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Water cooled minichannel heat sinks for microprocessor cooling: Effect of fin spacing

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HIGHLIGHTS

- Five heat sink geometries were tested to investigate the effect of fin spacing on microprocessors' operating temperature.
- Microprocessor heat was simulated using a heating block with 325 W power.
- Decreasing the fin spacing of the heat sinks increased overall heat transfer coefficient while thermal resistance decreased.
- 0.2 mm fin spacing heat sink produced the lowest base temperature of 40.5 °C at a heater power of 325 W.

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ABSTRACT

For effective thermal management of high heat generating microprocessors, five different heat sinks with fin spacings of 0.2 mm, 0.5 mm, 1.0 mm, and 1.5 mm along with a flat plate heat sink were investigated. Microprocessor heat was simulated by a heated copper block with water as a coolant. At a heater power of 325 W, the lowest heat sink base temperature of 40.5 °C was achieved by using a heat sink of 0.2 mm fin spacing which was about 9% lower than the best reported base temperature of 44 °C using a nanofluid with commercial heat sink in the open literature. The base temperature and thermal resistance of the heat sinks were found to drop by decreasing the fin spacing and by increasing volumetric flow rate of water circulating through the heat sink. For a flat plate heat sink, the maximum thermal resistance was 0.216 K/W that was reduced to as little as 0.03 K/W by using a heat sink of 0.2 mm fin spacing. The overall heat transfer coefficient was found to be 1297 W/m^2 K and 2156 W/m^2 K for the case of a flat plat and 0.2 mm fin spacing heat sinks, respectively, the latter showed about two-folds enhancement compared to the former.

1. Introduction

For the effective thermal management of high heat generating computer processors and to maintain operating temperature in a range of 60–80 °C, new and novel cooling techniques are being used. Air cooling techniques have reached their limit in heat removing capabilities. In recent years, attention is now focused on liquid cooling techniques due to higher heat transfer coefficients associated with liquids. Generally two approaches have been employed in order to optimize the performance of liquid cooling systems. The first approach was to modify the heat sink geometry using ordinary coolants while the second approach involved the modification of thermophysical properties of ordinary fluids in an effort to enhance their heat transfer performance.

A numerical study of the heat transfer characteristics of water cooled minichannel heat sinks was performed by Xie et al. [1] and concluded that the heat removed by a heat sink increases by decreasing the channel width of minichannels while the thermal resistance increases by increasing the channel width. Whelan et al. [2] designed a liquid cooling system for CPU cooling by considering the cost and ease of manufacture. This new block based on miniature jet stream design performed better than the commercially available cooling block [2]. In an effort to optimize the commercial liquid cooling systems, Naphon and Wongwises [3] performed an experimental analysis on the jet liquid heat transfer characteristics of the mini rectangular fin heat sink of a CPU based on real processor operating conditions and they concluded that the use of jet impingement cooling system resulted in a lower CPU operating

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temperature in comparison with conventional liquid cooling system. In order to increase the efficiency of liquid cooling systems further, an intermittent multi jet spray system for the cooling of microprocessors was employed by Panão et al. [4] which resulted in intelligent thermal management. A control strategy was devised based on the Intermittent Spray Cooling concept [4]. Bower et al. [5] experimentally investigated the heat transfer in water cooled silicon carbide milli-channel heat sink and they concluded that liquid cooled SiC heat sinks outperform air cooled heat sinks and compared favorably with copper equivalents, therefore a suitable option for better thermal management of electronics. Numerical techniques have also been employed to investigate the heat transfer characteristics of cooling systems for CPUs. Naphon et al. [6] conducted a numerical investigation to evaluate the heat sink's cooling performance based on real PC operating conditions.

Another aspect of enhanced liquid cooling that has received a great attention in recent years is the enhancement of thermophysical properties of liquids. This is mainly achieved by suspending nano meter sized particles in ordinary fluids and forming a stable suspension to produce nanofluids. Eastman et al. [7] reported a 40% enhancement in thermal conductivity as a result of 0.3% volume loading of copper nanoparticles in ethylene glycol. Choi et al. [8] also reported an anomalous enhancement of 160% in thermal conductivity at 1% volume concentration of Multi Walled Carbon Nanotube (MWCNTs) in oil. The work of Xie et al. [1] was extended by Ijam and Saidur [9] in which they compared the performance of water cooled and nanofluid cooled copper minichannel heat sinks and concluded that nanofluids give better heat transfer performance.

