International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Volume 1 Issue 8 (September 2014) www.ijirae.com

Natural convection heat transfer from a radial heat sink with Horizontal rectangular fins

Mangesh D. Shende[1], Dr. Ashish Mahalle[2]
[1](SHREEYASH COE & T, Aurangabad/ BAMU, University Aurangabad/India)
[2](LIT, Nagpur/RSTM University Nagpur/India)

ABSTRACT-- High heat flux of electronic devices, e.g. projector, LED, high power chip, etc., require efficient cooling methods for heat dissipation in a limited region. It means maintaining a small heat source at an acceptable temperature i.e. there is a continuous increase of the system power and the shrinkage of size. This resulted in inevitable challenges in the field of thermal management of electronics to maintain the desirable operating temperature. This paper presents the details study natural convection in a radial heat sink, composed of a horizontal circular base and rectangular fins. The general flow pattern is that of a chimney; i.e., cooler air entering from outside is heated as it passes between the fins, and then rises from the inner region of the heat sink. Experimental investigations are performed to compare the effects of three geometric parameters (fin length, fin height, and number of fins) and a single operating parameter (heat flux) on the thermal resistance and the average heat transfer coefficient for the heat sink array.

Keywords: Natural convection, Heat sink, Circular base, fins, heat flux

1. Introduction

The light-emitting diode (LED) lights have recently attracted the attention of the illumination industry, due to their lower power consumption, longer life, and smaller, more durable structure compared to other light sources. However, their use presents a thermal problem, since about 70% of their total energy consumption is emitted as heat. An efficient heat sink design is essential to solve this problem. Natural convection heat sinks are appropriate for LED lights, considering their overall advantages. However, natural convection heat sinks commonly have rectangular bases, whereas LED lights are generally circular. It is therefore desirable to investigate natural convection heat transfer via a heat sink with a circular base.In this study, the heat transfer of a radial heat sink was experimentally analyzed, considering natural convection. Numerous experimental [1–4] and numerical [5] studies of rectangular fin or pin fin heat sinks have been carried out. Starner and McManus [1] experimentally investigated natural convection heat transfer from four heat sinks of differing dimensions, with the heat sinks oriented vertically, at a 450 angle, and horizontally. Welling and Woolbridge [2] conducted an experimental study of vertically oriented rectangular fins of constant length attached to a vertical base. They found that there exists an optimal fin height, corresponding to a maximum rate of natural convection heat transfer, for any given fin spacing. Harahap and Mcmanus [3] performed experiments to calculate the average heat transfer coefficients for two different fin lengths, and established a correlation with non-dimensional parameters and relevant fin dimensions. However, most of these studies were concerned with heat sinks with rectangular bases, which might be inefficient for cooling circular LED lights. In this study, natural convection from a heat sink with a circular base and rectangular fins is experimentally analyzed, and the thermo-flow pattern is observed. The effects of the number of fins, fin length, fin height, and heat flux on the thermal resistance and the average heat transfer coefficient are investigated. Abdullatif Ben-Nakhi and Ali J. Chamkha [6] focused on the numerical study of steady, laminar, conjugate natural convection in a square enclosure with an inclined thin fin of arbitrary length. A numerical solution based on the finite-volume method is obtained & results for the local and average Nusselt numbers are presented and discussed for various parametric conditions. Experimental investigation of heat transfer and fluidflow characteristics in horizontal and vertical narrow closed enclosures having a heated finned base plate has been carried out. S.A. Nada [7] studied the effects of fin length and fin spacing for both orientations at a wide range of Rayleigh number. It has been found that insertion of fins with any fin array geometries increases the rate of heat transfer. Quantitative comparisons of heat transfer rate and surface effectiveness for both enclosure orientations have been reported. Optimization of fin-array geometries for maximum Nusselt number and finned surface effectiveness has been conducted. Also correlations were predicted and were compared with the present and previous experimental data and good agreement was found by S.A. Nada.

