International Journal of Heat and Mass Transfer 55 (2012) 2761–2768

Contents lists available at SciVerse ScienceDirect

International Journal of Heat and Mass Transfer

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

Effect of full length twisted tape inserts on heat transfer and friction factor enhancement with Fe_3O_4 magnetic nanofluid inside a plain tube: An experimental study

L. Syam Sundar [a,*], N.T. Ravi Kumar [b], M.T. Naik [b], K.V. Sharma [a,b]

[a] Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
[b] Center for Energy Studies, J.N.T.U. College of Engineering, Kukatpally, Hyderabad 500085, India

ARTICLE INFO

Article history:
Received 27 April 2011
Received in revised form 24 January 2012
Accepted 24 January 2012
Available online 3 March 2012

Keywords:
Fe_3O_4 nanofluid
Forced convection
Twisted tape insert
Heat transfer enhancement

ABSTRACT

Turbulent convective heat transfer and friction factor characteristics of magnetic Fe_3O_4 nanofluid flowing through a uniformly heated horizontal circular tube with and without twisted tape inserts are estimated experimentally. Experiments are conducted in the particle volume concentration range of $0 < \varphi < 0.6\%$, twisted tape inserts of twist ratio in the range of $0 < H/D < 15$and Reynolds number range of $3000 < Re < 22000$. Heat transfer and friction factor enhancement of 0.6% volume concentration of Fe_3O_4 nanofluid in a plain tube with twisted tape insert of twist ratio H/D = 5 is 51.88% and 1.231 times compared to water flowing in a plain tube under same Reynolds number. Generalized regression equation is presented for the estimation of Nusselt number and friction factor for both water and Fe_3O_4 nanofluid in a plain tube and with twisted tape inserts under turbulent flow condition.

1. Introduction

Nanofluid is a fluid containing nanometer-sized particles, called nanoparticles. These fluids are engineered colloidal suspensions of nanoparticles in a base fluid have been explained by Buongiorno [1]. The nanoparticles used in nanofluids are typically made of metals, oxides, carbides or carbon nanotubes and the common base fluids include water and ethylene glycol. Nanofluids have novel properties that make them potentially useful in many applications in heat transfer, including microelectronics, fuel cells, pharmaceutical processes and hybrid-powered engines that have been explained by Das et al. [2]. Nanofluids exhibit enhanced thermal conductivity and the convective heat transfer coefficient compared to the base fluid by Kakaç and Pramuanjaroenkij [3].

Thermal conductivity of Fe_3O_4 nanofluid is explained by many researchers. Parekh and Lee [4] have observed 30% enhancements in thermal conductivity with 4.7% volume concentration in the temperature range of 25-65 °C with Fe_3O_4 nanofluid of 9.9 nm particle size. Fertman et al. [5] have investigated the temperature range of 20–80 °C and volume concentration range of 0.01–0.2% of thermal conductivity of hydrocarbon-based magnetic fluids containing colloidal Fe_3O_4 particles coated with oleic acid. Philip et al. [6] have been observed thermal conductivity enhancement of Fe_3O_4 nanofluid up to 300% with volume concentration of 6.3% and particle size of 6.7 nm under the influence of an applied magnetic field. Yu et al. [7] have found 34.0% enhancement in thermal conductivity for 1.0% volume fraction with an average particle size of 155 nm in the temperature range from 10 to 60 °C using the kerosene based Fe_3O_4 nanofluids and oleic acid.

Convective heat transfer enhancement with different kinds of nanofluid in a plain tube is explained by many researchers. Wen and Ding [8] have conducted the experiments in the Reynolds number range of 700 and 2050 in plain tube with Al_2O_3 nanoparticles and found significant heat transfer enhancement. Heris et al. [9] under isothermal wall boundary condition and observed that enhancement of heat transfer takes place with increase of Peclet number and volume concentration. Xuan and Li [10] have preformed the Cu nanofluid in circular tube under turbulent flow conditions and regression equation is presented. Pak and Cho [11] conducted the experiments with Al_2O_3 and TiO_2 nanofluids in plain tube in turbulent region and also developed the regression equation.

Convective heat transfer enhancement of single phase fluid with twisted tape inserts in a plain tube is explained by many researchers. Smithberg and Landis [12], Lopina and Bergles [13], Manglik and Bergles [14], Sarma et al. [15], Kishore [16] and Lecjaks et al. [17] have found the significant heat transfer enhancement of single phase fluid with twisted tape inserts in a plain tube.

Convective heat transfer enhancement of Al_2O_3 nanofluid in a plain tube with inserts is explained by many researchers. Sharma

* Corresponding author.
E-mail address: sslingala@rediffmail.com (L. Syam Sundar).

