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Review of Performance of Rectangular Fins under Natural Convection at Different Orientation of Heat Sink

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ABSTRACT: Among heat transfer augmentation techniques, passive cooling technique found more suitable for electronic cooling than active technique. In this paper, natural convection heat transfer analysis through rectangular fins is reviewed. Various experimental studies have been made to investigate effect of fin height, fin spacing, fin length and fin thickness over convective heat transfer. Effects of thermodynamic properties like heat input, base-to-ambient temperature difference are also studied by many researchers. Some investigators make known sets of correlations screening the relation between various parameters of heat sink. Experiments are taken by some researchers for upward and downward facing rectangular fins. Also, trivial investigation has been carried out for different angle of inclination of the heat sink. The sensitivity of inclination over geometric parameters found to be great importance.

KEYWORDS: rectangular fins, convective heat transfer, heat sink, angle of inclination.

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 [8]. 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.

COOLING TECHNIQUES

Passive cooling methods are widely preferred for electronic and power electronic devices since they provide low-price, noiseless, and trouble free solutions. Some passive cooling techniques include: heat pipes, natural convection air cooling, and thermal storage using phase change materials (PCM). 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., see fig. 1-1, depending on the application. Rectangular fins are the most popular fin type because of their low production costs and high thermal effectiveness [5]. Configurations of rectangular fins protruding from rectangular bases are popular because they offer an economical, trouble-free solution to the problem [4]. Heat sinks with rectangular fin geometry have been used for both forced and natural convection. In the case of forced convection, the geometric parameters of a heat sink highly depend on the remaining components of the cooling system, such as the fan and the enclosure; therefore, the optimal values of these parameters depend on the considered application. In contrast, in natural convection, it is possible to optimize the parameters of the heat sink geometry in an application independent manner. Thus, study and selection of heat sink geometry viz. fin length, fin height, fin spacing, angle of inclination found to be essential.

Fig. 1.1 Types of fins

REVIEW OF PREVIOUS WORK

Wide review has been made in this paper initiating from pioneering experimental work by Starner and McManus [1]. They presented natural convection heat transfer performance data for four large rectangular fin arrays with the base vertically, at 45° and horizontally oriented. The range of geometric parameter variation was limited to inter-fin separation distances (S) of 6.35 or 7.95 mm, and fin heights (H) of 6.35, 12.70, 25.40, or 38.10 mm. Parameters kept constant were the fin length (L), thickness (t), and the width of the base plate (W). Only one base-plate width to the fin length ratio, W/L=0.5 (W=127 mm and L=254 mm), was employed. They concluded that relative to the horizontally based, the use of the vertically based orientation is the most favorable system for achieving high heat-transfer rates for arrays of the same geometric dimensions and power input. F. Harahap, Daru Setio [2] studied experimental data for heat dissipation from five duralumin horizontally oriented fin array. Effect of fin length and optimal inter-fin distance was investigated. Thus, two sets of correlation was developed showing fin length and optimum fin spacing as prime function of thermal performance of heat sink. F. Harahap, H. Lesmana [3] studied heat dissipation from miniaturized vertical rectangular fin arrays. Experiment was conducted under steady state heat dissipation and dominant natural convection condition for 3mm and 11mm fin spacing. They concluded that effect of the parameter W/L on heat dissipation rate is relatively less for the vertically base array. Also, higher heat dissipation rate was observed for non-square base, same base area and orientation with fins parallel to short side of the base plate than fin parallel to longer side (W/L≤1) of the base. B. Yazicioglu, H. Yuncu [4] 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. The range of base-to-ambient temperature was kept quiet wide from 30 to 150K for fin height and fin spacing from 5 to 25mm and 4.5 to 85.5 mm, respectively. It was found that optimum fin spacing varies for each fin height which is between 6.1 and 11.9mm. They developed Eq.1 to evaluate the optimum fin spacing value and corresponding maximum heat transfer rate at given fin length and base-to-ambient temperature difference for vertical base fin array. They commented that the larger fin height results in higher convective heat transfer from fin array but for low base-to-ambient temperature difference it was insignificant. H. Yuncu, G. Anbar [5] 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, meanwhile fin length and fin thickness was kept constant at 100 and 3mm, respectively. They concluded that fin spacing to fin height ratio is strong factor influence for convective heat transfer. They commented that optimum fin spacing is not dependent on temperature difference but it decreases with increase in fin height. For fin height 16 and 26mm, optimum fin spacing found 11.6 and 10.4mm, respectively. Eq.2 shows a correlation presenting relation between enhancement of heat transfer from fin array with fin spacing, fin height and number of fins. S. Baskaya, M. Sivrioglu, M. Ozek [6] analyzed parametric effect of horizontally oriented fin array over natural convection heat transfer. They stated that to obtain optimum performance in terms of overall heat transfer, interaction of all design parameters must be considered. They found that optimum fin spacing for L=127mm and L=154mm are S_{opt}=6 and 7mm, respectively. Q/A_b values found reduced with increase in fin length since flow pattern changes from single chimney to multiple chimney flow. L. Dialameh, M. Yaghoubi, O. Abouali [7] studied 128 fin geometries with short length and thick fins. Aluminum rectangular fins of 3mm< t < 7mm with length L≤ 50mm were tested. They illustrated two type of flow pattern in channel. They concluded that for maximum heat transfer, optimum value of fin spacing S_{opt}=7 for fin arrays with H/L≤0.24. They commented that for fin arrays with H/L>0.24 and S/L<0.2, air enters from the fin end region while another range, air enters from middle parts of fin. H. M. Mobedi, H. Yuncu [8] numerically studied steady state natural convection heat transfer from short fin array for Rayleigh number ranging from 120 to 39000. They concluded that H/L ratio is governing parameter for fluid field and flow pattern. Furthermore, for H/L≤0.25 and S≥10mm, flow field is up and down type flow pattern. For wide range of angle of inclination of heat sink was tested by Ilker Tari, Mehdi Mehrtash [9, 10, 11] with upward and downward orientations. By modifying Grashof number with cosine of inclination angle, they suggest the modified correlation given by Eq.3 which is best suited for inclination angle interval of -60° ≤ θ ≤ +80°. Combined convection and radiation analysis have been done by V. Dharma Rao, et.al. [14].

