Review of Convective Heat Transfer from Plate Fins Under Natural and Mixed Convection at Different Inclination Angle

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Abstract – All ***electronics components generates heat during their operation which must get dissipated to the surrounding to ensure satisfactory performance of device and to avoid the damage to the components. One of the promising way to dissipate this heat is attaching heat sink to the device, i.e. transferring heat by convection. How much heat will get transferred by Convection depends upon geometrical parameter such as fin length, height, width, spacing, thickness ,operating parameter like heat supplied to device, temperature difference between surface and surrounding and few other parameters like fin material, fin array orientation, number of fins etc. Day by day size of electronic devices is reducing but amount of heat generated within device is increasing as surface area exposed to surrounding is reducing due to decrease in size of device. This paper reviews the parameter which affects convective heat transfer most for a constrained dimensions of heat sink. Also, this paper focuses on assistance of mixed convection to natural convection to enhance heat transfer.***

Key Words: *Heat transfer, Natural convection, Mixed convection, Geometrical parameters, Optimum fin spacing etc…*

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 [6]. 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 recommended temperature for its efficient working. Especially important in modern electronic systems, in which the packaging density of circuits can be high, engines, industrial equipment and a variety of mechanical devices, to overcome this problems fins as effective passive cooling device for thermal systems are suitable [1].

Use of fins is the simple and easiest way of rejection of heat from system to its surrounding, it used in various engineering applications successfully. To achieve the desired rate of heat dissipation, with the least amount of material, the optimal combination of geometry and orientation of the finned surface are required. Mostly rectangular types of fins are used because their low production cost, simple in construction, effectiveness, high cooling capability. Also rectangular fins array in two common orientations of rectangular fin horizontally based vertical fins and vertically based vertical fins are widely used in the applications [1].

It is possible to increase the heat transfer coefficient, h by forcing the air flow over the fins by using fans, but by using this option cost should be high and requires more space for to operate fans, therefore forced convection is not always preferable. Since the use of extended surfaces is often more economical, convenient and trouble free, most proposed application of increasing surface area is adding fins to the surface in order to achieve required rate of heat transfer. So, the designer should go for heat transfer by natural convection for dissipating unwanted heat from the fins. In order to increase the total heat transfer area by adding more fins to the base. The number of the fins and fin optimum spacing should be calculated because it is observed that adding more fins to base decreases the distance between the adjacent fins, because of this resistance to air flow and interference between boundary layers which affect in decrease the heat transfer coefficient [4].

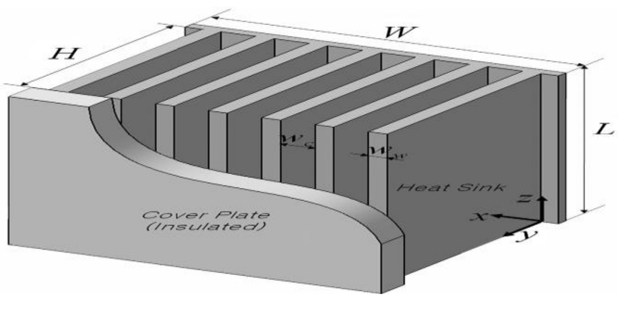

Fig -1: Heat sink with continuous rectangular fins [30]

2. LITERATURE REVIEW

Yazicioglu [1] investigated experimentally, the heat transfer performance of rectangular fins on a vertical base in free convection heat transfer. The effects of geometrical parameters and base-to-ambient temperature difference on the heat transfer performance of fin arrays were observed and the optimum fin separation values were determined. 30 fin configurations were tested. Two sets were prepared of fin length 250 mm and 340 mm. By keeping these fin length, width and thickness constant fin heights was varied as 5 mm, 15 mm and 25 mm. Fin spacing was also varied from 5 mm to 85.5 mm. It was observed that convective heat transfer depends upon the fin height, spacing and base to ambient temperature difference. Convective heat transfer increased as fin spacing increased, reaches to maximum at a certain fin spacing value, termed as optimum fin spacing and beyond that further increase in fin spacing leads to decrease in heat transfer

Cakar [2] investigated the heat transfer performance of rectangular fins on a vertical base in free convection heat transfer. The effects of geometric parameters and base-to-ambient temperature difference on the heat transfer performance of fin arrays were observed and the optimum fin separation values were determined.30 fin configurations were tested. Two sets were prepared of fin length 250 mm and 340 mm. By keeping these fin length, width and thickness constant. Fin height was varied as 5 mm, 15 mm and 25 mm. It was observed that convection heat transfer rate from fins increases with fin height for given fin spacing. Optimum fin spacing value for vertical fin arrays was approximately 9 to 13 mm.

