Experimental Analysis of Inclined Narrow Plate-Fins Heat Sink under Natural Convection

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Abstract
Steady state natural convection from heat sink with narrow plate-fins having parallel arrangement mounted on inclined base was experimentally investigated. Aluminum heat sink with two different lengths viz. 100mm and 200mm were modeled. Fin thickness was kept constant at 5mm. Fin height was selected 10mm, 20mm and 30mm for 100mm length of fin while it was 20mm, 40mm and 60mm for 200mm length of fin. Heat sink was kept at aspect ratio of 0.1, 0.2 and 0.3. Rectangular base was made incline for 0°, 10°, 20°, 45°, 70°, 80° and 90° keeping upward facing fins. Heat input was varied from 60 W to 100 W. Effect of fin height, fin length, inclination of base was determined. Range of angle of inclination was suggested showing equivalent heat transfer rate. Also, effect of aspect ratio over natural convection was examined.

Keywords: plate-fins, narrow, aspect ratio, natural convection.

1. INTRODUCTION
Many engineering systems during their operation generate heat. If this generated heat is not dissipated rapidly to its surrounding atmosphere, this may cause rise in temperature of the system components. This by-product cause serious overheating problems in system and leads to system failure, so the generated heat within the system must be rejected to its surrounding to maintain the system at recommended temperature for its efficient working. The techniques used in the cooling of high power density electronic devices vary widely, depending on the application and the required cooling capacity. The heat generated by the electronic components has to pass through a complex network of thermal resistances to the environment.
Passive cooling techniques found more efficient and economic for electronics component. Using fins is one of the most inexpensive and common ways to dissipate unwanted heat and it has been successfully used for many engineering applications. Fins come in various shapes; such as rectangular, circular, pin fin rectangular, pin fin triangular etc. Rectangular fins are the most popular fin type because of their low production costs and high thermal effectiveness. Study of influence of geometric parameters viz. fin length, fin height, fin spacing over heat dissipation found important.

2. PREVIOUS WORK
Many investigators experimentally studied the effect of geometric parameters viz. fin length, fin length, fin thickness and fin spacing. B. Yazicioglu, H. Yuncu [1] performed experiments over thirty different fin configurations with 250 and 340 mm fin length. Optimum fin spacing of aluminum rectangular fins on vertical base was examined. It was found that optimum fin spacing varies for each fin height which is between 6.1 and 11.9mm. H. Yuncu, G. Anbar [2] investigated natural convection heat transfer for 15 sets of rectangular fin array with horizontal base. Fin spacing and fin height was varied from 6mm to 26mm and 6.2 to 83mm, respectively. For fin height 16 and 26mm, optimum fin spacing found 11.6 and 10.4mm, respectively. S. Baskaya, M. Sivrioglu, M. Ozek [3] analyzed parametric effect of horizontally oriented fin array over natural convection heat transfer. They found that optimum fin spacing for L=127mm and L=154mm are Sopt=6 and 7mm, respectively. For wide range of angle of inclination of heat sink was tested by Ilker Tari, Mehdi Mehrtash [6, 7, 8] with upward and downward orientations. Also, they found that the optimum fin spacing does not significantly change with inclinations suggesting the value as 11.75. The fin length range was from 100 mm to 500 mm, the fin height from 5 mm to 90 mm, the fin thickness from 1 mm to 19 mm, the width of rectangular base plate from 180 mm to 250 mm was examined by Burak Yazicioglu and Hafit Yüncü [9]. Experiential analysis of natural convection heat transfer from horizontal rectangular notched fin arrays was studied by Suneeta Sane and Gajanan Parishwad [10]. U. V. Awasarmol, A. T. Pise [11] analyzed comparative effect of rate of heat transfer with solid and permeable fins and the effect of angle of inclination of fins. The sink was made incline with 0°, 15°, 30°, 45°, 60°, 75°, and 90°from horizontal.
From this extensive review, it is clear that optimum fin spacing varies with fin length [2]. Experimental model can be design by developed relations. Thus, fin spacing for fin length, L=100mm and 20mm is selected as 7.5mm and 10mm, respectively. However, combine effect of fin length and fin height for optimized fin spacing at certain orientation has not studied. Also, study of slight inclined model from vertical or horizontal position of heat sink seems importance for closely packed model. Also, downward facing inclination has poor heat transfer rate than upward facing, only upward facing heat sink is modeled and examine. Objective of present study is to find out effect of fin length, fin height, aspect ratio over free convection. Also, to find out effect of upward facing inclination of heat sinks over heat dissipation. Attempt is made to determine range of inclination angle showing identical heat transfer rate. Many researchers investigated optimum fin spacing for corresponding fin length.

