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Experimental study on laminar pulsating flow and heat transfer of nanofluids in micro-fins tube with magnetic fields

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ABSTRACT

A combined heat transfer enhancement techniques: pulsating flow, nanofluids, micro-fins tube, and magnetic field on the heat transfer and flow characteristics in the micro-fins tube are investigated. Experiments are performed under conditions of nanofluids Reynolds number varying from 1000 to 2400 and nanofluids concentrations of 0.25%, 0.50% by volume. The inlet nanofluids and uniform wall heat input are 20 °C, and 120–160 W, respectively while the nanofluids frequency pulsating flow through the test section is 10–20 Hz. The results obtained from the micro-fins tube with magnetic field are compared with those without magnetic field and those from the smooth tube with and without magnetic fields. It can be seen that a combined heat transfer enhancement techniques are a good potential to improve the thermal performance of thermal devices. The pulsating flow and magnetic field have an advantage on the Brownian motion of nanoparticles in the base fluid flowing through the system. Results show that the heat transfer enhancement increases significantly with increase in nanoparticle concentration, magnetic field strength, and with the pulsating frequency. However, they are slightly effect on the pressure drop.

1. Introduction

In generally, the heat transfer enhancement techniques are classified into two groups; passive and active techniques. Passive techniques employ special surface geometries, or additive for enhancement while active techniques require external power, such as electric acoustic fields and surface or/and fluid vibration. The thermal cooling enhancement of the cooling system is seriously issue to maintain these devices run in design temperature region. There are many papers presented on the heat transfer enhancement by various techniques. Al-Haddad and Al-Binally [1] predicted the pulsating heat transfer coefficient. Takahashi et al. [2] investigated the two-phase pressure drop and heat transfer of a helium-lithium flowing in a circular channel with a uniform transverse magnetic field. Sellers and Walker [3] predicted effect of magnetic field on the flow behavior of a liquid-metal flowing through a rectangular duct. Habib et al. [4], proposed the correlation for predicting the heat transfer coefficient of the turbulent pulsating air flows. Ghasemi et al. [5] examined the natural convective heat transfer of nanofluids in an enclosure with magnetic field effect. Hamad and Pop [6] investigated the unsteady magneto-hydrodynamic flow of a nanofluids past an oscillatory moving vertical permeable semi-infinite flat plate. The most productive studies have been continuously carried out by Sheikholeslami et al. [7,9,11,16,20,24,33]. They numerically investigated the forced convective heat transfer of nanofluids in a concentric annulus between a cold outer square and heated inner circular cylinders and enclosures in the presence of static radial magnetic field. In addition, they also applied the finite element method to analyze the natural convection heat transfer of Cu–water s in a cold outer circular enclosure containing a hot inner sinusoidal circular cylinder and a half-annulus enclosure with the presence of the magnetic field. Rahgoshay et al. [8], studied the pulsating nanofluids flow and heat transfer behaviors in a circular tube. Effect of magnetic fields on the heat transfer enhancement are continuously performed by many researchers [10,12–15]. They analyzed the effect of magnetic field effect on the heat transfer enhancement in various systems. Jajja et al. [17,18], considered effect of fin spacing and multi walled carbon nanotube nanofluids on the thermal cooling for microprocessor cooling of personal computer. Malvandi et al. [19,22], theoretically investigated the laminar flow and convective heat transfer of water/alumina nanofluids inside a parallel-plate channel in the presence of a uniform magnetic field. Arizian et al. [21], studied effect of external magnetic field on the laminar heat transfer and flow characteristics of magnetite nanofluids.

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Nomenclature

A	surface are [m^2]
C_p	specific heat [$kJ\,kg^{-1}\,°C^{-1}$]
D	tube diameter [m]
f	friction factor [–]
h	heat transfer coefficient [$kW\,m^{-2}\,°C^{-1}$]
k	thermal conductivity, [$kW\,m^{-1}\,°C^{-1}$]
I	electrical current [A]
L	tube length [m]
m_{nf}	nanofluids mass flow rate [$kg\,s^{-1}$]
Nu	Nesselt number [–]
P	pressure [$kN\,m^{-2}$]
Pr	Prandtl number [–]
Q	heat transfer rate [kW]
Re	Reynolds number [–]
T	temperature [°C]
U	velocity [$m\,s^{-1}$]
V	voltage [V]

