, and it creates clamor too. Then again, heat expulsion from

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numerous electronic and media transmission gadgets are finished by detached cooling, on account of its great characteristics, for example, being quiet, dependable, and savvy [6,7]. Air cooling is one of the most prominent cooling technique either passive or active heat sinks are installed to remove heat from the electronic equipment and also Nano-fluids being used for more effective cooling. [8, 9]. Danish Ansari et al. [10] numerically investigated and compared Hotspot thermal management using a micro channel pin-fin hybrid heat sink. Erfan Rasouli et al. [11] experimentally studied and varied various pitch and aspect ratios of eight micro pin-fin heat sink characterized under single-phase liquid flow and also investigated their heat transfer and pressure drop across the pin-fins. Sanchai Ramphueiphad et al. [12] In this paper junction temperature and fan pumping power of the heat sink were optimized and experimentally investigated on multiobjective optimization of a multi cross-section pin fin heat sink (MCSPFHS) used in electronic devices. Xiangrui Meng et al. [13] the impact of mounting edge on heat dissipation performance of a heat sink under natural convection condition is researched in this paper by numerical simulation and experimental tests. Z.G Liu et al. [14] experimentally proved that pin-fin shape significantly affects heat transfer at larger Reynolds number. Joo and Kim [15] this paper presents that the heat transfer and pressure drop are likely dependent on the effective width, length, spacing, and height of the pins over the heat sink. By decreasing and increasing the length and height of the fins accordingly may affect the heat transfer and efficiency of the heat sink. Hongxia Zhao et al. [16] experimentally investigated with different models and shapes that triangular pin-fins has larger flow resistance and elliptical pin-fin has better streamline with lower thermal resistance.
Weilin Qu et al. [17, 18 in this paper, the roughness viscosity model and viscosity model were proposed to interpret experimental data and analyzed the results using three-dimensional conjugate model numerically over the micro-channel heat sink. R. Sajedi et al. [19] the numerical investigation was carried out for considering the effect of a splitter on the hydrothermal behavior of a pin-fin heat sink, frequently expanding the heat transfer zone to reach the maximum rate of heat losses in a constrained space to avoid or weaken the stream separation and reduction of the pressure drop through the heat sink.

2 METHODOLOGY

The aim of the present work is to simulate heat sink (HS) by considering both natural convection and forced convection using two different geometry of fins and materials. Considered geometries for the present work are rectangular prism and rectangular pyramid with constant height. The 3D models of the heat sinks have been generated in Solidworks software and imported into Ansys workbench design modeller in neutral file format. Required geometric operations have been carried out to simplify the geometry for improved meshing.The viscosity term is considered. Therefore the governing equations for the fluid flow and heat transfer are the accompanying type of in-compressible continuity equations, Navier – stokes conditions x-y and z-direction momentum, and energy equation together with the equation of state.

Governing equations are:

Continuity equation

$$\nabla(\rho V) = 0 \tag{1}$$

Momentum equation

$$(u.\nabla)\rho V = -\nabla P + \mu\nabla^2 V \tag{2}$$

Energy equation

$$V.\nabla T = \frac{k}{\rho C_P}\nabla^2 T \tag{3}$$

Governing equation for heat sink is given by

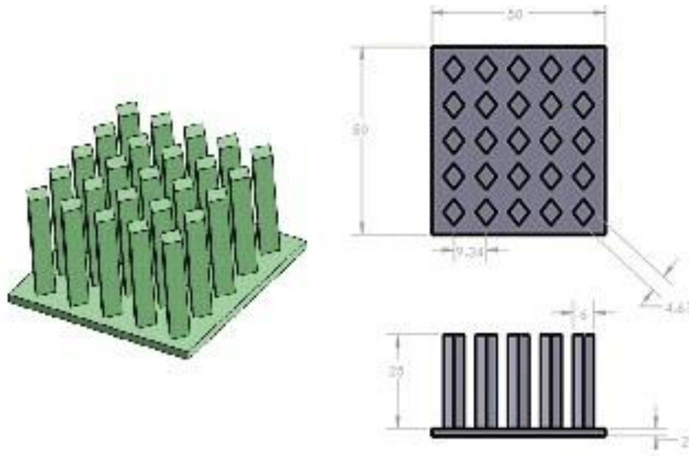
$$\nabla^2 T = 0 \tag{4}$$

2.1 Heat Source

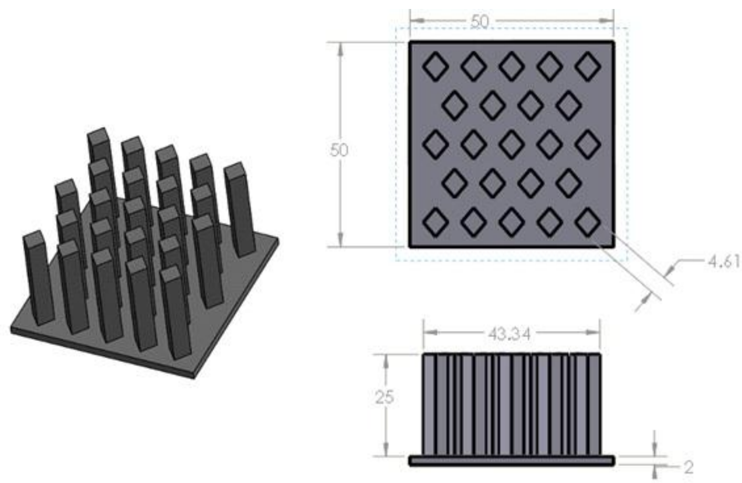
The heat sink base dissipates heat at the rate of 50 W at the peak load of utilization. The heat sink is modelled as a 3D area which dissipates 50 W. The 50mm x 50mm cross-sectional area of a heat sink base. Within the power supply case is assumed to have a negligible effect on the base plate temperature. Subsequently, in the present numerical model, the heat dissipation inside the power supply case is not considered and the heat sink is evaluated with natural convection phenomenon to locate thermal distribution in fins.

2.2 Heat Sink

The rated wattage at the peak load working of base is 50 W is applied to the processor bottom face. The various parameters of heat sink is designed as per the previous studies depending on the sufficient heat dissipation rate and the heat sink is mounted on the processor. [2, 10].



(a)



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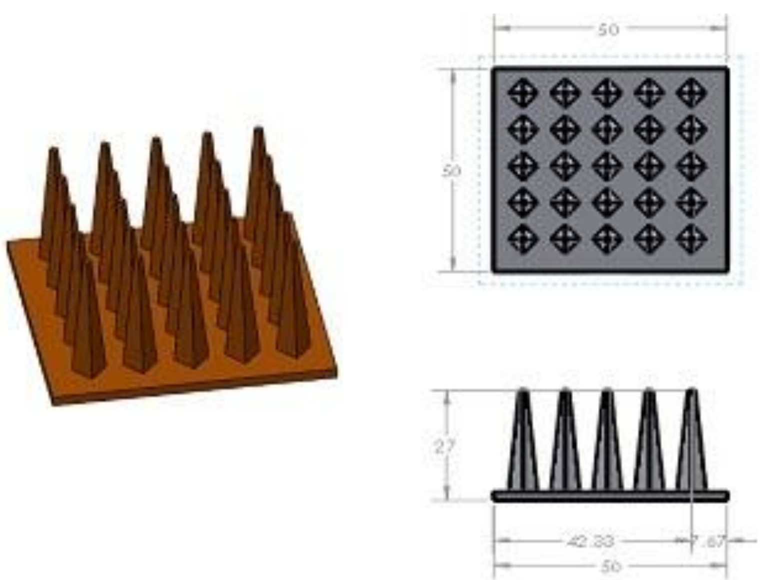

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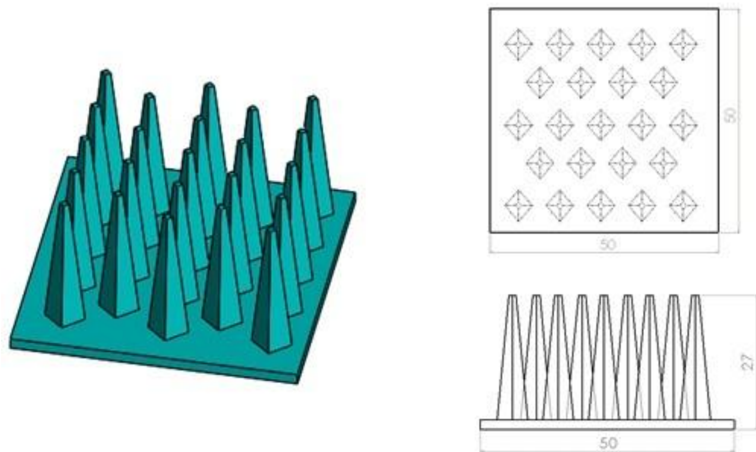


