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Performance analysis of heat sink for microprocessor

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ABSTRACT

The microprocessor is the key component in all type of PC systems. As the performance of all computer operations totally depends on microprocessor and health of this microprocessor affected by heat energy or temperature. If the temperature of this microprocessor is kept within permissible limit then the life of microprocessor increase and this is done by a component called heat sink. There are few design parameters which affects the heat transfer rate of heat sink like fin shape, material, the thickness of fin, number of fins, the spacing between two fins and base plate thickness etc. instead of aluminum copper has high heat transfer rate but as cost increases it cannot use copper as sink material. As base plate thickness increases the rate of heat transfer also improve but because of space limitation of every heat sink in the computer we cannot increase this base thickness beyond the limit. Also, increase the number of fins is not feasible solution to increase the performance of heat sink. So finally the shape is the parameter which is studying in this work for optimum results. Here in this work different shape of fin profile like circular, trapezoidal, rectangular and triangular are consisted of numerical study using the ANSYS software. According to the results, it is clear that heat transfer rate is increased by using triangular fin shape as compared to rectangular fin heat sink. The modified triangular heat sink shows that there was an increase in heat transfer rate by 9% as compared to rectangular fin heatsink.

Keywords*- Microprocessor, Heat sink, Permissible limit, Fins*

1. INTRODUCTION

Power is mostly dissipated as heat energy, in microprocessors, this conversion to heat energy is nothing but the simply a function of the operating frequency of the processor and the size of the wires and transistor. As transistors get smaller, the depletion region gets smaller and current leaks through the transistor even when it is off. This leakage produces additional heat and wastes additional power. Heat can also cause materials to expand, which can alter the electrical characteristics of the tiny transistors and wires. Many small microcontrollers don't need to worry about heat because they generate so little, but larger modern general purpose processors typically need to be accompanied by heat sinks and fans to help cool the processor. The higher-speed processors consume more power and therefore generate more heat. The processor is usually the single most power-hungry chip in a system, and in most situations, the fan inside the computer case is incapable of handling the load without some help. To ensure a constant flow of air and more consistent performance, most processors include some form of the heat sink, which is designed to draw heat away from the processor. Additionally, most heatsinks incorporate fans so they don't have to rely on the airflow within the system. Heat sinks with fans are referred to as active heat sinks as shown in Figure 1 a heat sink is an environment or object that absorbs and dissipates heat from another object using thermal contact (either direct or radiant). Heat sinks are used in a wide range of applications wherever efficient heat dissipation is required; major examples include refrigeration, heat engines, cooling electronic devices, and lasers. [1]

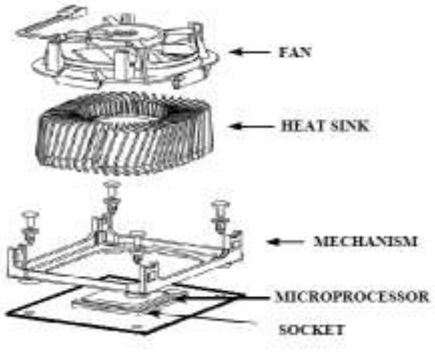


Fig. 1: Assembly of microprocessor and heat sink

The performance criterion of heat sinks is the thermal resistance, which is expressed as the temperature difference between the electronic components and ambient per watts of heat load. It is expressed with units K/W. Today's electronic chips dissipate approximately 100 W [4] maximum whereas this number will be multiples in the near future. The temperature differences from the heat sink surface to the ambient range from 10ºC to 35ºC according to the heat removal capability of the installed heatsink. Heat sinks may be categorized into five main groups according to the Cooling mechanism employed [18].

- Semi-active heat sinks which leverage off existing fans in the system
- Passive heat sinks which are used generally in natural convection systems.
- Active heat sinks employing designated fans for forced convection system.
- Phase change recalculating systems including two-phase systems that employ a set of boiler and condenser in a passive, self-driven mechanism
- Liquid cooled cold plates employing tubes in block design or milled passages in brazed assemblies for the use of pumped water, oil or other liquids, and

In this study, the shapes of fins for heat sink are investigated for efficient cooling of the microprocessor.

