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Natural Convection in Cross Plate-fin and Pin-fin Air Cooled Heat-Sinks - A Review

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Abstract— *Heat-sink is one of the most reliable cooling systems for compact devices. Cooling of devices through natural convection has always been a challenge. Many researchers are working on the heat transfer through natural convection in various geometries of heat-sinks. In this paper, some of the most simple and effective geometries have been discussed for the effective cooling of the electronic devices.*

Keywords: *Natural convection, Plate-fin, Pin-fin, Plate Circular Pin-fin, Heat-sinks.*

1. INTRODUCTION

A heat-sink is a mechanical device that is attached to a hot machine component to remove excess heat from the machine component and transfer it to the surrounding. There are two options of air-flow over the heat sinks; they are natural convection and forced convection. While in case of natural convection air flow takes place naturally due to density gradient, in forced convection air flow is aided by an external device like a fan. As in other cases, heat dissipation through the heat-sink is more in case of forced convection. However, the reliability of such devices decreases due to the use of additional devices. Therefore, natural convection is preferred in applications where the requirement of reliability is high while a low rate of heat transfer can be accepted.

The heat sink is a very important component for the cooling of electronic devices, Fifty-five per cent of failures of modern electronic devices is due to high temperature and high power density [1]. Heat-sinks are also used for the dissipation of heat through Dye-Sensitized Solar Cell [2].

Most commonly used heat-sinks have plate-fins or pin-fins. Plate-fin heat-sinks have a base plate and rows of thin plates attached to it. A simple plate-fin heat-sink is shown in figure-1. On the other hand, pin-fin heat-sinks have a base plate and a matrix of pin-fins attached to it. A simple pin-fin heat-sink is shown in figure-5a. Airflow in plate-fin heat-sinks is unidirectional while in pin-fin heat-sinks it is omnidirectional.

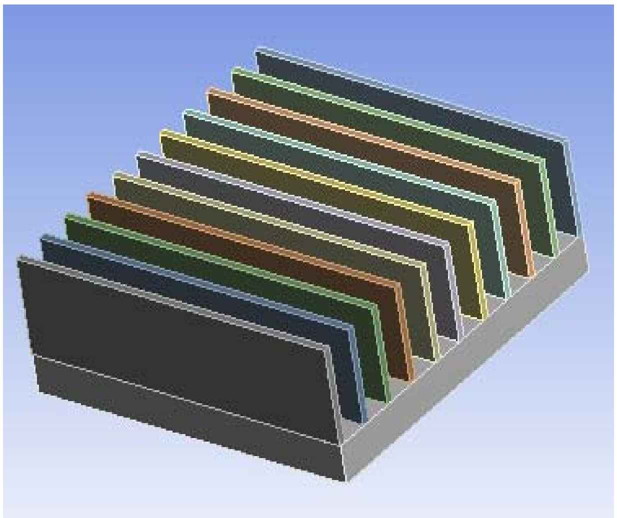

Fig. 1. Conventional plate-fin heat-sink

Bodoia and Osterle [3] studied experimental and theoretical solution for heat removal through natural convection in plate fins. And many other researchers gave empirical relations to optimize geometrical parameters for the plate-fin heat-sinks [4-10].

Heat transfer rates in pin-fin heat-sinks are higher due to the higher surface area to volume ratio and turbulence. Consequently, they are more suitable for cooling of compact electronic components or electronic components where fans can't be used due to space restriction. Pin-fins having a smaller height to diameter ratio are used in turbines where they provide rigidity along with high heat transfer rates [11]. Various modifications in pin-fin heat-sinks have been studied by different researchers. Shaeri and Jen [17-18], Dhanawade and Dhanawade [19], and Hopton and Summers [20] studied the effect of circular perforations through pin-fins on heat transfer. Feng, Feng, and Wang [22] and Haghighi and Goshayeshi [23] studied different combinations of plate-fins and pin-fins.