3. EXPERIMENTATION

Aerated concrete block is fixed on the frame which ensures one dimensional heat dissipation. The front surface of the frame has removable acrylic sheet so as to replace fin arrays. Heater plate is placed on the concrete block. Base thickness of the array is 5mm so as to distribute power supply uniformly. Heater covered by cases fully consists of nichrome wire wound around thin mica plate and mica sheet. Heater plate rated for 300W and 220V, AC. The test section was kept insulated and controlled room to establish free convection over fin arrays. The aerated concrete block has 1mm depth to fit heater plate into it. This help to insulate rear surface of heater and four lateral surfaces of heater. Extruded surface is kept over fin array for fitting to aerated concrete block. Concrete block has in-built 4 bolts to tight fin array over heater plate. Thus, air gap between heater plate and fin array is consider to be negligible. Also, heat loss through excess portion to the fin arrays to be assumed negligible for comparative analysis. Aerated concrete block has high insulation quality and high temperature resistance (thermal conductivity, k ~ 0.15 W/m.K). In addition, it can be shaped very easily so that required processes can be performed.

<table>
<thead>
<tr>
<th>Table1: Dimension of set-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component</td>
</tr>
<tr>
<td>Frame</td>
</tr>
<tr>
<td>Heater</td>
</tr>
<tr>
<td>Concrete</td>
</tr>
</tbody>
</table>

The fin configurations were produced by milling longitudinal grooves in one of the faces of rectangular bar. The fin arrays were produced from rectangular bars with dimensions 200x140x60 mm and 100x150x30 mm. Fins were kept integral with the base plate of thickness 7mm while, fin thickness was kept constant, 3mm. Geometry of fin array is shown in the Figure 1. The fin material was selected as aluminum because of its high thermal conductivity, k ~ 130 W/m.K at 20°, low emissivity (~ 0.2 at 20°).

![Figure 1](a) Fin geometry (b) photograph of experimental setup

The front surface of the frame is covered with acrylic sheet, which has arrangement to replace fin arrays. The experimental set-up primarily consists of an aerated concrete base and supporting frame on which the concrete is mounted and various instruments for measuring the ambient temperature, base-plate temperature and the power input for the heater. Whole frame is mounted on single shaft which has bearing at the support. At one end of the shaft, protractor is kept in-built so as to measure inclination of the heat sink, as shown in fig.1 (b).
Table 2 Fin specification

<table>
<thead>
<tr>
<th>Block. No</th>
<th>Fin length (mm)</th>
<th>Fin width (mm)</th>
<th>Fin spacing (mm)</th>
<th>Fin thickness (mm)</th>
<th>Fin height (mm)</th>
<th>No of fins</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>200</td>
<td>140</td>
<td>10</td>
<td>5</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>140</td>
<td>10</td>
<td>5</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
<td>140</td>
<td>10</td>
<td>5</td>
<td>60</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>155</td>
<td>7.5</td>
<td>5</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>155</td>
<td>7.5</td>
<td>5</td>
<td>20</td>
<td>13</td>
</tr>
<tr>
<td>6</td>
<td>100</td>
<td>155</td>
<td>7.5</td>
<td>5</td>
<td>30</td>
<td>13</td>
</tr>
</tbody>
</table>

4. DATA REDUCTION
a. Base area:
\[ A_b = \text{fin length} \times \text{width of fin} \]
b. Exposed fin area:
\[ A_e = (\text{fin height} \times \text{fin length} \times 2) + (\text{fin thickness} \times \text{fin height} \times 2) + (\text{fin length} \times \text{fin thickness}) \]
c. Total exposed area:
\[ A_t = (\text{no. of fins} \times \text{exposed fin area}) + (\text{fin length} \times \text{fin spacing} \times (\text{no. of fins} - 1)) \]
d. Heat loss by convection \( Q_c \):
\[ Q_c = h_{avg} \times A \times \Delta T \]
\[ Q_c = \varepsilon \sigma A_r (T_{avg}^4 - T_b^4) \]
e. Average heat transfer coefficient:
\[ h_{avg} = \frac{Q_c}{A \times \Delta T} \]
f. Mean film temperature:
\[ T_f = \frac{T_{avg} + T_b}{2} \]
g. Average Nusselt No.:
\[ \text{Nu}_{avg} = \frac{(h_{avg} \times L)}{k} \]
\[ \text{Ra} = \frac{g \mu \sigma (T_{avg} - T_b) \times L \times B}{V^4} \]

5. EXPERIMENTATION PROCEDURE
The predetermined heater inputs were adjusted with the help of dimmerstat. The temperatures of assembled fin array at different positions and ambient temperature were recorded at the time intervals of 30 min. up to steady condition. Generally it takes around 2 hours to attain steady state condition. Arrival of steady state was assumed as temperature reading does not vary by 0.5°C. The heater input was kept constant by adjusting the dimmer-stat, which was provided with stabilized voltage input. Steady state observations were recorded and used for calculation. Six thermocouples were used. Five thermocouples were attached to the base and one was kept suspended in channel to measure ambient temperature.

