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Study of Heat Transfer through Finned Heat Sinks by Natural Convection

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Abstract: Electronic circuits are used in diverse fields such as aircraft, locomotives, space applications, ships, submarines, communication systems, defense applications, etc. Also, the miniaturization of electronic devices has put a lot of constraints on the heat dissipation pattern of the circuit boards. These electronic circuits generate heat that must be dissipated while keeping chip temperature inside cabinet within safe limits for optimum performance. This is done by heat sink. So prediction and measurement of temperature of heat sink becomes essential. In the present work the heat sink is electrically heated with heating coil attached to it. Power input is calculated by measuring the input voltage and current. Temperature measurement is done using thermocouples for varying heat inputs. Heat transfer co-efficient is calculated from the measured data. This is done for different configurations of the heat sink. The experiments have been conducted by keeping the heat sink in open air. The experimental results for heat sink temperatures and heat transfer coefficients have been compared with analytical results for the heat sink being kept in open air.

Keywords: Heat sink, Natural convection, Steady state temperatures, Heat transfer coefficient.

I. INTRODUCTION

Heat is generated as a by-product in many engineering applications. This usually unwanted by-product can decrease the performance of the systems since almost every engineering system is designed to work in a certain temperature limit. If these limits are exceeded by overheating, this may even lead to total system failure. Therefore many engineering systems try to avoid this overheating problem as much as possible by using different methods for dissipation of heat away from the system to surrounding. The heat sink is a very important component in cooling design. It increases the component surface area significantly while usually increasing the heat transfer coefficient as well. Thus, the total resistance from the component junction to the surroundings is reduced significantly, which in turn reduces the junction temperature within a device. As a result, obtaining correct performance characteristics for heat sinks is extremely important in cooling design solutions. Using fins is one of the cheapest and easiest ways to dissipate unwanted heat and it has been commonly used for many engineering applications successfully. Rectangular fins are the most popular fin type because of their low production costs and high effectiveness. Rectangular fins can be used in two different orientations as vertical and horizontal. Convection and radiation heat transfers are two modes of heat transfer that take place while dissipating heat from fins to surrounding. Since all the considered fin configurations are made of aluminum alloys, which have low emissivity values, radiation heat transfer values are low. Therefore convection heat transfer is the dominant heat transfer mode while dissipating heat from fins.

Rate of heat dissipation from a fin configuration by convection heat transfer depends on the heat transfer coefficient and the surface area of the fins. It is possible to increase the heat transfer coefficient, h by forcing the fluid to flow over the fins by means of fans. But this option costs more and also requires more volume for the fans to operate. Therefore sometimes the designer has to rely on natural convection heat transfer for dissipating unwanted heat from the fins. The surface area of the fins can also be increased by adding more fins to the base material in order to increase the total heat transfer from the fins. But the number of the fins should be optimized because it should be noted that adding more fins also decreases the distance between the adjacent fins. This may cause resistance to air flow and boundary layer interference which in return decrease the heat transfer coefficient.

II. EXPERIMENTAL DETAILS

- **The Heat Sink and Heating Coil**

In the present work heat sinks with 9 fins and 5 fins have been studied. It should be noted that the heat sinks employed in the present experiments are symmetric in geometry. Two halves which are geometrically similar are joined together with the heating coil in the middle. This makes the heat sinks geometrically similar and they are employed in experiments in such a way that the flow around the heat sinks is also symmetric. Since the geometry and flow are symmetric, the configuration is equivalent to study of one half of the heat sink. The present study of symmetric heat sink then will be equivalent to one half of the heat sink, with only one half of the heat generated by the heating coil. This is because the heat generated is equally distributed between the two halves of the heat sink.

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- **Heat sink with 9-fins**

The heat sink with 9 fins has been prepared with 6 mm of equal spacing between the fins. The geometric details of the heat sink with 9 fins are given in Fig.1. The front view, top view and the side view is shown in Fig.1. As may be seen that the heat sink has a vertical base plate and 9 horizontal fins. Fig.2 shows the drawing of the symmetric heat sink assembled from the two halves, with heating coil placed in between.

