A Comparable CFD Study of Hexagonal Pin Fin Heat Sink with other Pin Fin Shapes for Central Processing Unit

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Abstract: **Heat sink is a fundamental device that is used mostly in electronic circuits for purpose of cooling. By increasing of power consumption in CPU processor, and by reducing the dimension of electronic circuits has become important in dealing with the thermal problem. This problem will minimize the performance of the CPU processor substantially. Also, it this issue will affect the lifetime of the processor. To avoid such problem, heat sink is used to distribute the heat flux in a CPU processor the arrangement of suitable heat sink shapes needs a compromise with many aspects such as space, weight and cost. This study aims to compare the effect of a pin fin, as a heat sink, shapes in terms of heat transfer rate with another researchers' work. Also, to investigate the effect of fluid flow on the heat transfer near the heat sink. In this study, the analysis is done using COMSOL Multiphysics software.**

Keywords: Arrangement, CFD, CPU, Heat Sink, Hexagonal, Pin Fin.

I. INTRODUTION

The applications of heat sinks are now employed in many applications in industry which involves electrical circuits, telecommunications, heat exchangers and more. the main job for heat sink is to cool an electronic device and some components in automotive industry to maximize the performance of such devices.

There are numerous kinds of heat sink like exotic geometry, plate fin and pin fin. Heat sinks with pin fin are generally utilized dependent on the capacity to build their surface area through the expansion in the quantity of pins. They are generally layered over the base of a heat sink in a predefined request in order to improve air flow. One preferred standpoint of utilizing pin fins over plate is that the surface area is less than the plate fin. Also, the direction of stream does not need to be predefined accurately since all sides work as inlet or outlet. The direction of flow inlet and outlet is crucial to increase the performance of the pin fin and must be taken into account when placed on the object to be cooled [3]. Zheng and Wirtz [4] studied heat transfer and pressure drop correlation in a pin-fin fan heat sink and came to the same conclusion as Seri Lee [5] from his study. Their work showed that different optimal pin-fin configurations provide different results depending on the design criteria imposed on the flow. Gupta et al. [6] worked on CFD and thermal analysis of rectangular plate fin and cylindrical pin fin heat sinks with a primary focus on temperature and heat flux distribution. The results of this work showed that with the same dimensions and boundary conditions total heat transfer rate of rectangular plate fins are greater than cylindrical pin fins as expected. Lindstedt et al [7] investigated the optimal shape of single fin and fin array heat sinks. He considered three different heat sink geometries: rectangular, triangular, and trapezoidal. It was found that due to the coupling of convection and conduction, the most concave geometry i.e. triangular explicitly serves as the optimal single fin heat sink geometry. On the other hand, with fin array heat sinks, trapezoidal fins were determined to give the best practical compromise for thermal resistance, fan power, and mass proving that optimal shapes of single fin heat sinks cannot be used to optimized fin arrays in heat sinks. Various geometries of the pin-fins, such as rectangular, rhombic, cylindrical, elliptic, stepped, tapered, and a combination of different geometries, can be considered. And, the pin-fin arrays may be either staggered or in line with respect to the flow direction. Changing the cross-sectional shape of the pin-fins from the circle may increase the overall heat transfer rate, but also increase the pressure loss [8].

II. STUDY OVERVIEW AND ASSUMPTIONS

The modeled system consists of an Aluminum heat sink for cooling of components in electronic circuits mounted inside a channel of rectangular cross section as shown in Figure 1. Such a setup is used to measure the cooling capacity of heat sinks. Air enters the channel at the inlet and exits the channel at the outlet. The base surface of the heat sink receives a 1 W heat flux from an external heat source. All other external faces are thermally insulated.

Figure 1 shows the idea of cooling a CPU chip by the means of using a heat sink. When the processor is heated, due to processing the data in the computer, then the heat will sink overall the pin fins through the base surface and hence getting rid of heat from processor and a fan is used to cool down the heat absorbed by the fins in order to allow them to absorb more heat from the processor. This is useful when it comes to the performance, lifetime and fast response of the processor. In Figure 1, the channel purpose is to support the pin fins as well as the fan to create a good environment for the CPU chip.