Tari and Mehrtash [3] investigated steady state natural convection from heat sink of rectangular fins on a vertical base. The effects of geometric parameters and base-to-ambient temperature difference on the heat transfer performance of fin arrays were observed and the optimum fin separation values were determined. 30 fin configurations were tested. Two sets were prepared of fin length 250 mm and 340 mm. By keeping these fin length, width and thickness constant. Fin height was varied as 5 mm, 15 mm and 25 mm and fin spacing from 5 mm to 85.5. It was observed that convective heat transfer increases as fin spacing increases, reaches to maximum at a certain fin spacing value, termed as optimum fin spacing and beyond that further increase in fin spacing leads to decrease in heat transfer rate. Optimum fin spacing was observed between 10 mm to 12 mm for a proposed range of fin length, width, height. A correlation for optimum fin spacing was proposed.

Tari and Mehrtash [4] tested heat sink for wide range of angle of inclination with upward and downward orientations. By modifying Grashoff number with cosine of inclination angle, they suggested the modified correlation, which is best suited for inclination angle interval of $-60° \leq \theta \leq +80°$. It was also observed that the flow separation inside the fin channels of the heat sink is an important phenomenon. For upward facing inclinations, they observed that the flow separation location plays an important role. Also, they found that the optimum fin spacing does not significantly change with inclinations. Maximum convective heat transfer rate was obtained for vertical orientation.

Yazicioglu and Yuncu [5] performed experiments over thirty different fin configurations with 250 mm and 340 mm fin length. Optimum fin spacing of aluminium rectangular fins on vertical base was examined. 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 10 and 12 mm. They concluded that geometrical parameter affects the convective heat transfer. It was higher for vertical orientation. Larger fin height resulted in higher convective heat transfer from fin array. Fin spacing depends upon fin height, length, base to ambient temperature difference. They developed equation to evaluate the optimum fin spacing value and corresponding maximum heat transfer rate at given fin length

Yuncu and Anbar [6] investigated natural convection heat transfer for 15 sets of rectangular fin array with horizontal base experimentally. Fin spacing and fin height was varied from 6mm to 26mm and 6.2 mm 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 which influenced convective heat transfer. They commented that optimum fin spacing is not dependent on temperature difference but it decreases with increase in fin height.

Baskaya et al.[7] 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 7 mm, respectively. They commented that since shorter fin produce more dominant single chimney flow, the overall value for the heat transfer coefficient reduces with fin length. On other hand, the heat transfer coefficient values increase with increase in the fin height.

Naidu et.al [8] studied effect of inclination of base of heat sink on heat transfer. Experimental study was conducted. Five different inclination angles 0°, 30°, 45°, 60°,90° were selected. Fin length was kept at 153 mm, width at 100 mm. fin thickness was selected as 3 mm. Fin height was varied for 20 mm and 40 mm. Fin spacing was varied for 7, 19, 47 mm. It was observed that the convection heat transfer rates are increasing from 0°, decreasing from 30° to 45° and again increasing from 45°

to 60° and 60° to 90° inclination for orientation of vertical base with vertical fins.

Yazicioglu and Yuncu [9] developed a new correlation to predict optimum fins-spacing for vertical rectangular fin array. To develop that correlation literature review of nine papers was considered. That literature review was mainly conducted to verify range of dimensions of geometrical parameters i.e. fin length, width, height, spacing on which till now experiments were conducted to verify effect of these geometrical parameters on convective heat transfer rate from vertical rectangular fin array. A correlation to predict optimum fin spacing was developed.

