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Design of Heat Sink for Thermoelectric Module Utilizing Waste Heat Energy

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Abstract: *Waste heat is the free energy available and can be used to drive something or to improve efficiency of the same machine by converting into useful energy. Waste heat is produced both by machines that do work and in other processes that use energy. These energy forms typically include some combination of: heating, air conditioning, mechanical energy and electric power. A heat engine can never have perfect efficiency, according to the second law of thermodynamics; therefore a heat engine will always produce a surplus of low-temperature heat, commonly referred to as waste heat. The largest proportions of total waste heat are from power stations and vehicle engines. Less than 50% of the energy generated in industrial activities is wasted and combustion engines are even worse, there only 25-40% of power reaches the wheels of a typical automobile, most of the remaining energy is lost as heat. Since most of the energy consumed by an internal combustion engine is wasted, capturing much of that wasted energy can provide increase in energy efficiency.*

To trap the waste heat from combustion engines we can either work at the hot engine side or at the rear hot exhaust. Heat exchangers are metal plates with high thermal conductivity;they can be used to remove heat from a device so that efficiency increases. Thermoelectric modules can be used to generate electrical energy which works on the principle of seebeck effect where in the temperature difference between the two surfaces of the thermoelectric module generates electricity. Thermoelectric materials are packed between the hot-side and the cold-side heat exchangers. The thermoelectric materials are made up of p-type and n-type semiconductors. Electricity can thus be generated and used or stored in the storing devices and can be used later on for running small applications.

I. Introduction

As we all know the only source of available energy on the Earth was the heat energy, using this heat energy effectively was the only goal of all the engineers and scientists. All the engineers worked together and have used this available source of energy in much better way; in vehicles to produce power, In Power stations to generate electricity etc. Though these were effective and efficiently built, out of total energy available only 25 to 40% was used to generate power rest goes out as waste. As we know that Heat energy is mostly obtained from burning of fossil fuels which are non-renewable resources, utilization of the above mentioned waste heat becomes necessary in order to use the resources available most effectively.

The two most important sources of waste heat are Power stations and I.C Engines. Traditional thermodynamic steam cycles require large amounts of heat to convert the working fluid into a vapour form before it is passed through a turbine. That turbine drives a generator to create electricity. However, in low heat applications, it is inefficient to use a traditional cycle, such as the Rankine cycle, because there is insufficient heat to properly convert the working fluid to a vapour. The initial cost of the equipment necessary for a Rankine cycle, such as pumps and turbines, also makes traditional cycles unappealing due to the low rate of return. As there are less number of Power stations as compared to I.C Engines, therefore their waste heat may not be that significant. But increasing demand of Automobiles has lead to large number of S.I Engines, thus increasing the amount of waste heat in this area. Therefore utilization of waste heat from Automobile exhaust becomes more important than power stations.

The best way for utilizing waste heat from S.I Engines is by using thermoelectric modules. Thermoelectric power generators are being investigated aggressively as a viable source of waste heat recovery from automobile exhaust gases. The principle involved is the Seebeck effect which allows for the conversion of a temperature gradient into electrical power. Since there is already a high temperature source available in the form of exhaust gases, thermoelectric devices may be used to harness this temperature difference between the hot gas and the atmosphere or coolant. Waste heat energy recovery using thermoelectric elements may be used in any such application where a hot source and a cold sink are available. The working of thermoelectric generators is based on thermoelectric principles. Therefore we need to study thermoelectric effect first.

II. Literature Survey

SantoshKansal et al., (2015), studied heat sinks having fins of various profiles namely rectangular fins, Trapezoidal, rectangle Interrupted, Square, circular inline and staggered. It was found that circular pin fin with 7 mm fin dia. and 18 mm fin spacing has better performance than the other ones and the maximum temperature obtained is 318 K at 12 m/s lower than other cases. They also noticed that Nusselt number increases by increasing velocity and is maximum for circular pin fin design, thermal resistance decreases by increasing velocity and is minimum for circular pin fin design and pressure drop increases by increasing velocity and is maximum for circular staggered design and minimum in case of rectangular heat sink design. [1]

R. Mohan et al., (2015), investigated about pin fin and slot parallel plate heat sinks with Copper and Carbon Carbon Composite (CCC) base plate material mounted on CPU’s. It was observed that the conduction rate is high in CCC base plate rather than Copper base plate and also it is enhanced by increasing the number of fins. It was also noticed that the performance of heat sink is increased by increasing the thickness of fins instead of increasing number of fins. They also noticed that, 5mm thick base plate heat sinks perform well as compared to 2.5 mm thick base plate heat sinks. [2]

Pradeepsingh et al., (2014), analyzed the heat transfer performance on fins with various extension such as rectangular extension, triangular extension, circular segmented extension, and trapezoidal extension. The design model of different fin extension is built by using CAD software and simulation is carried out by assigning load and constraints. The analyses show that the fins with extension give efficient heat transfer near about 5% to 13% more than fin without extensions. Among all fins stated above the rectangular extension fin gives higher heat transfer.[3]

Channamallikarjun (2014), investigated optimal plate fin heat sink design and cylindrical fin heat sink design with variable Copper base plate. It was found that the performance of plate fin heat sink model was better when compared to all cylindrical fin heat sink models. It was also noted that Copper base plate heat sink performs well when compared to Aluminium base plate heat sink. [4]