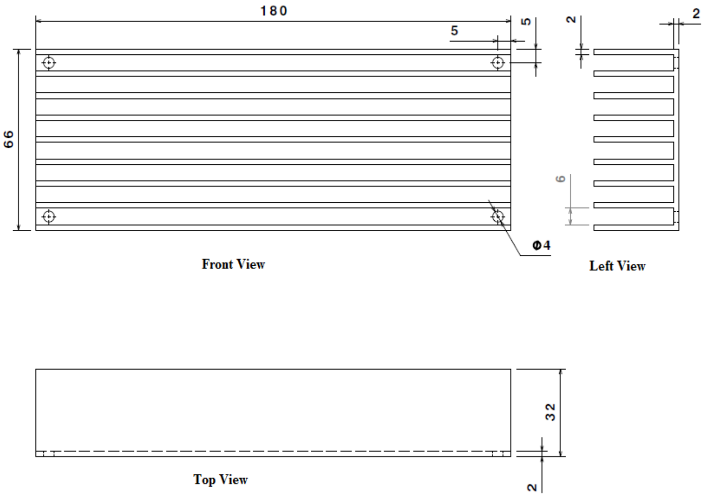

Fig. 1: Geometric details of one half of the 9-fin heat sink in front view, side view and top view.

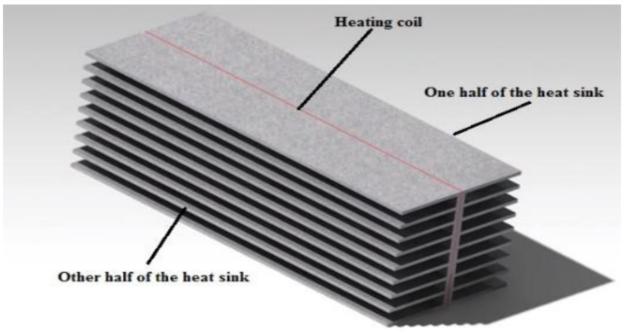

Fig 2: Assembly drawing showing heating coil placed between the two halves of the heat sink.

A schematic diagram of one half of the heat sink indicating the notations used for various dimensions is shown in Fig. 3.

Where,
L - Length of the heat sink.
W - Width of base of the heat sink.
S – Spacing between the adjacent fins.
H – Height of the fins.
t_f – Thickness of the fins.
t_b– Thickness of the base of the heat sink.

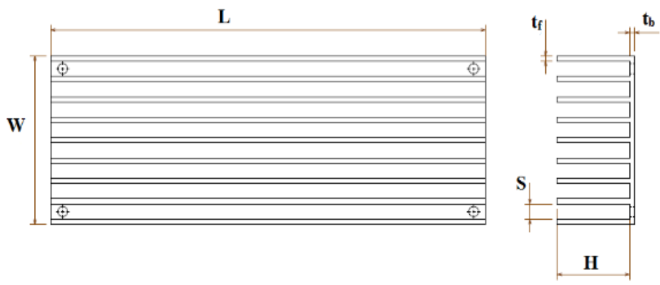

Fig 3: Schematic diagram of one half of the heat sink indicating the notations used for various dimensions.

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- **Heat sink with 5-fins**

From 9 fin heat sink the heat sink with 5 fins is prepared in the following way. After completing the experiments with the 9 fin heat sink, the 5 fin configuration was obtained by removing 4 fins out of the 9 fins to get a 5 fin heat sink with an equal spacing of 14 mm between the fins.

- **Material properties**

The heat sink is made of Aluminium alloy 6082 (HE-9). It is a medium strength alloy with excellent corrosion resistance. Table I shows some physical properties of the above alloy.