Harahap and Setio [10] developed a correlation for optimum fin spacing which will give maximum heat transfer rate. For this purpose experimental data from previously done experiments for heat dissipation from five aluminium horizontally oriented fin array was referred. Effect of fin length and fin spacing was investigated. Results of mathematical modelling showed that fin length and optimum fin spacing were main parameters which affected convective heat transfer rate of heat sink.

Harahap and Lesmana [11] investigated heat dissipation from miniaturized vertical rectangular fin arrays. Experiment was conducted under steady state heat on 10 sets of fin array. Mathematical model was developed to propose a correlation to predict optimum fin spacing for miniaturized vertical rectangular fin arrays. It was observed that convective heat transfer got affected due to variation in fin spacing. effect of the parameter W/L on heat dissipation rate is relatively less for the vertically base array. Correlation was also proposed by considering fin length as a prime parameter.

Wankar and Taji [12] investigated natural convection heat transfer and flow patterns for various fin spacing through rectangular fin under natural convection Base heat transfer coefficient value increases with optimum spacing and again decreases. For short longitudinal fin array, single chimney flow pattern was observed and for long longitudinal fin array air is stagnant at central zone. Thus, heat transfer coefficient is high for short fin arrays.

Saad [13] carried out experiment on longitudinal trapezoidal fins. Effect of orientation of fins on natural convective heat transfer was investigated. Experiment was conducted for trapezoidal fins. Sideward and upward orientation with horizontal and vertical fins was analyzed. It was observed that sideward horizontally oriented fins had lowest heat transfer coefficient. Heat transfer coefficient of the sideward vertical fins was higher by than the heat transfer coefficient of the upward by 12 %.While it was higher than the heat transfer coefficient of the downward by 26% and by 120% with the sideward horizontal fins. Test result showed that the sideward horizontal fin orientation yield the lowest heat transfer coefficient.

Wadhah et al. [14] investigated the enhancement in natural convection heat transfer from rectangular fins by providing circular perforations. It was concluded that heat transfer coefficient for perforated fin was higher than heat transfer coefficient of non-perforated fins. Also heat transfer coefficient for perforated fin that contained a larger number of perforations was higher than the perforated fin that contained a small number of perforations. Decrease in the perforation dimension reduced the rate of temperature drop along the perforated fin. Heat transfer coefficient for perforated fin that contained perforations with large diameter was higher than the perforated fin that contained perforations with smaller diameter.

Fahiminia et al. [15] tested vertical base plate under natural convection to determine heat transfer coefficient. Different configuration of the rectangular fins was tested, keeping base of fin array vertical. It was found that convective heat transfer depends upon variation in fin spacing fin spacing, fin height and base to ambient temperature difference. The natural convection coefficient increased substantially as the fins spacing was increased. It reached to maximum at optimum value of fin spacing. Further increase in fin spacing decreased the heat transfer rate.

Mahmoud et al. [16] investigated experimentally, the heat transfer performance of micro fin geometry on horizontal microstructure. It was observed that convective heat transfer depends upon the fin height and spacing. Convective heat transfer increased as fin spacing was increased, reaches to maximum at a certain fin spacing value, termed as optimum fin spacing and beyond that further increase in fin spacing leads to decrease in heat transfer rate. And it was observed maximum convective heat transfer rate was found at the lowest fin height of 0.25 mm and maximum fin spacing of 1.0 mm.

Kharche et al.[17] analyzed heat dissipation for natural convection for notched fins. Notches of different geometrical shapes were also analyzed. Copper fin for greater heat transfer rate was chosen for analysis It was found that the average Heat transfer rate is higher in notched fins than un-notched fins. If notch area is increased heat transfer rate also increases.

Sane et al.[18] tested natural convective heat transfer from notched fin arrays. Experiments were conducted on notched and un-notched fin array. It was observed that heat transfer rate was higher in notched fins than un-notched fins. Heat transfer rate increased with increase in notch depth. Heat transfer rate depends upon how much area is removed.

