EXPERIMENTAL STUDY ON HEAT TRANSFER PERFORMANCE OF VARIABLE AREA STRAIGHT FIN HEAT SINKS WITH PCM

by

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The thermal performance of heat sinks with variable area straight fins with and without PCM is quantitatively explored in this article. The effects of diverse fin geometries (constant area straight fin, variable area straight fin, circular pin fin, hemispherical pin fin, and elliptical pin fin), varying Reynolds numbers, and fin densities on boosting electronics cooling performance were investigated. The goal of this research is to develop the best fin geometry for electronics cooling technologies. This research demonstrates that altering fin density can improve heat sink thermal performance while also reducing heat sink weight. The base temperature of the heat sink is found to be lower in variable area straight fins. In comparison to alternative configurations for heat transfer with PCM, the results show that variable area straight fin heat sinks are the most effective. The thermal resistance of the improved heat sink with variable fin density was reduced by 9%.

Keywords: *variable area straight fin, Reynolds number, PCM, CFD*

Introduction

Because of recent advances in semiconductor technology, the power density of electronic and microelectronic equipment is increasing dramatically. As a result, in a fiercely competitive electronic equipment industry, increasing the heat transfer rate of such devices is crucial for long-term reliability. Natural convection cooling of electronic equipment with finned heat sinks is a prevalent practise in industry for a variety of reasons (*e.g.* easy fabrication, powerless operation, and high reliability). Heat sinks, as well as peripherals such as jets and fans, are always improving to meet the demand for greater heat dissipation. A numerical analysis was conducted on the thermal performance of a hemispherical pin fin (HSF) heat

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sink by adjusting fin height to channel height for various Reynolds numbers, with the finding that the heat sink's volume is reduced when compared to the reference case [1]. Saravanan *et al*. [2] investigated the heat transfer properties of a triangular pin fin heat sink using a variety of cooling fluids and nanoparticle volume concentrations. When nanofluids were utilised, the heat dissipation rate of the finned heat sink rose, but the performance index of nanofluids was marginally lower when compared to base fluids [3, 4]. Adeel Tariq *et al*. [5] looked at the thermal performance of a plate fin heat sink with holes and slots to see whether it may reduce pressure drop and heat sink weight. Thermal performance was better for plate fin heat sinks with perforations and slots than for flat plate fin heat sinks [6]. Zhong and Shi [7] looked at ways to optimise the heat sink base numerically to reduce the heat sink's thermal resistance in various cooling methods. Perumal *et al*. [8] suggested a micro-channel heat sink with perforated baffles and perforated walls to numerically improve the heat sink's bottom surface temperature. The influence of the rectangular hole's width on the baffle, as well as the distance between channel wall perforation, on the heat sink's thermal performance, was explored by Liu [9]. Ghasemi *et al*. [10] computationally and experimentally presented the thermal and hydraulic performances of heat sinks with varying hydraulic diameters of channel. The findings revealed that increasing channel diameter lowers thermal resistance and reduces pressure drop in the heat sink. The thermo-hydraulic performance of a hybrid water-cooled heat sink was studied experimentally by Gonzalez-Valle [11]. In order to find the lowest core temperature with the least pumping power, the impacts of the number and distribution of jet nozzles, the depth of the flood chamber, and surface enhancing characteristics were explored in terms of hydraulic and thermal performance. When paired with fans and jets, finned heat sinks, which are classified as plate-fin or pin-fin configurations, provide a major solution for boosting natural convection thermal performance. Arshad *et al*. [12] looked into the performance of a cooling system that used paraffin wax as heat sinks as a baseline comparison. Different fin thicknesses, PCM volume percentages, and heat fluxes are compared for better performance. According to the results, a 2 mm thick square pin-fin heat sink filled with PCM at a vol.% of 1 achieves maximum operating period heat transmission. The effect of different pin-fin shapes on convection and radiation heat transport was studied statistically by Dogan *et al*. [13] Heat transfer coefficients were calculated using several formulae, indicating the impact of geometrical parameters on fin array design. The optimal fin distribution for a PCM-filled heat sink was proposed by Saha *et al*. [14] and Saha and Dutta [15] TCE was made of aluminium, and they found that an 8 vol.% of TCE was superior for thermal regulation. Another study looked at the distinct connections of dimensionless Nusselt number, Reynolds number, Stefan number, and Fourier number based on the characteristic length of various enclosures and the suited characteristic length for each plate-fin enclosure design. To reduce the height of the latent heat thermal management system, a numerical optimization was developed by Levi *et al.* [16]. Heat sinks with no fins, rectangular, square, and circular pin-fin PCM filled heat sinks were tested for three input power levels. The circular pin-fin was found to be the most efficient of all the internal fin configurations. The impacts of various fin geometries (constant area straight fin – CASF, variable area straight fin – VASF, circular pin fin, HSF, and elliptical pin fin – EF), Reynolds numbers, and fin densities on enhancing electronics cooling performance were explored in this research work.