2. DESIGN PARAMETERS

The design parameters include the heat sink material, the number and geometry of the fins, alignment and the base plate thickness. In order to obtain the minimum thermal resistance and pressure drop, each of these parameters must be designed well. Research is focused on shape parameter only instead of Materials, a number of the fins, Fin alignment, Baseplate thickness and fin height.

2.1 Fin shapes: Different kinds of heat sink geometries are possible. Pin fins, straight fins, fluted fins, wavy fins and fins with non-standard geometry are possible. The most common ones are pin fins whose cross-section can be round, square, elliptical, hexagonal or any other suitable geometry. Straight fins that have rectangular cross sections are also widely used. Depending on the spacing between the fins of a heat sink, flow requirements and pressure drops may differ. Design engineers try to achieve the minimum thermal resistance with the pressure drop as low as possible by modifying the fin shapes. Extensive literature is available on this subject. [7]

2.2 Heat transfer in heat sink: Heat sinks function by efficiently transferring thermal energy ("heat") from an object at a relatively high temperature to the second object at a lower temperature with a much greater heat capacity. This rapid transfer of thermal energy quickly brings the first object into thermal equilibrium with the second, lowering the temperature of the first object, fulfilling the heat sink's role as a cooling device. Efficient function of a heat sink relies on the rapid transfer of thermal energy from the first object to the heat sink, and the heat sink to the second object. The most common design of a heat sink is a metal device with many fins. The high thermal conductivity of the metal combined with its large surface area due to the fins result in the rapid transfer of thermal energy to the surrounding, cooler, air. This cools the heat sink and whatever it is in direct thermal contact with. Use of fluids (for example coolants in refrigeration) and thermal interface material (in cooling electronic devices) ensures good transfer of thermal energy to the heat sink. Similarly, a fan may improve the transfer of thermal energy from the heat sink to the air by moving cooler air between the fins. A heat sink transfers thermal energy from a higher temperature device to a lower temperature fluid medium. The fluid medium is frequently air, but can also be water, refrigerants or oil. If the fluid medium is water, the heat sink is frequently called a cold plate. In thermodynamics, a heat sink is a heat reservoir that can absorb an arbitrary amount of heat without significantly changing temperature. Practical heat sinks for electronic devices must have a temperature higher than the surroundings to transfer heat by convection, radiation, and conduction. [10]

Applying the conservation of energy, for steady-state conditions, and Newton's law of cooling to the temperature nodes gives the following set of equations:

$$Q = m \times C_p \times \Delta T$$

Where,
m = Mass of fluid.
C_p = Specific heat of fluid.
ΔT =Temperature difference.

In the present work, the fin is assumed to be losing heat at the tip. The material of the fin is taken as aluminum. The various geometrical and physical properties for the fin are given in the following table.

Table 1: Geometrical and physical properties for the rectangular fin

Property	Value
Length of fin	83mm
Thickness of fin	1mm
Width of fin	28mm
Number of fins	23
The thermal conductivity of aluminum	228w/mk

The temperature at the base of the heat sink is found to be 80ºC; ambient temperature is to take as 27 ºC. This problem is to be analyzed by considering the force convection. The velocity of air is found to 13 m/s. The physical properties of air are calculated at a mean film temperature of 53.5 ºC. These properties are given in the table as follows.

Table 2: Thermophysical properties of air

Property	**Value**
Density ρ	1.078 kg/m^3
Specific Heat Cpa	1.008 kJ/kgK
The coefficient of kinematic viscosity $_\gamma$	18.40X 10-6
Thermal conductivity K	28.15 X 10^{-3} w/mK
Prandtl number Pr	0.703

In the analysis, the flow of air is taken as flow over the flat rectangular plate.

Using correlation:

$$\mathrm{Nu} = 0.664 \times \mathrm{Re}^{0.5} \times \mathrm{Pr}^{1/3}$$

Where, Re is Reynolds no. and can be found out by using:

$$\mathrm{Re} = \frac{\mathrm{V} \times \mathrm{L}}{\gamma}$$

$$\mathrm{Re} = \frac{13 \times 0.037}{18.40 \times 10^{-6}}$$

$$\mathrm{Re} = 26141.30$$

$$Nu = 95.46$$

From Nusselt no. heat transfer coefficient can be found out.