TABLE I Typical physical properties for Aluminium alloy 6082

PROPERTY	VALUE
Density	2680 kg/m^3
Melting Point	660°C
Modulus of Elasticity	70 GPa
Electrical Resistivity	0.031x10^{-6}Ω
Thermal Conductivity	200 W/mK
Thermal Expansion	23.5x10^{-6} /K

- **Instrumentation and the experimental setup.**

A list of the important instruments employed in conducting the experiments in the present study is given below. They are,

1. Thermocouples,
2. Digital Ammeter,
3. Digital Voltmeter,
4. Temperature Indicator.

Fig. 4: Experimental set up

- **Experimental procedure**

The following procedure is followed in conducting experiments:

1. A.C. power is supplied to the heating coil from mains. The voltage across the heating coil and the current passing through it are indicated by the digital voltmeter and ammeter. The digital voltmeter indicates the voltage values up to an accuracy of one decimal place. The digital ammeter indicates the current values up to an accuracy of two decimal places.
2. Four thermocouples T_1, T_2, T_3 and T_4 are fixed tightly with screws and nuts at the drilled hole locations (refer Fig. 1) for the measurement of the surface temperature. Two of the thermocouples which are diagonally opposite (T_1, T_2, T_3, T_4) are placed on either side, one on each half of the heat sink. Another thermocouple is used for measurement of the ambient temperature, T_{amb} .
3. The voltage and current are set at the required values and the temperature readings of the all the thermocouples T_1, T_2, T_3, T_4 and T_{amb} are noted.
4. The calculations are done without considering the heat losses by radiation and convection through the edges of the heat sink.
5. Analysis is carried out in ANSYS software for steady state thermal conditions. It is observed that the experimental and analytical values of heat transfer coefficients and fin temperatures are approximately equal.

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- **Formulae and notations**

It should be noted that in the formulas we consider only one half of the heat sink geometry.

- $Q_{input} = V\, I/2$
- $T_{avg} = \frac{T1+T2+T3+T4}{4}$
- $\Delta T = T_{avg} - T_{amb,\ indicator}$
- $h\ (\text{Base Area}) = \frac{Q_{input}}{A_{base} * \Delta T}$
- $h\ (\text{Total Area}) = \frac{Q_{input}}{A_{total} * \Delta T}$

Where,
Q_{input} = Heat input by the heating coil (W).
V = Voltmeter reading (V).
I = Ammeter reading (A).
T_1, T_2, T_3, T_4 = Temperature readings of thermocouples (^oC).
T_{amb} = Ambient temperature indicated by the digital temperature indicator (^oC).
T_{avg} = Average temperature of heat sink as obtained by the digital temperature indicator (^oC).
$h_{(Base\ Area)}$ = Heat transfer coefficient calculated based on base area of the heat sink (W/m^2K).
$h_{(Total\ Area)}$ = Heat transfer coefficient calculated based on Total area of the heat sink (W/m^2K) .

- A_{base} =Base area of the heat sink available for heat transfer (m^2).
  = L*W… (Refer Fig. 3)
- A_{total} = Total area of heat sink available for heat transfer (m^2).
  = $L*W + 2nH\,(L+t_b) + 2t_f *(L+W)$… (Refer Fig. 3)

L = Length of the base (m).
W = Width of the base (m).
H = Height of the fin (m).
t_b = Thickness of the base (m).
t_f = Thickness of the fin (m).
n = Number of fins.

III. PRESENTATION AND DISCUSSION OF RESULTS

Experiments conducted in the present work may be summarized as follows:

1. Fins in horizontal orientation
   (i) 9-fin configuration
   (ii) 5-fin configuration
2. Fins in vertical orientation
   (i) 9-fin configuration
   (ii) 5-fin configuration