Experimental set-up and procedure

A test set-up for evaluating pressure loss and heat transfer through heat sinks is shown in fig. 1. An electrical heating element, thermocouples, power supply, and data collec-

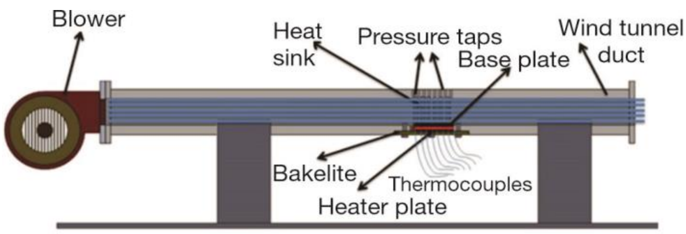

Figure 1. A schematic diagram of the experimental set-up

tion equipment are all part of the experimental set-up, which comprises a heat sink filled with PCM and surrounded by insulating material (thermal conductivity of 0.037 W/mK) to reduce thermal losses. The test setup uses air as the fluid and comprises an inlet and outlet, as well as a flow straightener, to ensure that the flow is uniform and straight throughout the system. Temperature and pressure measurement units are present on both the input and output. A blower is used to provide a constant supply of air into the system while also allowing the flow rate to be adjusted. Controlling the heater's input voltage regulates the input power. To prevent any heat loss in the system and to deliver a superior result, the heater and heat sink are thoroughly insulated. The temperature was measured using fourteen *J*-type thermocouples. Six thermocouples were inserted through 5 mm thick holes in the base plate and separated by 7 mm to measure the heat sink's maximum temperature. The first thermocouple is 8 mm from the leading edge of the heat sink, and the last thermocouple is 8 mm from the end of the heat sink. The average of all six thermocouple data in the heat sink's substrate is used to calculate the base temperature. The measurements are continuously input into the data gathering system for plotting and reading purposes. The heat sink to be tested is placed on the heater, as shown in fig. 1. A constant input power of a certain amount in 100 W will be provided to the heat sink. The fan will blast out the fluid, which in this case is air. When air passes through a heat sink, a certain amount of heat is transferred. The heat sink's heat sink profile and fins determine the amount of heat it can dissipate. The temperature before and after the heat sink is measured for the calculations. A heat sink's performance is frequently assessed by determining how much heat it can dissipate from its surface. For a period of 3 minutes, the change in the maximum temperature of the heat sink was assumed to be less than 0.1 ºC. The temperatures are recorded and used to calculate the heat transfer performance's thermal resistance as:

$$R = \frac{T_{w,\max} - T_{bm,\text{in}}}{Q} \tag{1}$$

Heat sink configurations

For this project, a 54 mm × 65 mm rectangular heat sink base plate was chosen. 40 mm fin height, 54 mm × 65 mm heat sink base plate for all fin shapes is shown in fig. 2(a) and 2(b). Aluminium materials are used to finish the various shapes of extruded fins (CASF, VASF, circular pin fin, HSF, and EF) and a 3.5 mm thick base plate. The heat sinks are also filled with a constant volume of PCM (50 ml) to improve heat conduction, resulting in a 54 mm height in the heat sink. The PCM levels vary depending on heat sink cavity layouts, but PCM volume remains constant.