Experiments were conducted for horizontal fins over vertical base. Natural convection and radiation heat transfer from a vertical base and horizontal fins in a fin array was theoretically formulated. Vinod Wankar, S.G.Taji [15] investigate flow pattern through rectangular fin under natural convection. Nusselt number for 10mm fin spacing was 58.35. The highest value of h_a is 5.7929 W/m^2 K at the spacing of 12 mm. Maximum value of Nu_L for fin spacing 10mm was found 58.35. Effect of orientation of fins was tested by Saad M. J. Al-Azawi [16]. They performed experiments for trapezoidal fins maintaining Rayleigh number ranging from 1400 to 3900. Sideward and upward orientation was kept with horizontal and vertical fins. Sideward horizontally oriented fins had lowest heat transfer coefficient. The heat transfer coefficient of the upward orientation is less than that is for sideward orientation by 12%. A correlation was found for vertically oriented sideward fin array, given by Eq.4. Enhancement in natural convection heat transfer was studied for circular perforations to rectangular fins by Wadhah Hussein Abdul Razzaq Al- Doori [17]. They concluded that Heat transfer coefficient for perforated fin that contained a larger number of perforations higher than the perforated fin that contained a small number of perforations. Vertical base plate was tested by Mahdi Fahiminia et.al [18] under natural convection to determine heat transfer coefficient. Different configuration of the rectangular fins was tested, keeping vertical base of fin array. Experimentation was carried out for fixed value of fin length, fin height, fin width. They found that optimum fin spacing value decreases from 6.42mm to 5.84mm with increase in base-to-ambient temperature difference. The CFD simulations were carried out using fluent software. Micro-fin geometry was tested under natural convection by S. Mahmoud [19]. Copper heat sink was kept horizontally oriented to determine effect of micro fin height and fin spacing keeping fin height ranging from 0.25 to 1.0 mm and fin spacing from 0.5 to 1.0 mm, respectively. The highest value for convective heat transfer coefficient of was recorded at the lowest fin height of 0.25 mm and spacing of 1.0 mm. Notched fin arrays were tested by S.S. Sane, N. K. Sane and G.V.Parishwad [20].They found 41.82% enhancement in heat dissipation through notch fins. Fluent software was used for computational fluid dynamic analysis. Study on effect of inclination of base on heat transfer has been made by S. V. Naidu, V. Dharma Rao et.al [21]. Five different inclination angles 0°, 30°, 45°, 60°,90° were selected. Heat dissipation was analyzed for natural convection by Shivdas S. Kharche, Hemant S. Farkade [22]. Moreover notches of different geometrical shapes have also been analyzed. Copper fin for greater heat transfer rate was chosen for analysis. They found that the average heat transfer coefficient for without notched fin is 8.3887 W/m^2K and for 20% notched fins it is 9.8139 W/m^2K. A correlation was developed to investigate optimum fin spacing of vertically based rectangular fin arrays by Burak Yazicioğlu and Hafit Yüncü [23]. The average relative improvements in convection heat transfer rates from identically spaced fin arrays for fin heights of 5, 15 and 25 mm are 37.44 %, 39.01 % and 41.28 %, respectively. Experiential analysis of natural convection heat transfer from horizontal rectangular notched fin arrays was studied by Suneeta Sane and Gajanan Parishwad [24]. The performance of notched fin arrays is 30 to 50% superior to corresponding unnotched arrays. They commented that to investigate further the optimization of all geometrical parameters