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Free Convection Heat Transfer Augmentation through a Vertical Fin Array: A Review

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Abstract—*In this review, the vital techniques and arrangements that have been developed so far to enhance the convective heat transfer coefficient and heat transfer rate is being discussed. Among all the methods, Fins are widely used to enhance the natural heat transfer rate because of its low cost, compactness and easy manufacturing. In this paper, the rectangular fin array is reviewed and study is being concentrated on different arrangements and augmentations of heat sinks at various orientation angles and then optimized the parameters (fin height, fin length, fins spacing) to get the maximum heat transfer rate under natural convection heat transfer. Many experimental and numerical analyses have also been carried out to enhance the heat transfer by creating the protrusions, some interruptions and impressions on the extended fin surfaces.*

Keywords*: heat sink, fin array, Perforations, impressions.*

Nomenclature

Pr- Prandtl Number
Ra- Rayleigh Number
Nu- Nusselt Number

1. INTRODUCTION

It has already become a big issue, how to increase the heat transfer rate from a flat surfaces in various situations. Fins offer an economical and trouble free solution in many situations demanding natural convection heat transfer. Heat sinks, in the form of fin arrays on horizontal and vertical surfaces used in variety of engineering applications. Studies of heat transfer and fluid flows associated with such arrays are of considerable engineering significance. Heat sinks with fins are normally used to augment the heat transfer rate in many industrial applications such as cooling of electronic, power electronic, telecommunication and automotive components. Due to the ease of manufacturing, the parallel rectangular fin arrangements were preferred with a flat base plate which is commonly known as heat sink. This type of heat sink configuration could be used for both natural and forced convection. The only change will occur in the parameters that, in forced convection heat sink highly depended on the other parameters except fin geometry like enclosure and fan. In contrast, it is possible to optimize the parameters of heat sink to augment the heat transfer rate in natural convection. The heat transfer mainly occurs due to the density gradient. There are various types of methods for augmenting the heat transfer rate from the flat surfaces such as line interruption, staggered interruption and impressions on the fin surfaces. in addition, the method of interruptions reduces the weight and lead to reduction in manufacturing cost. In the vertical and horizontal fin array configuration the flow pattern which is observed is a single chimney flow pattern. A vertical component of velocity is developed resulting the air to leave in upward direction in the central portion of the array.

2. LITERATURE REVIEW

The natural convection between the two isothermal vertical plates with different temperature with an air layer enclosed between them was investigated with the help of Zehnder-Mach-interferometer by Eckert and Carlson [1]. It was studied that the conduction mode contributes in the central part of the layer in the heat transfer and convection mode contributes only in the corner region for the Grashof number below a certain value. It was found that the temperature increases in the vertical direction. Some fluctuations in the flow and wave motion were observed.

Starner and McManus [2] studied four different configurations of fin arrays on three different base plates to calculate the natural convective heat transfer coefficients by varying fin spacing and the fin height and found that found that the coefficients could be reduced sharply by preventing three-dimensional flow and also showed that the best configuration is vertical fins with vertical base plate.

The vertically based fin array orientation was superior amongst all types of fin arrays corresponding to the different fin heights were investigated experimentally by Welling and Wooldridge [3]. The variation of temperature with the change in the fin height to spacing ratio was discussed and an equation for optimum value of the fin height to fin spacing ratio was suggested.

C.B. Sobhan and Venkateshan [4] carried out an experiment on horizontal fin arrays by using differential interferometric technique with the transient heating and cooling regime on two materials (aluminum and mild steel). By varying the spacing between the fins array, they calculated the average value of heat transfer coefficient and compared it with the vertical isothermal flat plate and found the differences in between both the cases.

Chaddock [5] endowed that the radiation mode only devotes about 20% of the total heat transfer by varying the fin spacing and fin height in vertically based heat sink arrangement.

S.Naik and Probert [6] was investigated experimentally, the steady state natural convection heat transfer from a horizontally based, vertical rectangular fins by placing an adiabatic horizontal shroud just above the vertical fin tips, when the fins base is maintained at constant uniform temperature of 40k above that of the environment temperature. It was seen that a marginal variation was found in average Nusselt number and heat dissipation rate.

