International Journal of Heat and Mass Transfer 93 (2016) 293–300

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

Experimental investigation the nanofluids heat transfer characteristics in horizontal spirally coiled tubes

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ARTICLE INFO

Article history:
Received 26 August 2015
Received in revised form 17 September 2015
Accepted 18 September 2015

Keywords:
Nanofluids
Heat transfer characteristics
Spirally coiled tube

ABSTRACT

The heat transfer and flow characteristics of the nanofluids in the horizontal spirally coiled tubes are investigated. The spirally coiled tubes are fabricated by bending a 8.50 mm inner diameter straight copper tube into a spiral-coil of five turns. The test section with three different curvature ratios of 0.035, 0.043, 0.06 are tested. Effects of curvature, nanofluids concentration and hot water temperature on the nanofluids heat transfer characteristics and pressure drop are considered. The results showed that the Nusselt number is about 21.29%, 29.02%, 34.07% for (0.01%, 0.025%, 0.05% by volume concentration, respectively) higher than the Nusselt number obtained for water as working fluid. However, the friction factor of nanofluids as working fluid increase slightly compared that of water as working fluid. Two correlations for predicted the Nusselt number and friction factor in the spirally coiled tube under constant wall temperature are proposed.

1. Introduction

Due to the high level of generated heat and working fluid transport properties limitation, one of the methods for the heat transfer enhancement is the application of additives to the working fluids to change the fluid transport properties and flow features. Therefore, in order to further enhance thermal performance of heat exchanger, the use of nanofluids is proposed. In addition, the change flow behavior of working fluid has been introduced as one of the heat transfer enhancement technique for electronic cooling. The turbulent flow and convective heat transfer in a curved tube are complicated as comparing the straight tube. The secondary flow in the curved tube is caused by the centrifugal force. Therefore, the curved tubes are the most widely used tubes in several heat transfer applications, for example, heat recovery processes, air conditioning and refrigeration systems, chemical reactors, food and dairy processes. There are many paper presented the heat transfer and flow characteristics in the curved tube [1–2]. Suresh et al. [3] experimentally studied effect of turbulent convective heat transfer and friction factor characteristics of water and CuO in the plain and the helically dimpled tube. The results showed that the Nusselt number with dimpled tube was higher than the Nusselt number obtained with plain tube while the pressure loss of the nanofluids increase slightly compared with that of distilled water. Huminic and Huminic [4] studied the laminar heat transfer characteristics of a double tube helical heat exchanger. Water and CuO and TiO_2 nanoparticles with volume concentrations between 0.5% and 3.0% were used as the working fluid. Agus et al. [5] numerically studied the laminar flow of CuO and Al_2O_3 nanofluids in square cross section tubes, i.e., straight, conical spiral, in-plane spiral and helical spiral. Pakdaman et al. [6,7,21] considered effect of the thermo-physical properties, the heat transfer and the pressure drop of MWCNT/ oil nanofluids flow inside vertical helically coiled tubes under constant wall temperature boundary condition. Kannadasan et al. [8] compared the heat transfer and pressure drop characteristics of water-based copper oxide nanofluids in a helically coiled heat exchanger. It can be found that there is no difference between horizontal and vertical arrangements. In addition, two correlations for the Nusselt number and the friction factor are proposed. Hashemi and Behabadi [9] studied pressure drop and heat transfer characteristics of oil and copper oxide inside horizontal helically coiled pipe under constant heat flux boundary condition. The results showed that the nanofluids have better heat transfer characteristics when they flow in helical tube rather than in the straight tube. A new correlation for the Nusselt number is proposed. Naghmeh et al. [10] studied the laminar heat transfer and the pressure drop of alumina nanofluids with volume concentration of 1% and 2% inside helical coils. Mohammed and Narrein [11,19] considered effects of the geometrical parame-

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http://dx.doi.org/10.1016/j.ijheatmasstransfer.2015.09.089
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Nomenclature