Kim at al. [19] performed both experimental and numerical studies and suggested a closed form correlations that allow for thermal optimization of vertical plate-fin heat sinks under natural convection in a fully-developed-flow regime.The correlations showed that the optimal fin thickness depends on the height, the solid conductivity, and the fluid conductivity only and is independent of the Rayleigh number, the viscosity of the fluid, and the length of the heat sink. Results revealed that the optimal fin thickness was shown to depend only on the height, the solid conductivity, and the fluid conductivity. . The optimal fin thickness was linearly proportional to the height. The optimal channel width was a complicated function of the fluid properties, the solid properties, and the total size of the heat sink.

Kim [20] optimized vertical plate-fin heat sinks with fins of variable thickness under natural convection. Optimization was done to check thermal performance of a vertical plate-fin heat sink under natural convection by varying fin thickness in the direction normal to the fluid flow. It was observed that the thermal resistance gets reduced by up to 10% compared to that of the heat sinks with fins of uniform thickness by employing fins of variable thickness in the case of an air-cooled heat sink. However, the amount of the reduction decreases as the heat flux decreases or as the height of the heat sink decreases.

Doganand Sivrioglu [21] investigated mixed convection heat transfer from longitudinal fins in a horizontal channel. Experimentation was conducted to investigate effects of fin spacing, fin height and magnitude of heat flux on mixed convection heat transfer from rectangular fin arrays heated from below in a horizontal channel. It was also observed that the mixed convection heat transfer depends on the fin height and spacing. The average heat transfer coefficient increases with the increase in fin height for each fin spacing heat transfer coefficient increases with fin spacing up to the optimum value of fin spacing and after that it decreases.

Nada [22] investigated the natural convection heat transfer and fluid flow characteristics in horizontal and vertical narrow enclosures with heated rectangular finned base plate. It was observed that at which Nusselt number (Nu) and finned surface effectiveness were maximum at optimum fin spacing. It was also observed that fin spacing is a function of fin length and fin height. While convective heat transfer is a function of fin spacing, length, height. Nusselt number and finned surface effectiveness increased with decrease in S/H until S/H reaches a certain value beyond which the Nusselt number and finned surface effectiveness start to decrease with further decreasing of S.

Chen et al. [23] investigated heat transfer characteristics in plate-fin heat sink. In this study the inverse method was used in conjunction with the experimental temperature data to investigate the accuracy of the heat transfer coefficient on the fin in the plate-fin heat sink for various fin spacing. Finding was that the calculated fin temperatures obtained from the commercial software were in good agreement with the experimental temperature data at various measurement locations. The inverse results also agreed with those obtained from the commercial software or the correlation. This implied that the present results have good accuracy.

Dialameh et al. [24] conducted numerical study to predict natural convection from an horizontal array of aluminum rectangular fins. It was observed that there exist two types of flow pattern in channel. For fin arrays with $H/L>0.24$ and $S/L<0.2$, air can enter into the channel only from the fin end regions. However for lower value of $H/L \leq 0.24$ and higher value of $S/L \geq 0.24$, air can enter into the channel from the middle parts between fins. And for second type of flow pattern, heat transfer coefficient was smaller than for the first type of flow pattern

Mousa [25] discussed air cooling characteristics of a uniform square modules array for electronic device heat sink. For this purpose various square modules array were experimentally investigated. The results indicated that the average heat transfer coefficient little increased with increasing the modules array temperature, but the increase was significantly higher with increasing the flowing air velocities. The increasing of module to channel height ratio seems to increase the average heat transfer coefficient.

Baby and Balaji [26] experimentally investigated on phase change material based finned heat sinks for electronic equipment cooling. He investigated thermal performance of finned heat sinks filled with phase change materials for thermal management of portable electronic devices. The results indicated that the operational performance of portable electronic device can be significantly improved by the use of fins in heat sinks filled with PCM operational performance of portable electronic device can be significantly improved by the use of fins in heat sinks filled with PCM

Kandasamy et al. [27] evaluated transient cooling of electronics using phase change material (PCM)-based heat sinks. A three-dimensional computational fluid dynamics model was proposed to simulate the problem and demonstrated good agreement with experimental data. Results showed that when PCM-based heat sink was used, increased power inputs enhanced the melting rate as well as the thermal performance of the heat sink.