The authors are using a licensed COMSOL software at the national university of Malaysia laboratory.

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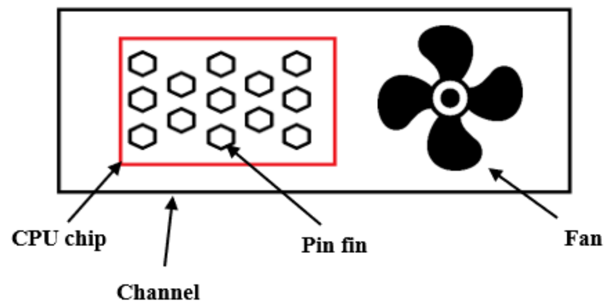

Fig. 1: Study overview

TABLE 1: Material and dimensioning of pin fin heat sink model

Name	Value	Description	Material
L_channel	0.07 m	Channel length	Aluminum 3003-H18
W_channel	0.03 m	Channel width	
H_channel	0.015 m	Channel height	
L_pin	0.010 m	Pin length	
W_pin	0.002 m	Pin width	

In Table 1, the dimensions of the channel and the CPU chip is inserted in COMSOL Multiphysics as well as the material. The reason of choosing Aluminum is that it has a high thermal conductivity, 180 W/m-k, different than the CPU chip material. Also, Aluminum is light in weight due to its low density which is 2800 kg/m^3. This will allow the heat to transfer from the least thermal conductivity to the most thermal conductivity. Thus, this is to be achieved for this study numerically to show the great effect of heat transfer between the most heat area to the least heat area.

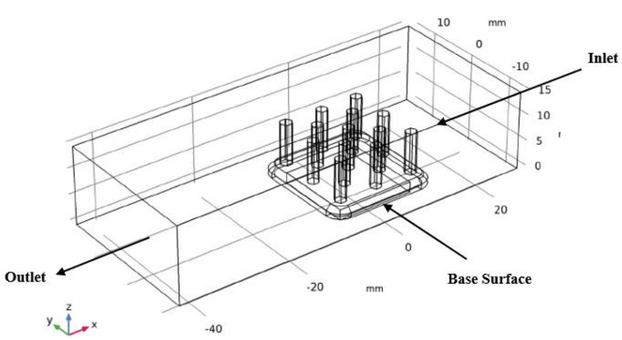

Fig. 2: Study CAD model

In Figure 2, the study is done on this CAD provided by COMSOL Multiphysics to apply the study of our own. It is clearly shown that the inlet is on the right-hand side and it is the same place for the fan for air flow, and the outlet is on the left-hand side of the CPU chip. The base surface acts as a support for the pin fins heat sink and the CPU chip is underneath the channel where it is at the same place of the base surface. The base surface has the same dimensions of the CPU chip (which is 20x20 mm). the boundary conditions are applied as the inlet velocity is 0.05 m/s, and the outlet is at zero atmospheric pressure. To be assumed that the base surface receives 1 W heat flux from the CPU chip.

III. SIMULATION RESULT AND DISCUSSION

Figure 3 shows the discretization of the study model to maintain the numerical simulation results of the thermal transfer throughout the domain. The mesh shape applied is tetrahedral and the it is extra coarse. Also, the size of mesh element would be normal. Now, after building all the settings for the mesh, the temperature distribution is shown in Figure 4&5.