The heat transfer from the heat source to the heat-sink base and then to the fins occurs by conduction and heat transfer from the fins to the surroundings occurs by convection. Heat-sink helps in increasing the heat transfer coefficient and the surface area of the component. The resistance of the heat sink to heat transfer is the sum of both the conduction and the convection resistances. Convection resistance typically forms the major part of the overall resistance to heat transfer. Conduction resistance can be decreased by selecting a material having higher conductivity or by changing the geometry of the heat-sink, while convection resistance can be reduced by increasing the convective heat transfer coefficient or by increasing the surface area [13].

2. NATURAL CONVECTION IN A CROSS PLATE-FIN HEAT-SINK

Shangsheng and Meng [12] designed a heat-sink which includes short and long fins, which were placed mutually perpendicular to each other. The main objective of the above exercise was to reduce the temperature of the base plate of the cross plate heat-sink by 5-7 degree Celsius.

The temperature and velocity distribution in cross plate-fins and simple plate-fins were identical in the long passage. However, in the case of cross plate-fins, air penetrates the entire passage of the short fins and hits at the walls of the long fins. This leads to higher heat transfer in case of cross plate-fins.

Heat transfer through radiations in cross plate-fins and simple plate-fins is the same. However, overall heat transfer in the case of cross plate-fins is higher and therefore cross plate heat-sinks are useful in improving the heat transfer where space is a constraint, without increasing the manufacturing or material cost [12].

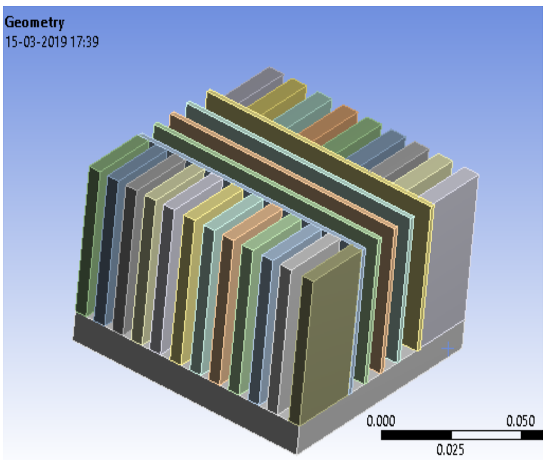

Fig. 2. Cross plate heat-sink

3. NATURAL CONVECTION IN THE PIN-FIN HEAT-SINK

3.1 Circular Pin-fin

Pin-fin heat-sink is one of the most common types of heat-sinks. Unlike plate-fins pin-fins don't restrict the flow of air in any direction. They provide better heat transfer due to a free flow of air through them and increased surface area of the fins due to their shape. Pin-fins can be circular, rectangular or elliptical.

Saha and Chanda [11] studied the effect of the fin spacing, Nusselt number and Grashof number on heat transfer in pin-fin heat-sinks. They also examined the effect of fin spacing on the critical Grashof number at which flow becomes unsteady and observed that there is an inverse relationship between the two. Similarly, an inverse relationship was seen between the Nusselt number and the fin spacing. Further, it was found that for a given fin spacing, the Nusselt number increases with the Grashof number.

Deshmukh and Warkhedkar [14] examined elliptical pin-fin heat-sinks, both for natural convection and forced convection.

