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An experimental study on the thermal and hydraulic performances of nanofluids flow in a miniature circular pin fin heat sink

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ABSTRACT

This study presents the experimental thermal and hydraulic performance of heat sink with miniature circular pin fin structure using two different types of nanofluid as coolant. ZnO and SiO_2 nanoparticles dispersed in DI water with particle volume fraction of 0.2, 0.4 and 0.6 vol.% are tested and compared with the data for water. A heat sink with inline arrangement of circular pins is designed and made from aluminum material. The height, diameter, pitch, and number of pins are 1.2, 1.2, 2.4 mm and 143, respectively. Uniform heat flux at the bottom of the heat sink is performed. The present work is conducted at fluid temperature of 15 °C. The mass flow rate ranged from 0.65 to 3.32 kg/min and the heat flux ranged between 20 and 48 kW/m^2. The effects of particle type, particle concentration, and mass flow rate on the thermal and hydraulic performances are reported. The measured data show that the heat transfer performance of the nanofluid-cooled heat sink is higher than that of the water-cooled heat sink. Comparison between ZnO and SiO_2 nanofluids, higher heat transfer performance for ZnO–water nanofluids is observed by about 3–9%. For hydraulic performance, the results show that the addition of nanoparticles in the base fluid have a small effect on the pumping power. Finally, new heat transfer and pressure drop correlations are proposed to predict the Nusselt number and pressure drop of nanofluids flow in heat sinks with pin fin configuration.

1. Introduction

Today, much advanced electronic equipment generates high heat flux. Thus, a high heat dissipating rate is the main topic for cooling modern electronic devices such as integrated circuits (IC) and computer chips. Heat sink is a component to dissipate heat from the electronic devices by means of temperature difference between the system and the heat transfer fluid. The purposes of using of a heat sink are divided in two folds: (1) to increase the heat dissipation rate for improving the thermal performance of the system, and (2) to augment the reliability and functionality of the electronic device. In the past, the air-cooled method is very popular. However, a limitation due to the thermal performance of air is reached [1,2]. Later, the water-cooled method is used to compensate the disadvantage of the air-cooled systems. A number of researchers have reported that the heat transfer performance of water-cooled systems is significantly higher than that of the air-cooled systems. However, based on modern trends in micro-scale and nanoscale heat transfer equipment, the heat transfer performance of the water-cooled system may be limited when used to dissipate the high heat load from an advanced electronic system.

In order to solve this problem, nanofluid-cooled heat sinks are used to replace the water-cooled heat sinks. Many researchers indicated that the use of nanofluids as coolant significantly increase the heat transfer performance compared with common base fluids [3–6]. Beyond improving in the heat transfer performance of coolants, reducing in the channel diameter of cooling devices should be performed to increase the thermal performance. The concept of heat sink with a small flow channel (microscale) was first reported by Tuckerman and Pease [7] in 1981. A new class of heat sinks for high heat load applications can be created based on a microchannel structure which have received attention due to high amount of heat load can be dissipated. Moreover, Kim and colleagues [8] stated that a pin fin heat sink is one of the most efficient ways to increase the thermal performance of a high heat flux system. Some researchers [9–11] have reported on the other advantages of the pin fin heat sink such as compactness, high surface area density, high heat transfer capability, low thermal

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Nomenclature

A	area (m^2)
B	base thickness (m)
C	thermal resistance (°C/W)
C_p	specific heat (J/kg K)
d	nanoparticle diameter (m)
D_H	hydraulic diameter based on the each flow channel (m)
h	heat transfer coefficient (W/m^2 °C)
k	thermal conductivity (W/m K)
L	heat sink width (m)
$\dot{m}$	mass flow rate (kg/s)
Nu	Nusselt number
n	number of pin fin
ΔP	pressure drop (Pa)
q	heat flux (W/cm^2)
Q	heat transfer rate (W)
Re	Reynolds number
T	temperature (°C)
t	fin height (mm)
u	mean velocity (m/s)
$\dot{V}$	volume flow rate (m^3/s)
W	heat sink width (mm)
W_p	pumping power (W)

Greek symbols

ϕ	volume fraction
Ø	pin fin diameter (mm)
ρ	density (kg/m^3)
μ	viscosity (kg/ms)

Subscript

ch	channel
in	inlet
out	outlet
P	pitch
p	particles
nf	nanofluid
s	surface
th	thermal
w	water

resistance, and can be used with various type of coolants without clogging problem.

