Effect of lateral perforation on the performance of rectangular heat sinks – A Review

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Abstract- **Heat dissipation is a drastic issue to tackle due to continued integration, miniaturization, compacting and lightening of equipment. Heat dissipaters are not only chosen for their thermal performance; but also for other design parameters that includes weight, cost and reliability, depending on application. The present paper represents a review study to investigate the heat transfer enhancement of rectangular heat sinks with lateral perforation by forced convection. It is observed that the Reynolds number and number of perforations have a larger impact on Nusselt number for the both type of perforations.**

Index Terms- **Heat transfer enhancement, heat Sinks, perforation, forced convection.**

1. INTRODUCTION

Advanced technologies need high performance heat transfer equipments. Enhancement of heat transfer is of vital importance in many industrial applications. The thermal systems must be designed and sized to generate, transmit, or dissipate the appropriate amount of unwanted heat with required demand. The removal of excessive heat from system components is essential to avoid the damaging effects of burning or overheating. Heat sinks have been quite common as heat transfer enhancement devices A heat sink is a passive heat exchanger that transfers the heat generated by an electronic or a mechanical device to a fluid medium, often air or a liquid coolant, where it is dissipated away from the device, thereby allowing regulation of the device's temperature at optimal levels. The enhancement of heat transfer from heat sinks is an important subject of thermal engineering. A large number of studies have been conducted on optimizing heat sink shapes. Other studies have introduced shape modifications by cutting some materials from sinks to make cavities, holes, slot, grooves or the channels through the heat sink body to increase heat transfer areas and the heat transfer coefficient. Enhancing the heat transfer rate from air-cooled heat sinks is necessary due to the low thermal performances of air as the coolant. The heat transfer from surface may in general be enhanced by increasing the heat transfer coefficient between a surface and its surrounding or by increasing heat transfer area of the surface or by both. Methods for improving heat transfer classified in two categories: active and passive methods. Active methods require external power to enhance heat transfer and passive methods do not require external power. Extended surfaces or heat sinks are example of passive methods that are commonly used in variety of industrial applications to enhance the rate of heat transfer between primary surface (heat sink) and ambient fluid. For most applications, the rectangular heat sinks are used to reduce cost of manufacturing. Based on the widespread application of rectangular heat sinks, they are commonly used for heat exchangers, the understanding of convection mechanisms and prediction of heat transfer performance on rectangular heat sinks are usually analysed by the flow and heat transfer simultaneously Related studies about heat sinks and thermal efficiency for various shapes and geometries of heat sinks are extensive In addition, heat transfer rate can be improved by employing lateral and longitudinal perforations, porosity or slots.

2. PERFORATION IN HEAT SINKS

Interrupting the boundary layer in order to hinder its further growth over the surface is a potential technique to enhance the heat transfer rates, since a boundary layer acts like an insulation layer over the surface. Among different proposed techniques for the boundary layer interruption, perforated fins result in another advantage as lighter systems, due to perforations. On the other hand, due to restrictions in setup space and economical reasons, heat transfer equipments have been required to be much more compact in size and lighter in weight. So while a simple solid baffle plate attached to the duct wall enhances heat transfer, a perforated plate attached to the same duct wall poses less resistance to the flow and, thus, might have a better performance. Perforated fins have higher contact area with fluid in comparison with solid fin. So the average friction drag for perforated fins is lower compared to solid fin and also it increases by adding perforations. By increasing number of perforations, the size of formed wake behind the fin decreased. Accordingly, the form drag for solid fin is the highest and it decreases with increase of perforations. By increasing number of perforations, the length of recirculation zone around the lateral surfaces of fin reduced. In fact, solid fin has the largest recirculation zone at its lateral surfaces. Temperature drop from fin base to fin top surface increases with addition of perforations. For fins with perforation, drag force reduces. Also drag ratio becomes smaller by increasing Reynolds number. Fins with the same porosity but larger perforation sizes have higher Nusselt number than fin with smaller perforations. The perforation of fins enhances heat dissipation rates and at the same time decreases the expenditure of the fin material. However, since perforated fins result in lighter devices because of perforations, they are particularly attractive in weight sensitive applications. There are mainly two types of perforations for the heat sinks