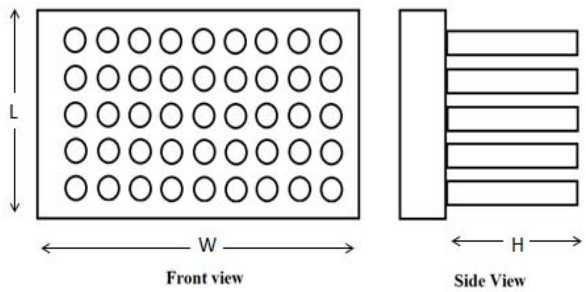

Fig. 3: Inline pin-fin configuration

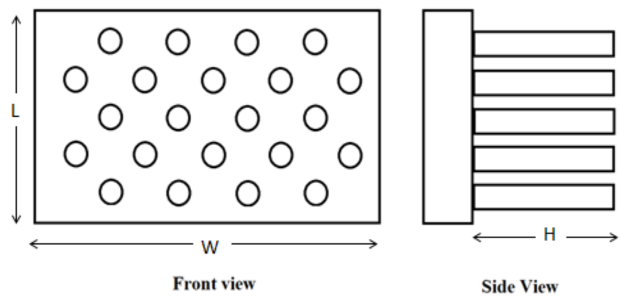

Fig. 4: Staggered pin-fin configuration

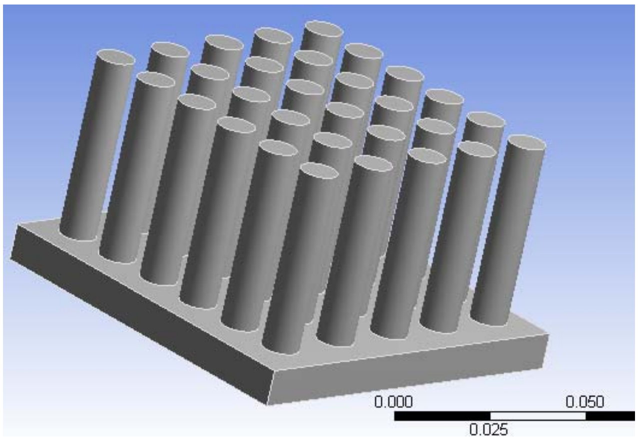

Fig 5. Solid Pin-fins

In the mixed convection region, the effect on thermal resistance is minimal. A 30% change in diameter shows a 7% change in thermal performance for lower velocities [15]. The height of the fin plays an important role in the performance of the pin-fin heat-sinks. A too short pin-fin decreases the heat transfer which results in excessive heating of the heat-sink. The height of the fin is the function of fin efficiency and effectiveness. As the height of the fin increases, fin effectiveness increases, at the cost of fin efficiency. Therefore the too long pin-fins are avoided. The spacing between the pin-fins cannot be too wide; else there will be less number of pins on the base plate, which results in poor performance.

Pin-fins can be an efficient alternative to plate-fins because of their shape which leads to an increase in heat transfer due to an increase convective heat transfer area and air flow through the fins [16].

3.2 Perforated Pin Fin

An innovative approach to increase the performance of the pin-fins is to provide one or more holes in the pin-fins. Shaeri and Jen [17-18] showed that 80% heat transfer rate increased by doing a single perforation on the pin-fins. Dhanawade and Dhanawade [19] studied the effect of circular perforations through pin-fins on heat transfer. They observed that, as the number of perforations increases, the Nusselt number also increases linearly. The perforations, larger in sizes, are favourable for low heat fluxes while the perforations, smaller in sizes, are favourable for high heat fluxes [20].

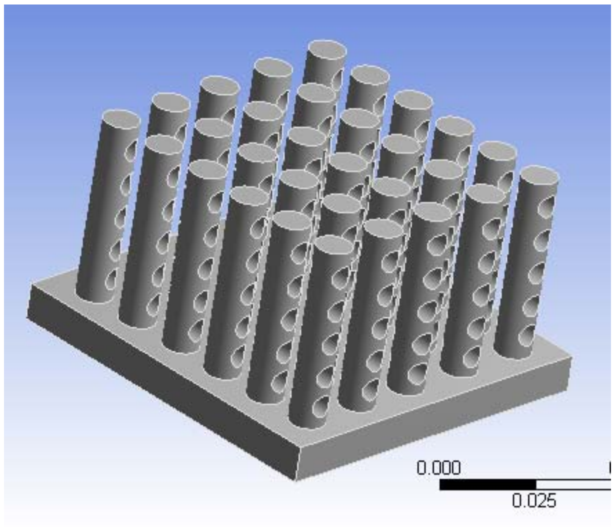

Fig 6. Perforated Pin-fins.