Nadaf et al., (2014), Studied the waste heat potential of the engine and various possible uses of waste heat and temperature ranges. Exhausts gas the best quality and quantity of waste heat. Five waste heat recovery technologies are discussed from the perspective of technical, economic and environmental aspect. Thermoelectric modules take heat and convert it into usable electricity. TEG system can only capture a small percentage of heat from the engines waste heat but on a global scale they may account for huge potential savings. It was identified that there are large potentials of energy savings through use of waste heat. [5]

Prathameshramade et al., (2014), worked on automobile exhaust thermo electric generator design and performance analyses. This paper demonstrates the potential of thermo electric generation under various engine speed 30% of energy is wasted in exhaust gases and we catch this 30% energy of exhaust gases converted in to useful energy. A hot side heat exchanger and as well as cold side heat sink was designed and inserted on 3 cylinder, 4 stroke, Maruti 800 cc SI engine. After doing assembly on exhaust line of maruti 800 cc engine, Voltage and current at different engine speed are measured on digital multimeter to study the performance of the system. At engine speed of 3970 RPM the power generated was 15.12 W and efficiency of the system was 5.0708 %. Double stacked type cold side heat sink gives better temperature gradient across TEG, which reduces the wastage of energy and improves the overall efficiency of vehicle. [6]

Deepak Gupta et al., (2014), performed CFD analyses and simulation of pin fin for optimum cooling of mother board. They used CFD to identify cooling solution for desktop computer, which uses 5w CPU. In this paper they have selected two types of fins cylindrical and rectangular and changed the number of fins for both the cases. In cylindrical pin fin they used 45 fins and 81 fins and got heat transfer rate as 4.398w and 5.623w respectively. Where as in rectangular cross sectional having 81 fins, heat transfer was found to be 4.632w. As the numbers of fins were increased total heat transfer also increased. The total heat transfer rate of 81 cylindrical pin fins is greater than 81 fins of rectangular cross section. [7]

Seri Lee, (2013), analyzed and put forward basis and terms for the selection of the design for heat sink. When selecting a heat sink, it is necessary to classify the air flow as natural, low flow mixed, or high flow forced convection. Natural convection occurs when there is no externally induced flow and heat transfer relies solely on the free buoyant flow of air surrounding the heat sink, Forced convection occurs when the flow of air is induced by mechanical means, usually a fan or blower.The next step is to determine the required volume of a heat sink. The volume of a heat sink for a given flow condition can be obtained by dividing the volumetric thermal resistance by the required thermal resistance. The average performance of a typical heat sink is linearly proportional to the width of the heat sink in the direction perpendicular to the flow, and approximately proportional to the square root of the fin length in the direction parallel to the flow. It is beneficial to increase the width of a heat sink rather than the length of the heat sink. [8]

JathaoJs et al., (2013), has analyzed the possibility of heat recovery from IC engine and various ways to achieve it. They compared the various possibilities like thermoelectric generation and piezo electric generation.

They found that in thermoelectric generation, optimal temperature difference is sufficient to produce the required power. [9]

C. Ramesh Kumar et al., (2011), Modeled various design of heat exchanger using computer aided design and analysis was done using CFD. From the simulated results it was found that rectangular shaped heat exchanger met the requirements and satisfied the space and weight constraints. A rectangular heat exchanger was fabricated and the thermoelectric modules were incorporated on heat exchanger for performance analysis. The study revealed that energy can be tapped efficiently from the engine exhaust and in future thermoelectric generator can reduce size of the alternator or eliminate them in automobile. [10]

Mukeshkumar et al., (2013), checked optimum design and selection of heat sink .The main purpose of optimum design and selection of two sink and mainly the possibilities of reducing size, weight and cost as compared to current design available in the market .for design and selection of heat sink .we have to choose different design perimeter.in terms of manufacturing matters and their final form of shapes. Longer fin height provide additional surface area for greater heat dissipation and improve thermal performance.in this paper comparison between heat sink without cut and with cut for 100w, 120w consumption .it was found that temperature variation was more for a heat sink with cut as compare to heat sink without cut leading to higher heat transfer and an optimum selection of heat sink is to be depending upon the industrial application. [11]

R. sam et al., (2013), performed modelling and analyses of heat sink with rectangular fin having through holes. The objective was to present a best possible heat sink for efficient cooling of electronic devices. In this paper they have compared Interrupted rectangular fins with continuous rectangular fins having holes using CFD analyses .They found that heat transfer increased in interrupted rectangular fins with holes. They also found that through holes for interrupted fins has better performance than interrupted rectangular fins of heat sink. They also found that reduction in material also results in reduction of weight and optimum cooling is achieved by the heat sink which contains interrupted fins with holes. [12]

Michail Octavian Cernaianu et al., (2012), performed tests on TEM and found that the values of Seebeck coefficient, Voltage and Internal resistance were not constant but were temperature dependent. The Voltage was observed to be increasing linearly with increase in temperature difference. The Seebeck coefficient increases slightly during low temperature difference and remains almost constant after that. While internal resistance increases linearly with increase in temperature difference but with lesser slope as compared to Voltage. [13]

D.D.L. Chung (2001), gave a review of materials for thermal conduction including materials of high thermal conductivity and thermal interface materials. He reported that without good thermal contacts between the two surfaces across which heat transfer occurs, the use of expensive thermal conducting materials for the components is not cost-effective. He also reported that the requirement for the thermal conductor material is not just its high thermal conductivity, but low coefficient of thermal expansion as well. [14]

III. Numerical Simulations

The ".IGES" file was imported in the Design Modeler of ANSYS Workbench (Fluent) and the computational domain was created. A Domain of Influence was created surrounding the heat sink so that the mesh around the heat sink is denser and thus results obtained are more accurate around the heat sink.