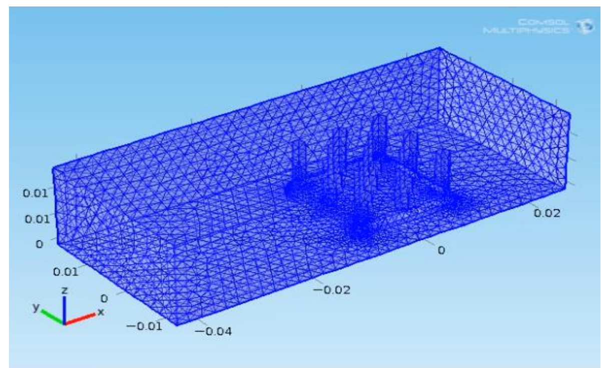

Fig. 3: Study mesh

There are many kinds of arrangement for pin fin heat sink such as inline, staggered and others. So, this study deal with the staggered (3-2-3-2-3) arrangement and tries to compare with other researcher work, relevant to only staggered arrangement, in terms of different number of fins, shape and boundary conditions in order to see the suitable heat sink model.

In this study, the simulation was done under Conjugate Heat Transfer Interface module on a laptop that is equipped with 8GB RAM and Intel Core i7-3632QM 2.4 GHz processor. This study solves a thermal profile for the heat sink and air inlet flowing inside the channel box. Various pin fin heat sinks model is widely used as a heat dispersion in electronical components. Thermal energy is transferred through conduction from the chip processor (high temperature) to the Aluminum pin fin of the heat sink (low temperature) component.

From Figure 4 and 5, to be noticed that the area of heat sink base near to inlet has the minimum temperature value due to the flowing air, 293.04K as minimum, and the other side has the maximum temperature value, 393.15K, due to the blockage of pin fins. Whenever the area of the pin is high, the heat transfer will be high. Also, the pins' cross-sectional area is hexagonal, so the area is exposed to air flow for each side in the hexagonal, and hence this will increase the heat transfer. In addition to that, the idea behind pin fins arrangement is to increase the heat transfer, in this study, and we have chosen the staggered arrangement because the authors think that it is better than inline arrangement since the air will hit five pins as shown in figure 6&7, but with inline the air will hit only three pins. Although, the change in air velocity with this arrangement will be less than the inline arrangement due to the number of pins within two rows.

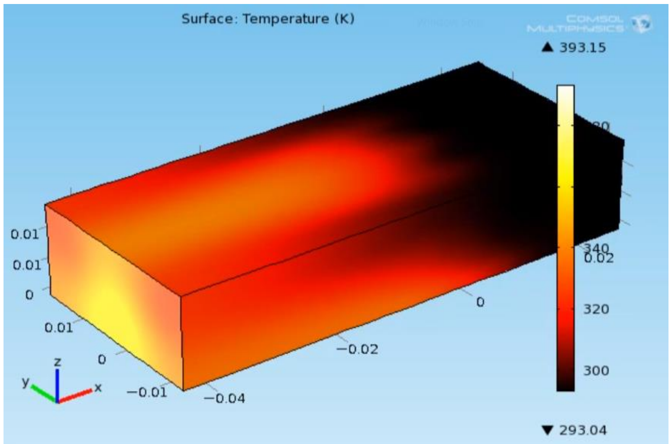

Fig. 4: Temperature distribution outside the channel view

R. Rosli et al. [9] studied different arrangements, for circular pin fin heat sink, which are inline, staggered and random. They used 5.5W as a heat source, and the initial velocity of air is 0.01 m/s. Also, the dimensions are different than what we have chosen. Moreover, they chose the number of pin fins to be 36, unlike us we chose 13 pin fins. However, they compared three different arrangements and chose the optimum arrangement. Our study is to compare the arrangement, staggered, with different number of pins, cross-sectional area and different dimensions. Although, the velocity is different than our study but since their number of pins is higher than us, therefore it is not an issue.

The approach, in this study, is to find and compare with another researchers' work in terms of best thermal performance of a single pin fin by dividing total heat flux to the total number of pin fins. The results of maximum temperature value for staggered arrangement in circular and square cross-sectional area in Rosli's study are compared with our pin's cross-sectional area, Hexagonal, as shown in Table 2. For circular pin, the maximum temperature value is 97.366°C, while it is 90.399°C for square cross-sectional area. They found that square cross-sectional area has the best thermal performance than circular.

