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Experimental analysis of energy and friction factor for titanium dioxide nanofluid in a water block heat sink

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ABSTRACT

Heat dissipation is a critical issue in modern electronic components, due to the technological advances that have reduced their size and caused their heat flux to rise. Different types of heat sinks are promising for cooling of such electronics and nanofluid can enhance the cooling performances. In this present work, a titanium dioxide (TiO_2/water) nanofluid (with a volume fraction of 0.1%) is prepared by dispersing nanoparticles in distilled water. The nanofluid is then passed through the heat sink at various flow rates (1.00, 1.25, and 1.50 L/min). The interface temperature of the water block was reduced up to 6.40 °C by using the nanofluid, as compared to water. Due to the decline of interface temperature the heat transfer coefficient was improved by 20.82% compared to water. The maximum energy efficiency found 77.56% for nanofluid. Therefore, the titanium dioxide nanofluid is a superior coolant than pure water. Moreover, the heat transfer effectiveness and energy effectiveness were found highest at the minimum flow rate of 1.00 L/min.

1. Introduction

Advances in technology and consumer demands are driving electronics industries to create new designs with a higher level of integration, compactness, and performance. As a result, the need to dissipate the heat generated by these electronic devices and circuitry, to prevent premature failure and improve reliability, has also been elevated. Researchers have introduced the liquid cooling system for electronics items, and nanofluids are promising to increase the heat dissipation rate of these systems.

A pioneering analytical study by Ijam and Saidur [1] reported the effect of using TiO_2–water and SiC–water nanofluids on heat flux and pumping power of a minichannel heat sink. Selvakumar and Suresh [2] conducted experiments with a thin channeled copper water block having the overall dimension of 55 × 55 × 19 mm. A 29.63% higher convective heat transfer coefficient (HTC) was observed by using the nanofluid composed of 0.2 vol.% of copper oxide mixed with water, compared to deionized water alone. Similarly, Jung et al. [3] observed up to 32% higher convective HTC compared to distilled water (in a laminar flow regime) without significant friction loss for the nanofluid composed of 1.8% volume fraction of an aluminum oxide (Al_2O_3) mixed in water. Pak and Cho [4] measured the convective HTC of aluminum oxide (γ-Al_2O_3) and titanium dioxide (TiO_2) nanoparticles dispersed in water. Their experimental results showed that the HTC increased in direct proportion to the volume fraction of nanoparticles and the Reynolds number of the nanofluid. Abbasi et al. [5] studied the influence of Cu–water nanofluid in a microchannel heat sink (MCHS). The thermal dispersion coefficient and Reynolds number on thermal fields were investigated. Moreover, the impact of flow turbulence on the heat transfer rate was considered. They found that the overall Nusselt number was increased with increasing nanoparticle concentration, thermal dispersion coefficient, and Reynolds number.

Nguyen et al. [6] experimentally studied the heat transfer enhancement behavior of a nanofluid (aluminum oxide mixed with water) for cooling the microprocessors. A maximum of 40% HTC was found to be increased compared to water. Mohammed et al.

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Nomenclature

A	area (m^2)
C	heat capacity rate (kW/K)
c_p	specific heat (J/kg·K)
D_h	hydraulic diameter of the fluid flow (m)
f	friction factor
H	height (mm)
h	heat transfer coefficient ($W/m^2 \cdot K$)
HTC	heat transfer coefficient ($W/m^2 \cdot K$)
k	thermal conductivity (W/m·K)
L	length (mm)
L	liter
$\dot{m}$	mass flow rate (kg/s)
N	number of channel
Nu	Nusselt number
$\dot{Q}$	total heat dissipation from heater (W)
Re	Reynolds number
R_{th}	thermal resistance (K/W)
P_p	pumping power (W)
ΔP	pressure drop (N/m^2)
T	temperature (°C)
f	friction factor
V	volume flow rate (L/min)
W_{ch}	channel width (mm)

Greek symbols

ε	effectiveness
ρ	density (kg/m^3)
μ	viscosity (Ns/m^2)
η	efficiency (%)
ϕ	particle volume concentration (%)

