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Study on heat transfer and friction factor characteristics of γ-Al_2O_3/water through circular tube with twisted tape inserts with different thicknesses

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ABSTRACT

An experimental study was carried out to investigate heat transfer and friction factor characteristics of γ-Al_2O_3/water nanofluid through circular tube with twisted tape inserts with various thicknesses at constant heat flux. In this work, γ-Al_2O_3/water nanofluids with two volume concentrations of 0.5% and 1% were used as the working fluid. The twist ratio of twisted tape remained constant at 3.21, while the thicknesses were changed through three values of 0.5 mm, 1 mm and 2 mm. The experiments were performed in laminar flow regime from 150 to 1600 Reynolds numbers. Results indicated that twisted tape inserts enhanced the average convective heat transfer coefficient, and also more the thickness of twisted tape is more the enhancement of convective heat transfer coefficient is. Also, the highest enhancement was achieved at maximum volume concentration. Results showed that nanofluids have better heat transfer performance when utilized with thicker twisted tapes. At the same time, the increase in twisted tape thickness leads to an increase in friction factor. In the end, the combined results of these two phenomena result in enhanced convective heat transfer coefficient and thermal performance. Finally, two new correlations were offered for Nusselt number and thermal performance based on our experimental observation.

1. Introduction

Due to the important role that heat exchanging equipment plays in different industries, it is very important to maximize their efficiency in order to conserve energy. One way, to achieve this goal, is the use of nanofluids instead of traditional coolants such as water, ethylene glycol and cooling oils. This method has been the subject of much attention in recent years and many studies have been conducted to determine the benefits and heat transfer characteristics of nanofluids. Nanofluids are made by dispersing nano-sized particles in base fluids such as water, ethylene glycol and oils. Choi [1] was the first person to do so and he named the resulting solution "nanofluid". Further research revealed that nanofluids have enhanced thermo physical properties compared to their base fluids. Choi et al. [2] observed a 160% heat transfer enhancement by adding carbon nanotubes to traditional motor oil, as base fluid, with 1% volume concentration. Wen and Deng [3] experimented on Al_2O_3/water nanofluids under laminar flow conditions and constant heat flux. They observed an enhancement in heat transfer coefficient with an increase of Reynolds number and nanoparticle concentration. Experimental investigation were done by Ding et al. [4], using carbon nanotubes, showed a significant increase by 350% in convective heat transfer at Reynolds number of 850. This increase is due to particle rearrangement, decrease in shear stress, flattening of the thermal boundary layer thickness and high aspect ratio of carbon nanotubes. Anoop et al. [5] conducted experiments in the developing region tube flow with Al_2O_3/water nanofluid. They found that nanoparticles with 45 nm diameter have higher heat transfer coefficient than particles with 150 nm diameter. Yu et al. [6] found 34% enhancement in heat transfer capabilities of kerosene based Fe_2O_3 nanofluids and oleic acid, with 155 nm diameter particles, in the temperature range of 10–60 °C. Asirvatham et al. [7] studied experimentally the heat transfer properties of CuO/water nanofluids inside the tube under laminar flow conditions, and they observed a significant increase in heat transfer with an increase in Reynolds number.

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Nomenclature

A	cross-sectional area, m^2
C_p	specific heat, J/kg K
D	tube diameter, m
f	friction factor
h	heat transfer coefficient, w/m^2 K
k	thermal conductivity, w/m K
L	length of the test section, m
$\dot{m}$	mass flow rate, kg/s
Nu	Nusselt number
P	perimeter, m
Pr	Prandtl number
q''	actual heat flux, w/m^2
Re	Reynolds number
T	temperature, K
v	velocity, m/s
x	axial distance, m
d	tape width, m
H	pitch length of twisted tape, m
H/d	twist ratio
t	twisted tape thickness
x_*	$=x/D \cdot Re \cdot Pr$

