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Thermal performance and second law characteristics of two new microchannel heat sinks operated with hybrid nanofluid containing graphene–silver nanoparticles

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ABSTRACT

This study attempts to evaluate the flow, heat transfer and second law characteristics of a hybrid nanofluid containing graphene–silver nanoparticles inside two new microchannel heat sinks. The temperature dependent thermophysical properties are employed in the simulations. Because the flow is divided uniformly between the channels of heat sinks, a rather uniform temperature distribution is obtained on the heating surface. By increasing either velocity or concentration at both heat sinks, the surface temperature reduces; the cooling uniformity improves; and the maximum temperature also decreases which reduces the possibility of hot spot formation. Moreover, increase of the velocity or concentration intensifies the pumping power in both heat sinks. Figure of merit, i.e. the ratio of heat transfer enhancement to pressure drop increment in the case of using the nanofluid instead of pure water, shows a greater value for the heat sink with more path changes. The results reveal that the heat transfer has a greater contribution in the entropy generation compared to the friction. Moreover, greater fraction of thermal entropy generated in the heat sinks occurs in the fluid part. Based on the results obtained, it is found that employing the heat sink with more path changes and also using the nanofluid as heat transfer fluid can be promising options to be utilized in electronics cooling regarding both first and second laws of thermodynamics.

1. Introduction

Among different types of thermal devices, microchannel heat sinks have received noticeable attention in the recent years [1]. Recently, microchannel heat sinks are employed in important industries such as microelectronics, aerospace, and so on. Based on the definition presented by Kandlikar and Grande [2], channels with hydraulic diameter between 10 µm and 200 µm can be called microchannel. Many scholars have carried out experimental, theoretical, and numerical studies on microchannel heat sinks by considering significant parameters such as heat transfer rate and pressure drop [3]. Tuckerman and Pease [4] were pioneers in the investigation of forced convection in microchannel heat sinks. They found the advantages related to using micro heat sinks in electronics cooling.

It is noteworthy that there are two causes that limit the performance of micro heat sinks: the decrease in the channel dimensions is accompanied by greater pressure drop, and the rate of heat transfer is limited by the heat transfer fluid employed. Therefore, applying innovative geometries and using fluids with excellent thermal features can improve efficacy of the micro heat sinks.

Many efforts have been made for modifying configuration of microchannels in order to enhance the performance of these devices. Leela Vinodhan and Rajan [5] evaluated flow and heat transfer in four microchannel heat sink configurations. The microchannel heat sinks consisted of four compartments with separate coolant inlet and outlet ducts for each part. The presence of several regions of developing flow in some of these designs resulted in greater Nusselt number and heat transfer rates. Moreover, at a constant pumping power, thermal resistance was examined for different designs. Ramos-Alvarado et al. [6] studied the thermal performance of liquid-cooled heat sinks with conventional and novel microchannel flow field configurations. Details of the thermal efficiency, particularly the uniformity of temperature distribution on the solid surface and pumping power for the relevant heat sinks were determined. Comparisons of the flow distribution uniformity in multiple flow channels, temperature uniformity on heating surfaces, and pumping power of heat sinks with new flow field outlines and ordinary flow field configurations were made. It was found that the new proposed outlines possess significant advantages for utilization in heat sinks.

The thermal characteristics are limited by the heat transfer fluids

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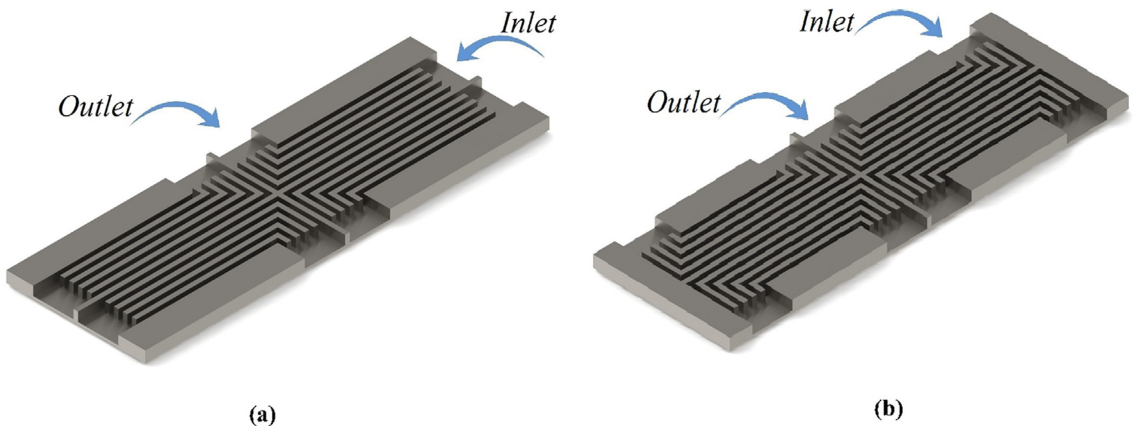

Fig. 1. The microchannel heat sinks under study: (a) heat sink A, (b) heat sink B.