- **Heat sink orientations**

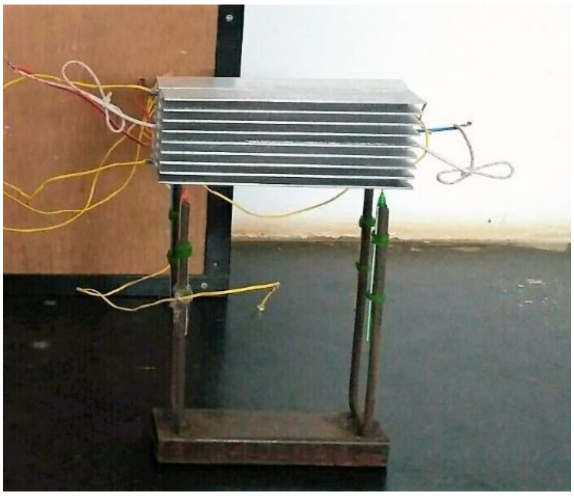

Fig. 5: Photograph of 9-fin heat sink in horizontal orientation

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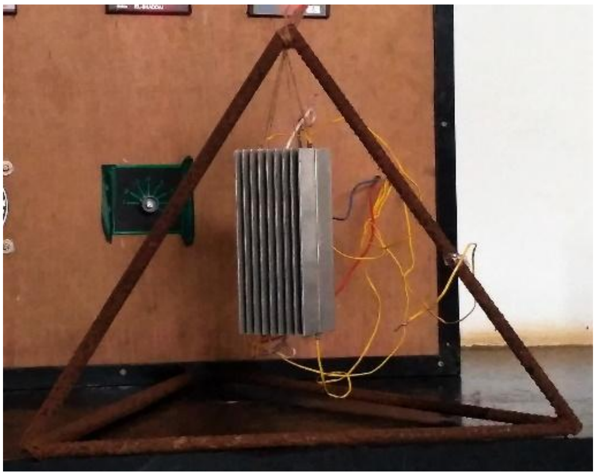

Fig. 6: Photograph of 9-fin heat sink in vertical orientation

The calculations for temperature difference ΔT and heat transfer coefficient h for total area & base area are done. Graphs are plotted for various parameters and the conclusions are obtained.

Abbreviations used for different configurations:
H9 - Heat sink with 9-fins in Horizontal orientation.
H5 - Heat sink with 5-fins in Horizontal orientation.
V9 - Heat sink with 9-fins in Vertical orientation.
V5 - Heat sink with 5-fins in Vertical orientation.

- **Comparison of H9 V9 H5 V5 for h (total area)**

Fig. 7 shows heat transfer co-efficient h (Total Area) is plotted against heat input Q. It can be seen that the h (Total Area) is in general increasing with increase in heat input for all the cases.