H. Yuncu and G. Anbar [7] experimentally investigated the natural convection heat transfer from rectangular fin arrays. The testing on different configurations was conducted to optimize the values of parameters- fin height and fin spacing, when thickness and length of fins were kept constant. The base to ambient temperature was also varied independently. It is found that the convection heat transfer rate is strongly dependent on the fin spacing to fin height ratio. A correlation was also presented, related to enhancement of heat dissipation rate from the fin array in term of other parameters.

Leung [8] described the steady-state heat dissipation rates from an array of vertical, rectangular polished duralumin fins under the free convection heat transfer with the base is at uniform temperature and found that the optimal thickness for 60 mm protruded fins rose from 2.0 mm to 4.5 mm when the separation of the fins was rose from 20 mm to 60 mm.

Ko and Leung [9] experimentally studied the heat dissipation rate from an array of stainless-steel, vertical rectangular fins, under natural-convection conditions. They outlined the optimal fin-separation of the vertically-based finned system with respect to changes of the temperature excess from 20 to 40 K.

Bayram and Alparslan [10] have suggested the new fin configurations to upgrade the fins technology, including fins made of anisotropic composites, porous media and perforated plates. In addition to that the already existed shapes have been remodeled by the removal of material to form cavities, slots, holes , grooves or channels in the fin body in order to augment the heat dissipation rates per unit weight of the fin.

Mahdi Fahiminia and Mohammad Mahdi Naserian [11] was investigated the natural convection heat transfer Coefficient on Extended Vertical Base Plates computationally and found that the natural convection coefficient increases substantially as the gap between fins increases. They have studied it for 2.1 to 18.6 mm gap and found an optimized value for the fin spacing and the fin height.

Sable et al. [12] investigated the heat transfer characteristics of a vertical based heated plate with a multiple V-type partition plates placed in the stagnant surrounding. It was shown that the V-type fin array performed better than the rectangular vertical fin array and the V-fin array with bottom spacing design. The study showed that the effectiveness could be further increased with the increase in the height of the V-plates.

Maziyar et al. [13] numerically investigated the effect of perforations on extended surfaces on the thermal performance of a channel with a heater mounted on floor. It was observed that the application of the perforations with the higher value inclination angles lead to higher heat transfer enhancements. A perforation pitch lower than the rib pitch was responsible for the collision of streams in the downstream direction that results in higher turbulence intensity and larger heat transfer coefficient. Perforation always caused less resistance to blocks against the stream and that result in the reduction of friction factor as compared to smooth fin. For same open-area ratio (OAR), higher thermal performance was achieved for the hole perforations.

Mostafavi [14] investigated experimentally, the effect of attaching interruptions to the vertical fin and calculated the optimum values for different geometrical parameters of the fin array(fin height, fin length and fin spacing). An experimental investigation has also been carried out by Fujii [15] and studied that the thermal boundary layer was interrupted by the fins.

Yazicioglu and Yuncu [16] carried out an experimental investigation to determine the effects of fin height, fin spacing and temperature difference between the fin base and the surroundings on the natural convection heat transferfrom rectangular fin arrays on a vertical surface and optimized the fin height and fin spacing for the two length as 250 and 340 mm. Al-Doori [17] performed an experimental study to enhance the heat transfer through fins having circular perforation. They filed that the temperature drop along the perforated fin length is consistently higher than that for the equivalent non-perforated fin. The enhancement in the heat dissipation rate from the perforated fin was strongly dependent on the perforation size and lateral spacing.

The heat transfer characteristics and pressure drop in the channel with V corrugated lower and upper plates was subjected to constant heat flux was investigated by Naphon [18]. For particular values of air Reynolds number and heat flux, the average plate temperatures at a higher wavy angle were found lower than those from a lower wavy angle. However, the pressure drops obtained from the channel with higher wavy angle are significantly higher than those with lower angles.