Subscript

av	average
b	base of the heat sink
ch	channel
e	environmental
f	fluid
hs	heat sink
nf	nanofluid
in	inlet
m	mean
out	outlet
tc	thermocouple
ht	heat transfer
nf	nanofluid
p	nanoparticle

[7] numerically studied the heat transfer and fluid flow characteristics in a rectangular-shaped MCHS with the dimension of 10 mm in length, 280 μm of channel width and 430 μm of channel height using an alumina–water nanofluid. They observed that nanofluids with 5 vol.% do not increase the heat transfer rate appreciably more than the pure water. Xie et al. [8] found an increase in the HTC when Cu–water nanofluid was used in a brass tube with an inner diameter of 10 mm. Khaleduzzaman et al. [9] analyzed the thermal performance of a rectangular-shaped MCHS using various nanofluids: aluminum oxide and water, silicon carbide (SiC) and water, and copper (II) oxide and water. They found that the highest heat flux improvement (8.51% compared to pure water) occurred for 4% volume fraction of copper (II) oxide and water nanofluid (at 0.5 m/s flow rate). The aluminum oxide and silicon carbide based nanofluids showed 6.44% and 5.60% improvements, respectively. Some more studies observed significant improvement of HTC. Ho et al. [10] studied the thermal performances of a copper MCHS by using Al_2O_3–water nanofluid. They observed about 70% higher HTC for 1 vol.% of the nanofluid compared with water. Nazari et al. [11] studied the thermal performances of CPU cooling using nanofluids and found 13% higher HTC for CNT nanofluids with 0.25 vol.%. Khaleduzzaman et al. [12] observed 18.91% higher HTC for 0.1 vol.% of TiO_2–water nanofluid in a rectangular water block heat sink.

Most nanofluid studies applied to cooling electronics systems have focused on thermal performance area. Energy, friction factor, and waste heat analysis in electronic systems are generally not considered. However, to achieve improved performance, it is important to optimize a system's energy utilization and waste heat recovery. Hot water has been proposed for cooling an electronic data center, to achieve a high system exergetic utility. Jeng and Teng [13] developed a hybrid cooling system by using Al_2O_3–water nanofluid and hydrocarbon refrigerant for the cooling of a CPU. They observed greater heat dissipation and a lower surface temperature on the heater for the nanofluid instead of distilled water. Kahani et al. [14] showed the improvement of heat transfer by using the dual method of helical coils and nanofluids, which caused an enhancement of energy efficiency. They applied water with Al_2O_3 (35 nm) and TiO_2 (50 nm) nanoparticles (0.25–1.0% volume fractions). Hamut et al. [15] studied the performance of a coolant circuit in a vehicle. Second thermodynamic law analysis was used to examine areas on the system with low exergy efficiencies. Zaki et al. [16] used second law analysis in a water-chiller cooler that was used to cool the intake air in gas turbines. An average of 8.5% exergetic power gain ratio was dropped. Khaleduzzaman et al. [17] studied the exergy and entropy generation in a water block operated with 0.10 vol.% of TiO_2–water nanofluid and changed the flow rate from 1.0 to 1.5 L/min. They observed a maximum of 39.63% exergy efficiency enhancement.

In this research, the thermal performance of a titanium dioxide nanofluid with a thin-channeled water block was experimentally measured and analyzed. The base temperature difference, thermal resistance, heat transfer coefficient, heat transfer effectiveness, Nusselt number and Reynolds number variation, energy efficiency, energy effectiveness, friction factor, pressure drop, pumping power, and performance index are calculated and compared to water. These comparative results were used to define the cooling performance of the titanium dioxide nanofluid.

2. Methodology

2.1. Experimental setup

The schematic diagram of the experimental set-up is shown in Fig. 1. This Fig. 1 shows a closed-loop electronics cooling system, consisting of a water block heat sink, cooling fluid loop and data-acquisition system. The connections within the piping system and test section are designed so that the parts can be changed or repaired easily. The closed loop consists of the storage tank, pump, volumetric flow meter, and an air cooled radiator.

The process begins by filling the storage tank with the working fluid (at ambient conditions). A pump (model: XSPC X20 750) is