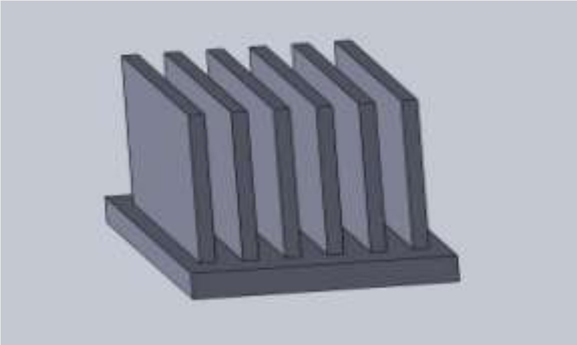


Figure.1. Model of the heat sin

Table .1 Specifications of the computational domain

Parameters	Value
Length of the domain	100mm
Breadth of the domain	100mm
Height of the domain	100mm

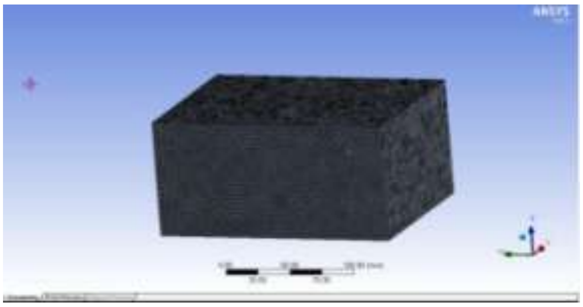


Figure 2. Mesh of the entire domain

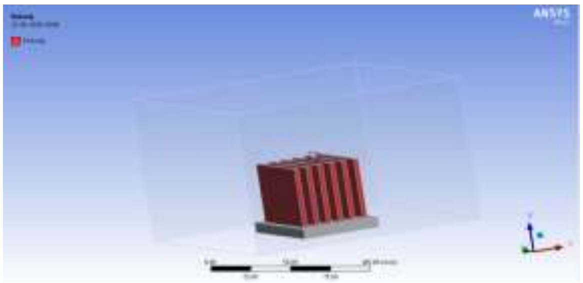


Figure. 3. Mesh of the heat sink

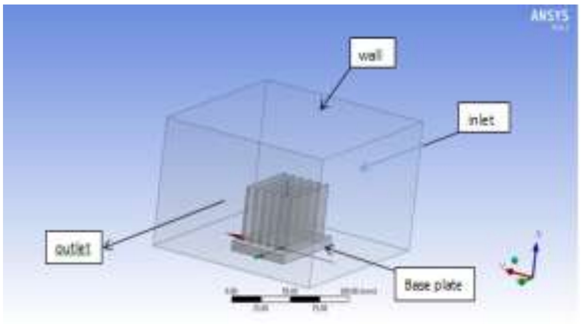


Figure. 4. Named selection

Table .2. Specification of Boundary Conditions

Named Selection	Boundary Conditions
Inlet	Velocity (0.11 m/s)
Outlet	Pressure (0 Gauge)
wall	Symmetry
Base plate	Temperature (160 ºC)

IV. Results And Discussions

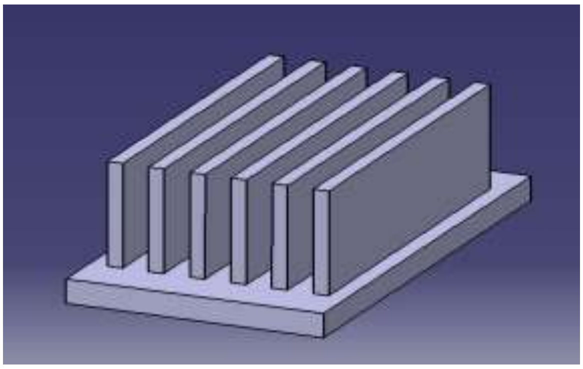
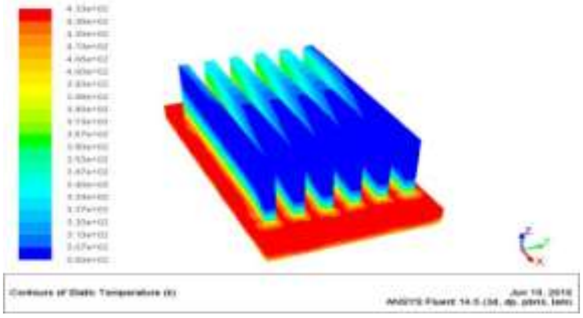


Figure 6.1: Geometry of rectangular heat sink

Rectangular Fins Based On Varying Fin Heights and One Sided Flow



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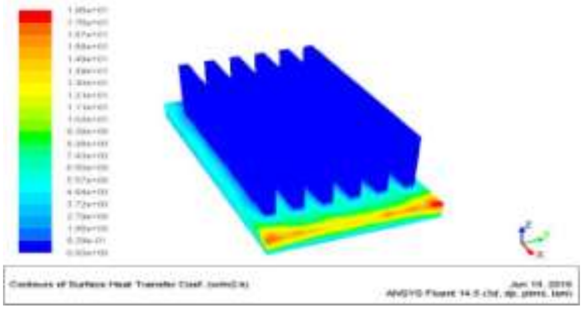