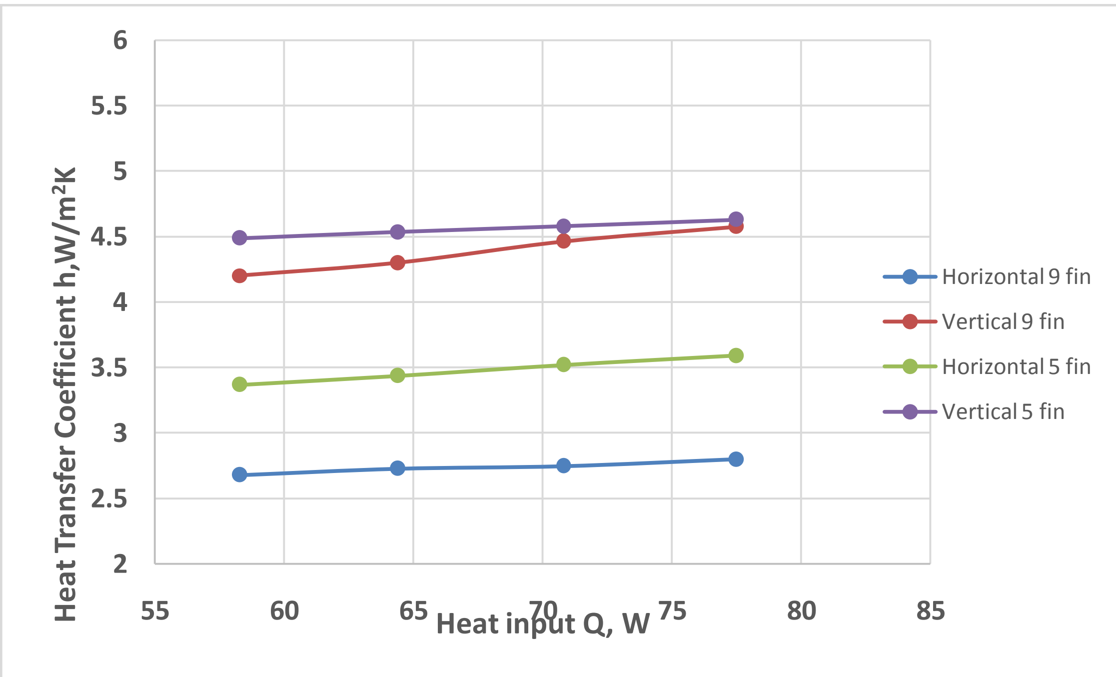

Fig. 7: Heat transfer co-efficient h based on total area of the heat sink plotted against the corresponding heat input Q for 9-fin and 5-fin heat sink with fins in horizontal and vertical orientations.

- **Comparison of H9 V9 H5 V5 for h (base area)**

Fig. 8 shows heat transfer co-efficient h (Base Area) is plotted against heat input Q. It can be seen that the h (Base Area) is in general increasing with increase in heat input for all the cases.

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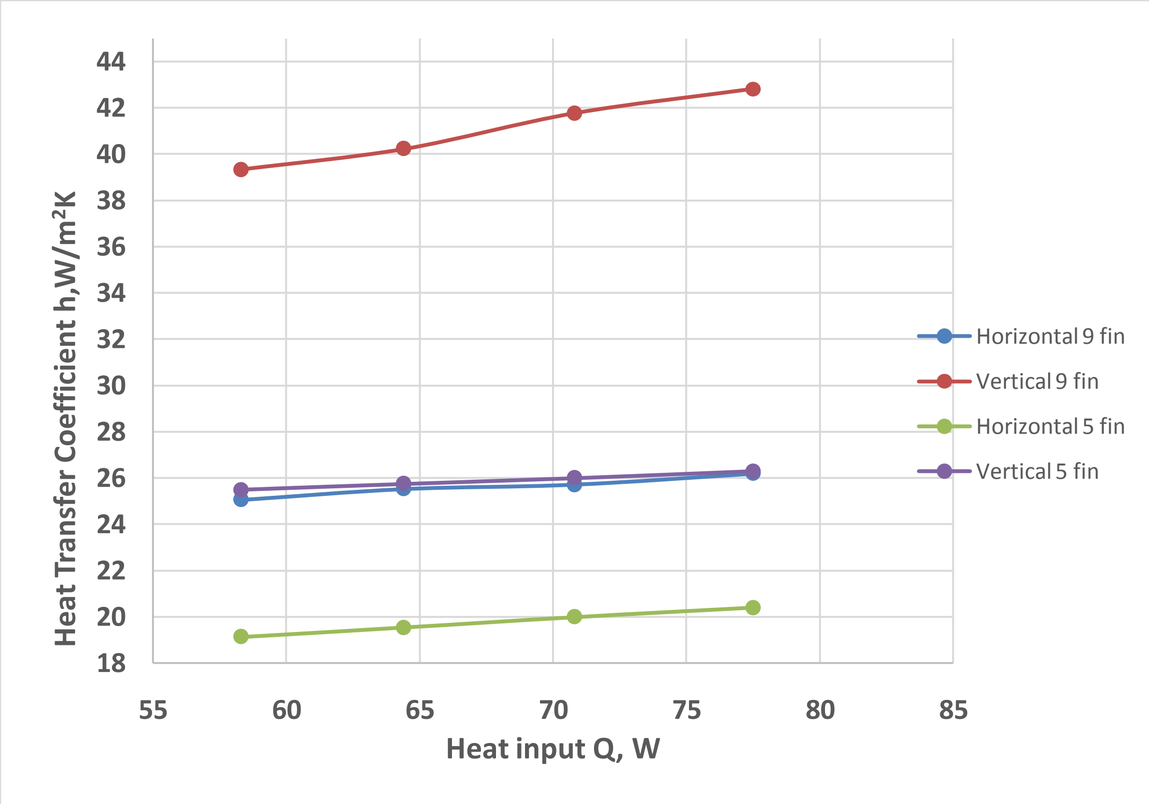

Fig. 8: Heat transfer co-efficient h based on base area of the heat sink plotted against the corresponding heat input Q for 9-fin and 5-fin heat sink with fins in horizontal and vertical orientations.

