International Journal of Heat and Mass Transfer 117 (2018) 223–234

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

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

Turbulent heat transfer and friction factor of nanodiamond-nickel hybrid nanofluids flow in a tube: An experimental study

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ARTICLE INFO

Article history:
Received 26 February 2017
Received in revised form 24 August 2017
Accepted 26 September 2017

Keywords:
Hybrid nanofluids
Heat transfer enhancement
Friction factor

ABSTRACT

Turbulent heat transfer and friction factor of nanodiamond-nickel (ND-Ni) hybrid nanofluids flow in a horizontal tube has been investigated experimentally. The ND-Ni nanoparticles were synthesized using *in-situ* growth and chemical co-precipitation method and characterized by XRD, TEM and VSM. The hybrid nanofluids were prepared by dispersing ND-Ni hybrid nanoparticles in distilled water. The thermal conductivity and viscosity enhancements were observed as 29.39% and 23.24% at 0.3% volume concentration of hybrid nanofluid at 60 °C compared to distilled water. The heat transfer and friction factor experiments were conducted at different Reynolds numbers (3000–22,000) and particle volume concentrations (0.1% and 0.3%). The Nusselt number enhancement of 0.3% volume concentration of hybrid nanofluid is 35.43% with a friction factor penalty of 1.12-times at a Reynolds number of 22,000 compared to distilled water data. The obtained experimental Nusselt number of hybrid nanofluids was compared with other kind of hybrid nanofluids available literature. New Nusselt number and friction factor correlations were proposed based on the experimental data.

1. Introduction

Nano-meter size particles dispersed in base fluids (water, ethylene glycol, propylene glycol and engine oil) are called as nanofluids [1], which are having great potential applications in many heat transfer areas because of their higher thermal conductivity, long term stability and reduction of sedimentation [2–4]. Different nanoparticles (Al_2O_3, CuO, Cu, carbon nanotubes, Fe_3O_4, Fe_2O_3, graphene, nano-diamond, Ni, SiC, SiO_2, TiO_2, etc.) have been used as for the preparation of nanofluids. The heat transfer enhancements of various nanofluids, among others, Al_2O_3, CuO, Fe_3O_4, CNT, ND, Ni, TiO_2, SiO_2, SiC, have been studied by many researchers [5–12]. Among all the nanofluids, nanodiamond (ND) based nanofluids focuses more interest, because those are prepared with ND particles, which are having superior hardness, Young's modulus, high thermal conductivity and electrical resistivity, chemical stability, and biocompatibility compared to other kind of nanoparticles.

A very few reports are available related to the convective heat transfer of ND nanofluids; some of them are discussed below. Torii and Yang [13] estimated the convective heat transfer of ND nanofluids experimentally and observed enhancement of 16% at 1.0% volume concentration at a Reynolds number of 6000. Ghazvini et al. [14] observed heat transfer enhancements of 64% and 53% for 2% volume concentration of ND/engine oil nanofluid at heat fluxes of 5 kW/m^2 and 26 kW/m^2, respectively. Ding et al. [15] estimated convective heat transfer of ethylene glycol based titania nanofluids and aqueous based ND nanofluids in laminar flow. Xie et al. [16] prepared 55W:45EG based nanodiamond nanofluids and observed heat transfer enhancement of 300% at a Reynolds number of 834 at 0.05% volume fraction.

The heat transfer enhancement of base fluids (W, EG, PG, and EO) are also possible by dispersing hybrid nanoparticles, which is also another way for heat transfer augmentation. The hybrid nanoparticles are combination of two or more nanoparticles in nano-meter range, which are attached with each other by chemical bond. The fluids prepared with these hybrid nanoparticles are called as – hybrid nanofluids, which is the fastest developing area in materials science and engineering. A very few reports are available related to the thermal properties and convective heat transfer of hybrid nanofluids; some of them are discussed below. Qing et al. [17] investigated thermal conductivity, electrical conductivity and viscosity of SiO_2-graphene dispersed in naphthenic oil and observed thermal conductivity enhancement of 80% and electrical conductivity enhancement of 557% at 0.08% weigh percentage.

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https://doi.org/10.1016/j.ijheatmasstransfer.2017.09.109
0017-9310/

Nomenclature

A	area
C_p	specific heat
f	friction factor
h	heat transfer coefficient
I	current
ID	inner diameter of the tube
k	thermal conductivity
L	length of the tube
$\dot{m}$	mass flow rate
Nu	nusselt number, hD/k
OD	outer diameter of the tube
P	power
Pr	Prandtl number, $\mu\, C_p/k$
Q	heat flow
q	heat flux
Re	Reynolds number, $4\, \dot{m}/\pi D\mu$
T	temperature
V	voltage
v	velocity

Greek symbols

δ	uncertainty
Δp	pressure drop
ϕ	volume concentration of nanoparticles, %
μ	viscosity
ρ	density

Subscripts

b	bulk temperature
Exp	experimental
i	inlet
o	outlet
Reg	regression
w	wall temperature

Abbreviations

XRD	X-ray diffraction
TEM	transmission electron microscope
VSM	vibrating sample magnetometer