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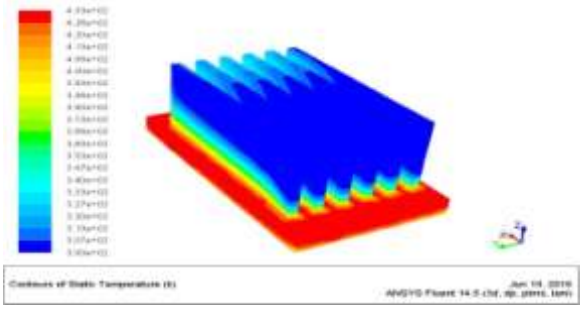

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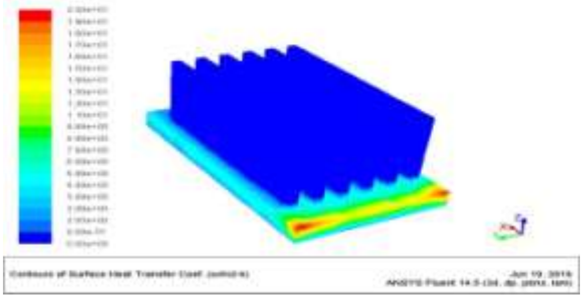

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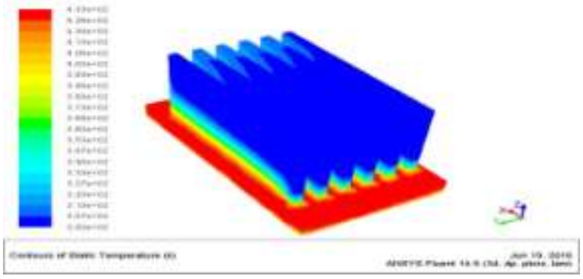

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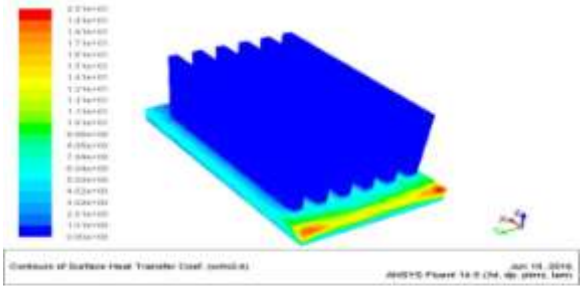

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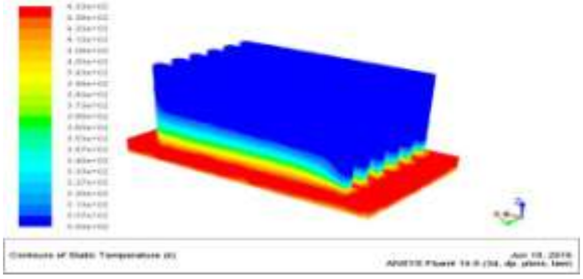

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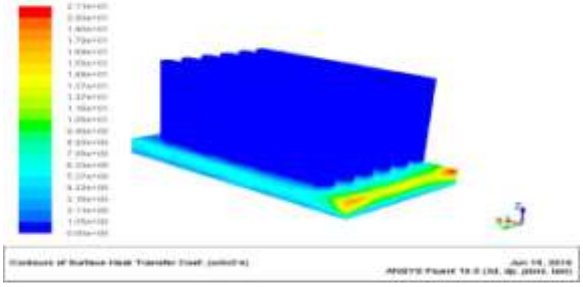
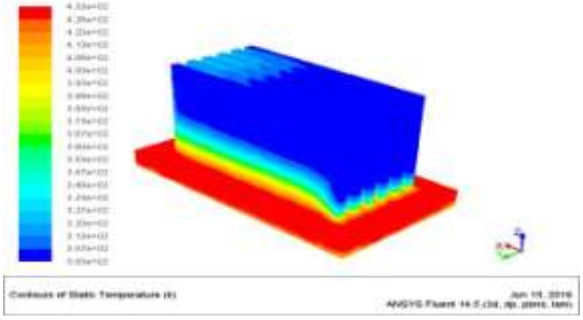


Figure 6.5 (b)

Rectangular Fins Based on Fixed Fin Height, Varying fin spacing and One Sided Flow

The temperature difference obtained at 40mm fin heights is best, so we keep 40mm fin height as base and vary the fin spacing's in steps of 1mm from 3mm to 6mm respectively.



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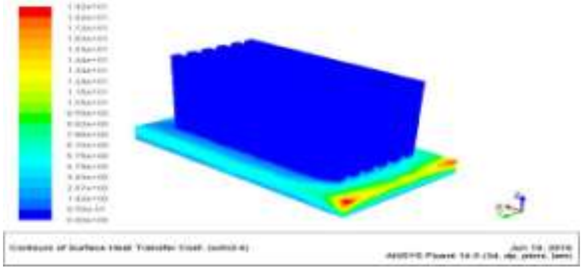

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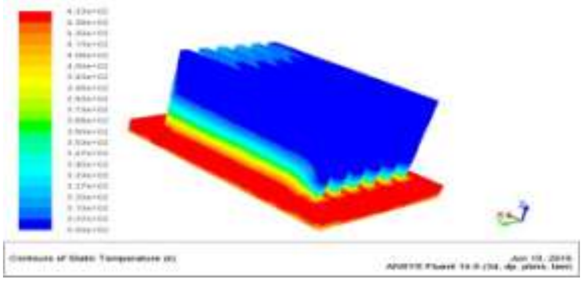