that are employed in micro heat sinks. The recent development of nanotechnology has resulted in the concept of using solid nanoparticles in ordinary liquids to enhance the heat transfer attributes of the base fluids [7]. These suspensions are termed as nanofluids, which possess excellent thermal properties according to many studies carried out in this area [8]. Many researchers have investigated the performance of nanofluids in different devices some of which have evaluated application of nanofluids in micro heat sinks [9]. Bahiraei and Heshmatian [10] examined hydrothermal attributes of a biological nanofluid in a liquid block heat sink for cooling of an electronic processor. The liquid block possessed 20 channels, and its bottom surface was attached with a processor. By increase of Reynolds number and particle concentration, temperature distribution became more uniform in processor surface and heat transfer coefficient enhanced as well. Moreover, the surface temperature reduced with increase in the concentration and Reynolds number. Al-Rashed et al. [11] assessed the effect of nanofluids on the performance of a micro heat sink for CPU cooling experimentally and numerically. For the range of mass flow rate and heat load values under study (115 and 130 W), thermal enhancement was obtained up to 7.7% in the case of using nanofluids rather than water. Sarafraz et al. [12] investigated the heat transfer efficacy of a cooling liquid block heat sink operating with gallium, CuO–water nanofluid and water. The CPU employed in this work was researched at three situations of standby, normal and overload working modes. The results revealed that gallium was the more efficient fluid than the nanofluid and water based on convective thermal efficiency, however, the significant penalty for pressure drop and pumping power occurred with the utilization of gallium. The CuO–water nanofluid, however, demonstrated a greater thermal efficiency than the water, while had less pressure drop and pumping power compared with the gallium, offering a trade-off state in comparison with the gallium.

Other than the first law of thermodynamics, it is vital to pay special attention to the second law of thermodynamics in investigation of thermal devices [13]. The second law of thermodynamics indicates that energy conversion direction is from high quality to low quality. Conserving useful energy is dependent on how to execute a heat transfer process from the thermodynamic viewpoint. Irreversibility values occurred during a process are determined via calculating entropy generated [14]. Energy conversion processes lead to an irreversible increment in entropy. Hence, although energy is conserved, its quality decreases by converting it into another form of energy at which lower work can be obtained. Indeed, reducing the produced entropy leads to more efficient plans of energy systems [15].

A review of the literature reveals that very few studies have been carried out on the entropy generation in heat sinks in which the working fluid is a nanofluid. Khaleduzzaman et al. [16] investigated exergy and entropy generation of TiO_2–water nanofluid for cooling of an electronic device. The TiO_2–water nanofluid with the concentration of 0.1% was passed within the heat sink. It was concluded that the base temperature decreases with the increase of flow rate, and increases with the adding the nanoparticles. Exergy loss was found to be reduced by increasing flow rate of the coolant. In addition, thermal entropy generation rate reduced, while frictional entropy generation rate intensified with the flow rate increment. In the study conducted by Sohel et al. [17], Al_2O_3–water nanofluid was passed within a copper minichannel heat sink which was connected to an electronic heat source. The results revealed that the nanofluid reduces the heat sink temperature in comparison with the ordinary coolant. In addition, it was perceived that the thermal entropy generation rate decreases by use of the nanofluid rather than the pure water. Moreover, increase of the frictional entropy generation rate and pressure drop was insignificant in comparison with the pure water. Finally, the authors suggested that nanofluids can be employed as superior alternative coolants in electronics cooling rather than conventional fluids.

In the present contribution, thermal performance and second law attributes of the graphene–silver nanofluid are researched in two new microchannel heat sinks in order to cool an electronic processor. The important parameters such as thermal resistance, surface temperature, pumping power, figure of merit, as well as local and global entropy generation rates are evaluated. The mentioned novel heat sinks have been suggested by Leela Vinodhan and Rajan [5] for cooling via liquid water. To our knowledge, the current study is the first research that reports the results of applying nanofluids in these new micro heat sinks.

2. Definition of the microchannel heat sinks and nanofluid

In this study, attributes of two new microchannel heat sinks operated with the graphene–silver nanofluid are investigated. As can be seen in Fig. 1, the micro heat sinks are created by four similar quadrants with separate inlet and outlet. The purpose of these designs is to reach a more uniform cooling on heating surfaces. The difference between heat sinks A and B is observed in their inlets such that the flow enters the heat sink A straightforwardly, while it enters the heat sink B with experiencing a 90° rotation (see Fig. 1). The area of heat sinks bottom is 111.6 mm^2, while the length and width of them are 18 mm and 6.2 mm, respectively. The material of the heat sinks is copper, and all surfaces are adiabatic except the bottom surface. The wall thickness for the bottom of heat sinks is 0.1 mm, and the heat flux applied on the bottom surface is considered as 100 W/cm^2. Moreover, a cover with the thickness of 0.1 mm is installed at the top of the heat sinks. In order to reduce the computational time, only one quadrant of the heat sinks is numerically analyzed because the geometries are symmetrical. The distance between inlet and the beginning of the channels, and distance between outlet and the end of the channels are considered 1 mm. The