Energy, Exergy, and Friction Factor Analysis of Nanofluid as a Coolant for Electronics


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ABSTRACT: Power dissipation, chip power consumption, and heat flux in electronic devices have been steadily increasing over the past decade. Creating a need for improved methods of cooling them. Nanofluids can be used as coolant for these electronics to improve their thermal performance. This paper presents an analysis of the energy, exergy, and frictional efficiencies of different nanofluids that are used to cool electronics. This was done by creating an analytical model in which different nanofluids flowed (at 0.5 m/s) through a rectangular-shaped microchannel heat sink (with a constant heat flux). These different nanofluids consisted of water as a base fluid, with 0.4 to 2.0 vol% of copper oxide (CuO), aluminum oxide (Al2O3), and titanium dioxide (TiO2) nanoparticles. The results generally showed that thermal resistance decreases as the volume fraction of nanoparticles is increased. The CuO-water nanofluid was found to be the best coolant in terms of both minimizing thermal resistance and maximizing the pressure reduction. The energy efficiency of the heat sink increases as the volume fraction of nanoparticles increases. A maximum energy efficiency of 98.9% was obtained using the CuO-water nanofluid (at 2.0 vol%). The Al2O3-water and TiO2-water nanofluids (also at 2.0 vol%) produced a maximum energy efficiency of 77.5% and 68.4%, respectively. The lowest exergy losses were: 19.2, 20.9, and 25.1 W for TiO2-water, Al2O3-water, and CuO-water nanofluids (all at 0.4 vol%), respectively. The dimensionless friction factor was reduced as the nanoparticle volume concentration increased. Also, the pumping power increased (to a high of 0.0173 W) as the mass flow rate increased.

1. INTRODUCTION

Modern electronics consumers are continuously demanding technological improvements such as increased transistor densities, miniaturization, and other innovations designed to obtain faster computational speeds. Greater heat fluxes are generated as a consequence of these innovations, which in turn requires the thermal management of these electronic components to be improved.1 The increased cooling demands of next generation 3D integrated chip designs imply that a future switch to liquid cooling systems is inevitable.2 Before designing a liquid cooling system for electronics, properties such as the: heat transfer coefficient, thermal resistance, energy and exergy efficiency, friction factor, and pumping power must be calculated. Therefore, it is prudent to derive analytical solutions for determining these parameters, prior to experimental analysis. Tuckerman and Pease3 tested a compact, water-cooled integral heat sink for integrated circuits. They found that, for laminar flow in confined channels, the heat transfer coefficient (h) scaled inversely with channel width, making microscopic channels desirable. They measured a maximum power dissipation density of 790 W/cm² with a thermal resistance of 0.1 °C/W for a 1 cm² area, whereas a high pressure reduction of 2 bar was also observed. Choi and Huang4 studied silicon microchannel heat sink performance using CuO-water nanofluid. They showed the performance of heat sink greatly improved due to an increase of thermal conductivity and thermal dispersion effect. Sohel et al.5 experimentally investigated heat transfer enhancement of a minichannel heat sink using Al2O3-water nanofluid. They found the heat transfer coefficient enhanced up to 18% successfully. These studies showed the potential of nanofluids as a good liquid coolant for electronics devices.

A nanofluid is a solid–liquid mixture that consists of a base fluid and nanoparticles. The term "nanofluid" was first introduced by Choi.6 Nanofluids are prepared by dispersing nanometer-sized particles (generally less than 100 nm) in a base fluid such as water, ethylene glycol, propylene glycol, oil, and other conventional heat transfer fluids. The addition of high thermal conductivity metallic nanoparticles (e.g., copper, aluminum, silver, etc.) to the base fluid increases the thermal conductivity of the mixture, thus enhancing its heat transfer capability. Bhattachary et al.7 numerically studied the impact of Al2O3-water nanofluid on rectangular microchannel heat sink (MCHS) and found that the nanofluid coolant improves MCHS performance by reducing its thermal resistance. Also, Ebrahimi et al.8 investigated the temperature contours and thermal resistance on microchannel heat sink with multilawed carbon nanotubes (MWCNTs)/water nanofluid. They showed that the microchannel heat sink temperature gradient was decreased with the increase of nanolayer thickness of