Khan et al. [28] examined the effect on overall thermal/fluid performance associated with different fin geometries, including, rectangular plate fins as well as square, circular, and elliptical pin fins They concluded that the preferred fin profile is very dependent on these parameters. Also the elliptical geometry is the next most favorable geometry from the point of view of total entropy generation rate for higher Reynolds numbers and with smaller axis ratios. It offers higher heat transfer coefficients and lower drag force as the axis ratio is decreased and the approach velocity is increased.

Karathanassiset al. [29] investigated the effect of buoyancy forces on laminar heat transfer inside a variable width plate-fin heat sink is numerically analyzed. The numerical results indicate that the joint action of the buoyancy-induced rolls and the combined secondary flow pattern has a beneficial impact on the heat sink thermal performance, a fact quantified through the circumferentially averaged local Nusselt number distributions. The comparative results reveal that the introduction of stepwise channels leads to superior heat transfer performance, i.e. lower values of the total thermal resistance with mitigated pressure drop penalty and increased temperature uniformity on the cooled surface.

Shaalan et al. [30] evaluated thermal performance of a shielded heat sink. Effect of using a heat shield on the performance of a parallel plate -finned- heat sink was studied. A parametric study was conducted to study the effect of varying the design parameters on the performance of the heat sink. These parameters included Reynolds number, fin height, number of fins and the shield inclination angle.

Puet al. [31] carried experimentation on vertical packed channels. The experimental results of mixed convection heat transfer in a vertical packed channel with asymmetric heating of opposing walls are reported. A correlation equation for Nusselt number in terms of Peclet number *Pe* and Rayleigh number *Ra* was obtained from experimental data.

Table -1: Experimental works on the Fins in natural convection for plate fin

Ref. No.	Fin Length (mm)	Base Width (mm)	Fin Height (mm)	Fin Thickness (mm)	Fin Spacing (mm)	Optimum Fin Spacing (mm)	No. of Fins	Angle from Vertical θ°
1	250,340	180	5,15,25	3	5.85,8.8,14.7,16.4,32.5	9-13	3,6,11,16,21	-
2	250,340	180	5,15,25	3	5.85,8.8,14.7,16.4,32.5	9-13	3,6,11,16,21	-
3	250,340	180	5,15,25	3	5.85,8.8,14.7,16.4,32.5	10-12	3,6,11,16,21	-
4	250,340	180	5,15,25	3	5.85,8.8,14.7,16.4,32.5,85.5	9-13	3,6,11,16,21	+,-4,10,20,30,45,60,80,90
5	250	180	5,15,25	3	5.85,8.8,14.7,16.4,32.5,85.5	10-11	3,6,11,16,21	-
	340	180	5,15,25	3	5.85,8.8,14.7,16.4,32.5,85.5	11-12	3,6,11,16,21	-
6	100	-	6,16,26	3	6.2,9.4,19,35,83	10.4-11.6	41,27,14,8,4	-
7	127	-	6.3,13,25,38	-	4-38.1	5-7	-	-
	254	-	6.3,13,25,38	-	4-38.1	6-8	-	-
8	153	100	20,40	3	7,9,14	-	4,17,18	0,30,45,

								60,90
9	100-500	180-250	5-90	1-19	3-85	7-19	-	-
10	127,254	-	6.35,13.1,23.9	1.27,2.3,3.10	6.25,6.35,6.4,7.35,7.95	-	10,13,17,33	-
11	25,49	25,33,49	13.5	1	3-11	-	3,5,9,17	-
12	200	100	40	-	2-12	-	-	-
15	80	59.8	29.2	1	2.1,3.9,7.4,8.8,13.7,18.6	-	-	-
16	31.5	31.5	0.25,0.5,0.75,1	-	0.5,0.75,1	-	-	-

SUMMARY

This review reveals that convective heat transfer from rectangular plate fin array depends upon various factors such as geometrical parameters, operating parameters, fin material, fin array orientation, number of fins etc. But geometrical parameters affect most. As there are limitations to increase the size of fin array in order to increase surface area due to limitations on proposed length and width of fin array, optimal fin spacing was found most important factor to enhance convective heat transfer. Instead of only going for natural convection or forced convection, mixed convection was also proposed for better enhancement in convective heat transfer as mixed convection enhanced natural convection.

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