$$\frac{h \times L}{ka} = 95.46$$

$$h = 72.627 \times 10^{-6}\mathrm{W/mm^2K}$$

The rate of heat transfer through the fin is calculated as follows:

$$Q_{Fin} = \sqrt{hPKA_c} \times (T_o - T_\infty) \times \frac{sinh(mL) + (\frac{h}{mK})cosh(mL)}{cosh(mL) + (\frac{h}{mK})sinh(mL)}$$

$$P = 2(w + t) = 2(28 + 1) = 58\ mm$$

$$A_c = 28 \times 1 = 28\ mm^2$$

$$m = \sqrt{\frac{hP}{KA_c}}$$

$$m = \sqrt{\frac{72.627 \times 10^{-6} \times 58}{228 \times 10^{-3} \times 28}}$$

$$m = 0.02568$$

Therefore,

$$Q_{fin} = 0.1160\ W$$

$$Q_{total} = 23 \times 0.1160$$

$$Q_{total} = 2.668\ W$$

$$q_{fin} = \frac{2.668}{28 \times 1}$$

$$q_{fin} = 0.09528\ W/mm^2$$

3. PROBLEM STATEMENT

As the heat sink is a very important device for the microprocessor cooling system, to cool the microprocessor the efficient heat sink is required. In the current scenario, the rectangular fin-type heat sink is used to cool the microprocessor in the CPU [5]. As the fin shape is a very important parameter to design the heatsink it requires to optimize the shape of the fin to increase the heat transfer & efficiency of the heat sink.

3.1 Problem Definition: As Microprocessors are an important part of our lives today. However, some processors, such as those used in modern desktop computers generate a lot of heat. Because they are so small and powerful they generate too much heat so it is a requirement to remove heat from the processors otherwise it may stop the system. A heat sink is able to keep processor within functional temperature range even under a full load condition. Designing of the heat sink is more important to cool the processors. Some important factors when designing a heat sink are size, the shape of fins, airflow, materials, cost, and weight. The shape of the fin is one of the important parameters for increasing the efficiency of the heat sink.

3.2 Objectives:

- To study the heat sink considering geometrical parameter (for different shapes).
- To study the effect of fin shape (Rectangular, circular, triangular, trapezoidal) for heat sink over heat transfer rate numerically.
- Compare the heat transfer through different shapes of fin heat sink from numerical results with ANSYS.

4. METHODOLOGY

To check numerical results for different fin shapes heat sink. For this purpose, ANSYS software is used to analyze particular Shapes of fins.

4.1 Numerical Methodology: Numerical analysis had been done with the help of ANSYS software. Forgetting numerical results there is a requirement of cad model. CATIA is the cad software used for design and creates the model. ANSYS is the analysis software in which different models are used to solve the model.

4.2 CATIA modeling: The software provides advanced technologies for mechanical design. CATIA has an innovative and instinctive user interface that unleashes the designer's creativity. With the help of this software different heat sink models have been developed. Figure 2 shows the heat sink model with specified dimensions.

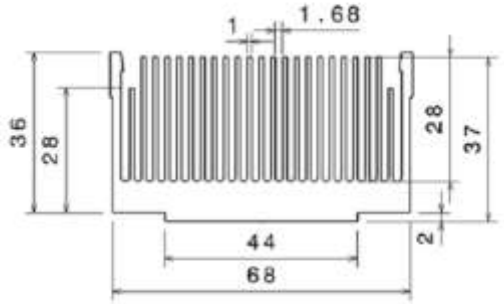


Fig. 2: Rectangular fin heat sink

4.3 ANSYS Process: ANSYS is the analysis software in which numerical analysis can be done. The below chart shows the flow diagram of a procedure for simulating the results.