Greek letters

φ	volume concentration
ρ	density, kg/m^3
μ	dynamic viscosity, kg/ms

Subscripts

f	fluid
bf	base fluid
nf	nanofluid
in	inlet
out	outlet
p	particle
w	tube wall

Passive techniques are also used to further enhance the heat transfer capabilities of nanofluid coolants by using of twisted tape inserts and utilization of grooved tubes. All swirl flow devices, such as twisted tapes, helical screw tapes and etc., are used to create tangential velocity, thin boundary layer, and enhancement in the tangential and radial turbulent fluctuations [8,9] which cause augmentation in heat transfer and friction factor inside tubes. Due to these capabilities, twisted tape inserts are used in many sectors including chemical engineering processors, chemical engineering industry, chemical reactors, power plants and nuclear reactors. Therefore, many studies have been done in recent years in order to better understand their effects on heat transfer augmentation of these devices. Sivashanmugam and Suresh [10,11] experimentally investigated heat transfer and pressure drop characteristics of laminar flow through a tube fitted with full length helical screw inserts with different twist ratios. They reported that heat transfer coefficient and friction factor increase as twist ratio rise. Sharma et al. [12] experimented with low volume concentrations of Al_2O_3/water nanofluid inside a tube fitted with twisted tape and found an increase in convective heat transfer compared to water. Eiamsa-ard et al. [13] studied the convective heat transfer inside the tube fitted with short length twisted tapes under constant heat transfer conditions. Akhavan-behabadi et al. [14] showed the effects of twisted tape inserts on heat transfer and pressure drop in horizontal evaporators with R-134 as working fluid. Chandrasekar et al. [15] investigated the heat transfer properties and pressure drop of Al_2O_3/water nanofluid with 0.1% volume concentration inside a tube fitted with wire coil under laminar flow conditions. They found a 12.24% increase in Nusselt number at $Re = 2275$ compared to water. Chang et al. [16] conducted an experimental work on friction factor and heat transfer characteristics in a tube fitted with regular twisted serrated-tape inserts which were modified by ribs on both sides of tapes surface to enhance the turbulence of the flow. They found that the tube fitted with serrated-tape increased heat transfer performances compared to the plain tube. Heat transfer and pressure drop inside a spirally grooved tube fitted with twisted tape were investigated for laminar to fully developed turbulent regions by Bharadwaj et al. [17]. They also studied the effect of swirl direction (clockwise or counter clockwise) on thermo-hydraulic properties. Eiamsa-ard et al. [18] investigated the heat transfer and pressure drop behavior in a double pipe heat exchanger fitted with regularly-spaced twisted tapes with different twist ratios.

According to the literature in recent years and our recent study [19], nanofluids enhance heat transfer capabilities compared to regular coolants, moreover, the use of inserts can further increase these enhanced capabilities. Therefore, in recent years many studies have been carried out in order to find an optimum geometry that produce greater heat transfer enhancement with nanofluids. These efforts include the use of short length twisted tapes [20], tapes with alternate axes [21,22], serrated tapes [23] and many more. In this study, we considered the effect of another aspect of the insert geometry, one which there is no previous literature on, that is the effect of the thickness of the insert tapes on heat transfer enhancement. Therefore, in this experimental investigation, the effects of different twisted tape thicknesses were studied on heat transfer and friction factor characteristics. The twist ratio is kept constant at 3.21 and three different thicknesses ($t = 0.5$ mm, 1 mm and 2 mm) are used in the range of different Reynolds number from 150 to 1600. Finally, two new correlations were presented for Nusselt number and thermal performance.

2. Nanofluid preparation

The nanofluid was made by dispersing nanoparticles (purchased from TECNAN Company) [24] in distilled water. By this way, Al_2O_3/water nanofluid with 1% and 0.5% volume concentrations were prepared as working fluids. Physical properties of the nanoparticles are listed in Table 1. The method used for stabilizing the working fluid was a four hour period of ultrasonication (CD-4820 cleaner with 170 W and 50 Hz) and electromagnetic stirring. The particles have a diameter of 10–20 nm. Therefore, the average particle size is considered to be 15 nm in this work. No surfactants were used and the PH level remained constant throughout the testing period.

Table 1
Physical properties of the Al_2O_3 nanoparticles.

Chemical formula	Color	Morphology	Crystal phase	Specific surface area (SSA)	True density	Pore volume	Average pore size
γ-Al_2O_3	White	Spherical	Gamma	90–160 m^2/g	3.65 g/cc	0.391 cc/g	133.64 Å