(d)

Figure 1 (a, b, c, d): *Three views namely iso, top, front represented in the above figures for inline and staggered heat sink with Rhombus prism pin fin and also heat sink with Rhombus pyramid pin fin.*

3 BOUNDARY CONDITIONS

3.1 Forced convection

The Boundary conditions are applied on the geometric entities for forced convection cases. Heat flux of 20,000 w/m^2 i.e. 50 W for current heat sink base area has been applied. Right face as shown in figure is assigned as pressure outlet, all the remaining faces act as wall in the fluent simulations. Left face of the fluid domain as shown in figure is assigned as velocity inlet with as 3 m/s.

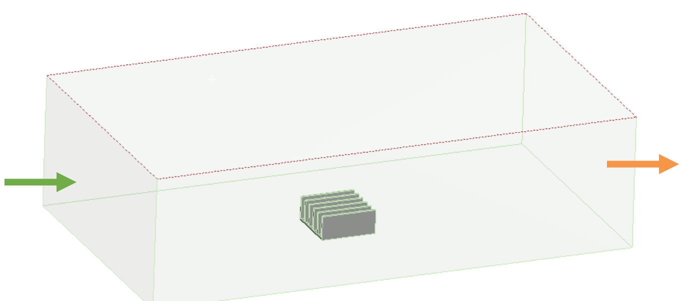


Figure 2: Boundary conditions for forced convection case.

3.2 Natural convection

The boundary conditions are applied on the geometric entities for natural convection cases. Heat flux of 20,000 w/m^2 i.e. 50 watts for current heat sink base area has been applied. Left face and right face of the fluid domain as shown in figure are assigned as pressure inlets whereas top face is assigned as pressure outlet. All the remaining faces are assigned as wall in the fluent simulations.

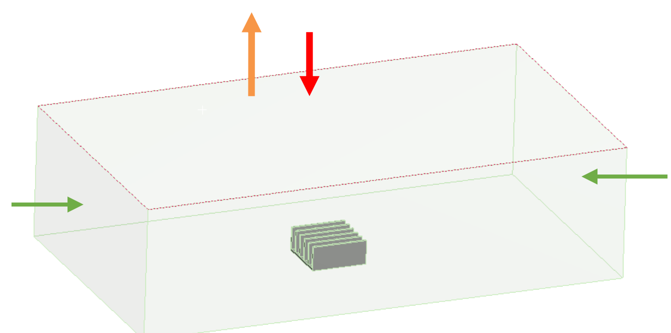


Figure 3: Boundary conditions for natural convection cases.

4 ANALYSIS

CFD Analysis of heat sink is performed in Ansys Workbench. Ansys workbench is used for pre and post processing whereas Fluent Solver is used for solving. By varying the material, fin geometry-shape with natural and forced convection conditions have been analyzed with ten cases of the heat sinks.

In all the simulations constant heat flux of 50w has been assigned to the base of the heat sink are simulated with copper and Aluminium material in both natural convection and forced convection conditions. Fluid domain representing the air medium around the heat sink has been created with 450mm*250mm*125mm dimensions as shown in figures 2, 3.

4.2 Meshing

Global mesh control parameters assigned to the geometry and the imported 3D model is meshed with 645254 of elements, the complete mesh model of the heat sink with fluid domain is shown in the figure.