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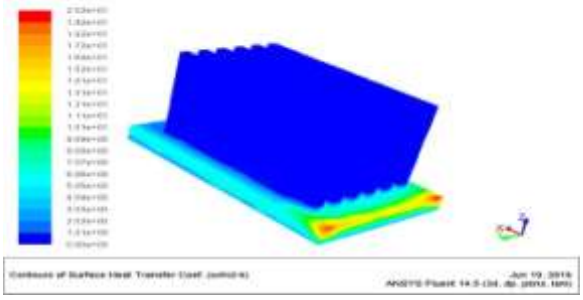

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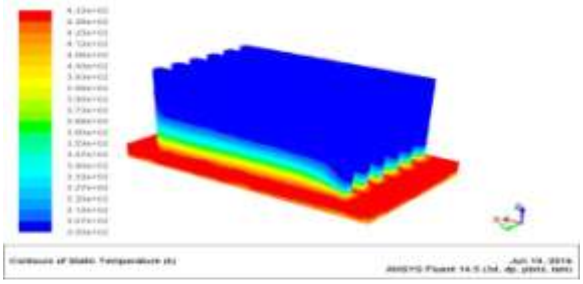

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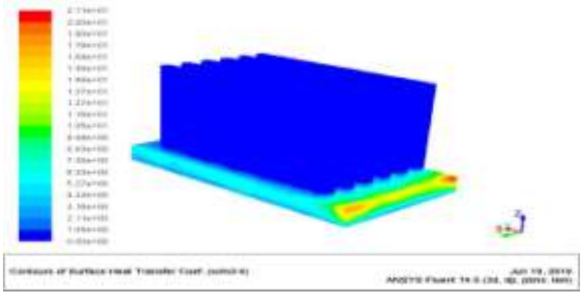

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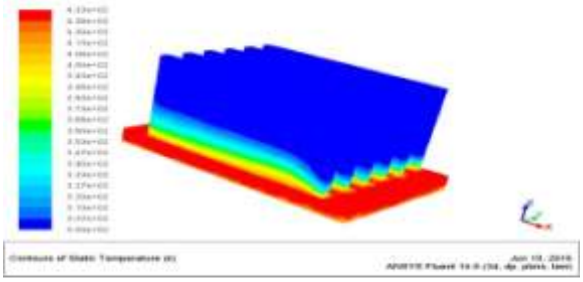

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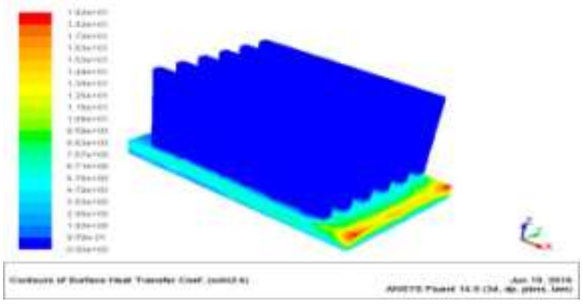
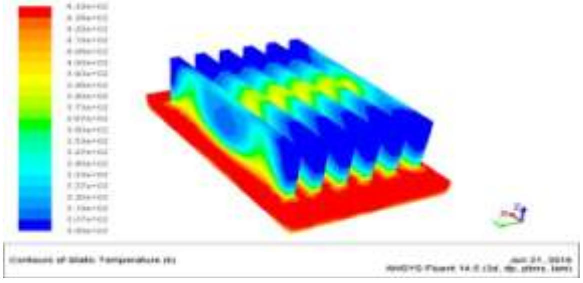


Figure 6.9 (b)

Rectangular Fins Based On Varying Fin Heights and Two Sided Flow



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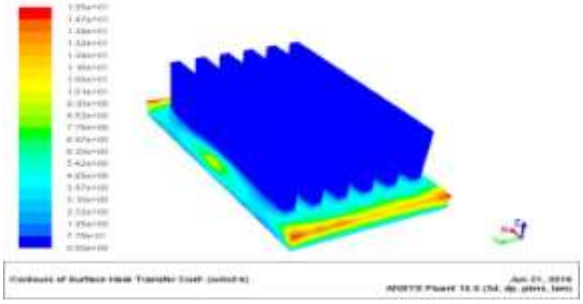

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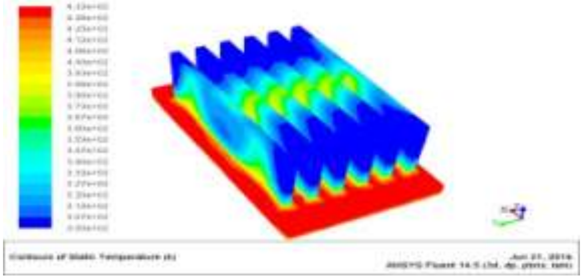

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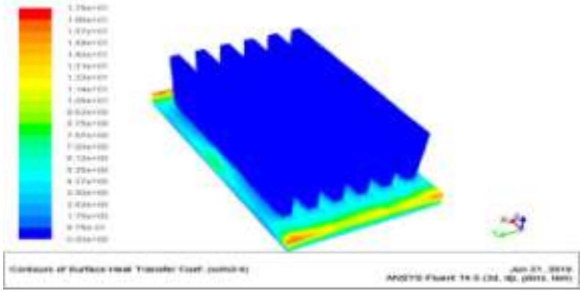