Nomenclature

h	*heat transfer coefficient, $W/m^2\,K$*	*r*	*radius, mm*
H	*fin height, mm*	*T*	*temperature, K or ^0C*
k	*thermal conductivity, W/m^0C*	*t*	*fin thickness, mm*
L	*fin length, mm*	*A*	*Total surface area*
Nu	*Nusselt number, hL/k*	*Subscripts*	
n	*number of fins in the normal direction*	*avg*	*average*
Pr	*Prandtl number*	*f*	*fluid (air)*
p	*pressure, N/m^2*	*i*	*inner*
q	*heat flux, W/m^2*	*o*	*outer*
R_{TH}	*thermal resistance, $^0C/W$*	*s*	*solid (heat sink)*

2. Experimentation

Methodology : In experiment set up consists of the different aluminum radial fin structures and nine thermocouples are placed at different location on fin structure to measure fin surface temperature. Experiments are performed and steady-state observations are recorded. The Taguchi method is efficient for a design problem with several parameters and is frequently used in industry because it can readily improve a reference model based on the objective function without repeating experiments. In order to minimize the number of tests required, fractional factorial experiments (FFEs) were developed. FFEs use only a portion of the total possible combinations to estimate the effects of main factors and the effects of some of the interactions. To provide efficient optimization, traditional optimization techniques like Design of Experiments are generally chosen as a tool. The heat sink geometry design factors like length of the fin (L), height of the fin (H), and number of fins (N) are chosen as the design parameters at three different levels to increase the total heat transfer from heat sink and are shown in table below.

Table 1.Parameter & Level

Parameter	**Code**	**Level**		
		1	**2**	**3**
Length of fin (m)	L	35 mm	45 mm	55 mm
Height of fin (m)	H	15 mm	25 mm	35 mm
Number of fin	n	24	28	32

The minimum number of experimental combinations (MNE) for conducting simulations are given by MNE = kn in this research nine experiments were conducted at different parameters. For this Taguchi L9 orthogonal array was used, which has nine rows corresponding to the number of tests, with three columns at three levels.

Table 2. Different setups for experiments

Model No./Exp. No.	**Level 1**	**Level 2**	**Level 3**
Model 1	1	1	1
Model 2	1	2	2
Model 3	1	3	3
Model 4	2	1	2
Model 5	2	2	3
Model 6	2	3	1
Model 7	3	1	3
Model 8	3	2	1
Model 9	3	3	2

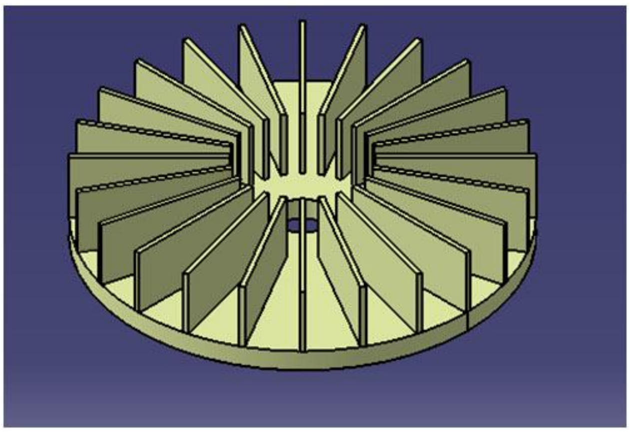

Fig. 1. Radial heat sink with a circular base and rectangular fins & experimental setup.

The experiment set up consists of different aluminum radial fin structures and nine thermocouples are placed at different location on fin structure to measure fin surface temperature. By using taguchi optimization technique, nine different models were manufactured by varying length of fin, height of fin and number of fin by using L9 arrays. Copper and aluminum are among the most-frequently used materials for this purpose within electronic devices. Copper is significantly more expensive than aluminum but is also roughly twice as efficient as a thermal conductor. Aluminum has the significant advantage that it can be easily formed by extrusion, thus making complex cross-sections possible. Aluminum is also much lighter than copper, offering less mechanical stress on delicate electronic components. Some heat sinks made from aluminum have a copper core as a trade off. The heat sink is made of aluminum (Al2014), with no additional surface treatment. The experimental analysis of natural convection around radial heat sink is carried out by using following specification as listed below:-

Outer radius of base of fin (r_o) = 80 mm
Thickness for all configuration of fin (t) = 2 mm
Accuracy of thermocouples = ± 2^0.