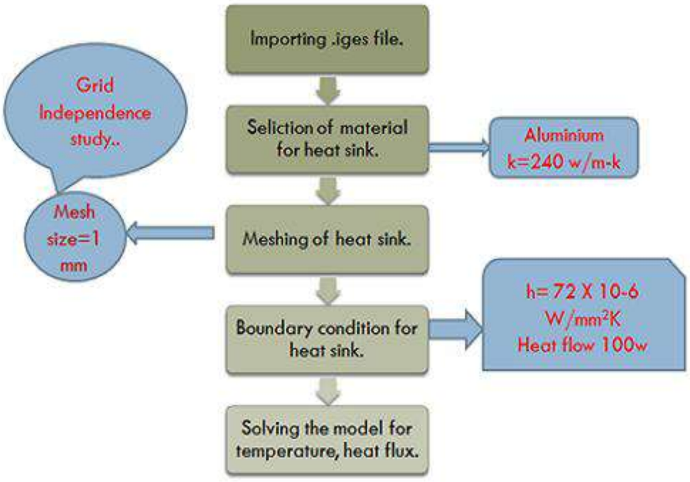


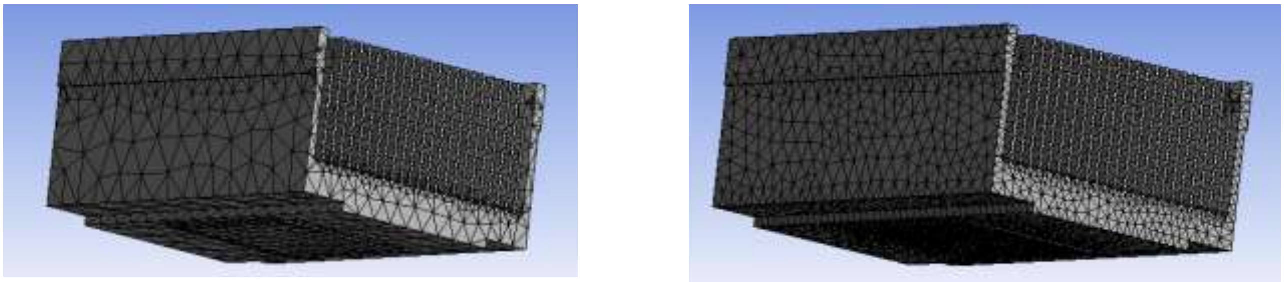
Fig. 3: Flowchart of Numerical Procedure

4.4 Grid Independence Study: A grid generation program has been used to create a grid. Generation of the grid has a greater influence on solutions in the numerical process. A sincere effort has been made to get accurate solutions.

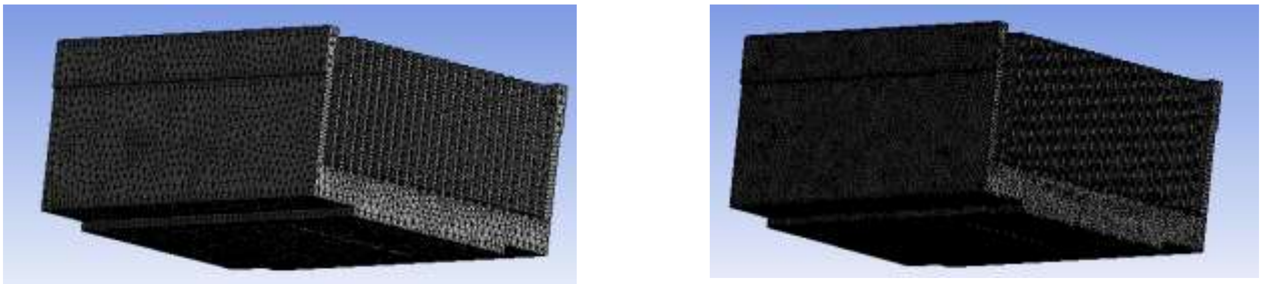
Four mesh cases are considered for this problem Case I, Case II, Case III and Case IV Table 3 shows the description for all the above Cases considered for Grid independence study for Numerical Simulations.

Table 3: Description of Grid Cases

Case	Element size (mm)	No. of Nodes	No. of Elements
Case I	5	85955	44995
Case II	2	133467	70953
Case III	1	378488	203234
Case IV	0.5	1341033	740156