Iiker Tari and Mehdi Mehtrtash [19] studied the natural convection heat transfer from heat sink with parallel arrangements of rectangular cross-section vertical plate fins on a vertical base plate was investigated numerically to augment the heat transfer rate by changing the inclination orientations of a heat sink. It was observed that with the change in inclinations angles a very slight or almost negligible enhancement in the convective heat transfer was noticed. The correlations that holds good for the vertical fins are also obtained by modifying the grashof number with the cosine of inclination angle and the results has been shown by streamlines for the vertical, downward and upward inclinations at 45º, 60º 75º, 85º and 90º.

Park et al. [20] experimentally examined the effect of various heat sink angles, fin numbers, and fins base temperatures for the vertical cylinders having branched plate fins. A contour map showing the thermal resistance as a function of the fin number and fin thickness was prepared using the correlation of the Nusselt number and It has been expressed that the branched fins exhibit thermal resistances up to 36% lower than those of cylinders with plate fins.

The literature review reveals that, the surface modification in the form of interruptions, impressions and perforations regenerates the thermal boundary layer after every interruption that leads to the higher turbulence near the wall which could be responsible for greater heat transfer rates. Now a day, Perforations in the fins were suggested as one of the type of surface interruption and are widely used in different heat exchangers, air-conditioners, and solar collector applications. A large number of studies had been cited on the optimization of fin shapes by removing the material from fins to make cavities, slots, and holes to not only increase the heat transfer area but also the heat transfer coefficient, which in turn give an advantage of less weight.

The irregularities can also be created in the form of embossing by embossing technique which could further increase the heat transfer rate and through the same area and without removing the material from the fin body and it could be possible as at every interruption in the form of embossing regenerates the thermal boundary layer.

3. FIN GEOMETRY

There are different types of fin configurations of heat sink, some of them are shown below:

The above fig.1 shows the extension of the surfaces on the flat plate in which W, L, S, and H represents heat sink width, length, fin spacing and fin height respectively. t and d represent the thickness of the fin and . These are the parameters which need to be optimized and in the earlier research, a lot of work has already been done in this regard. the present study has come to an end to augment the heat transfer rate by creating perforations and impressions on the surfaces of the fin which leads to an increase in the heat transfer rate.

By using the ANSYS [21] software, many of the researchers reported a CFD analysis to enhance the heat transfer rate.

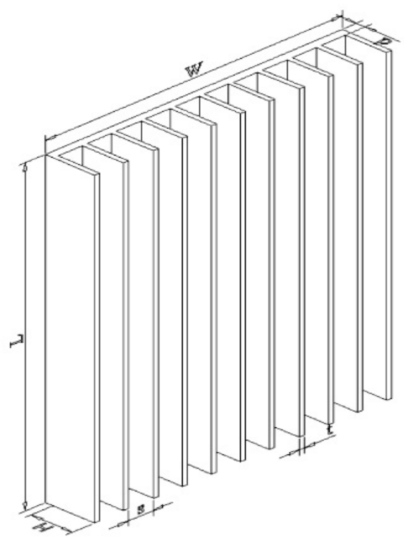

Fig. 1: Vertical fins with vertical base configuration

4. VERTICAL MODEL VALIDATION

There are some studies available which are based on the software and need to be validated first. The correlations present which has already been derived to validate the model with the simulated and experimental results.

Mc Adam's relation [22]

$$\overline{Nu_L} = 0.59 Ra^{1/6}$$

Churchill and Chu's first relation [23]

$$\overline{Nu_L} = \left[0.825 + \frac{0.387 Ra^{1/6}}{\left[1 + \left(\frac{0.492}{\mathrm{Pr}} \right)^{9/16} \right]^{8/27}} \right]^2$$

Churchill and Chu's second relation [23]

$$\overline{Nu_L} = 0.68 + \frac{0.67 Ra^{1/4}}{\left[1 + \left(\frac{0.492}{\mathrm{Pr}} \right)^{9/16} \right]^{4/9}}$$

5. CONCLUSION

The investigators have studied the various fin configurations and optimized the parameters- fin height, fin length and fin spacing for different heat sinks to achieve a maximum heat transfer through an extended fin arrays and compared the results with the corresponding smooth surface. Based on the studies in the literature review it can be reported that heat transfer rate and coefficient of heat transfer can be enhanced by creating the perforation, impressions and interruptions on the extended surfaces.

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