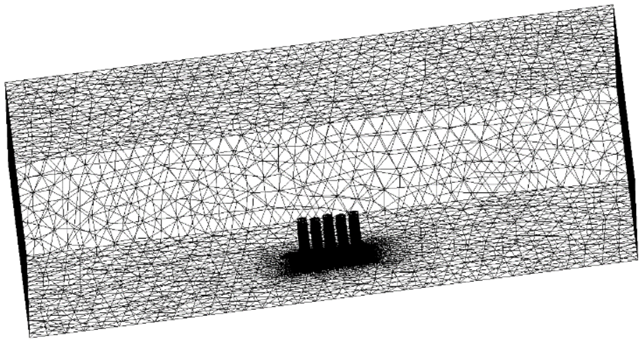


Figure 4: Mesh model of the heat sink with fluid domain

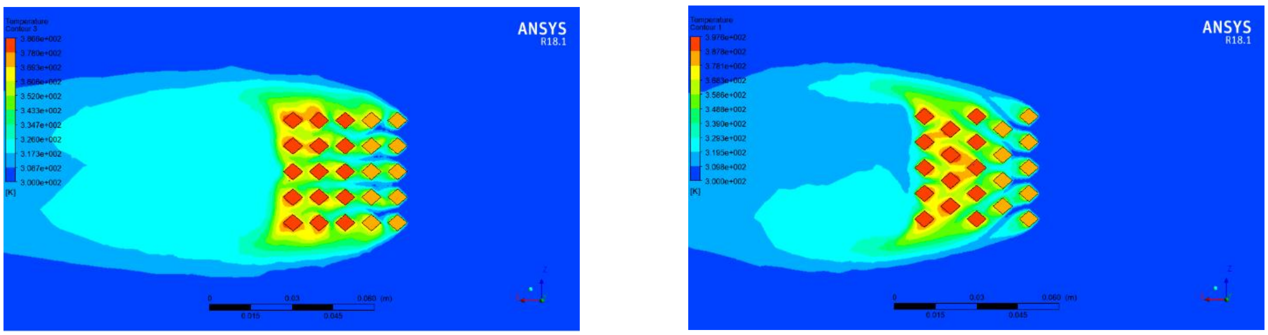
TABLE 1
Materials properties

Properties	Air	Aluminium	Copper
Density (Kg/m^3)	1.225	2719	8978
Specific heat (J/Kg-K)	1006.43	871	381
Thermal conductivity (W/m-^{o}K)	0.0242	202.4	387.6

5 RESULT AND OBSERVATIONS

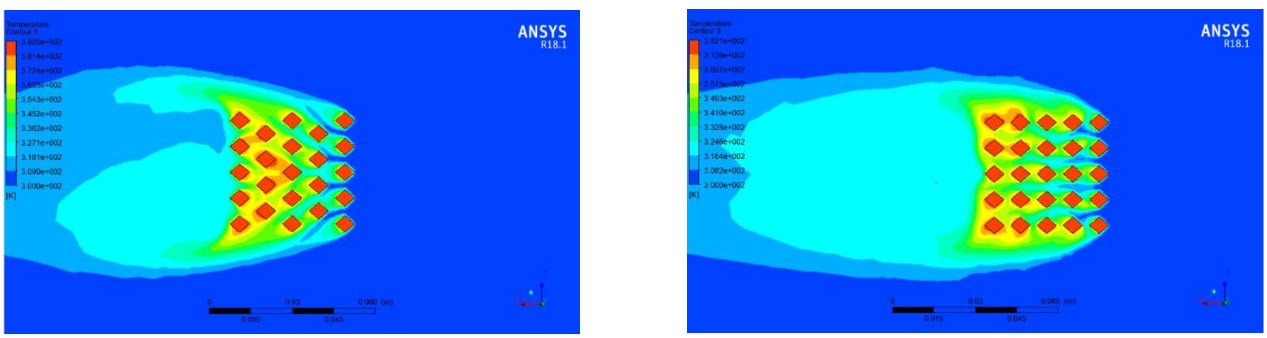
Computational fluid dynamics analysis has been performed to evaluate various types of heat sinks designs with copper and aluminum as materials and in forced and natural convection conditions. Results obtained in CFD analysis are presented below. We can clearly observe that the heat transfer rate is directly proportional to temperature gradient (ΔT).

