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Enhancement of Natural Convection Heat Transfer from Horizontal Rectangular FIN Arrays : A Review

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ABSTRACT

In this study, various fin geometries are referred for steady-state natural convection heat transfer. The effects of fin spacing, fin length, fin height, % of perforations, shape of perforations etc. are studied. For high powered street LED lights heat sinks with horizontal fin arrays are utilized. Large amount of heat generated in these street LED's must have to be dissipated effectively, so that the life span of the same can be enhanced. For the heat sinks currently utilized in the high powered street LED's a stagnation zone is formed at the symmetry centre of the fins this causes the problem in air circulation ultimately affects the heat dissipation capacity of the heat sink. Therefore there should be the proper provision for air to be drawn.

Keywords: Perforation, Fins, Steady state, Natural convection

I. INTRODUCTION

High–power LED is a promising technology for future lighting application since it can save energy and has a long life time. To obtain more lumen, the powerful electric current of LED chips grows fastly nowadays. However, as to the high power LED chips, generally nearly 80% of the input power is transformed into heat while the rest is converted into light, and this will lead to a series of penalties [1].Therefore, to gain a dependable and perfect product with good enactment, thermal management of high power LEDs is very important. To solve the LED heat dissipation, some methods can be taken, such as improving in chip luminous efficiency, which will drastically reduce the heat generation, improving in the package, which will reduce the inner thermal resistance, or improving in the heat transfer coefficient of heatsink, such as micro jet cooling system, heat pipe [2], etc. But these techniques are rarely put into use because of reasons including cost factors, high reliability and maintenance requirements. The life of LED lamp is usually about 100,000 hours, and it works in the outdoor environment. Therefore, the heat sink of high-power LED is usually cooled through the natural convection as shown in fig.

Figure 1. The heat sink of LED street lamp

The thermal management of LEDs for general illumination applications is of primary importance to their dependability and efficiency. In considering the thermal management of high power LED's, two main encounters must be considered. First, while a single device consumes relatively low power, large heat fluxes exist at the die level, of the order of 300W/cm2 or greater. Such high heat fluxes frequently require exceptional heat spreaders at the die level in order to help disintegrate such concentrated heat loads. Second, since the luminous output of an individual high power LED is insufficient to replace a traditional light source, multiple LED's are necessary for general radiance. With the use of large LED arrays, it is possible to generate large heat loads at the system level which can cause challenges for overall heat degeneracy, especially when cooling requirements call for passive methods. These two challenges work together to cause higher LED die temperatures. It has been predicted previously that the lifetime of a device decays exponentially as the temperature increases. This can result in a lifetime decrease from 42,000 h to 18,000 h when the device temperature increases from 40^0C to 50^0C [1].

The operation of many engineering systems results in the generation of heat. This unwanted by-product can cause serious overheating problems and sometimes leads to failure of the system. The heat generated within a system must be dissipated to its surrounding in order to maintain the system at its recommended working temperatures and functioning effectively and reliably. This is especially important in modern electronic systems, in which the packaging density of circuits can be high [3]. In order to overcome this problem, thermal systems with effective emitters as fins are desirable. A heat sink is a device used to remove the large amount of heat generated by components of electronic systems, including IC's, chipsets, etc. during their operation. A heat sink is used to increase the surface area which dissipates the heat faster and keeps the IC's under safe operating temperature. It usually consists of a base with one or more flat surfaces and an array of fin like projections to increase the heat sinks surface area contacting the air and thus increasing the heat dissipating rate.

In order 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 is required [4]. Among the geometrical variations, rectangular fins are the most commonly encountered fin geometry because of their simple construction, cheap cost and effective cooling capability. Two common orientations of rectangular fin configurations, horizontally based vertical fins and vertically based vertical fins, have been widely used in the applications. The heat dissipation from the finned systems to the external ambient atmosphere can be obtained by using the mechanisms of the convection and radiation heat transfer. The effect of radiation contribution in total heat transfer rate is quite low due to low emissivity values of used fin materials. The basic equation describing such heat losses is given by:

$$Q_c = h.A.\Delta T$$

As seen from Eq. the rate of heat dissipation from the surface can be increased either by increasing the heat transfer coefficient, h or by increasing the surface area, A. An enhanced value of h can usually be achieved by creating appropriate conditions of forced flow over the surface. Although such forced convection is effective, extra space will be needed to accommodate a fan which causes additional initial and operational costs. 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. However, the designer should optimize the spacing or the number of fins on base carefully; otherwise fin additions may cause the deterioration of the rate of heat transfer. Although adding numerous fins increases the surface area, they may resist the air flow and cause boundary layer interferences which affect the heat transfer adversely [5]. Natural convection from horizontal fin arrays has the advantages of economy and trouble-free operation. It meets the need of heat dissipation for outdoor high-power LED lamps and fan less electronic devices such as thin-client computers [6]. The experimental investigations related to the thermal performances of rectangular fins were reported extensively in literature review. However, except for a few of them, studies were performed numerically for limited ranges of fin configurations with perforations.

II. METHODS AND MATERIAL

A. Literature Review

The aim of this literature review is to come up with the understanding of the achievement and Natural convection heat transfer rate from fin arrays up to this moment of study.

Christensen and Graham [1], investigated the package and system level temperature distributions of a high power (>1W) light emitting diode (LED) array using numerical heat flow models. For this analysis, a thermal resistor network model was combined with a 3D finite element sub model of an LED structure to predict system and die level temperatures. The impact of LED array density, LED power density, and active versus passive cooling methods on device operation were calculated. Xiang-rui, et.al. [2], studied the natural convection heat transfer enactment of horizontal heat sink by numerical simulation and experiment. The numerical replication results show that there are some stimulating features in the flow field of heat sink model. Among the fins, the air vertically flows only through the fins in the symmetry centre of heat sink while it horizontally flows through the fins in other area. There is an air inactivity zone located at the fin root in the evenness centre of heat sink. These features both caused the decrease in heat transfer temperature difference and heat transfer area in fact. The natural convection heat transfer enactment of heat sink is affected at last. In order to eliminate the air inactivity zone and change in the flow way of air, some holes were pierced at the fin root. These holes play its role. With the rise in the number of holes, the natural convection heat transfer power of heat sink also increases. Starner and McManus [3], conducted one of the earliest studies about the heat transfer performance of rectangular fin arrays. In their experiments, four sets of fin arrays were tested to investigate free convection heat transfer performances. The fin arrays were positioned with three base types, vertical, 45 degrees and horizontal. The average heat transfer coefficients were obtained from all fin configurations for all test positions. The effect of fin height was also discussed and it was realized that fin height, fin spacing and base orientation affected the heat transfer performance significantly.

Leung and Probert [4], performed another experimental study to investigate steady-state rates of heat dissipation under natural convective conditions from either vertically based or horizontally based vertical rectangular fins. They tried to figure out the effect of fin height on optimum fin spacing. It was also deduced that the change of fin height and base-to-ambient temperature difference did not affect optimum fin spacing values for the orientations considered in the study. Leung et. al. [5], reported experimental investigation of the heat transfer rate from an array of vertical rectangular fins on vertical rectangular base. The fins were manufactured from light aluminium alloy. The spacer bars made of the same material was produced to adjust the separation between adjacent fins by predetermined amounts. The wooden case was located at the rear of the test section to cover thermal insulation and heater plate. For various fin configurations, the experiments were conducted at base temperatures 200C, 400C, 600C and 800C above the mean temperature of ambient air. It was determined that the optimum fin spacing, corresponding to the maximum rate of heat transfer, was 10 ± 1 mm.

Huang et al. [6], introduce perforations through the fin base to improve ventilation with cold air from below the fin base. Aluminium fin arrays with length = 380mm or 104 mm, fin height H = 38mm, fin thickness t_f= 1mm, and fin spacing S = 10mm are analysed numerically. In the main part of their study, they analyse a single channel with multiple equal-length, equally spaced rectangular perforations which cover the full width of the fin spacing and have a total perforation length of L/2 or L/4. In addition, a multi-channel analysis is conducted for a selected fin array configuration with the uniform heat applied on the bottom surface at the middle part and longitudinal perforations arranged on the fin base outside the heated region. The perforations, especially located in the inner region, improve ventilation and heat transfer performance significantly. The patterns with more dispersed shorter perforations exhibit better improvements. The overall heat transfer coefficients can be more than twice as large as that without perforations for long fin arrays.