Mechiri et al. [18] synthesized copper (Cu)-zinc (Zn) hybrid particles using mechanical alloying with compositions of 50:50, 75:25, and 25:75 by weight and then prepared vegetable oil based hybrid nanofluids and estimated thermal conductivity and viscosity experimentally. Safi et al. [19] observed thermal conductivity enhancement of 12.1% for the sample with 0.08% weight percentage of MWNT-TiO_2 compared to distilled water at 36 °C and 13.71% at 52 °C. Harandi et al. [20] prepared f-MWCNTs-Fe_3O_4/EG hybrid nanofluids and observed thermal conductivity enhancement of 30% at a temperature of 50 °C for solid volume fraction of 2.3%. Esfe et al. [21] studied thermal conductivity of single walled carbon nanotubes-MgO/EG hybrid nanofluids using artificial neural network (ANN) and observed 32% enhancement at 2.0% volume concentration. Kumar et al. [22] observed thermal conductivity enhancements of 36%, 42%, 48%; viscosity enhancements of 47%, 53% and 61% for 0.5% volume concentrations of Zn, Cu, and Cu-Zn nanofluids compared to base fluid (vegetable oil). Nine et al. [23] prepared Al_2O_3 (97.5)/MWCNTs (2.5) and Al_2O_3 (90)/MWCNTs (10) weight percentage of hybrid nanofluids and studied thermal properties between 1 wt% and 6 wt%. Sundar et al. [24] prepared nanodiamond-nickel (ND-Ni) hybrid nanofluids and estimated thermal conductivity and viscosity experimentally. Baby and Ramprabhu [25] observed thermal conductivity enhancement of 20% at 0.05% volume fraction of f-MWNT/f-HEG hybrid nanofluids.

A very few reports are available related to the heat transfer and friction factor of hybrid nanofluids; some of them are discussed below. Suresh et al. [26] observed heat transfer enhancement of 13.56% for 0.1% weight concentration of Al_2O_3-Cu/water hybrid nanofluids at a Reynolds number of 1730 when compared with water data. Sundar et al. [27] observed heat transfer enhancement of 31.10% for 0.3% of MWCNT-Fe_3O_4/water hybrid nanofluids with a friction penalty of 1.18-times at a Reynolds number of 22,000 compared with water data. Takabi and Shokouhmand [28] numerically analyzed the effect of Al_2O_3-Cu/water nanofluid flow in a circular tube in the Reynolds number range from 10,000 to 100,000 and in the volume concentration up to 2% and they observed heat transfer enhancement of 32.07% with a friction penalty of 13.76%. Madhesh et al. [29] prepared copper-titania (Cu-TiO_2) nanocomposite nanofluids in the volume concentrations between 0.1% and 2.0% and observed heat transfer coefficient, Nusselt number and overall heat transfer coefficient enhancements of 52%, 49% and 68% respectively at 1.0% volume concentration compared to base fluid. Selvakumar and Suresh [30] prepared Al_2O_3-Cu/water hybrid nanofluid and studied heat transfer for electronic cooling applications and developed Nusselt number correlation. Allahyar et al. [31] prepared 97.5% alumina-2.5% Ag/water based hybrid nanofluids and observed heat transfer enhancement of 31.58% at 0.4% volume concentration compared to distilled water. Hormozi et al. [32] prepared alumina-silver hybrid nanofluids at different concentrations of sodium dodecyl sulphate and nonionic poly vinyl pyrrolidone surfactants and observed maximum thermal performance in the presence of hybrid Alumina–Silver nanofluid and SDS anionic surfactant is 16% higher than that of the pure distilled water. Ahammed et al. [33] prepared graphene-alumina hybrid nanofluids and studied entropy generation in a multiport mini-channel heat exchanger. Mehrali et al. [34] prepared hybrid graphene/Fe_3O_4 ferro-nanofluids and observed local heat transfer enhancement up to 82% and total entropy generation rate was reduced up to 41% compared to distilled water. Sarkar et al. [35] covered the available hybrid nanofluids and their thermal properties in their review paper. Sundar et al. [36] presented the available Nusselt number and friction factor correlations for the hybrid nanofluids in their review paper.

The convective heat transfer and friction factor of nanodiamond-nickel (ND-Ni) hybrid nanofluids data is not available. Therefore, the present study is focused on the estimation of convective heat transfer and friction factor of ND-Ni/water hybrid nanofluids flowing in a tube under turbulent flow conditions. The synthesis procedure of Sundar et al. [24] has been used for the preparation of bulk ND-Ni nanoparticles. The hybrid nanofluids were prepared by dispersing ND-Ni in distilled water, after that the thermal conductivity and viscosity is estimated at different volume concentrations and temperatures. The convective heat transfer and friction factor of hybrid nanofluids were estimated and compared with literature values.

2. Experimental methods

2.1. Chemical required

The reagent grade chemicals such as nickel chloride ($NiCl_2{\cdot}6H_2O$), sodium borohydrate ($NaBH_4$), ethylene glycol (EG),