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Thermal performance of a heat sink microchannel working with biologically produced silver-water nanofluid: Experimental assessment

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ABSTRACT

Thermal performance of a copper-made heat sink with rectangular microchannel was assessed within laminar flow regime. Silver nanoparticles were synthesized and dispersed into the deionized water as a potential coolant. Pressure drop, friction factor, heat transfer coefficient and fouling thermal resistance parameter of the system were experimentally investigated for mass concentrations of 0.01%, 0.05%, and 0.1%. Results showed that the heat transfer coefficient of the microchannel is enhanced when deionized water (as a traditional coolant) is replaced with the nanofluid. Importantly, a small increase in pressure drop, friction factor and fouling thermal resistance parameter were reported when nanofluid is used in the system. With an increase in the flow rate and mass concentration of nanofluid, the heat transfer coefficient and pressure drop of the Microchannel Heat Sink (MCHS) increased. Likewise, the local heat transfer coefficient and overall thermal resistance of the microchannel decreased along with the length of the microchannel. The highest heat transfer coefficient (as a thermal performance index) was also seen in the entrance region of the microchannel. The highest value for the fouling thermal resistance parameter was observed for the highest mass concentration of nanofluid which was 1.07 for wt.% = 0.1. The flow rate of fluid was found to enhance the fouling thermal resistance parameter over the 1000 min of the operation. Despite the enhancement in the fouling thermal resistance parameter and friction factor, there was an optimum concentration for silver-water nanofluid in which the overall thermal performance of the system was maximized such that the overall thermal performance of the system can be enhanced up to 37% at Reynolds number 1400 and at wt.% = 0.05.

1. Introduction

With a continuous development in computer and microelectronic processors, fabrication of microelectronic chips and processors that can solve billions of commands has been accelerated [1–5]. These processes generate significant heat dissipation of more than 100 W/cm^2, which require an especial cooling system for controlling the temperature, operation and processor life time. Microchannel Heat Sinks (MCHS) are one of the heat transfer intensifying tools with high surface area to volume ratio for cooling the micro-devices [4,6,7]. MCHS enable one to transfer a significant amount of heat with the help of high surface area exposed to a convective heat transfer. To achieve this, air, water or ethylene glycol has been recognized to be a suitable coolant for microchannel heat sinks [8]. However, due to the demands for designing the superior processors, these coolants have reached their limitations as their thermal conductivity is limited (e.g. 0.65 W/m.°C). Thereby, there is a need to introduce a new coolant to intensify the convective cooling process inside the MCHSs [9].

Nanofluids are new-engineered coolants and colloidal suspensions comprising conductive solid particles (e.g. metallic particles) with a nominal size of 0–100 nm dispersed in conventional coolants (e.g. water or ethylene glycol). Generally, it is accepted that in the presence of solid nanoparticles, thermo-physical properties of the conventional coolant are considerably improved [10–13]. The most striking one is thermal conductivity and heat capacity. Therefore, extensive studies have been conducted to investigate the potential application of nanofluids in cooling systems to achieve higher thermal performance in comparison with the conventional coolants [14–21]. For example, Tuckerman and Pease [22] introduced a microchannel for cooling process of a processor, in which microchannel offered a higher surface area for the heat transfer. They demonstrated that thermal performance is higher than conventional coolers however, higher values of pressure drop is seen when a particulate working fluid are used as the working fluid. Since Choi et al. [23] introduced the application of nanofluid in cooling systems, especial attention was paid to nanofluids. For example, Choi et al. [24] conducted a numerical study to investigate the cooling

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Nomenclature

A	Area, m^2
C_p	kJ/kg °C
d	hydraulic diameter, m
H	height of microchannel, m
I	current, A
k	thermal conductivity, W/m °C
l	length, m
m	a constant, see data reduction section
$\dot{m}$	mass flow rate, $kg/m^2 s$
N	number of channels
Q	heat, W
Q”	heat flux, kW/m^2
R_f	fouling thermal resistance parameter of microchannel (m^2 °C/kW)
R_{th}	thermal resistance of microchannel (°C/W)
s	distance between thermocouple and wall of microchannel, m
T	temperature, °C
V	voltage, volt
W	width of microchannel, m
z	axial distance, m

Subscriptions

av.	average
b	bulk
in	inlet
Conv.	convection
out	outlet
th	thermocouple
w	wall
z	axial

Greek letters

η	Fin efficiency
ρ	density, kg/m^3
ν	fluid flow rate, m/s
μ	cP

performance of a microchannel heat sink with nanofluids. They introduced a theoretical model for Brownian motion and showed that temperature and thermal resistance of a microchannel heat sink are decreased if nanofluid is used in the system. They assessed the performance of the system for diamond nanofluid at 1 vol%. However, they ignored the role of stability and nanoparticle deposition inside the microchannel heat sink, which can deteriorate the rate of heat transfer.

