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Continuous nanofluids jet impingement heat transfer and flow in a micro-channel heat sink

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ABSTRACT

Experimental investigation on the TiO_2 nanofluids jet impingement heat transfer and flow characteristics in the micro-channel heat sink are carried out. In the present study, three heat transfer enhancement techniques; micro-channel heat sink, jet impingement, and nanofluids are considered in which included the effect of relevant parameters of the nanofluids concentration, nozzle diameter, nozzle-to-heat sink distances, mass flow rate of nanofluids on the heat transfer performance of a micro-channel heat sink are considered. The obtained results showed that the suspending of nanoparticles in the base fluid remarkably increases the convective heat transfer by 18.56% at 0.015% nanofluids concentration. In addition, the obtained heat transfer coefficient tends to increase with increasing the nozzle diameter and decreasing nozzle level height. While the pressure drop across the test section increases as the nozzle diameter decreases and nozzle level height increases. However, the suspending of nanoparticles bring almost no extra addition of pressure drop as comparing with the base fluid. However, the obtained results point out that the proper selection of the relevant parameters to enhancement of heat transfer is important.

1. Introduction

Due to high-density electronic components, small scale of electronic devices, and high generated heat rate, the dissipation of the generated heat is a momentous embarrassment. Therefore, many innovative ideas have been proposed for thermal cooling enhancement in the electronic devices. The most common heat transfer enhancement technique is the miniaturized technology, mini and micro-components with jet impingement technique for the electronic devices. There are some studies on the jet impingement heat transfer in the various configurations heat sink. For example, Naphon et al. [1,3] experimentally and numerically investigated the heat transfer characteristics of the jet liquid impingement with three different configurations heat sinks for the central processing unit of a personal computer. Effects of outlet port positions on the jet liquid impingement heat transfer characteristics. Yang and Lai [2,4] numerically studied the forced convection flow of Al_2O_3-water nanofluid in the radial flow cooling system using a single-phase approach model. Li et al. [5] applied the RANS-based k-u SST turbulence model to analyze the heat transfer and hydrodynamic behavior of various types of water-based nanofluids inside a typical radial flow. Lelea and Laza [6,12] presented the thermal and hydrodynamic analysis of the micro-heat sink with straight microtubes and multiple inlet jets. Dai et al. [7] studied a flow separation technique including pressure drop and heat transfer in the increased flow area. Jaberi et al. [8] studied heat transfer characteristics of nanofluids in the impingement of a fluid jet on a flat circular disk. Trainer et al. [9] experimentally studied the heat transfer performance of air-assisted liquid water jets impingement. Seyf et al. [10] presented a three-dimensional model describing thermal and hydrodynamic characteristics of a micro-tube heat sink. Kurnia et al. [11] evaluated the heat transfer performance of laminar non-Newtonian fluid flow in various configurations of coiled square tubes. Yue et al. [13] analyzed the hydraulic and thermal performances of a manifold micro-channel heat sink with and without nanofluids as working fluids. Xia et al. [14] experimentally and numerically studied the temperature distribution, flow field and pressure drops of the current complex corrugation micro-channel heat sink. Haridas et al. [15] presented the performance evaluation of two type nanofluids in the context of compact channels. Gong et al. [16] numerically studied the structures of micro-channel heat sinks for chip cooling. Srikanth et al. [17] studied on the multi-objective geometric optimization of a PCM based matrix type composite heat sink. Zhang et al. [18] numerically investigated the confined jet array impingement cooling with spent flow distraction

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Nomenclature

A	area, [m^2]
C_p	specific heat, [$kJ\ kg^{-1}\ °C^{-1}$]
h	heat transfer coefficient, [$W\ m^{-2}\ °C^{-1}$]
k	thermal conductivity, [$W\ m^{-1}\ °C^{-1}$]
Nu	Nusselt number, [–]
p	pressure, [Pa]
Pr	Prandtl number, [–]
Q	heat transfer rate, [kW]
T	temperature, [°C]
Greek symbols	
η	viscosity, [Pa s]
ρ	density, [$kg\ m^{-3}$]
ϕ	volume fraction of the nanoparticles, [–]
μ	fluid dynamic viscosity, [$kg\ m^{-1}\ s^{-1}$]
Subscripts	
ave	average
b	bulk
f	base fluid
hs	heat sink
in	inlet
l	liquid
LMTD	log mean temperature difference
m	mixture
n	nozzle
nf	nanofluids
out	outlet
p	particle
s	surface
th	thermal
w	water