1) Longitudinal Perforation
2) Lateral Perforation

Perforated-finned heat sinks are made by leveraging perforated fins in the heat sink construction, mainly by implementing two types of perforations either along the length of the fins or on the lateral surfaces of the fins; the corresponding heat sinks are called the longitudinally perforated-finned heat sink (LOPFHS), and the laterally perforated-finned heat sink (LA-PFHS), respectively. The heat transfer enhancement in a LO-PFHS is mainly due to an increase in the heat transfer area since each longitudinal perforation makes a channel along the fin length. Generally, fabrication of these heat sinks is costly and requires a complicated manufacturing technique because commonly used industrial heat sinks employ extremely thin fins with high aspect ratios. However, unlike LO-PFHSs, the mechanism of heat transfer rate in LAPFHSs is based on the frequent interrupting the boundary layer, as such, the boundary layer terminates and restarts over the perforations. Also, LA-PFHSs have the advantage that they can be fabricated through relatively simple and low-cost manufacturing techniques.

Generally, perforated fins are made by inserting perforations either along the length of the fins or on the lateral sides of the fins. Different researchers have performed various experimentations for the performance enhancement of heat sinks using perforations.

3. EFFECT OF PRESSURE DROP

Richard Boner, M.R. Sheari [1] investigated pressure drop and forced convection heat transfer from laterally perforated-finned heat sinks (LA-PFHSs) across a wide range of flow regimes ranging from laminar to turbulent. Thermal-fluid characteristics were investigated under the changes in both perforation size and porosity. The pressure drag in LA-PFHSs was found as the dominant component of the total drag compared with the friction drag. The main advantage of LA-PFHSs in weight sensitive applications was demonstrated through a new performance parameter as the mass-based thermal resistance, and 41–51% lower mass-based thermal resistance compared with that of the SFHS was achieved using LA-PFHSs with the maximum porosity, without increasing the pumping power. Pressured drops and heat transfer characteristics of LA-PFHSs in a forced convection heat transfer mode were experimentally investigated across all flow regimes ranging from laminar to turbulent. The results were compared with those of the SFHS. Pressure drops increased in LA-PFHSs due to more flow disturbances inside their channels, compared with the SFHS. The inaccuracy of reporting the cooling performance of a LA-PFHS based on its heat transfer coefficients that are calculated by using the exposed area of the LA-PFHS was demonstrated The pressure drag was found as the dominant component of the total drag in a LA-PFHS. At a given porosity, decreasing the perforation size enhanced the pressure drops due to more flow interactions over perforations with each other.

4. STUDY OF CONJUGATE CONDUCTIVE-CONVECTIVE HEAT TRANSFER

M.R. Sheari [2] studied the fluid flow and conjugate conduction-convective heat transfer from a three-dimensional array of rectangular perforated fins with square windows that were arranged in lateral surface of fins. For investigation, Naiver–Stokes equations and RNG based turbulent model was used. Finite volume procedure with SIMPLE algorithm was applied to coupled differential equations for both solid and gas phases. Computations were carried out for Reynolds numbers of 2000–5000 based on the fin thickness and Pr = 0.71. Numerical model was first validated with previous experimental studies and good agreement were observed. Based on a valid numerical model, numerical solution was made to find fluid flow and temperature distribution for various arrangements.

5. EFFECT OF HEAT SINK FIN SHAPE

There are different techniques to interrupt the boundary layer, including wavy fins, these techniques were demonstrated in [3, 4]. These techniques mainly include louvered fins [5, 6], offset strip fins [7, 8], vortex generators [9, 10], grooved channels [11, 12], pin fins [13, 14], converging diverging channels [15, 16], and perforated fins. Related studies about LO-PFHSs including studies by the authors can be found in [17-20]. Although the thermo-fluid transport phenomena in a solid-finned heat sink (SFHS, a regular/imperforated heat sink) have been well-documented and characterized through relatively accurate correlations, such knowledge is limited in LA-PFHSs. This is due to complex thermo-fluid physics in these devices and lack of detailed and fundamental research in this field.