Inner radius of base of fin (r_i) = 10 mm
Total number of thermocouple = 09
Temperature indicator: Type: K type,

For insulating the base of heat sink Sindanyo H91 as electrical & thermal insulator. The experimentation for above specification is carried out in room temperature

According to Newton's law of cooling,

$$Q = h\,A\,(\Delta T)$$

Therefore heat transfer coefficient,

$$h = \frac{Q}{A\,\Delta T} = \frac{(V \times I)}{A\,\Delta T}$$

Thermal resistance,

$$R_{TH} = 1/\,h\,A$$

3. Results and discussion

There are two flows, i.e., vertical and horizontal flows, around the radial heat sink. The vertical flow is in the upward direction, since air is heated by the heat sink (which is maintained at a higher temperature) and becomes lighter than the surrounding air. The horizontal flow is created by air entering from outside the heat sink to make up for the vertical flow in the inner region. Therefore, the overall flow pattern is chimney-like. The temperature of heat sink maintains almost uniformly high because of high conductivity of aluminum. The heat transfer rate in the outer region of the heat sink was higher than in the inner region. This was because the temperature difference between the air and the heat sink decreased as the cool air proceeded towards the inner region of the heat sink.

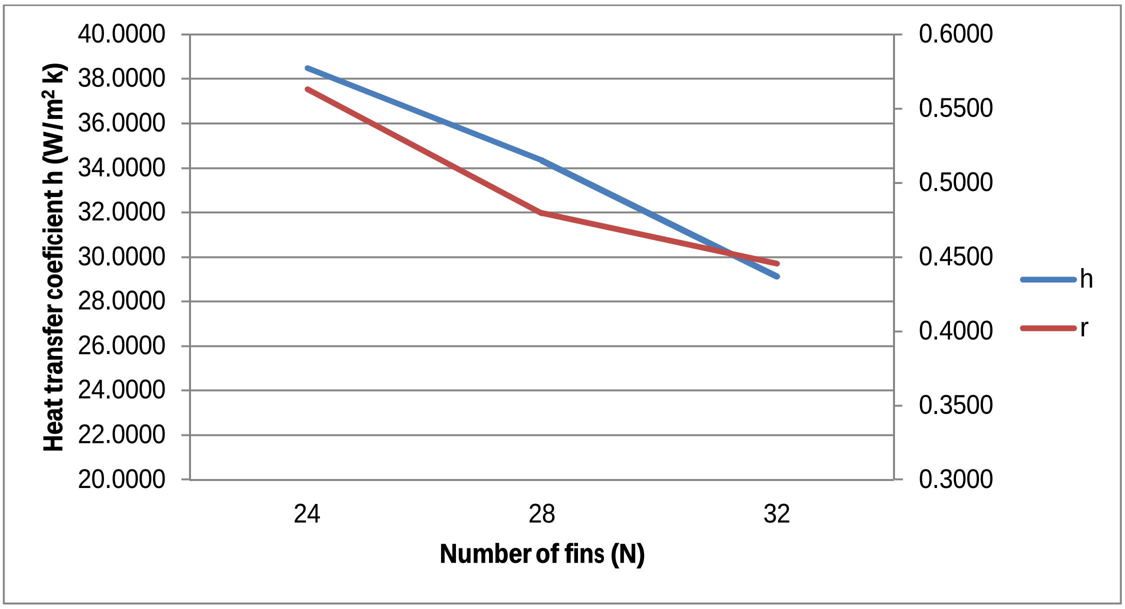

Fig. 2. Effect of number of fins on heat transfer coefficient (h) and thermal resistance (R_{th})

Fig.2 shows the average heat transfer coefficient decreases as the number of fins increased, since the flow rate of the cooler air entering the spaces between the fins decreased and the air was heated more quickly on account of the reduced space between fins. However, when the number of fins was less than 28, the thermal resistance of the heat sink decreased with increasing n, since the effect of the increased heat transfer surface area was larger than the effect of the decreased heat transfer coefficient. When the number of fins was greater than 28, the thermal resistance of the heat sink increased with increasing n, since the heat transfer coefficient was very small. Consequently, there exists optimum number of fins that gives the minimum thermal resistance.