Welling and Wooldridge [7], performed experimental study to compare actual rectangular fin experiments with those of vertical plate, enclosed duct and parallel plate data from previous studies. For a given base-to-ambient temperature difference, an optimum H/S (fin height to fin spacing) ratio at which heat transfer coefficient is maximum was determined from the considered fin configurations. Harahap and McManus [8], observed the flow field of horizontally based rectangular fin arrays for natural convection heat transfer to determine average heat transfer coefficients. The result of comparison indicated that the array having shorter fin length (by half) had higher average heat transfer coefficient because of its effective utilization caused by single chimney flow. This result revealed that single chimney flow pattern was favourable to high rates of heat transfer. Jones and Smith [9], performed an experimental study to predict optimum fin spacing in terms of fin height and base-to-ambient temperature difference for natural convection heat transfer from rectangular fins on horizontal surfaces. Fitzroy [10], discussed the problem of determining the optimum spacing between parallel vertical flat plates which are dissipating heat by natural convection to the environment.

Bar-Cohen [11], analytically investigated the effect of fin thickness on free convection heat transfer performances of rectangular fin arrays. It was suggested that in air, the optimum fin thickness value of an array can be taken approximately equal to optimum fin spacing value for the best thermal performance. Leung et.al. [12], studied the thermal performances of rectangular fins on vertical and horizontal rectangular bases, experimentally. Effect of fin length and fin thickness on heat transfer performance of fin arrays is significant [13, 14].

The steady-state rates of heat degeneracy from an array of vertical rectangular fins, under natural-convection conditions, have been measured experimentally [15] and the same study for horizontal rectangular fins were done experimentally [16]. Yüncü and Mobedi [18], performed a three dimensional numerical study on natural convection heat transfer from longitudinally short horizontal rectangular fin arrays. The effects of fin length and fin height on the heat transfer rate of horizontal fin array were also examined and it was concluded that an increase in these geometric parameters causes reduction in the rate of heat transfer from array. This is due to more boundary layer interference along the channels which lowers the amount of intake cold air in the channel.

Al-Widyan and Al-Shaarawi [21], considered a rectangular fin with a uniform cross section embedded with circular perforation attached to a surface at a constant temperature. The perforated fin was analysed under natural convection using FLUENT ANSYS for heat transfer enhancement relative to its solid counterpart. AlEssa, et. al. [22], examined the enhancement of natural convection heat transfer from a horizontal rectangular fin embedded with rectangular perforations of aspect ratio of two using finite element technique. The results for perforated fin have been compared with its equivalent solid one. The study investigated the gain in fin area and of heat transfer coefficients due to perforations. It was found that, for certain range of rectangular dimension and spaces between perforations, there is an augmentation in heat dissipation and a reduction in weight over that of the equivalent solid one. Also, the heat transfer enhancement of the perforated fin increases as the fin thickness and thermal conductivity increase. Wong and Huang [23], made a parametric study on the vigorous natural convection from long horizontal fin arrays (L = 128, 254 and 380mm) using a 3-D unstable numerical analysis.

Huang and Wong [24], mathematically analyses the vigorous behaviour of natural convection from horizontal rectangular fin arrays. Unsteady replications are conducted for different fin lengths. Luo et.al. [25], presented a design and optimization method of horizontally-located plate fin heat sink to improve the heat dissipation of high power LED street lamps. The experimental results confirmed that the maximal heat sink temperature remained to be stable at 45^0C when the ambient temperature was 25^0C, the maximal temperature difference between steady state temperature and environment temperature for the heat sink was less than 21^0C. Comparing the results achieved by the design with the ones by the experiment, it is found that the design and optimization method is practicable and works well for understanding the horizontally-located heat sink of such kind of high power LED street lamp.

III. CONCLUSION

From the overall spread of the above literature survey, it is clearly observed that the whole study is limited to the fin with perforation, fin without perforation, fin orientation, fin length, fin height, base to ambient temperature difference, % of perforation etc.

But in the applications of the fin arrays, one of the important applications is utilization of these fin arrays as a heat sink for high powered street LED lights. Large amount of heat generated in these street LED's must have to be dissipated effectively, so that the life span of the same can be enhanced [6]. From the literature review, for the heat sinks currently utilized in the high powered street LED's a stagnation zone is formed at the symmetry centre of the fins this causes the problem in air circulation ultimately affects the heat dissipation capacity of the heat sink. Therefore there should be the proper provision for air to be drawn. So there is wide scope of study w.r.t this parameter.

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