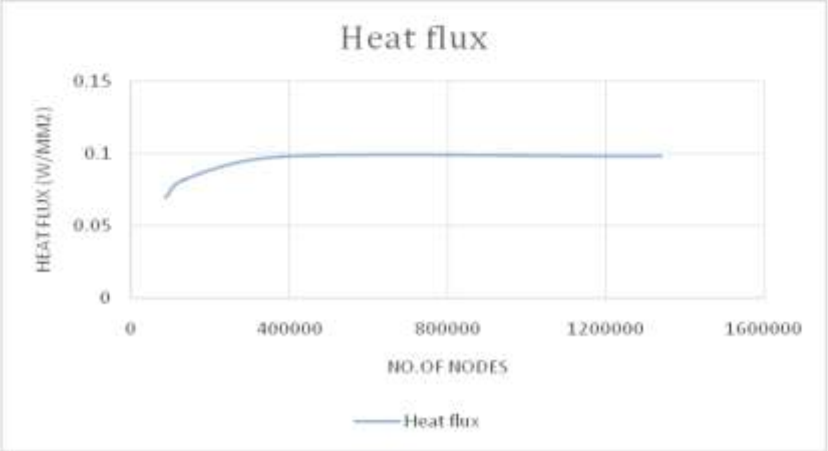
Mesh Case I **Mesh Case II**



Mesh Case III **Mesh Case IV**

Fig. 4: Different mesh cases.

The Different Mesh cases considered for analysis is shown in fig 4. Which resulted from the refinement process based on heat flux, yielding a total number of nodes 378488. The one finally selected for the calculations was dense enough to allow grid independent results. Indeed, calculations with the finest mesh used yielded very less difference in the heat flux for the heat sink; boundary conditions were applied for getting the FEA results. Convective heat transfer coefficient can be taken as h =72.627×10^{-6}W/mm^{2}K, which is applied for all the fin surfaces of the heat sink except the base of the heat sink. The second boundary condition of heat flow (q = 100w) was applied at the base of the heat sink. So heat flux, the temperature at different points can be taken out by solving the above model for the steady-state thermal condition. Using the above flowchart process and applying the boundary conditions for rectangular fin shape heat sink for getting the numerical results which can be validated with the experimental results. Thereafter numerically can be check for different fin shapes to maximizing heat transfer. Fin shapes of heat sink like trapezoidal, circular and triangular are to be check by applying similar boundary condition to getting optimum results of heat flux.



Graph 1: Number of nodes v/s Heat flux

5. RESULTS

Numerical analysis can give the contours of various parameters such as temperature, heat flux etc. these can give the clear idea for the heat transfer in the heat sink. The below figure 5, 6, 7, 8 shows the contours of temperature distribution and heat flux for various fin profiles for a heat sink (Rectangular, Circular, Trapezoidal and Triangular).