viz. aspect ratio of the fin array will be interesting. Effect of angle of inclination of permeable fins for natural convection was studied. U. V. Awasarmol, A. T. Pise [25] analyzed comparative effect of rate of heat transfer with solid and permeable fins and the effect of angle of inclination of fins. It was found that using permeable fins, heat transfer rate is improved and convective heat transfer coefficient increases by about 20% as compared to solid fins with reduction of cost of the material 30%. The sink was made incline with 0°, 15°, 30°, 45°, 60°, 75°, and 90°from horizontal. Burak Yazicioğlu [26] conducted the heat transfer performance of rectangular fins on a vertical base in free convection heat transfer. 30 fin configurations were tested. An optimum fin spacing value which maximizes the convective heat transfer rate from the fin array is made available for every fin height. The average relative improvements in the rates of convection heat transfer from identically spaced fin arrays for fin heights of 5 mm, 15 mm and 25 mm are 37.44 %, 39.01 % and 41.28 %, respectively. It is observed that the optimum fin spacing varies between 8.8 mm and 14.7 mm. Their conclusion reveals that the optimum fin spacing is sensitive to the variations in fin height, fin length and base-to-ambient temperature difference parameters. Kamil Mert Çakar [27] found optimum fin spacing from both numerically and experimentally studies. Natural convection from vertically placed rectangular fins is investigated numerically by means of a commercial CFD program called ICEPAK. They observed that convection heat transfer rate from fins increases with fin height for given fin spacing. They experimentally concluded that optimum fin spacing value for vertical fin arrays is approximately 10 mm and suggest a correlation for optimum fin spacing, by Eq.5. Investigation has been done for external natural convection heat transfer from vertically-mounted twelve rectangular interrupted fin arrays by Golnoosh Mostafavi [28]. A two-dimensional numerical model for investigation of fin interruption effects was developed by using FLUENT and COMSOL. The result showed that interrupted fins not only reduces weight of heat sink but also increases thermal performance. The optimum interruption length for maximum fin array thermal performance was found and a compact relationship for the Nusselt number based on geometrical parameters for interrupted walls was presented. They declared that the purpose of these interruptions was to reset the thermal boundary layer associated with the fin in order to decrease thermal resistance. The effect that reduction of the base-plate dimensions as on the steady-state performance of the rate of natural convection heat transfer was investigated by Filino Harahap, et.al [29]. They found results that shown a reduction in the base-plate area by 74 percent increased natural convection coefficient by 1.5 times to 26.0 $Wm^{-2} K^{-1}$ for single fin system and by 1.8 times to 18 W $m^{-2} K^{-1}$ for fin arrays. It was found that increasing the H/L ratio by reducing the base-plate area through reducing L under conditions of constant H, S, and n, has the effect of increasing the average natural convection coefficient of fin arrays. They suggested that the fin length *L* and the number of fins *n* are prime geometric variables. Fractile geometries, which have significant gains in available surface area without affecting fin volume, was studied experimentally by Daniel Dannelley [30] for his dissertation of the degree of Doctor of Philosophy. He observed that fractal-like fins could results in increased fin effectiveness per unit mass by as much as 59%.