The use of nanofluids for computer cooling applications has also been investigated. For this purpose commercially available liquid cooling kits have been employed. Some of the investigations involve mounting the cooling block over the actual processor while in other investigations the cooling blocks were attached to a heating block that simulated the processor heat. The later approach shows more control on the experimental conditions. The performance of Al_2O_3–water nanofluid in commercial liquid cooling system was evaluated by Roberts and Walker [10] and reported an enhancement of approximately 20%. They also observed that the temperature gained by nanofluids while passing through the cooling blocks was greater as compared to water passing through the same block at the same processor heat flux. Nguyen et al. [11] using Al_2O_3 nanofluid in jet type cooling block reported an enhancement of 38% in convective heat transfer coefficient. Nguyen et al. [12] reported for turbulent conditions, there was a greater decrease in the junction temperature as compared to the laminar flow regime when ethylene glycol based Al_2O_3 nanofluids were used. The use of oscillating heat pipe and nanofluids has been investigated for cooling of electronics. The use of diamond nanofluids with 1% volume loading was investigated by Ma et al. [13] and as a result they were able to reduce the temperature difference between the evaporator and the condenser from 40.9 to 24.3 °C at an input power of 80.0 W.

Rafati et al. [14] recently has reported an experimental investigation using a commercial liquid cooling kit (3D Galaxy II by Gigabyte). They used a base fluid made of 75% water and 25% of ethylene glycol. TiO_2, SiO_2 and Al_2O_3 nanoparticles with different volume loading in the base fluid was tested to achieve the lowest operating temperature of a quad-core processor (Phenom II X4 965 with thermal design power 125 W). Pure base fluid produced a temperature drop from 53.3 °C to 49.3 °C for flow rates of 0.5 L per minute to 1.0 L per minute, respectively. The lowest temperature drop was found using Al_2O_3 nanofluids with a 1% volume concentration in base fluid, which was 46.1–43.9 °C for flow rates of 0.5 L per minute to 1.0 L per minute, respectively.

From the above literature review it is revealed that researchers have used either commercial minichannels with pure liquids or nanofluids with commercial cooling kits to reduce the microprocessor temperature. No attempt has been made to investigate the systematic effect of sink geometry on the microprocessor temperature. On the other hand, the use of nanofluids is still ambiguous due to many problems associated with them, i.e. more maintenance required, higher cost, aggregation and deposition of nano particles [15]. In the present study, an attempt has been made to investigate the systematic effect of sink geometry (by reducing fin spacing) with water as fluid on the microprocessor base temperature. A cylindrical copper block with high power of 325 W is used to simulate a high heat generating microprocessor. The objective of the present study was to identify the potential of heat sink geometries that are sufficient to reduce the high heat generating (up to 325 W) microprocessors temperature to a safe operating value in comparison of the commercially available heat sinks and nanofluids.

2. Experimental apparatus

2.1. Heat sinks

To determine the suitable heat sink type for the thermal management of high heat generating microprocessors, five different copper heat sink geometries were tested. Four heat sinks (see Fig. 1) had a varying fin spacing of 0.2 mm, 0.5 mm, 1.0 mm and 1.5 mm while the fifth heat sink had a flat surface for comparison. The finned heat sinks were manufactured by electrode discharge machining (EDM) while the flat plate was manufactured by milling operation. The fin thickness and height was kept constant at 1 mm and 3 mm, respectively. The base of all the heat sinks had a square protrusion of 0.5 mm and dimensions of 28.7 mm × 28.7 mm. This protruded square base was used to mount the heat sinks on the heating block that simulated the microprocessor heat. Table 1 shows the dimensions of the heat sinks. The copper heat sinks were sealed using plexi-glass and rubber seals in such a way that fins tips were in complete contact to the plexi-glass allowing no fluid flow over the fin tips. Inlet and outlet nozzles were provided in the final heat sink assembly for the coolant to flow through the heat sinks.

2.2. Test loop

To simulate the processor, a heating block assembly was used as shown in Fig. 2. The reason for using the heating block was that processor heat varies with varying processor loadings and in this study a constant heat of 325 W was applied to copper block by two surface heaters. The heaters clamped the cylindrical copper block from the outside. In order to ensure constant power being delivered to the heater, a DC power supply (Loadstar 8109) was used which supplied constant voltage of 197 V and current of 1.65 A to give a total power of 325 W. The heat sinks were mounted on the top of the heated copper block and a heat sink thermal compound was applied between the two surfaces in order to ensure a perfect thermal contact. All exposed surfaces were insulated by using fiberglass wool.

A commercial CPU liquid cooling system (Galaxy by Gigabyte) was used in the present investigation. Fig. 3 shows the schematic diagram of the experimental setup. The test loop was modified to include a needle valve in order to control the flow of water and three different volumetric flow rates of 0.5 LPM, 0.75 LPM and 1.0 LPM were employed. The flow rate was measured by using an Omega rotameter (full scale accuracy: ±5%).