- **Comparison of H9 V9 H5 V5 for ΔT**

The steady state temperature difference ΔT reached by the heat sink is shown plotted against the heat input in Fig. 9. As may be expected the **Δ**T values are higher for higher heat input values.

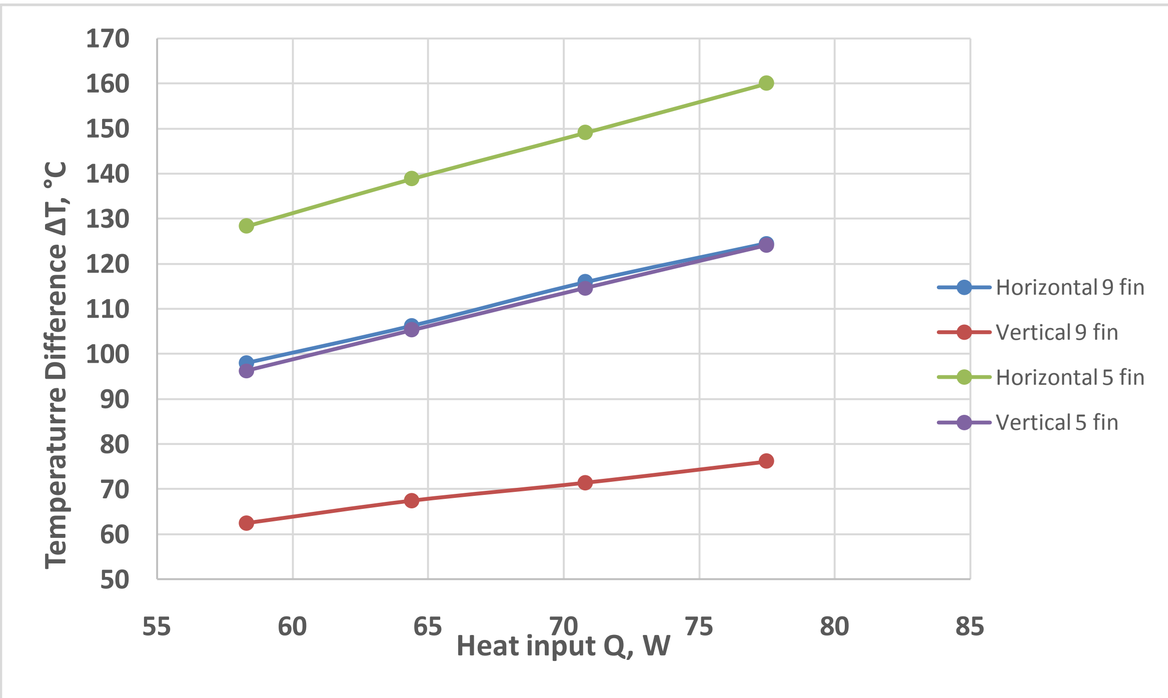

Fig. 9: Temperature difference ΔT of the heat sink plotted against the corresponding heat input values Q for 9-fin, 5-fin heat sink with fins in horizontal and vertical orientations.

