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Magnetic field effect on the nanofluids convective heat transfer and pressure drop in the spirally coiled tubes

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ABSTRACT

The experimental study has been performed on the convective nanofluids heat transfer characteristics and pressure drop in the spirally coiled tubes under the magnetic fields effect. The nanofluids flows into the spirally coiled tube at the innermost coiled turn and flows along the constant tube wall temperature and then flows out the test section at the outermost coiled turn. Three different magnetic fields strength of 0.12, 0.18, 0.23 μT are generated by the permanent external magnets. Effects of curvature ratios, nanofluids concentration and magnetic fields strength on the heat transfer and pressure drop are discussed. The obtained results are compared with the experiment without magnetic field under same condition which shows that the magnetic field effect increases the Nusselt number up to 16.97%, 25.83%, 31.15% for the magnetic fields strength of 0.12, 0.18, 0.23 μT, respectively. However, the enhancement of the pressure drop is slightly significant for under the magnetic field effect.

1. Introduction

Nanofluids, curved tube and magnetic field, three of the methods for the heat transfer enhancements are applied to change coolant transport properties and flow features of coolant in the system. The thermal cooling enhancement for electronic devices is seriously issue to maintain these devices run in design temperature region. There are many paper presented the heat transfer enhancement which almost works are concerning with the effect of magnetic field (MHD) on the hydrodynamics of working fluid with suspending nanoparticles (Ferrofluids and non-ferrofluids). Lian et al. [1] considered the external magnetic field effect on the temperature distribution and fluid flow in the miniature automatic energy transport device. Aminfar et al. [2,8] simulated the hydrodynamics and thermal behavior of ferrofluid flow in a vertical tube under a non-uniform magnetic field. It was found that the negative gradient magnetic field has significant effect on the heat transfer enhancement. Pakdaman et al. [3] investigated the overall performance of MWCNT and heat transfer characteristics of oil nanofluids with different concentrations flowing inside the vertical helically coiled tubes. Hina et al. [4] studied the heat and mass transfer behaviors in the peristaltic transport of Johnson–Segalman fluid in a curved channel with flexible walls. Sundarn and Singh [5] reviewed the convective heat transfer and friction factor correlations of nanofluids in a tube and with inserts. Hoquea and Alamb [6] numerically studied effect of the Magnetohydrodynamics incompressible viscous fluid flow in a curved pipe by using spectral method for the numerical simulation. Azizian et al. [7] investigated the influence of the strength and uniform of an external magnetic field on the convective heat transfer and pressure drop. It can be found that higher enhancement in the convective heat transfer can be achieved by increasing the magnetic field strength and gradient. Hajiani and Larachi [9] applied the magnetic field on the mixing of nanofluid in the separation and drug delivery system. Noreen et al. [10] numerically studied on the temperature and mass distributions of the peristaltic nanofluids flow in a curved channel under magnetic field. Kabeel et al. [11] presented the works concerning the application of magnetohydrodynamics in the medicine and engineering. Fakoura et al. [12] studied the effect of a transverse magnetic field on the laminar convective heat transfer in the permeable walls channel by using the least square method. Bahiraei and Hangi [13] summarized the works investigation on the effect of magnetic field on the nanofluids heat transfer, boiling and condensation processes and flow phenomena including their practical applications. Hayat et al. [14,15] studied the velocity and temperature distributions of fluid in the curved channel under magnetic field effect. Goharkhah et al. [16] considered the effects

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Nomenclature

C_p	specific heat, kJ/kg °C
C_r	curvature ratio
D	tube diameter, m
De	Dean number
k	thermal conductivity, kW/(m °C)
m_{nf}	nanofluids mass flow rate, kg/s
MFS	magnetic field strength, μT
Nu	Nesselt number
p	pressure, kN/m^2
Pr	Prandtl number
Q	heat transfer rate (kW)
r	radius, m
Re	Reynolds number
T	temperature, °C
V	velocity, m/s

Greek symbol

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

Subscripts

ave	average
c	curve
in	inlet
max	maximum
nf	nanofluids
p	particles
out	outlet
wall	wall
w	water

of magnetic field strength and frequency on the laminar convective heat transfer characteristics of ferrofluid in the uniform heated parallel plate channel. It can be found that the heat transfer rate were directly proportional with Reynolds number, ferrofluid concentration and magnetic field strength.

A review of the pertinent literature indicates that there are many papers presented the heat transfer characteristics of nanofluids in the curve tube with and without magnetic fields and study only one heat transfer enhancement technique for the problem analysis. In addition, there is not research paper reported effect of magnetic field strength on the heat transfer and hydrodynamics of nanofluids in the spirally coiled tube. Therefore, the objective of this paper is to study the effects of three different heat transfer enhancement techniques; nanofluids, curved tube and magnetic field strength on the convective heat transfer and pressure drop of TiO_2 nanofluids flowing through the spirally coiled tube with different curvature ratios under constant wall temperature.

2. Experimental method

2.1. Experimental apparatus

As illustrated in Fig. 1, a schematically experimental apparatus is consisted of a spirally coiled tube unit, magnetic field system, an ultrasonic bath system, nanofluids coolant loop and data acquisition system. The close-loop of the coolant nanofluids consists of a magnetic pump, weight scale system, an ultrasonic bath system. After the obtained homogeneous nanofluids by the ultrasonic bath system, it is pumped out of the ultrasonic bath by the magnetic pump into the cooling coil which submerged in the cold water tank to control inlet nanofluids temperature and flow through the rotameter, test section and then flow return to the ultrasonic bath. The cold water temperature is maintained by the refrigeration cooling system. 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 (see Table 1).

2.2. Nanofluids preparation

Titanium dioxide nanoparticles with an average particle size of 21 nm and purity >99.9% are used in the present study by dispersing in de-ionized water, as the base fluid. 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. The nanofluids with three different concentration (0.025%, 0.05% and 0.075% by volume) are prepared by ultrasonic bath system (DELTA, model DC200/DC200H) without using surfactant. The stirring process by ultrasonic bath has continuously performed for 1 h until the stable nanofluids is achieved. During the whole experiment process, the nanofluids sample suspensions are maintained in the stationary state with little apparent sediment by ultrasonic bath system run for 10 min each hour.

2.3. Magnet arrangement

In the present study, the permanent Neodymium magnets are used to generate the magnetic fields. The permanent Neodymium (N52) magnet has the length$*$width and the thickness of $100 * 50$ mm and 5 mm, respectively. Each magnet has resonance of 14,300 G and coercive force of 860 kA/m over the maximum temperature of 80 °C. Three different magnet configurations are arranged as shown in Fig. 3. The magnetic fields strength is measured by using the Triaxial Magnetic Filed Meter (TM-192) with resolution and accuracy of 0.01 mG and 30 mG, respectively. This instrument is a cost-effective hand-held tester that is designed and pre-calibrated to measure magnetic field radiation at different bandwidths from 30 to 2000 Hz.

2.4. Test section

The test section (the spirally coiled tube) is fabricated from the circular straight copper tube which in order to preserve the smoothness of the inner surface, the fine sand is filled into the circular copper tube before bending into the spirally coiled tube while experiment process, the test section is submerged in the uniform hot water storage tank. Six type T copper-constantan thermocouples with accuracy of ±0.10 of full scale are used to measure the nanofluids temperature distribution along the spirally coiled tube by extending inside the tube while the tube wall temperatures are measured by mounting on the tube wall and fixed with special glue. The thermocouple probe with 0.5 mm diameter has not significant effect on the flow disturbing of nanofluids flowing inside the test section. The DT85 data taker is applied 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 precalibrated by dry-block