TABLE 2: The best thermal performance of each type of single pin fin heat sink with different cross-sectional area

Circular	Square	Hexagonal
97.366°C	90.399°C	120°C
(5.5W/36pins) =0.153W	(5.5W/36pins) =0.153W	(1W/13pins) =0.076W
0.153W* 97.366°C =15 W°C	0.153W* 90.399°C =14 W°C	0.076W * 120°C =9.12 W°C

From Table 2, it shows the different in temperature between three different cross-sectional area, here Hexagonal in this study to be compared with Rosli's study. With different heat flux, Rosli's study uses 5.5W and 36 pins, whereas we chose 1W as heat flux with 13 pins. We have found the share of heat flux for each pin with different cross-sectional area. In addition, we found the ratio of the share of heat flux for each pin multiplied by the maximum temperature value has an inverse proportion with the thermal performance of each pin. Therefore, the hexagonal cross-section area is better than circular and square depending on the pre-defined relation.

TABLE 3: Percentage of thermal performance comparison between circular and square pins with hexagonal pin

Cross-section area	Circular	Square
Percentage	39.2%	34.8%

From Table 3, it shows that the new cross-sectional area, hexagonal, of the pin fin was able to give better thermal performances which are 39.2% for circular and 34.8% for square compared to staggered arrangement.

IV. CONCLUSION

This study was carried out to analyze the thermal performance of various cross-sectional area with staggered arrangement pin fin heat sink using COMSOL Multiphysics software. Based on the simulation, the various pin fin shapes with the same arrangement have been compared to see the suitable thermal performance of the heat sink. Different shapes of pin fin which are circular, square, in Rosli's study, have been compared with the new shape (Hexagonal) to find the best thermal performance. From the result, it can be concluded that the new shape of pin fin heat sink would give better thermal performance compared to the conventional shapes. The new shape of the pin fin was able to give better thermal performances which are 39.2% and 34.8% for circular and square, respectively. It is important to choose the best shape and number of pin fin heat sink in order to provide the best thermal performance.

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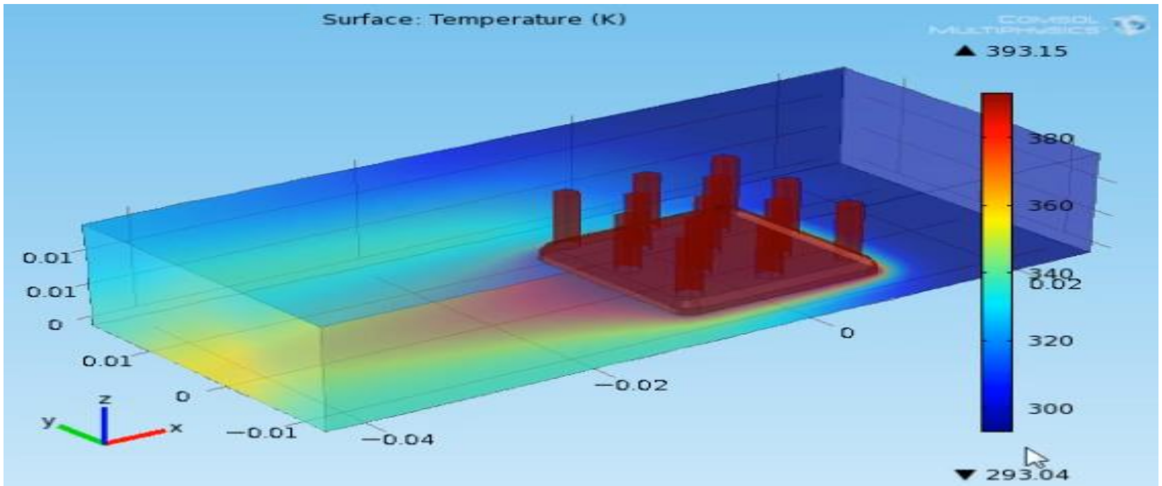