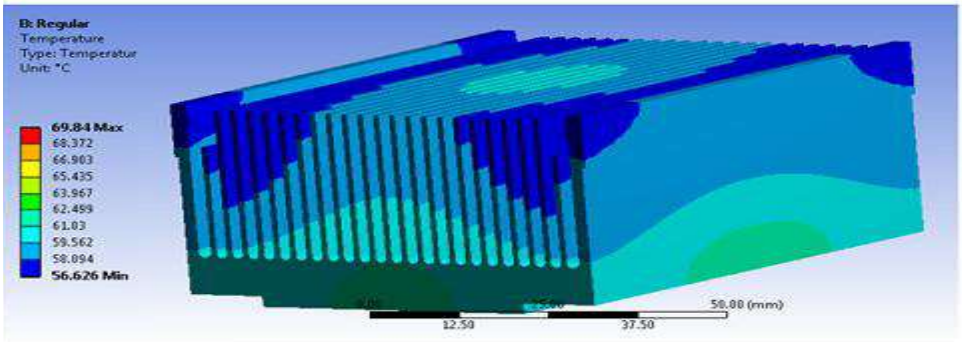


Fig. 5: Contour of temperature for a rectangular heat sink

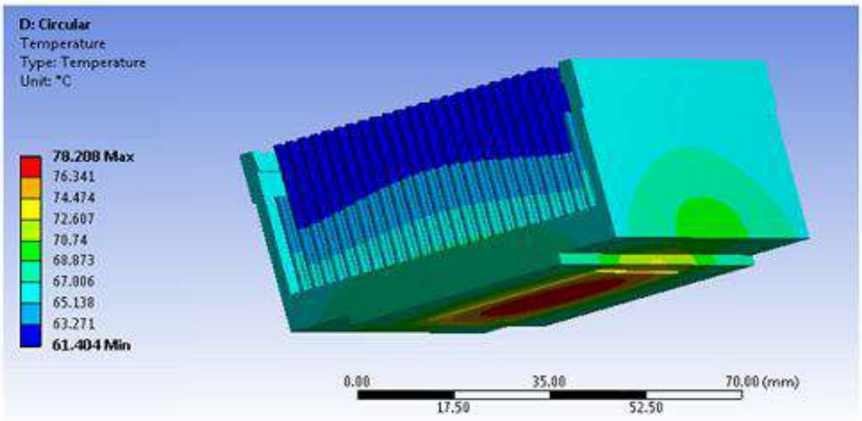


Fig. 6: Contour of temperature for a circular heatsink

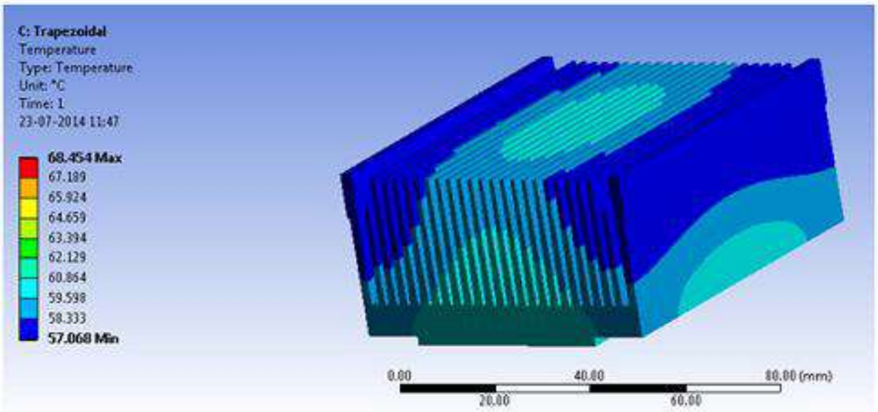


Fig. 7: Contour of temperature for a trapezoidal heat sink

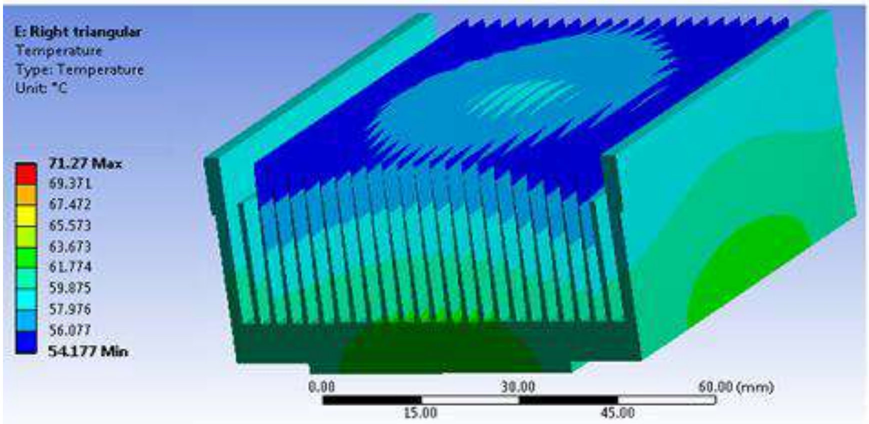
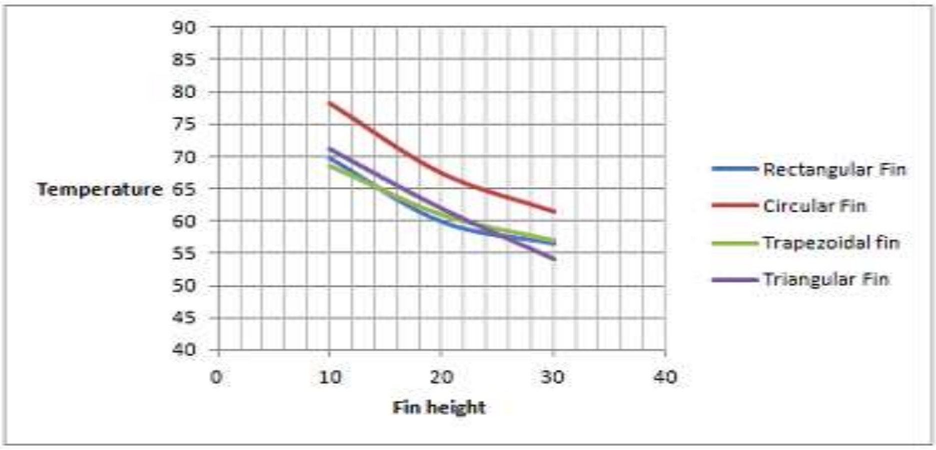
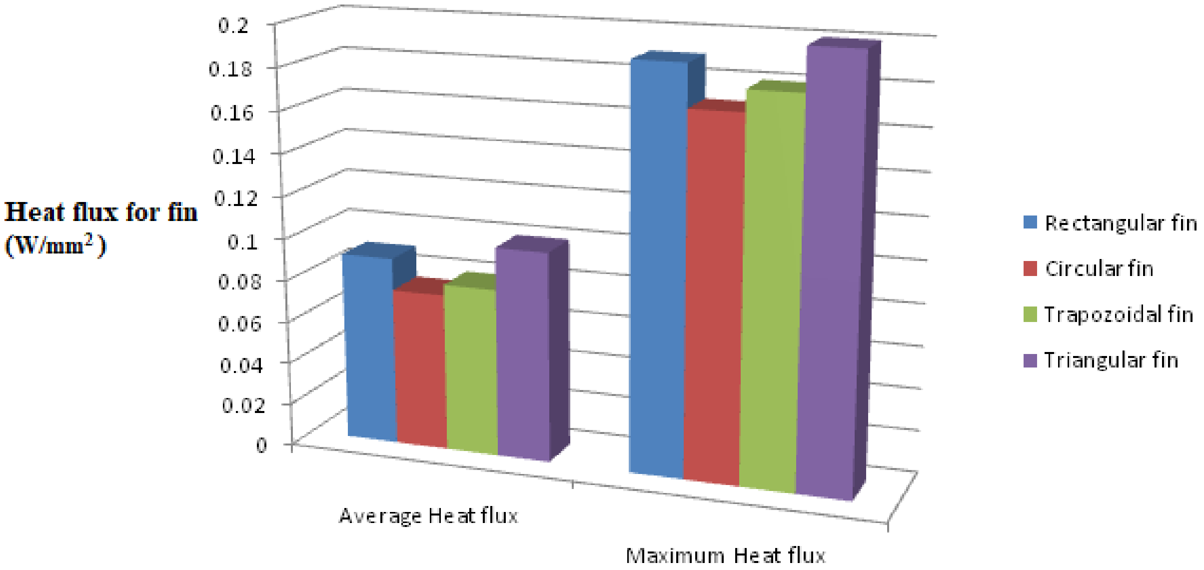