Greek symbol

ϕ	nanofluids concentration, %
ρ	density, kg/m^3
μ	viscosity, kg/ms

Subscripts

ave	average
in	inlet
nf	nanofluids
p	particles
out	outlet
w	water

Goharkhah and Ashjaee [23,27,30,37] numerically investigated the forced convective heat transfer of water based Fe_3O_4 nanofluids in the presence of an alternating non-uniform magnetic field. Ali et al. [25], experimentally studied the heat transfer characteristics of nanofluids in the car radiator. Sheikhnejad et al. [26], considered effect of different magnetic field distributions on laminar nanofluids heat transfer in the horizontal tube. Heidary et al. [28], numerically analyzed the heat transfer and nanofluids flow in a straight channel and micro-channel under magnetic field. Fakoura et al. [29] applied the least square method to analyze the laminar fluid flow and heat transfer in channel with permeable walls in the presence of a transverse magnetic field. Ganguly et al. [31] considered the heat transfer characteristics of thermally developing MHD flow of nanofluids through micro-channel. Hedayati et al. [32], considered fully developed convective heat transfer of nanofluids in micro-channel. Ali and Arshad [34,35] 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. Mousavi et al. [36], numerically analyzed the influence of magnetic field effect on the thermal performance of sinusoidal two-tube heat exchanger. Asfer et al. [38], investigated effect of magnetic field on the convective heat transfer and flow behaviors of ferrofluids flowing through the circular stainless steel tube. Arshad and Ali [39,40] experimentally studied on the heat transfer and pressure drop of grapheme nanoplateletes and TiO_2 nanofluids in the minichannel heat sink. Recently, Naphon et al. [41–43], considered effect of magnetic field on the continuous and pulsating nanofluids flowing through the spirally coiled tube and mini-channel heat sinks.

A review of the pertinent literature indicates that there are many papers presented the numerically studied on heat transfer characteristics of nanofluids with and without magnetic field effect. However, there is not research paper reported effect of magnetic field strength on the pulsating flow and heat transfer characteristics of nanofluids and there is still room to discuss, especially experimental study. Therefore, the objective of this paper is to study the effects of nanofluids, micro-fins tube, magnetic field and pulsating flow on the convective heat transfer and pressure drop of nanofluids flowing through the micro-fins tube. The results are compared with those from the continuous flow with and without magnetic field and those from the smooth tube.

2. Experimental method

Fig. 1 shows a schematically experimental apparatus which mainly comprises of a micro-fins tube test section unit, magnetic field system, peristaltic pump system, an ultrasonic bath system, nanofluids coolant loop and data acquisition system. The continuous nanofluids flowing through the micro-fins tube in the closed system is done by the magnetic pump while pulsating flow of nanofluids can be performed by the Longer peristaltic pump (YZ1515X) by squeezing the silicone tube of the three rollers. The peristaltic pump system comprises of peristaltic pump head, silicone tubing, coupling mechanism, inverter, and AC motor drive 3/4hp. The rotation speed of a shaft of the three rollers is measured by the portable tachometer (Testo 470). The inlet nanofluids temperature before entering the test section is controlled by cold water tank which maintained constant by R134a refrigeration cooling system. The nanofluids flow rate is 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.

Working fluids, two different nanofluids concentrations of 0.25%, and 0.50% by volume are stirred by ultrasonic bath system (DELTA, model DC200/DC200H). Due to cheap, a safe material, and excellent chemical and physical stability, the titanium dioxide nanoparticles with purity >99.9% are used for this study. Fig. 4 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. Before experimental process, the stirring process by ultrasonic bath has continuously performed for 1 h until the stable nanofluids is achieved. In order to maintain the stable nanofluids stationary sate during the whole experiment, however, the ultrasonic bath system has been stirred for 10 min each hour. For the physical properties of nanofluids, there are many proposed correlations for predicting. However, in this study, the proposed correlations of researchers [44–47] are used to calculate the nanofluids properties as following.

$$\rho_{nf} = \varphi\rho_p + (1-\varphi)\rho_w \tag{1}$$

$$(\rho C_p)_{nf} = \phi(\rho C_p)_p + (1-\phi)(\rho C_p)_w \tag{2}$$

$$\mu_{nf} = (1+2.5\phi)\mu_w \tag{3}$$

$$k_{nf} = \left[\frac{k_p + 2k_w - 2\phi(k_w - k_p)}{k_p + 2k_w + \phi(k_w - k_p)}\right]k_w \tag{4}$$

The details of the micro-fins tube test section unit and the thermocouple setup for measuring the temperature distributions is shown in Fig. 2. The details of the test section of the micro-fins