International Journal of Thermal Sciences 130 (2018) 148–156

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

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

Experimental comparative evaluation of a graphene nanofluid coolant in miniature plate heat exchanger

Zhe Wang[a,b,*], Zan Wu[a], Fenghui Han[c], Lars Wadsö[d], Bengt Sundén[a,*]

[a] Department of Energy Sciences, Lund University, Box 118, Lund, SE-22100, Sweden
[b] Energy Research Institute@NTU (ERIAN), Nanyang Technological University, Singapore, 639798, Singapore
[c] College of Maritime Engineering, Dalian Maritime University, Dalian, 116026, China
[d] Division of Building Materials, Lund University, Box 118, Lund, SE-22100, Sweden

A R T I C L E I N F O

Keywords:
Nanofluids
Heat transfer enhancement
Pressure drop
Coolant
Graphene nanoplatelets
Miniature plate heat exchanger

A B S T R A C T

As a novel coolant, the ethylene glycol-water (50 wt.%:50 wt.%) with graphene nanoplatelets nanofluids (GnP-EGW) were prepared at four weight concentrations (0.01, 0.1 0.5 and 1.0 wt.%), and heat transfer and pressure drop characteristics in a miniature plate heat exchanger (MPHE) were investigated. All nanofluid samples were prepared and diluted by ultrasonic vibration, and their thermal conductivity and dynamic viscosity were measured by a transient plane source method and a rotational rheometer, respectively. Firstly, the convective heat transfer coefficient (HTC) and pressure drop correlations were predicted under the condition that water was employed as working fluid in both the hot and cold sides of the MPHE. Then, the effects of GnP concentrations of nanofluids on the thermal and hydraulic performances have been determined for the MPHE with the nanofluid in hot side and the water in cold side. Parametric evaluation and performance comparison of the MPHE using GnP-EGW were analyzed via various operating conditions. Experimental analysis showed that: the proposed correlations from water can predict the experimental data of the base fluid and GnP-EGW nanofluids. In the proper concentration range from 0.01 to 0.1 wt.%, the GnP-EGW nanofluid has an acceptable pressure drop penalty but a higher heat transfer performance compared with the base fluid in the MPHE, which reveals that it might be a potential cooling medium.

1. Introduction

Along with scientific and technological progress in manufacturing, heat-exchange equipment with a small size, high-heat fluxes, and low losses have been upgraded significantly in many industrial applications. This trend is expected to continue unabated for the foreseeable future, and therefore heat transfer solutions are facing an enormous demand [1]. Many researchers have made efforts to enhance heat transfer, to reduce the thermal loss and to improve the energy efficiency [2,3], through passive and active heat transfer enhancement methods. One enhancement approach focuses on extending the heat transfer area, creating turbulence to destroy the boundary layer and adding vortex generators, etc. Such approaches often cause unnecessary pump work to overwork the flow resistance. For constant surface temperature, the Nusselt number is constant in the laminar flow fully-developed region, which indicates that the smaller the hydraulic diameter, the larger the convective heat-transfer coefficient [4]. The conventional direct technology such as those mentioned above might not be applicable for miniature equipment with higher heat fluxes. Another approach to improve the heat transfer is to use a fluid medium with better thermophysical properties [5]. With the ever-increasing heat flux and accelerating miniaturization in energy systems, these conventional coolants including water, ethylene glycol and engine oil are no longer able to satisfy high-performance systems. Hence, nanoparticles (metal, oxides, carbides, or carbon nanotubes) were added to the above conventional coolants, forming a colloidal suspension of nanoparticles [6], which is called nanofluids. These nanofluids usually have higher heat transfer performance than the base fluids and may cause little friction penalty [7]. Huminic et al. [8], Solangi et al. [9] and Kasaeian et al. [10] presented reviews of nanofluids for heat transfer applications, which implied that nanofluids could have greater potential for usage in microelectronics, fuel cells, heat exchangers, vehicle thermal management, domestic refrigerators, etc. Although a large number of studies have been reported on nanofluids for some particular applications, there is no clear result showing that a better and solid replacement of the existing coolants can be found regarding thermal efficiency and economics.

Recent investigations [11–13] show that the graphene nanoplatelet

* Corresponding authors. Department of Energy Sciences, Lund University, Box 118, Lund, SE-22100, Sweden.
E-mail addresses: zhe.wang.work@gmail.com (Z. Wang), bengt.sunden@energy.lth.se (B. Sundén).

https://doi.org/10.1016/j.ijthermalsci.2018.04.021
Received 5 September 2017; Received in revised form 22 February 2018; Accepted 16 April 2018

Nomenclature

a,b,c,d	constant parameters
P_w	pump power (kW)
A,B,C,D	constant parameters
V	volumetric flow rate (litre·s^{-1})
b_p	plate depth (mm)

Greek symbols

c_p	specific heat (J·kg^{-1}·K^{-1})
k	thermal conductivity (W·m^{-1}·K^{-1})
D_e	hydraulic diameter (m)
M	dynamic viscosity (Pa·s)
e	relative error
ρ	density (kg·m^{-3})
f	friction factor
ϕ	volume concentration
h	heat transfer coefficient (W·m^{-2}·K^{-1})
δ	plate thickness (mm)
L	length (mm)