Fig. 8: Contour of temperature for a triangular heat sink.

From the numerical results graphs were plotted for various fin profile of heat sink such as Temp V/s fin height and for maximum and average heat flux as shown in the graph- 2 and 3. It shows that temperature at the tip of the triangular fin is less as compared to the other profiles of the heat sink and the average heat flux and maximum heat flux for the triangular fin is maximum as compared to the other profiles of the heat sink. So it signifies that the heat transfer rate for triangular heat sink profile is better than the other profiles of the heat sink.



Graph 2: Temperature distribution over the fin height



Graph 3: Maximum and average heat flux for a different heatsink

6. CONCLUSION

The heat sink was used to control the temperature of the microprocessor in the permissible limit. The material is one of the parameters that increase heat transfer rate. If copper is used in place of aluminum then heat transfer rate increases but at the same time cost also increases. So heat sink design can give the desired results. The performance of heat sink also depends on various design parameters like a number of fins, fin thickness, fin shape, base plate thickness, etc. The heat sink base plate thickness is a parameter for improvement. When the base plate thickness was increased, the heat sink performed better. However, there are space limitations for every heat sink in a computer. So the fin shape is the parameter which can be studied in this work for better results. The various types of fin profile (rectangular, Circular, Trapezoidal and triangular) were studied. As per the criterion for the selection of heat sink, the heat sink should have lowest thermal resistance and maximum heat transfer coefficient. The purpose of this work was to analyze the varying fin shape for microprocessor cooling. Analytical and software studies were performed in order to establish optimized geometrical fin shape for forced convection heat transfer. For analytical method rectangular fin shape is analyzed for 100 W heat flow at the base and convective heat transfer coefficient $h = 72.627 \times 10^{-6}$W/mm^{2}K. The numerical results were successfully verified by ANSYS data for rectangular fin; the mean relative difference for temperature found was 7%. The modified triangular heat sink shows that there was an increase in heat transfer rate by 9% as compared to rectangular fin heat sink.

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