Later, the performance of MCHS using nanofluids was investigated by Chein et al. [25]. They performed a theoretical analysis, followed by an experimental investigation. In their theoretical model, it was shown that more heat dissipation and lower temperature in walls of the MCHS is seen, which shows better thermal performance. They attributed the findings to the presence of nanoparticles in the base fluid and enhancement of thermal conductivity. Then experiments were then performed to verify the theoretical predictions. CuO/water was used at volume fractions of 0.2–0.4%. It was found that MCHS with nanofluid absorbs more energy than water-cooled one when the flow rate was low. The measured wall temperature variations agreed with the theoretical predictions for low flow rate. However, for high flow rate, the measured MCHS wall temperatures did not completely agree with the theoretical prediction due to the particle agglomeration and deposition.

Xie et al. [26,27] performed a numerical study to investigate the thermal performance of a rectangular mini-channel heat sink under a constant heat flux for different dimensions and geometrical properties. They showed that geometrical properties such as cross section, dimension and size of channel played a critical role in the enhancement in pressure drop and thermal performance. However, deposition of nanoparticles were not considered in the simulations. Ijam et al. [28] conducted an investigation on the thermal performance of a microchannel cooling system working with silicon/water and titanium/water nanofluids. They found out that silicon nanoparticles presents higher thermal conductivity in comparison with titanium. However, they did not report any adverse effect of nanoparticle deposition or agglomeration on the overall thermal performance of the microchannel. Chai et al. [29–31] performed a study on the effect of the microchannel structure. They showed that an increase in heat transfer area and structure of MCHS changes the fluid flow and heat transfer mechanism towards the heat transfer improvement. Interestingly, there are studies such as [32]

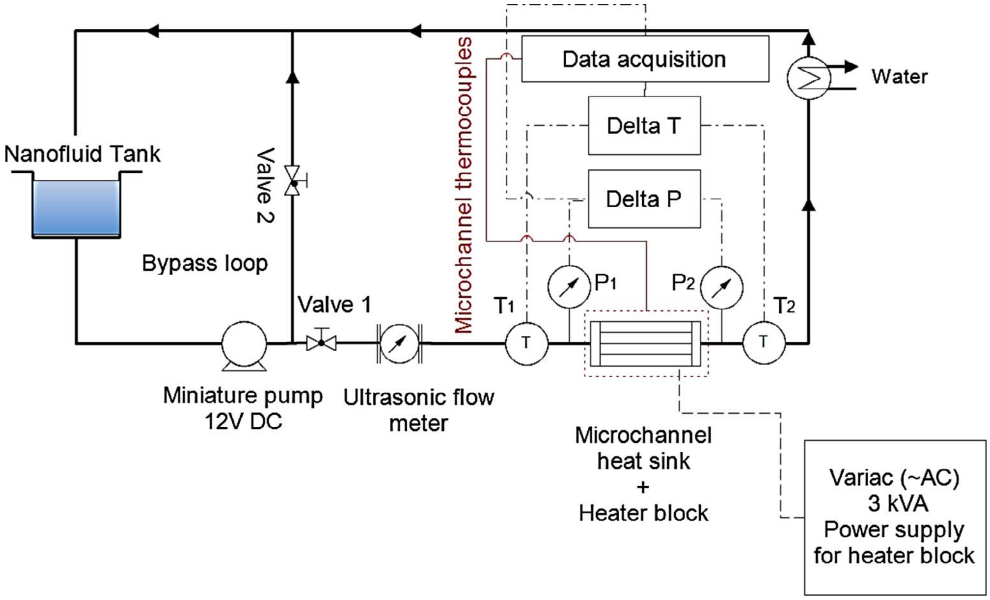

Fig. 1. Experimental setup.