using nano-encapsulated phase change material. Barik et al. [19] numerically studied the heat transfer performances of a Al_2O_3 nanofluid jet impinged normal to a protruded surface. Lam and Prakash [20] applied a finite element modeling to analyze the impingement cooling system with Al_2O_3/water nanofluids. Moreira et al. [21] experimentally investigated effect of adding nanoparticles to DI-water on the heat transfer coefficient during flow boiling in tube. Mastiani et al. [22] investigated the laminar mixed convection flow of Cu-water nanofluid using a pressure-based finite volume method. Hasan et al. [23] studied effect of nanoparticles on the electrical and thermal performance of a photovoltaic thermal collector equipped with jet impingement. Bayomy and Saghir [24] investigated the heat transfer characteristics and thermal performance of an ERG aluminum foam heat sink for cooling the Intel core i7 processor by using Al_2O_3-water nanofluid. Narkharintr et al. [25,26] presented the results of the magnetic fields effect and jet-plate spacing to jet diameter ratios on the heat transfer characteristics and pressure drop in a confined single jet impingement of mini-rectangular heat sink using T_iO_2 nanofluids mixture of de-ionized water. Vutha et al. [27] numerically studied the laminar and turbulent in a microchannel jet impingement cooling system with a single slot jet. Most of the previous studies on this area have been carried within the heat transfer enhancement of pin fin heat sinks and car radiator using nanofluids (Ali et al. [28–30]). They have been investigated on the heat transfer enhancement by using various heat transfer enhancement techniques. In addition, the thermal management of electronic devices by heat sinks with various configurations have been also considered (Ali et al. [31,32]). There are some papers presented on the thermal performance enhancement of minichannel and integral fin heat sink with nanofluids (Arshad et al. [33,34]). Arshad et al. [35–38] experimental studied on the thermal performance of various heat sinks configurations with phase change materials for electronic devices cooling.

As mentioned above, the numerous papers presented the study on the jet impingement heat transfer of the conventional coolant including air, water, oil and ethylene glycol mixtures. However, it is well known that the heat transfer capability is limited by the working fluid flow behaviors and thermal physical properties which results in poor heat transfer rate. However, there are many still room to discuss in the micro-channel heat sink especially effect of relevant parameters on the heat transfer enhancement of the system. Therefore, a combined three heat transfer enhancement techniques; jet impingement, nanofluids, micro-channel to the thermal performance of micro-channel heat sink (Copper JIS H1340) are investigated which considered effect of jet-plate spacing (H = 1.0–2.0 mm), jet diameter (D = 0.5–1.5 mm), flow rate (8.75–11.75 g/s), nanofluids concentration (0.001–0.015%vol.), and heat input (120–150 kW/m^2) on the heat transfer characteristics and pressure drop of TiO_2 nanofluids in the micro-channel heat sink.

2. Experimental apparatus and method

2.1. Experimental apparatus

This work primary tries to consider the jet impingement convective nanofluids heat transfer and flow characteristics in the micro-channel heat sink. A schematic diagram of the experimental apparatus is shown in Fig. 1. The facility comprises of a set of ultrasonic bath system, jet impingement cooling nanofluids loop and data acquisition system. The nanofluids after passing through the micro-channel heat sink unit is collected in the collecting tank for a period of time and the fluid mass is measured by an electronic weight scale while the rotameter is only used to monitor the nanofluids flow rate.

2.2. Nanofluids preparation and physical properties calculation

Nanofluids are prepared by Top-down approach in which nanoparticles are suspended in the base fluid (De-ionized water). An averaged particle size of 21 nm and purity > 99.9% of TiO_2 nanoparticles are dispersed in de-ionized water with three different concentrations of 0.005, 0.010, 0.015% by volume. The particles are further dispersed in the suspension using ultra-sonication which break down the alglomerates. Fig. 3 shows the scanning electron microscope (SEM) micrograph of the TiO_2 nanoparticles. However, further stability of nanofluids while experiments are achieved by continuously ultrasonic bath work in 10 min each hour. The physical properties of nanofluids depends on the suspending nanoparticles and the base fluid in which there are many proposed correlations for predicting the nanofluids physical properties. For this study, however, the properties of nanofluids can be