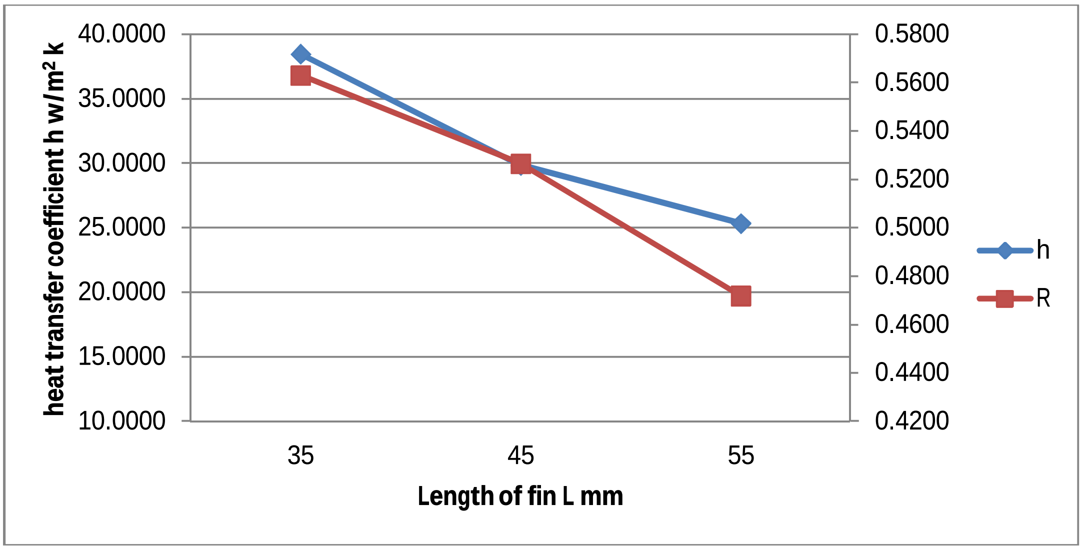

Fig. 3. Effect of length of fin on heat transfer coefficient and thermal resistance.

Fig. 3. shows the effect of the fin length. As the fin length increased, the thermal resistance and average heat transfer coefficient decreased. The thermal resistance leveled off and reached a steady value when the fin was longer than 55 mm. This was because the air temperature in the inner region was almost the same as the heat sink temperature, and hence any additional fin length beyond 55 mm did not contribute to the heat transfer rate.

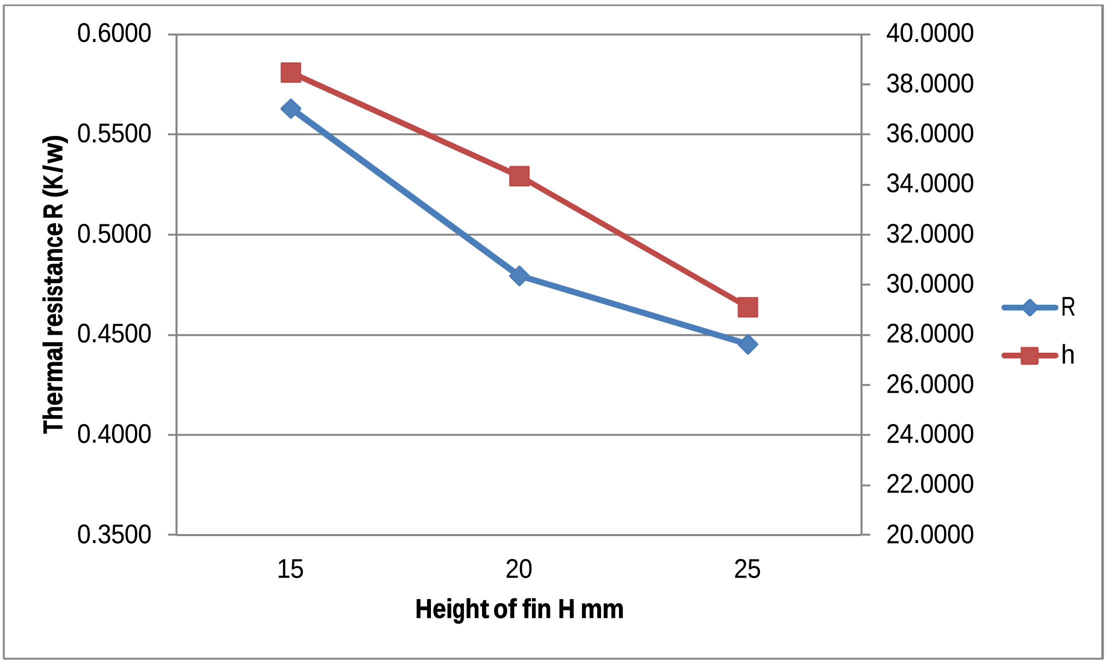

Fig. 4. Effect of height of fin on heat transfer coefficient and thermal resistance.

Fig.4. indicates the effect of the fin height. A lower thermal resistance resulted from the increased heat transfer surface area created by the incremented fin height. However, the change in the heat transfer coefficient was relatively small, since the velocity of the air entering from outside increased very little with increasing fin height.