Fig. 5: Temperature distribution inside the channel view

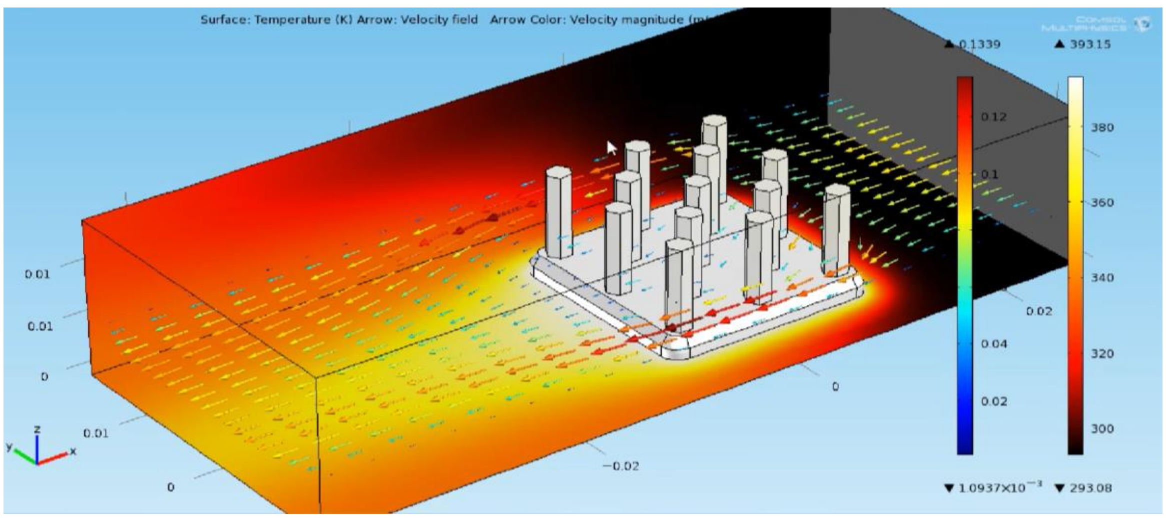

Fig. 6: CFD analysis of pin fin heat sink

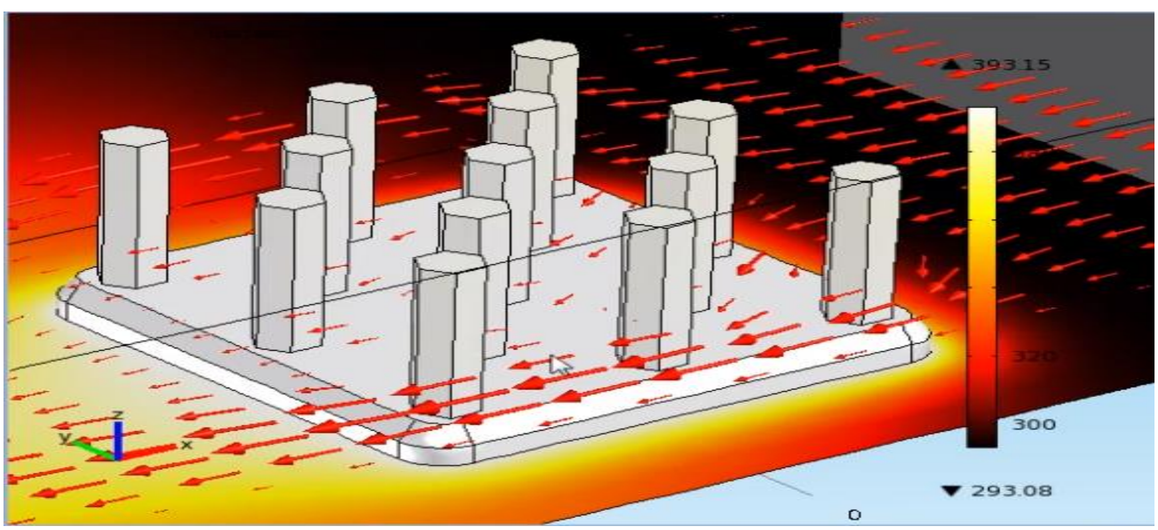

Fig. 7: Air flow through pin fin heat sink