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Effect of jet-plate spacing to jet diameter ratios on nanofluids heat transfer in a mini-channel heat sink

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ABSTRACT

Effect of jet-plate spacing to jet diameter ratios on the jet impingement heat transfer and pressure drop of TiO_2 nanofluids have been presented. The heat sink is fabricated from the aluminum by the wire electrical discharge machine with the length, the width and the base thickness of 50, 50, 3 mm, respectively. The parameters and the ranges under consideration are in the jet-plate spacing to jet diameter ratios ($H/D = 0.8–4.0$), the nanofluids concentrations (0.005–0.015% by volume), and mass flow rates (8–12 g/s). It can be found that the jet-plate spacing to nozzle diameter ratios have significant effect on the temperature and flow behaviors of jet impingement which results in increase turbulent intensity and then higher heat transfer rate. There is reasonable agreement between the predicted results and the measured data and gives average error of 3.34%.

1. Introduction

Higher density electronic components results in higher generated heat and the exceeding maximum allowable temperature of the personal computer or electronic devices. Therefore, the generated heat from these components must be ventilated by the electronic cooling systems. Many innovative ideas have been proposed for heat transfer enhancement in the electronic devices. The most common heat transfer enhancement technique is the miniaturized technology, mini and micro-components for the electronic devices. The development of the miniaturized technology, mini and micro-components has been introduced as one of the heat transfer enhancement techniques. Naphon and Wongwises [1,2] experimentally studied the jet liquid impingement heat transfer characteristics in the mini-rectangular fin heat sink for CPU cooling. In additional, they analyzed effects of outlet port positions on the jet impingement heat transfer and flow phenomena in the mini-fin heat sink by computational fluid dynamics. Dao et al. [3,8] experimental studied the flow boiling heat transfer for four jet impingement on smooth and enhanced surfaces using R134a as working fluid. Wong and Indran [4] numerically studied the fluid flow and thermal characteristics of an air-impinged plate fin heat sink. Yang et al. [5] numerically studied the turbulent fluid flow and heat transfer features of air jet impingement on the rotating and stationary heat sink. Jajja et al. [6,7] studied on the effect of fin spacing and multi walled carbon nanotube nanofluids on the thermal cooling for microprocessor cooling. Huang and Chen [9,11] applied the Levenberg–Marquardt Method to analyze the heat sink module design for obtaining the optimal non-uniform fin widths and heights. Yu et al. [10] studied the heat transfer and flow development of air jet impingement in heat sinks with piezoelectrically-driven agitators. Ali et al. [12] experimentally studied the heat transfer characteristics of nanofluids in the car radiator. Tan et al. [13] experimentally investigated the synthetic and continuous jet heat transfer characteristics. Barrau et al. [14] experimentally studied the effect of the nozzle geometry on the performance of a microchannels cooling system. Byon [15] studied the jet impingement heat transfer characteristics of aluminum foam heat sinks. Lin et al. [16] proposed the optimum design and heat transfer correlation of a mini-radiator with jet impingement cooling. Xia et al. [17] experimentally and numerically studied the fluid flow and heat transfer characteristics in complex structure microchannel heat sink. Ali and Arshad [18,24] studied on the thermal performance of water based rutile, grapheme nanoplatelets and anatase TiO_2 nanofluids in the staggered and inline pin fin heat sink. Friedrich et al. [19] considered effect of volumetric quality on heat transfer and fluid flow characteristics of air-assistant jet impingement. Husain et al. [20] analyzed the thermal performance of a hybrid micro-channel, -pillar and –jet impingement heat sink. Pakhomov and Terekhov [21] numerical studied the flow and heat transfer in a turbulent bubbly jet impingement.