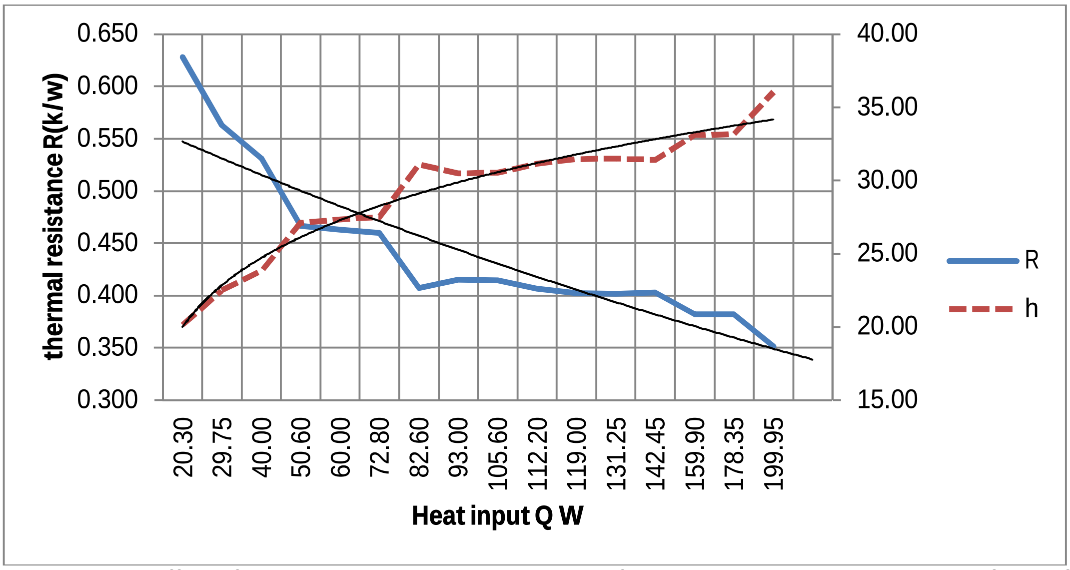

Fig.5. Effect of heat input on experimental value of thermal resistance and heat transfer coefficient.

Fig.5. illustrates the effect of the heat flux applied to the heat sink base. The decrease in thermal resistance due to increasing heat flux resulted in a greater rising air velocity, which in turn increased the flow rate of the cooler air entering from outside. Accordingly, the average heat transfer coefficient increased almost linearly, thanks to the enhanced effect of natural convection.

4. Conclusions

Natural convection from a radial heat sink was experimentally and numerically investigated. The general flow pattern was like that of a chimney; i.e., the cooling air entering from outside was heated as it passed between the fins, and then rose from the inner region of heat sink. Parametric studies were performed to compare the effects of the number of fins, fin length, fin height, and heat flux on the thermal resistance and the heat transfer coefficient. As the number of fins, fin length, and fin height increased, the thermal resistance and heat transfer coefficient generally decreased. However, there existed optimal values of the number of fins and fin length to obtain an effective low heat sink temperature. The thermal resistance decreased and the heat transfer coefficient increased in proportion to the heat flux applied to the heat sink base. A correlation was proposed to predict the average Nusselt number for a radial heat sink.

References

[1] K.E. Starner, H.N. McManus, An experimental investigation of free convection heat transfer from rectangular fin arrays, J. Heat Transfer 85 (2) (1963) 273–278.
[2] J.R. Welling, C.B. Wooldridge, Free convection heat transfer coefficients from rectangular vertical fins, Trans. ASME J. Heat Transfer 87 (3) (1965) 439–444.
[3] F. Harahap, H.N. McManus, Natural convection heat transfer from horizontal rectangular fin arrays, J. Heat Transfer 89 (1) (1967) 32–38.
[4] R.T. Huang, W.J. Sheu, C.C. Wang, Orientation effect on natural convective performance of square pin fin heat sinks, Int. J. Heat Mass Transfer 51 (9–10) (2008) 2368–2376.
[5] S. Baskaya, M. Sivrioglu, M. Ozek, Parametric study of natural convection heat transfer from horizontal rectangular fin arrays, Int. J. Therm. Sci. 39 (8) (2000) 797–805.
[6] Abdullatif Ben-Nakhi , Ali J. Chamkha, “Conjugate natural convection in a square enclosure with inclined thin fin of arbitrary length”, International Journal of Thermal Sciences 46 (2007) 467–478
[7] S.A. Nada, “Natural convection heat transfer in horizontal and vertical closed narrow enclosures with heated rectangular finned base plate” International Journal of Heat and Mass Transfer 50 (2007) 667–679