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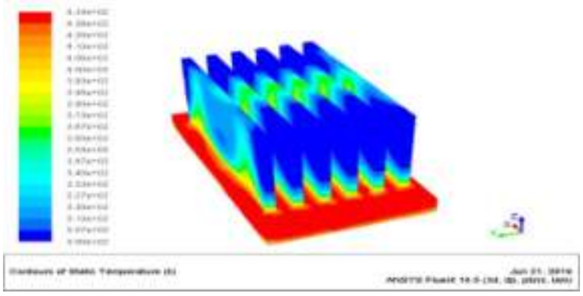

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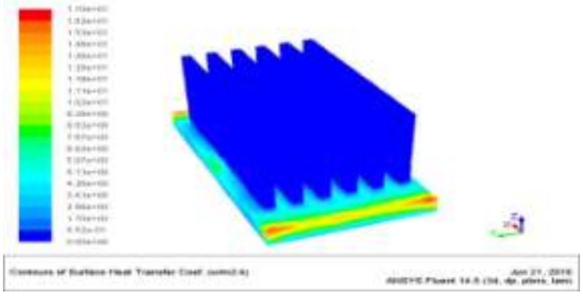

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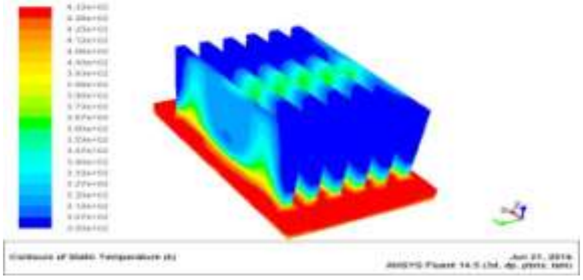

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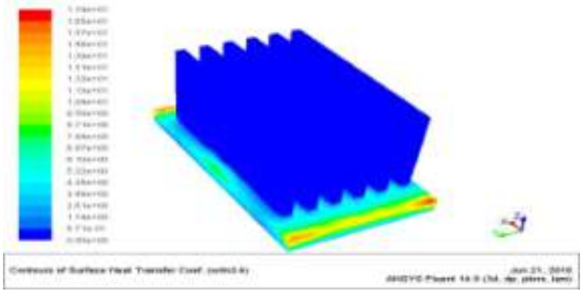
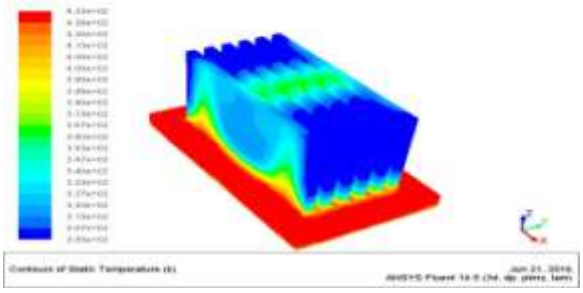


Figure 6.13 (b)

Rectangular Fins Based on Fixed Fin Height, Varying fin spacing and Two Sided Flow
The temperature difference obtained at 40mm fin heights is best, so we keep 40mm fin height as base and vary the fin spacing's in steps of 1mm from 3mm to 6mm respectively.



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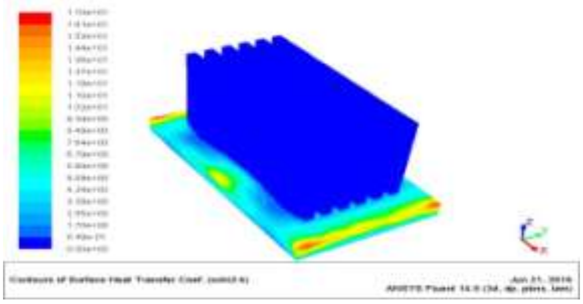

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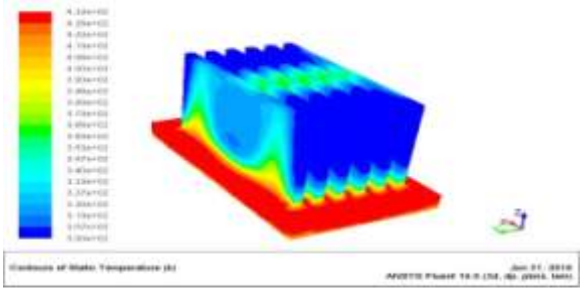

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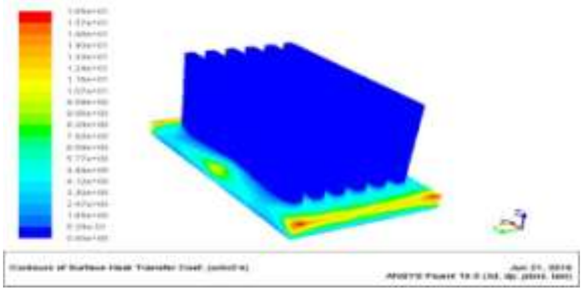

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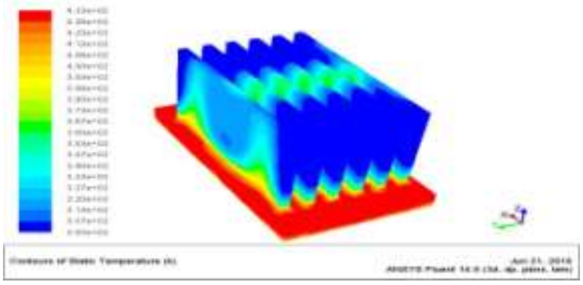