Parameters used for the study are as given below.
Heater input wattage \( (Q_{in}) \): 60W, 80W, 100W
Base temperature : \( T_1, T_2, T_3, T_4, T_5 \)
Ambient temperature : \( T_6 \)

6. MODEL VALIDATION
In order to validate inclined model below empirical relations were used. Considered co-relations are only valid for vertical heat sink. Therefore, as fig.2 shows, experimental results are in good agreement with relative error of 1.21% at vertical position (0°) of fin array. Furthermore, with 20° of upward facing inclination has 5.11% relative error.
Considered relations are:
Mc Adam’s relation- 
\[ \text{Nu}_L = 0.59 \text{Ra}^{1/4} \]  

Churchill and Chu’s first relation-
\[ \text{Nu}_L = \left( \frac{0.387 \text{Ra}^{1/4}}{1 + \left( \frac{0.592}{\text{Fr}^{1/3}} \right) \text{Pr}^{1/3}} \right)^{2} \] 

7. RESULT ANALYSIS
7.1 Effect of fin height over convective heat transfer
Fig.3 (a) shows heat transfer analysis of inclined heat sink with fin length L=200mm and fin height H=30, 60, 80mm. Heater input is kept at 100W. Heat transfer rate decreases from vertical position (0°) to upward facing horizontal position (90°). Also, as fin height increases, convective heat transfer increases. Fig.3 (b) shows heat transfer through heat sink of fin length L=100mm and Fin height H=10, 20, 30mm. For this trial, heater is kept at 60W. Identical nature of graphs is observed for both setups. Negligible variation in heat transfer rate is observed between vertical base and 10°, 20° inclination. Also, slight variation is present in heat loss for 70°, 80° and horizontal position.

7.2 Effect of fin length over convective heat transfer
Fig. 4 shows variation in heat transfer rate with inclination at different heater input while fin height was kept constant at 20mm for both setups. It indicates that at certain heater input, convective heat loss increases with reducing fin length from 200mm to 100mm. Fin length of 100mm, heat transfer rate decreases slowly from vertical position (0°) to horizontal position (90°).
7.3 Effect of heat input over convective heat transfer
Fig. 5 clearly indicates that heat transfer rate increases with increase in heater input from 60W, 80W and 100W. Slope of curve in Fig.5 (a), (b) more than that of in Fig.5 (c), (d). It shows that, for large fin length, convective heat transfer is more sensitive while it rotates from 0° to 90°.

![Figure 4](image)

**Figure 4** Variation in heat transfer with angle of inclination at L=100mm and L=200mm, H=20mm

![Figure 5](image)

**Figure 5** Variation in convective heat transfer with angle of inclination at 60W, 80W, 100W heater input (a) L=200mm, H=60mm (b) L=200mm, H=40mm (c) L=100mm, H=30mm (d) L=100mm, H=20mm

7.4 Effect of aspect ratio over convective heat transfer
Trial is conducted keeping narrow heat sink. So, effect of aspect ratio H/L=0.1,0.2,0.3 over heat transfer is shown in fig.6. Maximum heat transfer rate is observed for H/L=0.3 and L=200 till 45° upward facing inclination of channel, further it decreases till horizontal position. Maximum heat transfer rate for 70°, 80°, 90° inclination is observed to fin arrays with L=100mm and H/L=0.3. This nature is same for each aspect ratio of heat sink, as shown in fig.6.
8 CONCLUSION

- It is found that natural convection heat transfer is depending on fin height and fin length as predicted.
- For selected fin spacing, the convection heat transfer rate increases with fin height and decreases with fin length.
- Convective heat transfer increases with aspect ratio but this behavior is different for different angle of inclination.
- Smaller fin length has no influence over heat dissipation through inclined base.
- Natural convection heat transfer increases monotonously with heat input and therein with temperature difference.

References

[10] Suneeta Sane et.al, Experimental analysis of natural convection heat transfer from horizontal rectangular notched fin arrays,

Author

Avdhoot Walunj received the B.E degree in Mechanical Engineering from University of Pune in 2012. He is student of M.E. (Heat Power Engineering) in Matoshri College of Engineering and Research Center, Nashik (University of Pune).