5.1 Thermal analysis of heat sink



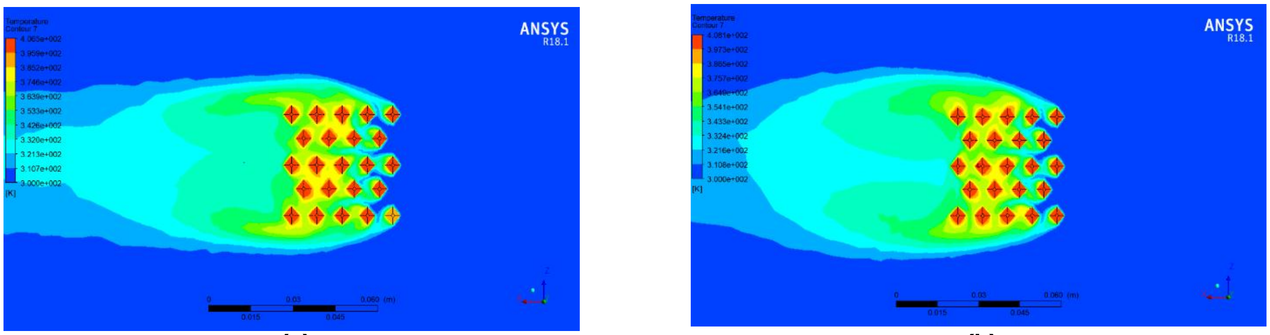
(a) **(b)**

Figure 5 (a), (b): Rhombus prism with staggered pins – (Al, Cu)



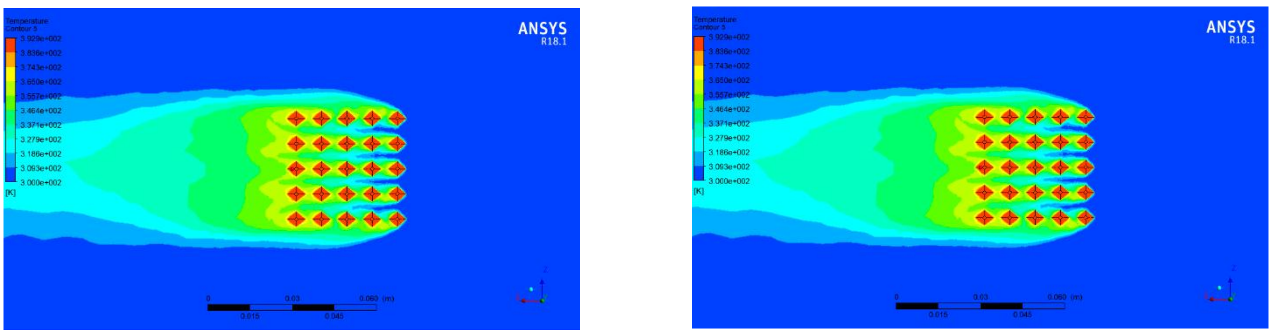
(a) **(b)**

Figure 6 (a), (b): Rhombus prism with inline pins – (Al, Cu)



