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Magnetic field effect on the enhancement of nanofluids heat transfer of a confined jet impingement in mini-channel heat sink

Lersak Nakharintr, Paisarn Naphon *

Thermo-Fluid and Heat Transfer Enhancement Lab. (TFHT), Department of Mechanical Engineering, Faculty of Engineering, Srinakharinwirot University, 63 Rangsit-Nakhornnayok Rd., Ongkharak, Nakhorn-Nayok 26120, Thailand

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ABSTRACT

The results of the magnetic fields effect on the heat transfer characteristics and pressure drop in a confined single jet impingement of mini-rectangular heat sink have been presented. The test section (heat sink) is fabricated from the brass block by the wire electrical discharge machine with the length $*$ width and the fin height of $50 * 50$ mm and 2 mm, respectively. The nanofluids mixture of de-ionized water and nanoscale TiO_2 particles with various concentrations of 0.005%, 0.010%, 0.015% by volume are used as working fluid. Two different magnetic fields strength of 0.084, 0.28 μT are generated by the Neodymium permanent magnetic bars. It is found that with the magnetic field effect, the Nusselt number tends to increase, compared to that without magnetic field effect, and the Nusselt number also increases with increasing the magnetic field strength. Due to the thin nanofluids concentration in this study, however, the nanofluids concentration has no significant effect on the pressure drop across the test section.

1. Introduction

There are many innovative cooling techniques for heat transfer augmentation in the electronic devices both active and passive techniques to maintain these devices temperature not exceeding maximum allowable temperature which significant effect on the thermal performance and reliability. Effect of magnetic field on the heat transfer characteristics in various systems has been continuously studied. Ming et al. [1] studied the thermal efficiency of the flat plate heat pipe with magnetic fluid as working fluid under magnetic field effect. Rahman et al. [2] analyzed the conjugated heat transfer in a composite channel with trapezoidal cross-section by using the magnetic field as the generated heat source. Aminossadati et al. [3] considered effect of magnetic field on the laminar convective heat transfer and flow characteristics of paramagnetic fluid in a partially heated micro-channel. Teamah et al. [4,5] numerically studied the double-diffusive laminar natural convective heat transfer and flow behavior in an inclined rectangular enclosure with the magnetic field effect. Mousa [6] experimentally studied the convective heat transfer and pressure drop, and thermal performance of pin–fin heat sink unit under magnetic fields effect. Recebli [7] numerically analyzed effect of perpendicularly applied magnetic field on steady state laminar convective heat transfer and friction factor of liquid lithium flow in a horizontal circular pipe. Abd-Alla et al. [8] investigated effect of rotation and initial stress on the peristaltic transport of fourth grade fluid with heat transfer and induced magnetic field effect. Naffouti et al. [9] considered effect of magnetic field direction on the natural convective heat transfer and flow behaviors. Dessie and Kishan [10] studied effects of viscous dissipation on the MHD boundary flow and convective heat transfer over stretching sheet embedded in porous medium. Kaneda et al. [11] studied on the laminar convective heat transfer of paramagnetic fluid in pipe under magnetic field effect. Hameed et al. [12] numerically investigated effect of magnetic field on the convective heat transfer on the peristaltic transport of a fractional second grade fluid in a vertical tube. Akbar et al. [13] considered effect of the induced magnetic field and heat flux on the suspension of carbon nanotubes for the peristaltic flow in a permeable channel. Rashidi and Esfahani [14] applied the finite volume method to analyze the effect of magnetic field on the heat transfer instabilities in a channel with obstacles. Hayat et al. [15,23] studied the inclined magnetic field on the nanofluids heat transfer and flow characteristics with nonlinear thermal radiation. Dhanai et al. [16] analyzed the slip flow and heat transfer of non-Newtonian nanofluids with variable magnetic field strength. Das et al. [17] studied the influence of uniform heat source or sink on nanofluids flow characteristics over a convectively heated shrinking sheet. Mabood et al. [18] considered effects of the variable thermal conductivity, viscous-Ohmic dissi-

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* Corresponding author.
E-mail address: paisarnn@g.swu.ac.th (P. Naphon).