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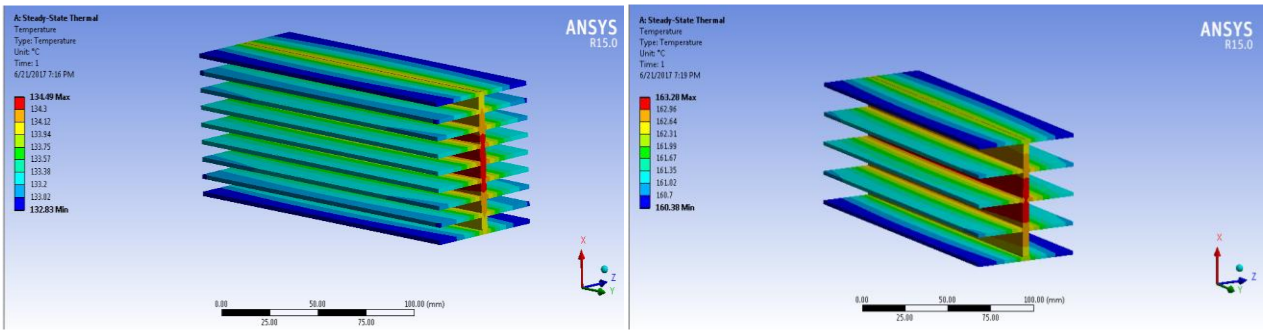
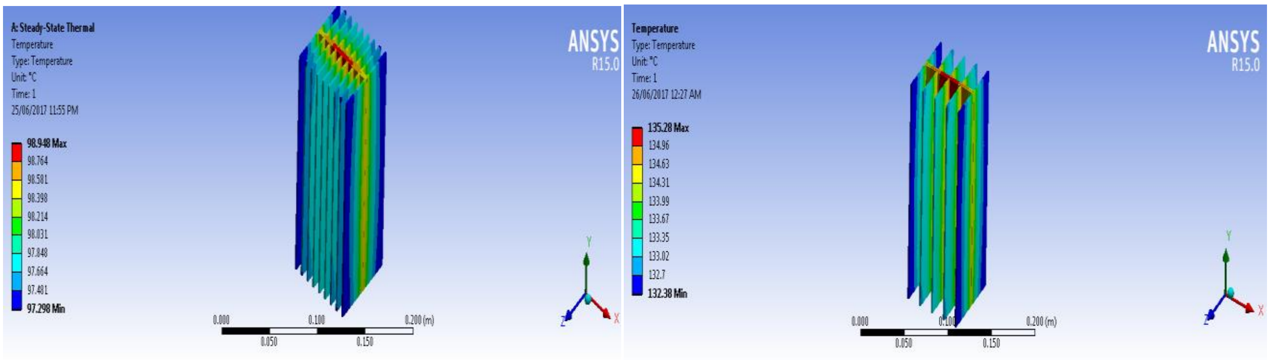
- **ANSYS results**



(a) (b)

Fig. 10: Surface temperatures (T_{avg}) for (a) 9-fin (b) 5-fin for horizontal orientation.



(a) (b)

Fig. 11: Surface temperatures (T_{avg}) for (a) 9-fin (b) 5-fin for vertical orientation.

IV. SUMMARY AND CONCLUSIONS

Experiments have been conducted to establish relation between heat sink temperature and corresponding heat inputs and associated heat transfer coefficient values.

In the present work the heat sink is electrically heated with heating coil attached to it. Power input is calculated by measuring the input voltage and current. Temperature measurement is done using thermocouples for varying heat inputs. Heat transfer co-efficient values are calculated from the measured data. This is done for different configurations of the heat sink.

Experiments have been conducted by keeping the heat sink in open air with fins in horizontal orientation and vertical orientation.

A few conclusions can be drawn from the present work as follows:
1. Heat transfer co-efficient h (Base Area) values are the higher for 9-fin configuration then 5-fin configuration. This is true for both cases, namely fins in horizontal orientation in open air and fins in vertical orientation in open air.
2. Heat transfer co-efficient h (Total Area) values are the higher for 5-fin configuration then 9-fin configuration. This is true for both cases, namely fins in horizontal orientation in open air and fins in vertical orientation in open air.
3. From the experimental results it could be seen that the heat transfer co-efficient values are the higher in case of vertical orientation of fins in open air and the lower in case of fins in horizontal orientation.

V. SCOPE OF FUTURE WORK

1. Heat sinks with fin spacing's and dimensions other than those studied in the present work, in particular, of different lengths, can be taken up in the future work.
2. Numerical modeling can be carried out.
3. Similar studies can be taken for heat sinks with non-rectangular geometries.
4. Optimization studies can be carried out to optimize fin spacing and heat sink dimensions.

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