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Study on the thermal behavior and cooling performance of a nanofluid-cooled microchannel heat sink

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ABSTRACT

This paper presents an analysis of the heat transfer characteristics and cooling performance of a microchannel heat sink with water–γAl_2O_3 nanofluids having different nanoparticle volume fraction. In view of the small dimensions of the microstructures, the microchannel heat sink is modeled as a fluid-saturated porous medium for problem solving. The Forchheimer–Brinkman–extended Darcy equation is used to describe the fluid flow and the two-equation model with thermal dispersion is utilized for heat transfer. Typical results for the temperature distributions of the fluid phase and the channel wall are presented for various values of nanoparticle volume fraction and the inertial force parameter. It is found that the temperature distribution of the channel wall is practically not sensitive to the inertial effect, while the fluid temperature distribution and the total thermal resistance change significantly due to the inertial force effect. In general, the effect of fluid inertia is to reduce the total thermal resistance and the temperature difference between the channel wall and the fluid phase. The total thermal resistances obtained from the present model with inertial effect match well with the existing experimental results, whereas the thermal resistance is overestimated as the inertial effect is neglected.

1. Introduction

In order to tackle the ever increasing demands from the electronic equipments, the modern cooling devices have to be compact and of high performance to provide reliable system operation. Several ideas for advanced cooling technology for electronic equipments with high heat dissipation rates have been proposed, but can be put into two approaches, e.g. [1–4]. The first is to find an optimum configuration of cooling devices for which the cooling performance is maximized. The second is to decrease the characteristic length of the cooling devices. Founded on the second approach, Tuckerman and Pease [1] proposed a high-performance microchannel heat sink (MCHS) for very-large-scale integrated (VLSI) circuits. They demonstrated that the extremely high-power density with a heat flux as high as 790 W/cm^2 could be dissipated by using water-cooled microchannel heat sinks. Following the work of Tuckerman and Pease, many researches have been conducted for microchannel heat sinks, as reviewed by Phillips [2]. The fin approach is employed in most of these studies. The fin approach is effective for the analysis of micro-scale heat transfer in many practical applications, and has been used recently to investigate the efficiency of micro-cell honeycombs in compact heat exchangers [5] and the design of cellar metal systems [6]. Several new designs and modeling approaches of high-performance cooling devices have been proposed. For example, in view of the small dimensions of the microstructures, Koh and Colony [7] modeled the microchannel as a porous medium based on Darcy's law. Tien and Kuo [8] expanded the porous medium model by employing the Brinkman-extended Darcy model for fluid flow and volume–averaging method for the heat transfer in microstructures. Later, Kim and his co-workers [9,10] have presented analytical solutions for velocity and temperature distributions in microchannel heat sinks by modeling the microchannel heat sink as a fluid-saturated porous medium. They also adopted the Brinkman-extended Darcy equation for the momentum equation but a two-equation model for heat transfer. It is noted that only boundary effect is considered in the above studies [8–10], but it might be more aptly to consider both the effects of the solid wall and the fluid inertial force for fluid flow through porous media (see, for example, [11–13]). Bearing this in mind, the present author [14] has recently presented an analysis of forced convection heat transfer in microchannel heat sinks using a general model for the fluid flow through porous media, i.e. the

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