However, the above articles dealt only with the single-phase fluids flow through heat sinks. For the case of nanofluid-cooled heat sinks with microchannel or pin fin structure, the data is quite small, especially experimental approach. For example, Lee and Choi [12] proposed the thermal performance of MCHS using NF_2 and NF_3 nanofluid as coolant, theoretically. Chein and Huang [13] introduced mathematical model to predict the heat transfer coefficient and pumping power of Cu–water nanofluid-cooled MCHS. Heat transfer and flow characteristics of nanofluid-cooled MCHS were conducted by different researches [14–20], numerically. Moreover, a series of works of Ijam and Saidur [21,22] reported numerical investigations on the thermal and flow characteristics of heat sinks with mini-flow channels working with TiO_2–water, Al_2O_3–water, and SiC–water nanofluids. Later, Hung et al. [23] simulated the thermal and hydraulic performance of a 3-D MCHS working with Al_2O_3–water and diamond–water nanofluid. Manay and colleagues [24], using the finite volume method, combined with the mixture model to simulate the heat transfer and pressure drop characteristics of Al_2O_3–water and CuO–water nanofluids flowing through MCHS with a square channel (0.4×0.4 mm) under a laminar flow condition. Tokit et al. [25] presented a numerical study on the thermal management of an interrupted microchannel heat sink (IMCHS) using different nanofluids as coolants. Hashemi et al. [26] studied the thermal performance of SiO_2–water nanofluids flow in a miniature plate fin heat sink, numerically. The entropy generation and heat transfer behavior of Al_2O_3–water nanofluids flowing through tangential MCHS was numerically studied by Shalchi-Tabrizi and Seyl [27]. The effects of Brownian motion and particle size on the thermal and hydraulic performances of nanofluid-cooled heat sinks with micro-pin-fin structure were conducted by [28–30].

For the experimental approach, the thermal and hydraulic performance of nanofluids flow in heat sinks with microchannel and pin fin structures were studied by several researchers. Jung and colleague [31] investigated the heat transfer coefficient and friction factor of Al_2O_3–water nanofluid-cooled MCHS. Ho et al. [32] reported the heat transfer performance of MCHS using Al_2O_3–water nanofluid as a coolant. Roberts and Walker [33] studied the heat transfer performance and pressure drop characteristics of Al_2O_3–water nanofluids flowing in commercial electronics cooling systems. Jasperson et al. [34] reported on the thermal performance, hydraulic performance, and cost of manufacturing of micro channel and micro pin fin heat sinks. Escher and colleagues [35] presented the heat transfer characteristics and flow behavior of SiO_2–water nanofluids flow in three different channel widths MCHS. Fazeli et al. [36] and Kalteh and colleagues [37] investigated the heat transfer performance of a miniature heat sink using nanofluids as coolant both experimentally and numerically. Selvakumar and Suresh [38] presented the heat transfer performance and pumping power of the CuO–water nanofluid flowing through MCHS under a turbulent flow regime. Nitiapiruk et al. [39] investigated the cooling performance and pressure drop characteristics of nanofluid-cooled MCHS under laminar flow regime. And, Naphon and Nakarintr [40] studied the thermal performance of TiO_2–water nanofluid flowing through a heat sink with different mini-rectangular fin structures.

As mentioned above, many researchers have reported that the nanofluid-cooled heat sink with microchannel and pin fin structures show significant heat transfer enhancement with small or no penalty drop in pressure. Even though there was significant research on the thermal and flow characteristics of nanofluid-cooled heat sinks, most researches have been restricted to the numerical approach. For experimental approach, few articles was conducted. So far, the present study aims to evaluate the thermal and hydraulic performance of two different types of nanofluid flowing through a heat sink with miniature circular pin fin structure and having small flow channel, experimentally. SiO_2 and ZnO nanoparticles with volume concentration of 0.2, 0.4 and 0.6 vol.% are used as coolant and then compared with the data for water. Heat sink made from aluminum material with a mean hydraulic diameter of 1.2 mm (for each flow channel) and heat transfer area of 1430 mm^2 is used as the test section. The effects of particle type, particle concentration, and flow rate on the thermal and hydraulic performances are presented. Moreover, new heat transfer and pressure drop correlations are proposed in a more convenient form for calculating the Nusselt number and the pressure drop of nanofluids flow in heat sinks with pin fin structure.