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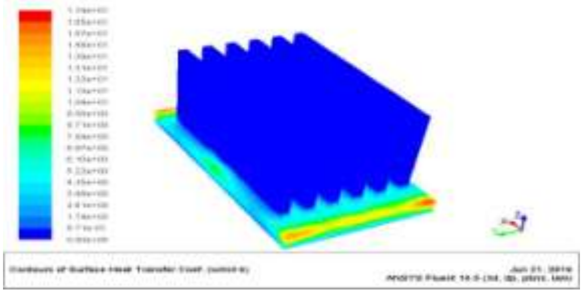

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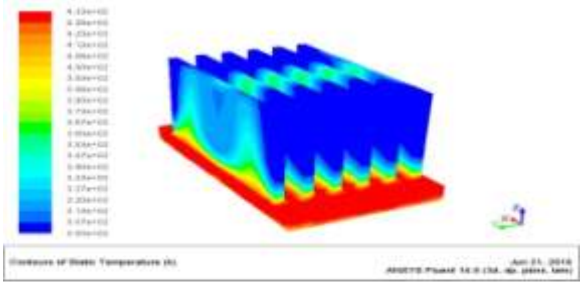

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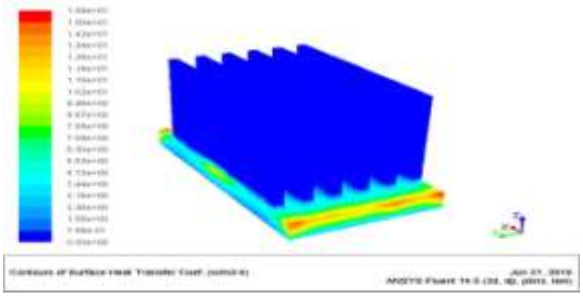


Figure 6.17 (b)

Circular Fins Inline Grid Structure

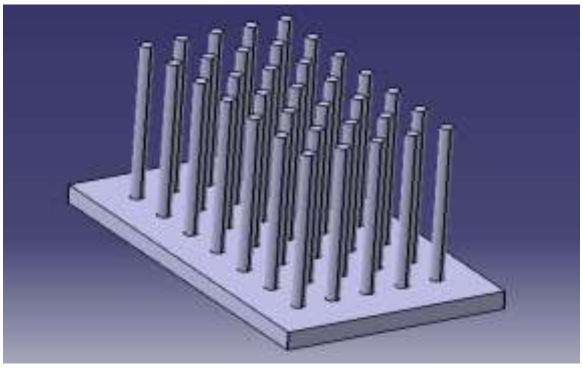
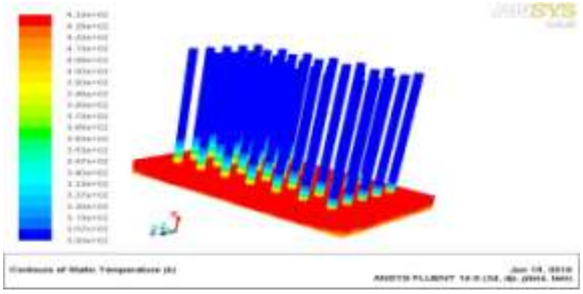


Figure 6.18: Geometry of circular fins
Base size = 90 mm x 50 mm x 7 mm
Fin height = 60 mm
Fin diameter = 3 mm
Longitudinal pitch = 8 mm
Transverse pitch = 11 mm
Number of fins = 35
Number of columns = 7
Number of rows = 5



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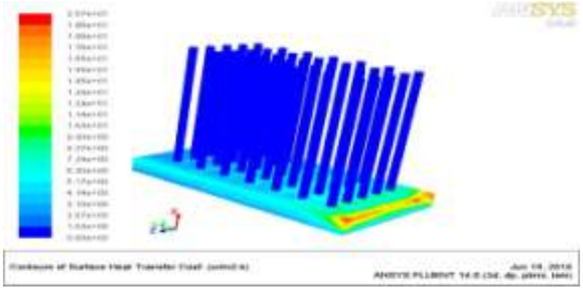

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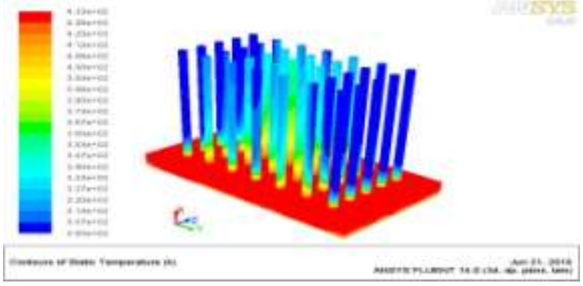

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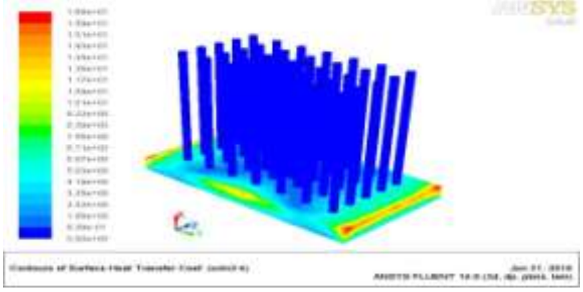

Figure 6.20 (b)