Subscripts

M	mass flow rate (kg·s^{-1})
avg	average
Nu	Nusselt number
Bf	basefluid
ΔP	pressure drop (kPa)
Exp	experimental
Pe	Peclet number
c,h	cold or hot side
Pr	Prandtl number
Nf	nanofluid
Q	heat (W)

Abbreviations

Re	Reynolds number
EGW	ethylene glycol-water
T	temperature (K)
GnP	graphene nanoplatelets
U	overall heat transfer coefficient (W·m^{-2}·K^{-1})
MPHE	miniature plate heat exchanger
U	velocity (m·s^{-1})
HTC	heat transfer coefficient

(GnP) could provide higher thermal conductivity enhancement in comparison to that of other examined material. Based on the special two-dimensional structure with a thickness from 5 to 10 nm, high crystal quality and ballistic electronic transport at room temperature, GnP has a high specific surface area (up to 750 m^2/g) and is also easy to disperse in water and organic solvents with standard equipment and techniques. Moreover, the high price of graphene compared to other materials such as carbon nanotubes is expected to be overcome. Seo et al. [14] converted conventional cooking oil into graphene. Due to extensive application potential, it is necessary to reveal the thermal and rheology properties of GnPs dispersed in various base fluids in different applied fields and conditions. Baby and Ramaprabhu [15,16] firstly reported the changing trends of the thermal conductivity and electrical conductivity of GnPs based on deionized (DI) water and ethylene glycol at different volume fractions (0.005%–0.05%) and temperatures (25–50 °C). They also carried out convective heat transfer experiments of GnP nanofluids in a simple horizontal pipe and found that there was a considerable enhancement in thermal conductivity and heat transfer. Ghozatloo et al. [17] analyzed the effects of temperature (25–38 °C) and concentration (0.05–0.1 wt.%) on heat transfer enhancement of HTC by GnP nanofluids in a shell-and-tube heat exchanger under laminar flow. Results show that the HTC ultimately increases by 35.6% at 0.1 wt% and 38 °C compared with DI water. Mehrali et al. [18] prepared stable GnP nanofluids in DI water and investigated different specific surface areas (300–750 m^2/g) and concentrations (0.0025–0.1 wt.%). Due to stability, homogeneity, and rate of agglomeration impact, the increase rate in thermal conductivity was very notable at a higher specific surface area. Sadeghinezhad et al. [19] synthesized aqueous GnP nanofluids with 0.025–0.1 wt.% concentrations using a two-step method. The HTC and the pressure drop characteristics were measured for nanofluids flowing through a circular tube. They claimed that the heat transfer performance of the GnP nanofluid was higher than that of the base fluid by approximately 13–160%. Arzani et al. [20] performed experiments and numerical simulation to analyze the performance of an annular heat exchanger with functionalized GnP based water nanofluids. Amiri et al. [21] used nitrogen-doped graphene nanosheets dispersed in an EGW mixture base fluid as advanced coolants in car radiators. Sadeghinezhad et al. [22,23] performed concerning experiment with the thermal performance of a heat pipe using GnP nanofluids. They obtained the changing trends by the effects of concentration, heat pipe inclination angle and input heating power. Esfahani and Languri [24] prepared graphene oxide using the modified Hummers method to oxidize purified natural flake graphite. Then, the performance of nanofluid samples in a shell-and-tube heat exchanger was studied experimentally. Exergy analysis showed that DI water caused 22% and 109% higher exergy losses compared with the graphene oxide nanofluids at 0.01 and 0.1 wt.% concentrations at laminar conditions, respectively. Apart from the works outlined above, many application cases about the GnPs or oxidized GnP nanofluids have been performed, such as nanofluids flowing in a horizontal/vertical tube [25,26], circular tube [27], and a loop heat pipe [28], etc. Although previous investigations found that using the GnPs improved heat transfer performance in some cases, these literature are confined to simple flow geometries at constant heat flux/wall temperature boundary conditions. The performance of nanofluids in complex geometries, especially in heat exchangers [29,30], has not been studied deeply.

The use of nanofluids in heat transfer systems shows some peculiar advantages despite of the problems highlighted by many researchers [31]. Based on the above literature review, the heat transfer performance and pressure drop characteristics of GnP-EGW nanofluids in an MPHE were investigated in the present article. The main reasons for choosing this are: no previous research has been performed regarding the effect of GnP-EGW nanofluids on MPHEs, and improvement in convective heat transfer coefficient may be obtained in MPHEs due to the high thermal conductivity of GnPs (3000–5000 W m^{-1} K^{-1}). This study tries to figure out two questions, first: nanofluid flow is described sufficiently employing Nusselt number correlations obtained for single-phase heat transfer liquids like water when thermophysical properties of GnP nanofluid are utilized and second: is the heat transfer enhancement provided by GnP nanofluid equal to the increase of thermal conductivity of nanofluid compared to base fluid independently of nanoparticle concentration at the MPHE working condition. Hence, systematic characterization and experiments are carried out for the GnP nanofluids including thermophysical properties and heat transfer measurements. A further analytical investigation is needed to reveal the