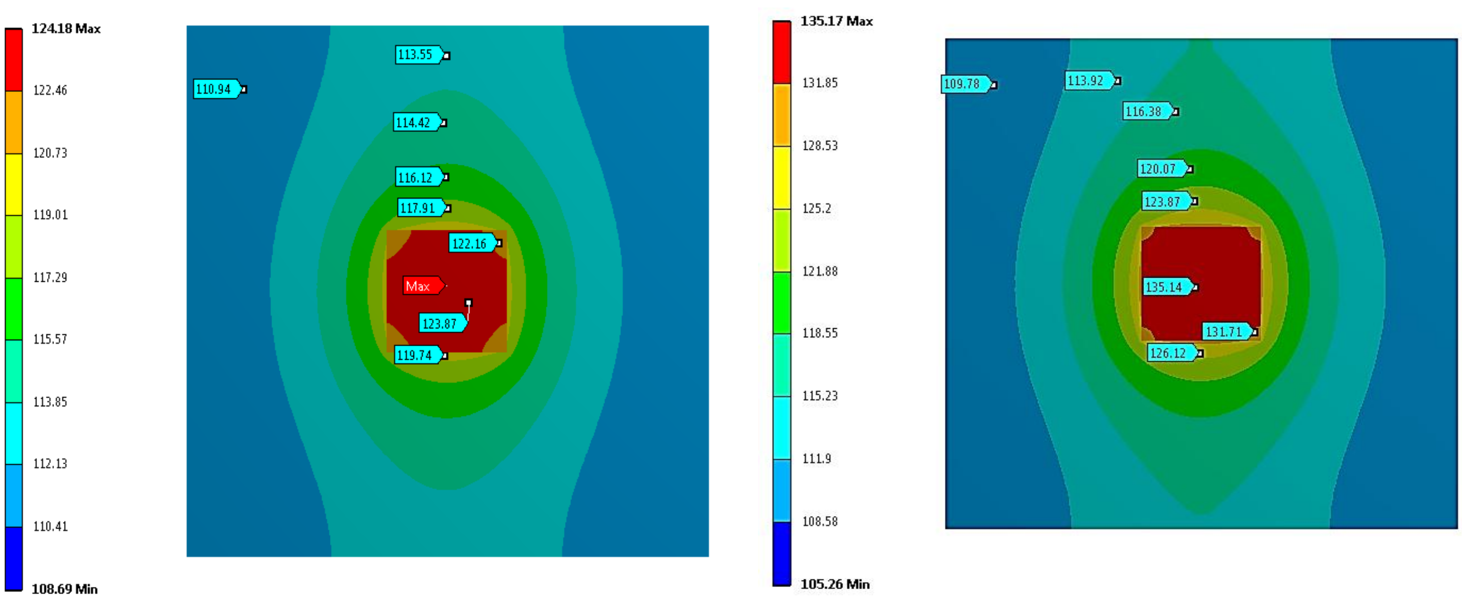
(a) **(b)**

Figure 7 (a), (b): Rhombus pyramid with staggered pins – (Al, Cu)



(a) **(b)**

Figure 8 (a), (b): Rhombus pyramid with inline pins – (Al, Cu)



(a) ***(b)***

Figure 9: *Temperature on base plate of Aluminum and copper model*

The above figure 9 (a) shows the temperature distribution on the base plate of heat sink with the aluminum as base metal. The maximum temperature of 135.14 ^{o}C is found on the core i.e. heat sources and the metal part exactly above base. The temperature profile is distributed uniformly on the base towards the other end. The minimum temperature is observed as 109.78 ^{o}C on the base plate. The above figure 9 (b) shows the temperature distribution on the base plate of heat sink with the copper as base metal. The maximum temperature of 123.87 ^{o}C is found on the core i.e. heat sources and the metal part exactly above base. The temperature profile is distributed uniformly on the base towards the other end. The minimum temperature is observed as 110.94 ^{o}C on the base plate.

TABLE 2
Forced convection

s.no	Heat sink	Number of fins	Temperature difference (ΔT) (°C)
1	Rhombus prism staggered - Al	23	97
2	Rhombus prism staggered - Cu	23	90.5
3	Rhombus prism inline - Al	25	86.6
4	Rhombus prism inline - Cu	25	82.1
5	Rhombus pyramid staggered - Al	23	108.1
6	Rhombus pyramid staggered - Cu	23	106.5
7	Rhombus pyramid inline - Al	25	92.9
8	Rhombus pyramid inline - Cu	25	89.3

TABLE 3
Natural convection

s.no	Heat sink	Number of fins	Temperature difference (ΔT) (°C)
1	Rhombus prism staggered - Al	23	100
2	Rhombus prism staggered - Cu	23	93.3
3	Rhombus prism inline - Al	25	89.7
4	Rhombus prism inline - Cu	25	85.2
5	Rhombus pyramid staggered - Al	23	110
6	Rhombus pyramid staggered - Cu	23	118.3
7	Rhombus pyramid inline - Al	25	96
8	Rhombus pyramid inline - Cu	25	93

6 CONCLUSION
In the current project the Computational fluid dynamics analysis of pin-fin heat sinks with fins is carried out by using the Ansys workbench Fluent solver. Various types of fin geometries with copper and aluminum as heat sink materials have been simulated in both natural convection and forced convection conditions. Various fin arrangements such as in-line & staggered arrangements in combination with variation in pin fins geometries have been simulated. Fin geometries such as Rhombus prism and Rhombus pyramid. Heat sink with Rhombus prism pin fins (HS-RPPF) is found to be more effective in dissipating heat compared to other configuration of fins, this is observed mainly due to the higher surface area. Rhombus tapered pins have lower heat transfer rate compared to all the other pin fins which have been simulated, considering the complexity of manufacturing involved, more feasibility study and optimization has to be carried out for these type of fins to be used.

7 FUTURE WORK
Size, aspect ratio, orientation and number of fins on a heat sink with rhombus pin fins has to be optimized further to improve the performance. Metal 3D printing of heat sinks can be considered and design can be further optimized where even complex profiles can be manufactured.

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