Circular Fins Staggered Grid Structure

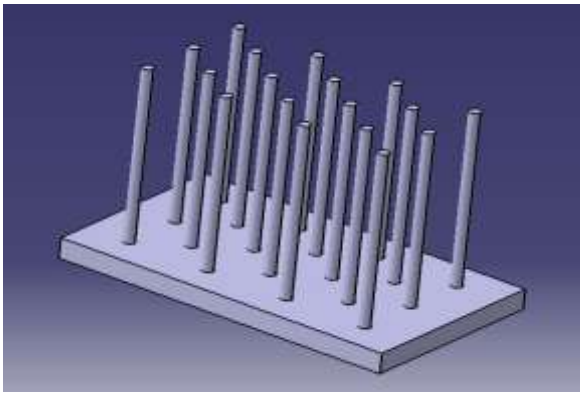

Figure 6.21: Geometry of staggered fins

Base size = 90 mm x 50 mm x 7 mm
Fin height = 60 mm
Fin diameter = 3 mm
Longitudinal pitch = 8 mm
Transverse pitch = 11 mm
Number of fins = 18
Number of columns = 7
Number of rows = 5

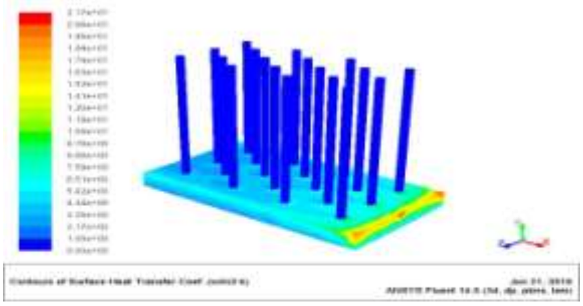

Figure 6.22 (a)

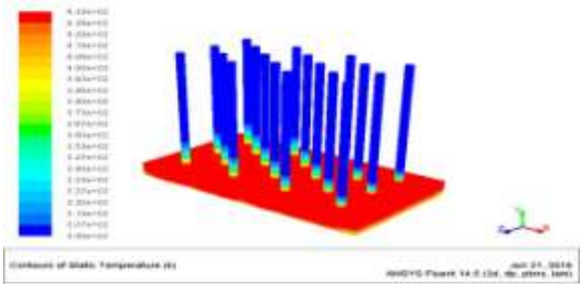

Figure 6.22 (b)

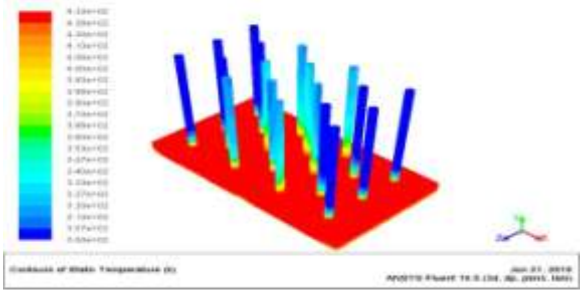

Figure 6.23 (a)

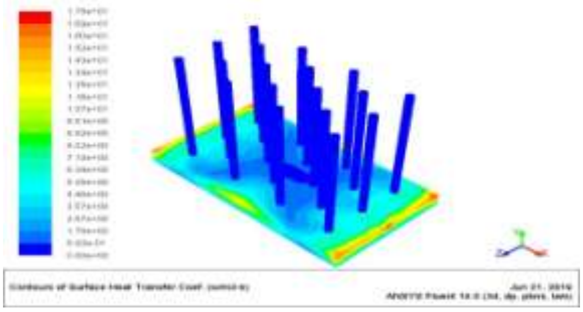

Figure 6.23 (b)

Table 6.1: Average temperature of fins with same spacing and varying height

Height of fins (mm)	Spacing between fins (mm)	Temp (one way air flow) (degree C)	Temp (two way air flow) (degree C)
25	5	116	113
30	5	123	118
35	5	126	123
40	5	133	127

Table 6.2: Average temperature of fins with same height and varying spacing

Height of fins (mm)	Spacing between fins (mm)	Temp (one way air flow) (degree C)	Temp (two way air flow) (degree C)
40	3	126	119
40	4	128	122
40	5	133	126
40	6	133	128

Table 6.3: Average temperature of staggered fins

Height of fins (mm)	Type of circular fins	Temp (one way air flow) (degree C)	Temp (two way air flow) (degree C)
70	inline	133	126
70	staggered	133	118

V. Conclusions

The temperature distribution in the one side entry and other end exit has higher heat dissipation at the inlet end of the fin as the fresh air comes in contact with the fin the temperature of air increases and the density decreases thus less air comes in contact with the base at the exit end.In the chimney flow pattern the temperature of the fin is high at the central bottom portion of the fin array assembly. As the air entering the fin array gets heated up which decreases the air density so the less air come in contact with the bottom portion of the fin array.

From the results of the simulation we can see that the temperature distribution in circular finned heat sink is better and even cooling rate is better than rectangular fins but the manufacturing of circular fins is complex then rectangular fins and costly too. So from the results we can conclude that the rectangular finned heat sink with 40mm fin height, 5mm spacing and one side entry and other end exit is best to manufacture as it is efficient as well as easy and cheaper than circular finned heat sink, thus this one is selected for our case.

Future Scope

Many more different types of models of heat sink can be designed and simulated and can be analyzed for different parameters. We used Aluminium as the material for heat sink, so next different kinds of materials can also be used. For better cooling a forced convection or water cooling can also be used. The heat sinks can be fabricated and can be used with thermoelectric devices as small primary sources of electric power in application where there long life without attention is attractive

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