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Nomenclature

A	area, (m^2)
a	acceleration, (ms^{-1})
C_p	specific heat, (kJ kg^{-1} °C^{-1})
C_d	drag coefficient, (–)
d_p	nano-particle diameter, (m)
F	force, (N)
F_{col}	particle-particle interaction force, (Pa m^{-1})
F_d	drag coefficient, (Pa m^{-1})
F_{vm}	virtual mass force, (Pa m^{-1})
f	friction factor, (–)
f_{drag}	drag function, (–)
G	particle-particle interaction modulus, (Pa)
g	gravitational acceleration, (ms^{-2})
h_v	volumetric heat transfer coef., (Wm^{-2} °C^{-1})
h_p	liquid-particle heat transfer coef., (Wm^{-2} °C^{-1})
h	heat transfer coefficient, (Wm^{-2} °C^{-1})
k	thermal conductivity, (Wm^{-1} °C^{-1})
Nu	Nusselt number, (–)
p	pressure, (Pa)
Pr	Prandtl number, (–)
Q	heat transfer rate, (kW)
Re	Reynolds number, (–)
R	thermal resistance, (KW^{-1})
T	temperature, (°C)
V	velocity, (ms^{-1})

Greek symbols

β	friction coefficient, (kg m^{-3} s^{-1})
η	viscosity, (Pa s)
ρ	density, (kg m^{-3})
ϕ	volume fraction of the nanoparticles, (–)
μ	fluid dynamic viscosity, (kg m^{-1} s^{-1})
τ	shear stress, (kN m^{-2})

Subscripts

ave	average
b	bulk
dr	drift
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
x	local

Greek symbols

β	friction coefficient, kg/(m^3 s)
η	viscosity, Pa s
ρ	density, kg/m^3
ϕ	volume fraction of the nanoparticles
μ	fluid dynamic viscosity, kg/ms
λ	thermal conductivity, W/(m °C)

Jeng and Hsu [22] experimentally studied the mixed convection heat transfer on the heated plate with the circular-nozzle synthetic jet. Teamah et al. [23] numerically and experimentally investigated the heat transfer and flow phenomena on the horizontal flat plate using Al_2O_3–water as working fluid. Arshad and Ali [25,26] experimentally studied on the heat transfer and pressure drop of grapheme nanoplateletes and TiO_2 nanofluids in the mini-channel heat sink.

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. It is well known that the thermal conductivity of these coolant are very low which results in poor heat transfer rate. However, there are many still room to discuss in the mini-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, mini-channel to the load-removal performance of mini-channel heat sink are investigated. To optimal heat transfer enhancement, however, effect of jet-plate spacing to jet-diameter ratios on the heat transfer and pressure drop of TiO_2 nanofluids with various concentrations in the mini-channel heat sink are considered.

2. Experimental apparatus and method

A schematic diagram of the experimental apparatus is shown in Fig. 1. The facility comprises of a set of ultrasonic system, jet impingement cooling nanofluids loop and data acquisition system. The jet impingement of nanofluids system consists of a storage tank, magnetic pump, ultrasonic bath, and the flow rate measurement system. The flow rates of the nanofluids are measured by collecting the nanofluids with the precise cylinder for a period of time and the fluid mass is measured by an electronic weight scale. It accuracy is 0.01% of full scale. To measure the pressure drop across the test section, the differential pressure transducer (Yokokawa) is used which it has accuracy of 0.02% of full scale. The type-T copper–constantan thermocouples are employed to measure the inlet and outlet nanofluids temperatures. An accuracy and uncertainty of thermocouple are 0.1% and ±0.1 of full scale, respectively. Data taker DT85 is used to display and collect the temperature outputs. All the thermocouples probes are pre-calibrated by dry-box temperature calibrator (Isotech) with 0.01 °C precision. The schematic diagram of the mini-channel heat sink is shown in Fig. 2 which fabricated from the aluminum by a wire electrical discharge machine (WEDM) with the widths $*$ length of 50 $*$ 50 mm. An AC power supply is used as the source of power for the plate type heaters. In order to minimize thermal contact resistance between the heat sink and the heater plate, a thin thermal interface material with high thermal conductivity is applied at their junction interface (see Fig. 3).

The nanoparticles agglomerates (Titanium dioxide (TiO_2) spherical nanoparticles) with an averaged particle size of 21 nm and purity >99.9% are dispersed in de-ionized water with three different concentrations of 0.005, 0.010, 0.015% by volume. Fig. 2 shows the scanning electron microscope (SEM) micrograph of the TiO_2 nanoparticles. As seen from the SEM image of the sample, the majority of the nanoparticles are approximately spherical shape and in the form of large agglomerates. In experiment process, the nanofluids dispersion can be performed by an ultrasonic bath (DELTA, model DC200/DC200H) for at least 60 min before experiment. However, in order to maintain the stable nanofluids stationary sate during the whole experiment, the ultrasonic bath system