$$\frac{S_{opt}}{L} = 3.94Ra_L \quad (1)$$

$$\frac{Q_{fc}}{Q_{pc}} = e^{[1.336(1^{-0.013n})\frac{H}{S}]} \quad (2)$$

$$\frac{Q_c}{kH\Delta T(W/L)}[H/L]^{032} = 1.24\,(Ra\cos\theta)^{0385} \quad (3)$$

$$Nu = 1.911\,Ra^{0.31} \text{ for } 1663<Ra<3540 \quad (4)$$

$$\frac{S_{opt}}{L} = 3.059\,Ra_L^{-0236} \quad (5)$$

Table 1 Range of geometrical parameter

Reference No.	Fin Length (L)	Base width (W)	Fin Height (H)	Fin Thickness (t)	Fin Spacing (S)	Optimum Fin spacing (S_{opt})	No. of fins	Angle from vertical (θ°)
1	127	254	6.35-25.4	1.02	6.35-7.95	-	-	0,-45,-90
2	177.5, 250	6.35, 13.1, 23.9	13.5	1.02-3.10	6.25, 6.35,6.40, 7.35	-	10,13,17	-90
3	25,33,49	25,33,49	13.5	1	3,11	-	3,5,7,9,13	0
4	250,340	180	5,15,25	3	5.85,8.8,14.7 ,32.4,85.5	10.4-11.9	3,6,11,16,21	0
5	100	250	6,16, 26	3	6.2,9.4,19,35,83	10.4,11.6,19.5	4,8,14,27,41	-90
6	127,254	-	6.3,13,25,38	-	6.3,8	6,7	-	0
7	50,25,12,7	-	7,12	3,7	4,7,10,12	7	-	-90
8	100,65, 130,195	130	34, 105, 215	2.2	7	-	-	+90
9,10,11	250,340	180	5-25	3	5-85.5	11.75		0,4,10,20,30,45, 60,75,80,85,90
14	250	-	10,20,30,40,50	-	7.3,16, 32.3,58.75	-	-	0
15	200	100	40	2	2,3,4,5,6,8,10,12	9-11	-	-90
16	100	110	67	-	-	-	-	0,+90,-90
18	80	59.8	29.2	1	2.1,3.9,7.4,8.8,13.7,18.6	5.86-6.42	4,5,7,8,13,20	0
19	31.75	31.75	0.25,0.5,0.75,1	1	0.5,0.75,1	1	-	-90
21	20,40	100	-	3	7,19,47	-	4,8,17	0,-30,-45,-60, -90
22	127	-	38	1	9	-	7	-90
23	100-500	180-250	5-90	1-19	2.85-85.5	-	-	0
24	150	100	50	-	6,8,10,12	8-10	9,11,13,17	-90
25	25	75	-	2	-	-	-	0
26	250,340	180	5,15, 25	3	5.75-85.5	8.8,14.7	3,6,11,16,21	0
27	250,340	180	5,15, 25	3	4.5,7.3, 16,32.3,58.75	10	5,8,14,25,34	0
28	25,49	25,49	13.5	1.5	10.25,10.37	-	3,5	-90

CONCLUSION

Compact, closely packed heat sink problem is vital to analyze to avoid electronics failure. Upward, sideward and downward facing fin arrays has been studied by some researchers. Geometric parameters of fin array i.e. fin height, fin spacing, fin length, fin thickness, number of fins affects convective heat transfer rate. Rectangular fins with vertical base vertically orientation has maximum heat transfer rate. Optimum fin spacing which maximizes heat transfer is a function of fin height and fin length. Fin thickness has not significant effect over heat dissipation. Different orientations of the fin arrays find sensitivity for convective heat loss.

From the extensive literature review, it is seen that many researchers have shown interest to analyze effect of geometric parameters over heat dissipation and to find out optimum fin spacing for different fin configuration. Furthermore, different orientations of the heat sink are tested and optimum orientation is find which maximizes heat transfer rate. Separate effect of fin length, fin height and fin spacing has been found. 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.

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LIST OF SYMBOL

Symbol	*Quantity*	*Units*
A	area	m^2
h	convection heat transfer coefficient	W/m^2K
θ	Angle of inclination from vertical	°
C_p	specific heat at constant pressure	KJ/Kg.K
g	gravitational acceleration	m/s^2
H	fin height	mm
k	thermal conductivity	W/mK
L	fin length	mm
m	mass flow rate	Kg/sec
β	volumetric thermal expansion coefficient	1/K
Gr	Grashof number	
Ra	Rayleigh number	
Nu	Nussult number	
n	Number of fins	
S	fin spacing	mm
t	Fin thickness	mm
W	Base plate width	mm
ν	Air kinematic viscosity	m^2/sec
α	Thermal diffusivity	m^2/sec
ε	Emissivity	
σ	Stefan-boltmann constant	W/m^2K^4
T_a	Ambient air temperature	K
T_w	Average base temperature	K
T_d	Base-to-ambient temperature difference	K
T_f	Film temperature	K
Q	Power input to the heater	W
Q_c	Convection heat transfer rate	W
Q_r	Radiation heat transfer rate	W