6. NARROW CHANNEL HEAT SINKS

Norman Goldberg initially investigated the Narrow channel heat sinks. [21] performed the experimentation for the effect of the channel width. Three different channel widths, 5,10, and 25 mils, were investigated. The measured values of individual heat sinks with 30 V_{min} air flow were 5.5,3.7, and 3.4"C/W for 25,10, and 5 mm channel widths, respectively. It was observed that narrow channel heat sinks using air as the cooling fluid can keep the temperature rise of 10^0 C/W chips on 1/2 in centres below 60 ^{o} C (6 ^{0} C/W). Furthermore, by eliminating the substrate from the thermal path, thermal resistance can be reduced to about ^{O} C/W. [22] Azar further investigated the performance of the narrow channel heat sinks. A narrow channel heat sink was designed and its thermal performance characterized and it was observed that Narrow channel heat sink's performance is not a strong function of flow direction. Tip clearance (flow bypass) adversely affects thermal performance of the heat sink. Narrow channel heat sinks require moderate pressure drop for their performance. This is readily attained with the standard fans. The Narrow channel heat sinks can be readily used for high power components. Components dissipating 20 W/cm^2 (based on heat source area) or higher showed temperature rise of 38^0C for moderate forced convection cooling.

7. EFFECT OF PERFORATION SHAPE AND GEOMETRY

Shaeri. etal.[2,23] computationally studied turbulent and laminar heat transfer as well as flow streamlines in LA-PFHSs with square cross sectional perforations by considering a broad range of perforation sizes and porosities. They illustrated recirculation inside the perforations, as well as different sizes of wakes that were formed behind the heat sinks. In addition, Shaeri et al. [2,23] studied the effects of perforations on the individual friction drag and pressure drag, as well as the temperature distributions across the surface of the fins. In conclusion, correlations were developed for the average Nusselt number as a function of both Reynolds numbers and porosity. However, these correlations are not physics-based and were developed by curve-fitting of the computational results. The studies performed in [2, 23] were motivations for further research in this field. Ismail et al. [24] repeated the study by Shaeri et al.

[2] only by changing the geometry of perforations from square to circular, hexagonal, and triangular cross sections, through computational research. Willockx [25] extended the study by Shaeri et al. [2], and applied the inverse heat conduction problem (IHCP) technique to a solid fin, and fins with one and two lateral perforations, respectively. However, in their experiments, a systematic error appeared in the temperature measurements for perforated fins due to the camera lens reflection, which affected the accuracy of the IHCP solution in their experiments. Nevertheless, Willockx [25] confirmed the results obtained by Shaeri et al. [2] about the thinning of the boundary layer due to a negative pressure gradient in the perforation. Dhanawade etal. [26,27] experimentally tested LA-PFHSs, and reported enhancement in heat transfer coefficients, by relying on the exposed area of the LA-PFHSs (including the surfaces inside the perforations). Enhancement in heat transfer rates from LA-PFHSs by relying on the open area of LA-PFHSs is reported in other studies, such as experimental works by Al-Doori [28]. Also, there are several studies about laterally perforated fins implemented on circular tubes. Karabacak and Yakar [29], Lee et al. [30], and Banerjee et al. [31] investigated the effects of angular positions of perforations on circular fins located on tubes. [32] showed the capability of LA-PFHSs to improve cooling performances of a heat sink without any penalty in pumping power. However, in that study, we did not describe the detailed of flow and heat transfer in LA-PFHSs. Besides, that study was performed for a limited number of perforation sizes and porosities.

8. CONCLUDING REMARKS

From this review paper it has been concluded that until now many studies have focussed on perforation in heat sinks and it has been observed that perforation leads to enhancement in heat transfer rate. The main highlighting points of the literature review are as given below. The main advantage of perforation is that perforation leads to disturbances in the boundary layer. These disturbances lead to creation of turbulence in flow. This turbulence created because of perforation enhances the heat transfer rate. Thus the Nusselt number increases with increasing number of perforations on laterally perforated heat sink. The laterally perforated finned heat sink is having high heat transfer coefficient than solid fin Heat sink thermal resistances changes due to change in the porosity at a given perforation size. The perforated fined heat sink is light in weight compared to solid finned heat sink. The perforated heat sink is economical as the material utilised by the perforated heat sink is less as compared to the solid finned heat sink. The heat transfer enhancement depends on the perforation length, the perforation geometry, and number of perforation and thermal conductivity of material. The heat transfer rate enhances because of perforation. The perforated heat sinks have better performance as compared to the Solid finned heat sinks Hence perforation is desirable for enhancing the heat transfer rate but this perforation is required in proper proportion as excess of perforation leads to large amount of pressure drop that results in an increase in required pumping power which leads to decrease in heat transfer rate. Thus perforation upto a certain limit of perforation length is desirable for enhancing the heat transfer rate through the heat sinks.

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