0017-9310/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijheatmasstransfer.2012.02.040

Nomenclature

C	specific heat, J/kg K
D	inner diameter of the tube, m
h	convective heat transfer coefficient, W/m^2 K
H	pitch for 180 degrees rotation, m
H/D	dimensionless twist ratio
k	thermal conductivity, W/m K
L	length of the tube, m
$\dot{m}$	mass flow rate, kg/s
Nu	Nusselt number, hD/k
P	power, watts
Pr	Prandtl Number, $\mu C/k$
Q	heat flow, W
Re	Reynolds number, $\frac{4\dot{m}}{\pi D\mu}$
T	temperature, K
V	velocity, m/s

Greek symbols

μ	dynamic viscosity, kg/m s
ρ	density, kg/m^3
φ	volume concentration of nanoparticles, %
δ	thickness of strip, m
ΔP	pressure drop across the tube, Pa

Subscripts

bf	base fluid
Exp	Experiment
nf	nanofluid
p	nanoparticle
Reg	regression
w	water

et al. [18], Sundar and Sharma [19] for the first time presented the empirical correlation for the estimation of Nusselt number and friction factor in transition and turbulent flow condition using water and different volume concentration of Al_2O_3 nanofluid in plain tube and with twisted tape inserts. Chandrasekar et al. [20] have observed the 15.91% convective heat transfer enhancement with Al_2O_3/water nanofluid in plain tube with wire coiled inserts under laminar flow. Chandrasekar et al. [21] have conducted the experiments of Al_2O_3/water nanofluid in plain with wire coiled inserts under Reynolds number range of 2500 to 5000. Pathipakka and Sivashanmugam [22] numerically investigated the convective heat transfer of Al_2O_3/water nanofluid in a tube with twisted tape inserts of H/D = 2.93 and found 31.29% enhancement at Re = 2039 with 1.5% volume concentration.

Most of the experimental work is undertaken for the estimation of heat transfer coefficient of Al_2O_3 and Cu nanofluids in plain tube and some researchers have concentrated for the estimation of heat transfer of coefficient of Al_2O_3 nanofluid in plain tube with twisted and wire coiled inserts.

Thermal conductivity of magnetic Fe_3O_4 nanofluid literature is available, experimental turbulent convective heat transfer and friction factor of Fe_3O_4 magnetic nanofluid for tube flow and with twisted tape inserts data is not available. The advantage with this fluid is separation of magnetic nanoparticles (Fe_3O_4) from the base fluid is possible, which is not possible with non magnetic (Al_2O_3, Cu and TiO_2) type nanoparticles. The present investigation is carried out to estimate turbulent forced convective heat transfer and friction factor at different volume concentrations of Fe_3O_4 nanofluid in a plain tube and with twisted tape inserts under turbulent flow conditions. Based on the experimental data generalized regression equations are developed for Nusselt number and friction factor.

2. Nanofluid preparation and properties

Average diameter of Fe_3O_4 nanoparticle is 36 nm procured from Sigma Aldrich Chemicals Ltd., USA is dispersed in distilled water (base fluid). The physical properties of distilled water and magnetite nanoparticles are listed in Table 1. The properties of distilled water are obtained from ASHRAE hand book [23]. Since the density difference between magnetite Fe_3O_4 nanoparticles and distilled water is large, the particles are to be prevented from sedimentation in water. Two kinds of techniques have been suggested by Masuda et al. [24]. One is to use the force of electrostatic repulsion between particle surfaces, and the other is with the use of surfactants. Since the first method is found to cause significant changes in the thermophysical properties of dispersed fluid, the second technique is used in the present study. When the metallic oxide nanoparticles comes in contact with water, a hydroxyl radical, ^{-}OH is formed at the surface of the metallic oxide particle. The overall behavior of the particle water interaction depends on whether the water is acidic or alkalic. For example, the particle surface in acidic water (i.e., having excess hydrogen ions) has a positive charge, since a hydrogen ion from the acidic water is combined with a hydroxyl radical at the surface of the metallic particle. Eqs. (1) and (2) show the reaction with acidic in water in general, respectively:

$$H_2SO_4 \Longleftrightarrow H^+ + HSO_4^- \quad \text{(Ionisation)} \tag{1}$$

$$M - OH + H^+ \Rightarrow M^+OH_2 \tag{2}$$

where 'M' indicates a metal cation. In summary, iron particles exhibit basic properties in the presence of strong acids. The reaction of the compound with hydrogen ions is given by Masuda et al. [24] as

$$Fe_3O_4 + H^+ = Fe^{4+} \tag{3}$$

$$Fe_3O_4 + OH^- = Fe(OH)_5 \quad \text{or} \quad FeO^{3-} \tag{4}$$

However, at a certain value of pH, the mixture reaches an equipotential (or equivalence) point, at which the numbers of positive ions, M^+OH_2 are exactly the same as the number of negatively charged ions. In other words, if the pH of a dispersed fluid is near the equipotential value, agglomeration of particles will take place. The equipotential point depends strongly on the type of metallic oxide particle. From several experiments, it is found that Fe_3O_4 nanoparticles are well dispersed at pH value of 3. At this value, an electric double layer is formed at the surface of the nanoparticle and subsequently, these particles are suspended in water without forming a cluster due to the repulsive force between them. In preparing dispersed fluids for a desired volume concentration, the required amount of particles are weighed with a precision balance, mixed with a carrier fluid, and the pH value of the dispersed fluid adjusted with an extremely small amount of sulfuric acid H_2SO_4.

After sonification for approximately 2 h, the dispersion of the nanoparticles is established by visual observation for nanoparticle sedimentation. The uniform dispersion is established by measuring the densities of nanofluid at different locations in the container. The volume concentration is evaluated from the following relation in percentage