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

Greek symbol

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

Subscripts

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

ters of helically coiled tube heat exchanger (the helix radius, helix pitch, annulus diameter and inner tube diameter) on heat transfer and fluid flow characteristics. Effects of different nanoparticles types (Al_2O_3, SiO_2, CuO, ZnO), with diameters between 25 nm and 80 nm and volume concentrations of nanoparticles in the range 0 and 4% in different types of base fluids (water, ethylene glycol, engine oil), on the hydraulic and thermal characteristics in helically coiled tube heat exchangers under laminar flow conditions. Kahani et al. [12] considered effects of nanofluids concentration on thermal characteristics flowing through the helical coils under constant heat flux boundary condition. Water and Al_2O_3 and TiO_2 nanoparticles were used as working fluids. The results showed that for both tested nanofluids, the convective heat transfer coefficient and the pressure drop increases with increasing nanoparticle concentrations as well as Reynolds number. Two correlations for the Nusselt number and one correlation for the pressure drop are proposed. Fazan et al. [13] experimentally and numerically studied the convective heat transfer and the pressure drop of water CuO inside in helically coiled tubes under constant wall temperature boundary condition. The presented results showed that the heat transfer coefficient and pressure drop of nanofluids increase by increasing the particles concentration. Srinivas and Vinod [14] considered effect of Al_2O_3 nanofluids concentration on the performance of an agitated helical coil heat exchanger. Wu et al. [15] investigated the pressure drop and heat transfer of water and alumina nanofluids in a double-pipe helical heat exchanger. The experiments performed for the nanoparticles concentrations of 0.78% wt., 2.18% wt., 3.89% wt., 5.68% wt. and 7.04% wt, A new correlation for the Nusselt number in laminar flow is proposed. Kahani et al. [16,17] considered effect of curvature ratio and coil pith on the heat transfer enhancement of nanofluids and helical coiling. Water and carbon nanotube with weight concentrations of 0.1%, 0.3% and 0.5% were used as working fluid. Jamal-Abad et al. [18] experimentally investigated the laminar heat transfer coefficient and friction factor of CuO, Al_2O_3 nanofluids flowing in a spiral coil under constant wall temperature boundary condition. The nanofluids with different volume concentrations of 0.55%, 1.12%, and 2.23% are used as working fluids. The results indicated that the use of nanofluids with the higher concentration provides considerably higher Nusselt numbers and pressure drop penalty was negligible with increasing the nanoparticles volume concentration. Khairul et al. [20] studied the effects of volume flow rate, nanoparticles volume fraction, mass flow rate, density, thermal conductivity, Reynolds number and Nusselt number on heat transfer coefficient and entropy generation rate of the helically coiled heat exchangers by using water and CuO, Al_2O_3 and ZnO nanoparticles with volume concentrations of between 1% and 4% as working fluids. Aly [22] considered effects of nanoparticle volume concentrations and curvature ratio of the helically coiled tube-in-tube heat exchangers on the heat transfer and pressure drop characteristics. Alumina nanofluids with volume concentrations of 0.5%, 1.0% and 2.0% in turbulent flow are used as working fluid. Doshmanziari et al. [23] investigated effect of pulsation on heat transfer of fluid flow inside a spiral-coil tube for pulsating flow.

A review of the pertinent literature indicates that there many papers presented the heat transfer characteristics of nanofluids in the curve tube. However, only three works [5,18,23] reported on the heat transfer and pressure drop of nanofluids in the spiral coil. There is still room to discuss especially effect of curvature ratio, nanofluids concentrations on the heat transfer and flow characteristics of the Titanium nanofluids in the horizontal spirally coiled tube. This work studies the effects of nanofluids concentrations and curvature ratios on the heat transfer and pressure drop of Titanium nanofluids in the horizontal spirally coiled tubes. Finally, two correlations of the Nusselt number and friction factor for the nanofluids flowing in the horizontal spirally coiled tube under constant wall temperature are proposed.

2. Experimental apparatus and procedure

2.1. Experimental apparatus

Fig. 1 shows a schematic diagram of the experimental apparatus which composed of a test section, refrigerant loop, ultrasonic system, hot water tank, nanofluids loop and data acquisition system. The test section and the connections of the piping system are designed such that parts can be changed or repaired easily. The test section is the horizontal spirally coiled tube which immerged inside the hot water storage tank. The close-loop of the nanofluids consists of a magnetic pump, ultrasonic system, an electric heater controlled by adjusting the voltage, and a cooling coil immerged inside a storage tank. The nanofluids temperature entering the spirally coiled tube is chilled by cold water system which the cold water is chilled by the refrigeration system. The nanofluids and hot water temperatures are adjusted to the desired level and controlled by temperature controller. The flow rate of the nanofluids is controlled by adjusting the valve and measured by the by collecting the fluid with the precise cylinder for a period of time during 15 min and the fluid mass is measured by an electronic weight scale with an accuracy of 0.01% of full scale.