Pin-fins are in use in aero engines, nuclear reactor, computers and microelectronic devices. With increasing miniaturization, there is an increase in power density in electronic components. Therefore, liquid cooling technology which is "dielectric liquid immersion cooling" is being used [21]. Air cooled heat sinks will always remain popular over liquid cooling technology due to its reliable cooling at low cost for quite some time, Zhou and Catton [16]. There is a linear increase in Nusselt number with the number of perforations. In the case of pin-fins with perforations, to increase the heat transfer rate, it was observed that the perforation should be aligned in the direction of the flow [21].

4. NATURAL CONVECTION IN PLATE AND CIRCULAR PIN FINS HEAT-SINKS

Plate and pin fin heat-sink has a combination of plate-fins and circular pin-fins which are arranged in between two plate-fins, refer figure 6. Feng, Feng, and Wang [22] studied experimental and theoretical solutions for heat-sinks having a plate and rectangular pin-fins. They observed that thermal resistance in case of heat-sinks having a plate and rectangular pin-fins is about 30% less than that with respect to the simple plate-fins.

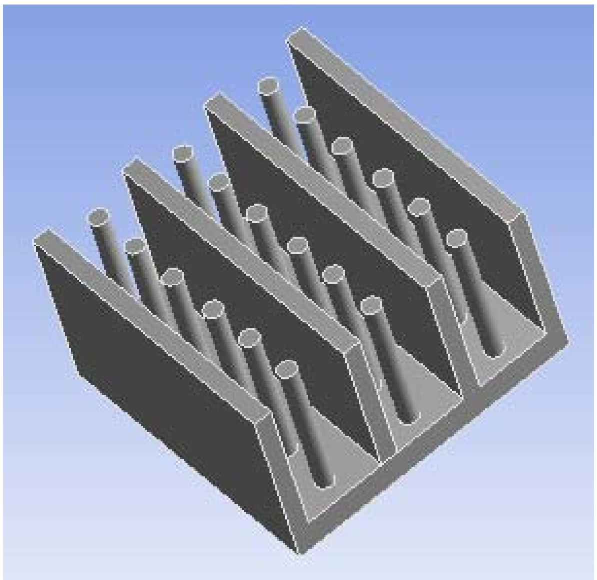

Fig. 7. Plate and Pin Fins

Heat transfer coefficient can be increased by increasing the surface roughness. Rough surfaces lead to more pressure fluctuation and an increase in the thermal efficiency of the system. If fins are placed too close, there is a decrease in heat transfer rate due to the overlapping of boundary layers of the neighbouring surfaces and low velocity of air through the gaps. If fins are located too far, heat transfer rate reduces due to the less surface area. Thus we need to choose the optimum spacing for fins, experimentally or theoretically. It was also observed that for the plate and pin fins, thermal resistance is lower than that of a simple plate-fins. [23].

5. CONCLUSION

- It was found that cross plate heat-sink has low thermal resistance and higher Grashof number and Rayleigh number when compared to simple plate fin heat-sink. Therefore, cross plate fin heat-sinks are useful in reducing the temperature of electronic devices.
- For simple plate-fin heat-sinks, fresh air has to travel a longer distance in the long fin-passages, which leads to lower heat transfer rate. However, for cross plate-fin heat-sinks, fresh air travels the entire distance in the short fin-passages and hits the walls of the long fins leading to higher heat transfer rates.
- The cross plate fins heat-sinks provide higher heat transfer for natural convection. They can be useful in places where space is a constraint, as they lead to an increase in heat transfer without increasing the amount of material and the cost of manufacturing.
- Perforated pin-fins provide more surface area as compared to the simple pin-fins, leading to higher heat transfer rates while reducing the weight of the heat sink.
- The Nusselt number increases linearly with an increase in the number of perforations.
- Plate and pin fin heat-sinks have higher heat transfer as compared to conventional plate-fin heat-sinks or conventional pin-fin heat-sinks.

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