Results and discussion

The thermal performance of a heat sink at a heat source of 70 W was experimentally compared using a CASF heat sink without PCM and with 50 ml PCM. Figure 3 shows the

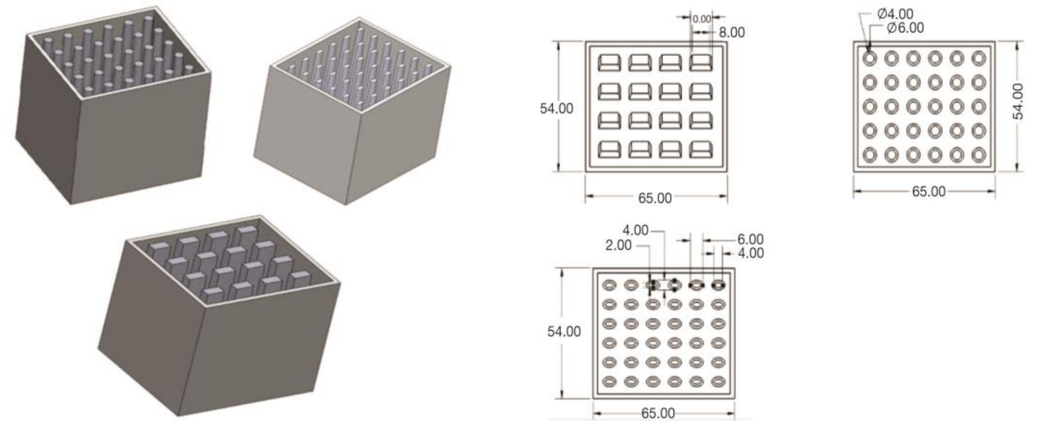

Figure 2. (a) Schematic diagram of the heat sink configuration (3-D) and (b) schematic diagram of the heat sink configuration (2-D)

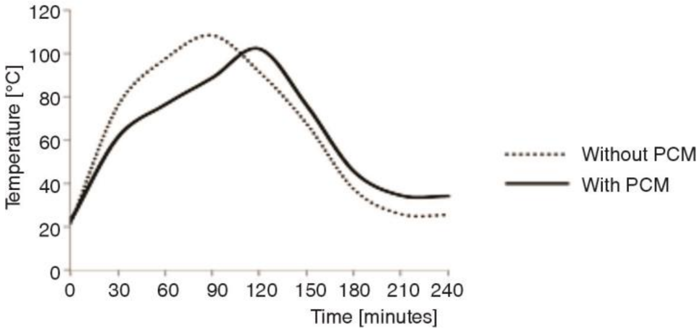

Figure 3. Temperature variation with respect to time

difference in temperature variation over time for CASF heat sinks with and without PCM. When compared to the heat sink with PCM (with reference to 89 ºC) during the same time, the heat sink without PCM temperature is high (with reference to 109 ºC). The thermal performance of a heat sink containing PCM is improved because PCM absorbs a large amount of latent heat while melting at 42 ºC, resulting in greater heat sink cooling. PCM heat capacity is boosted by increasing the volume of the material. However, when the heat source is removed, the PCM releases the stored heat into the environment. As a result, the heat sink with PCM cools down more slowly than one without PCM.

The thermal resistance of various heat sink fin shapes without PCM is shown in the fig. 4. A CASF heat sink without PCM has a significantly higher thermal resistance than in other cases. In all circumstances, when Reynolds number increases, the thermal resistance decreases. The VASF heat sink outperforms all other heat sinks in terms of thermal performance. When Reynolds number increases, the thermal resistance in the HSF heat sink decreases. As a result, beyond Re = 12000, the thermal resistance of heat sinks does not change significantly in other instances. The thermal resistance of a circular fin (CF) heat sink without PCM is lower than that of other heat sinks such as EF, HSF, and CASF. The EF heat sinks with no PCM outperform CF and VASF heat sinks in terms of thermal performance.

The thermal resistance of several shapes of heat sinks with PCM for fin pitch 5 mm is shown in the fig. 5. The thermal resistance of HSF and VASF heat sinks with PCM is identical, as can be seen. The CASF heat sinks with PCM have a lower thermal resistance than CF and EF heat sinks with PCM. The thermal resistance of the heat sink does not change substantially beyond Re = 12000. The thermal resistance of VASF, HSF, and CASF heat sinks with PCM decreases little above Re = 12000. The EF heat sinks with PCM outperform CF heat sinks with PCM in terms of thermal performance.