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Nomenclature

A	area, m^2
D_N	nozzle diameter, m
k	thermal conductivity, W/(m K)
m	mass flow rate, kg/s
p	pressure, Pa
Q	heat transfer rate, W
T	temperature, °C
C_p	specific heat, J/(kg K)
h	heat transfer coefficient, W/(m^2 K)
MSF	magnetic field strength, T
Nu	Nusselt number
Pr	Prandtl number
Re	Reynolds number
U	velocity, m/s

Greek symbols

ρ	density, kg/m^3
μ	fluid dynamic viscosity, kg/ms
ϕ	volume fraction of the nanoparticles

Subscripts

ave	average
in	inlet
m	mixture
out	outlet
s	surface
f	base fluid
LMTD	log mean temperature difference
nf	nanofluid
p	particle
w	wall

pation, and non-uniform heat sources on the mixed convective heat and mass transfer of micropolar fluid over a stretching sheet embedded in a non-Darcian porous medium with thermal radiation. Mahmoudi et al. [19] numerically studied the natural convective cooling of nanofluid in two vertical heat sinks under magnetic field effect. Jena et al. [20] analyzed the effect of magnetic field on MHD viscoelastic fluid flow over a porous vertical stretching sheet embedded in a porous medium. Raju et al. [21] considered the free convective heat and mass transfer of MHD non-Newtonian nanofluids flow over a cone of non-uniform heat source/sink. Gireesha et al. [22] numerically analyzed a steady two-dimensional hydromagnetic stagnation-point flow of nanofluids past a stretching surface with induced magnetic field effect. Srinivas et al. [24] studied on the MHD flow of a nanofluids in an expanding or contracting porous pipe with chemical reaction and heat source/sink. Maity et al. [25] studied the unsteady three dimensional flow of Casson liquid film over a porous stretching sheet under uniform transverse magnetic field effect.

As mentioned above, the numerous papers presented the heat transfer and flow characteristics of nanofluids in the mini-and micro-channel with wide variety of nanoparticles types. However, there are not papers presented the heat transfer augmentations both the active method and the passive method. Therefore, the purpose of this paper is to study in four heat transfer enhancement techniques (Mini-fin heat sink, jet impingement, magnetic field effect and nanofluids methods) in the mini-channel heat sink. The obtained results are compared with those without the magnetic field effect. The relevant parameters on the heat transfer characteristics and pressure drop are considered.

2. Experimental apparatus and method

2.1. Experimental apparatus

As illustrated in Fig. 1, a schematic diagram of the present study is consisted of the test section (a mimi-channel heat sink unit), magnetic field system, an ultrasonic bath system, nanofluids coolant loop and data acquisition system. The coolant nanofluids close loop consists of a magnetic pump, weight scale system, an ultrasonic bath system. The homogeneous nanofluids temperature is adjusted to the desired level and controlled by temperature controller in the cold water tank. After the obtained homogeneous nanofluids temperature, it is pumped out of the ultrasonic bath by the magnetic pump into the mini-channel heat sink (test section) and then flow return to the ultrasonic bath. The nanofluids flow rate is controlled by adjusting the valve and measured by the collecting the nanofluids with the precise cylinder for a period of time during 10 min and the fluid mass is measured by an electronic weight scale with 0.01% of full scale of accuracy. The temperature of cold water is maintained by the cooling system of R134a refrigeration system.

2.2. Test section

As shown in Fig. 2, the mini-channel heat sink is fabricated from the brass block with the length $*$ width and the fin height of 50 $*$ 50 mm and 2 mm, respectively. The supplied heat to the back wall of the heat sink can be done by the electric heater plate and then covered with the insulator mica plate, Aeroflex sheet, respectively. Type T copper-constantan thermocouples with accuracy of ±0.10 of full scale are used to measure the coolant inlet and outlet temperatures while the heater temperature distributions are measured by mounting on the back wall and fixed with special glue. The mini-channel heat sink is installed between two layers of permanent magnetic as shown in Fig. 3. The nanofluids flows into the test section by a single jet impingement with 2 mm nozzle diameter in the normal direction at the central zone and flows distribution through the fins unit and then flows out at the four corners of the test section. The DT85 data taker is used to display the thermocouple outputs which it is pre-calibrated to measure the temperature with accuracy of ±0.10 over the range of 10–90 °C. In addition, all the thermocouples are pre-calibrated by dry-block temperature calibrator with 0.01 °C precision. The YOKOKAWA differential pressure transmitter with the accuracy of ±0.02% of full scale is employed to measure the static pressure drop across the test section.

2.3. Nanofluids preparation

The coolant used in the present study is the nanotitanium (TiO_2) nanofluids with three different concentrations of 0.005%, 0.010% and 0.015% by volume which has an average particle size of 21 nm and purity >99.9%. To obtain stable nanofluids, the stirring process by ultrasonic bath has continuously done for 1 h., To be the stability and homogeneous nanofluids, the stationary state of nanofluids suspensions is maintained by ultrasonic bath system run for 10 min each hour during the whole experiment process.