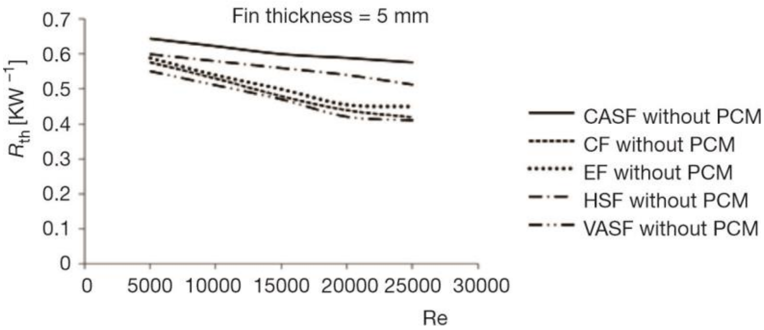

Figure 4. Thermal resistance of different geometry heat sink without PCM

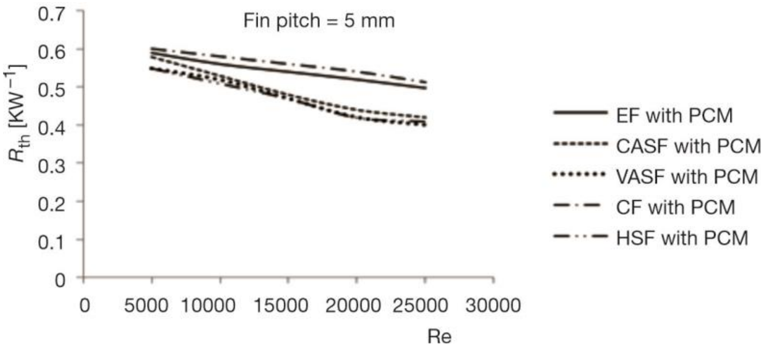

Figure 5. Thermal resistance of different geometry heat sink with PCM of fin pitch = 5 mm

In the fig. 6, the thermal resistance of various shapes of heat sinks with PCM for fin pitch 4 mm is displayed. The thermal resistance of the VASF heat sink with PCM is lower than in other circumstances. The thermal resistance of HSF heat sinks with PCM is lower than

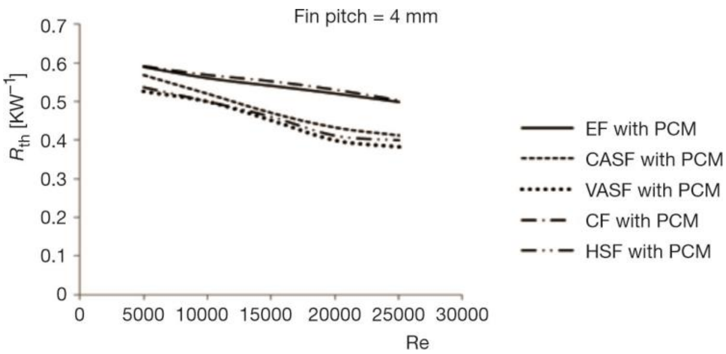

Figure 6. Thermal resistance of different geometry heat sink with PCM of fin pitch = 4 mm

that of VASF heat sinks with PCM. The CASF heat sinks with PCM have a higher thermal resistance than EF and CF heat sinks with PCM. The thermal resistance of the EF and CF heat sinks does not improve even when the fin density is increased. In most circumstances, increasing Reynolds number above 16000 does not significantly enhance the thermal resistance of the heat sink. There is no appreciable increase in thermal resistance while increasing heat sink fin densities with PCM.

Conclusion

The use of PCM based heat sinks improves the cooling of electronic devices dramatically. The influence of fin geometry and PCM on the thermal performance of PCM based heat sinks is investigated experimentally in this paper. The use of PCM reduces the heat sink's peak temperatures, as well as the cooling rate. In both cases of fin pitch, the thermal performance of the VASF heat sink outperforms all others. It has been discovered that increasing fin density has no effect on heat sink performance. When compared to all other scenarios, the thermal resistance of the VASF heat sink with PCM is reduced by 7%-12%. When compared to CF, CASF, and EF heat sinks, HSF heat sinks with PCM have a reduced thermal resistance.

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