Applied Thermal Engineering 123 (2017) 50–60

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research Paper

Enhanced heat transfer performance of an automobile radiator with graphene based suspensions

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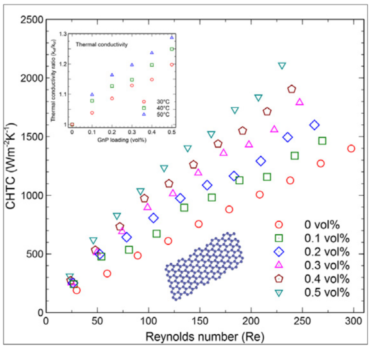
HIGHLIGHTS

- Graphene nanoplatelets/H_2O-EG nanofluids prepared by non-covalent method.
- Heat transfer coefficient and pressure drop in car radiator is investigated.
- Effect of nanofluids mass flow rate and inlet temperature is investigated.
- Heat transfer coefficient is enhanced by mass flow rate and temperature.
- The increase in pressure drop is limited beyond 0.2 vol% of GnP loading.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 23 October 2016
Revised 1 April 2017
Accepted 13 May 2017
Available online 17 May 2017

Keywords:
Graphene
Nanofluids
Automobile radiator
Convective heat transfer
Pressure drop
Thermal conductivity

ABSTRACT

We report the convective heat transfer coefficient and pressure drop of graphene nanoplatelets seeded in water-ethylene glycol mixture flowing through an automobile radiator. The volume concentrations of graphene nanoplatelets were varied from 0.1% to 0.5%. Thermophysical properties such as thermal conductivity, viscosity, density and specific heat capacity of nanofluids were measured experimentally. Mass flow rate of nanofluids were varied from 10 g/s to 100 g/s. Nanofluid inlet temperature was considered as 35 °C and 45 °C while the ambient air velocity was fixed as 3 m/s for the convective heat transfer experiments. The convective heat transfer coefficient of nanofluids increases with increasing loading of graphene nanoplatelets, nanofluid inlet temperature and mass flow rate. The enhancement of convective heat transfer coefficient for the highest concentration (0.5 vol%) and highest mass flow rate (100 g/s) was found to be 20% and 51% when the nanofluid inlet temperature was 35 °C and 45 °C respectively. The pressure drop of nanofluid increases with respect to graphene nanoplatelets loading and mass flow rate. As the loading of nanoplatelets increases from 0 to 0.5 vol% the pressure drop increases from 3.07 to 4.88 kPa at 35 °C while it increases from 3.02 to 4.04 kPa at 45 °C for 100 g/s. The present nanofluid has a potential to replace the conventional heat transfer fluids leading to compact thermal systems.

1. Introduction

Heat transfer performance of compact heat exchangers greatly depends on the convective heat transfer coefficient (CHTC) of the flowing fluids. Compact heat exchangers are used in exchanging heat between liquids and gases for industrial applications and for automotive applications like engine radiator, HVAC coils etc. In the case of liquid to gas heat exchangers, fins of innovative designs are utilized to enhance the gas side heat transfer coefficient. The liquids flowing inside the tubes have limited flow area, therefore enhancing the liquid side heat transfer coefficient predominantly

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http://dx.doi.org/10.1016/j.applthermaleng.2017.05.076
1359-4311/

Nomenclature

A	inner surface area of radiator tube (m^2)
A_{min}	minimum free-flow area (m^2)
A_{fr}	frontal area (m^2)
Cp	specific heat capacity (kJ/kg K)
C_k	enhancement coefficient of thermal conductivity
C_μ	enhancement coefficient of viscosity
D_h	hydraulic diameter (m)
h	convective heat transfer coefficient (W/m^2 K)
k	thermal conductivity (W/m K)
L	length (m)
m	mass flow rate (kg/s)
n	number of tubes
Q	heat transfer rate (W)
U	Velocity (m/s)
U_{max}	maximum velocity (m/s)
v	kinematic viscosity (m^2/s)
W	weight of the nanoparticles (g)

Greek symbols

μ	dynamic viscosity (kg/m s)
ρ	density (g/cm^3)
σ	minimum free flow area/frontal area
φ	volume concentration of nanoparticles

Subscript

bf	basefluid
nf	nanofluid

Abbreviation

CHTC	convective heat transfer coefficient
EG	ethylene glycol
H_2O-EG	water-ethylene glycol mixture
GnP/H_2O-EG	graphene/water-ethylene glycol mixture nanofluid
GnP	graphene nanoplatelets
H_2O	water
Nu	Nusselt number
Pr	Prandtl number
vol%	volume fraction of the nanoparticles
wt%	weight fraction of the nanoparticles

depend on the thermal characteristics of the heat transfer fluid. Intrinsic thermal conductivity of such heat transfer fluids are limited which lies in the range of 0.2–0.6 Wm^{-1} K^{-1}. The lower thermal conductivity of such conventional fluids can be enhanced by seeding high thermal conductive nanoparticles of various shapes [1].

Thermal conductivity enhancement of conventional heat transfer fluids with spherical nanoparticle based inclusions possess limited benefits due to high interfacial thermal resistance between the nanoparticles and the surrounding basefluids [2,3]. Therefore, higher volume concentration of spherical nanoparticles is used to enhance the thermal conductivity and convective heat transfer coefficient. This approach resulted in increasing the viscosity of nanofluids significantly, which lead to high penalty in the pressure drop in heat transfer systems.

The use of low density, high thermal conductivity materials such as carbon nanotubes (CNTs) and graphene nanoplatelets (GnP) in basefluids may alleviate the problems associated with the utilization of spherical nanoparticles. The thermal conductivity of GnP is very high (3000 W/m K) and its 2D structure can significantly increase the thermal conductivity and heat transfer coefficient of the nanofluid. Experimental investigations [4–9] on the convective heat transfer characteristics of nanofluids consisting of CNT and GnP inclusions were performed in different test sections. Previous research results reveal that the presence of carbon nanostructures significantly enhance the thermal conductivity and heat transfer coefficient as compared to other nanomaterials due to their high intrinsic thermal conductivity and high aspect ratio. Recently we demonstrated that the use of 2D nanostructure (GnP) containing lower volume concentration ($\varphi < 1\%$) in basefluid will increase the thermal conductivity and heat transfer coefficient significantly with limited increase in viscosity [9].

Few researchers [10–17] reported on the improvement in heat transfer performance of automotive radiators with nanofluids seeded with metallic and metal oxide nanoparticles. Peyghambarzadeh et al. [11–13] reported that the addition of CuO and Fe_2O_3 to water in the radiator has resulted in an improvement of 7.5% and 9% respectively in the overall heat transfer coefficient. Amiri et al. [17] studied the heat transfer performance of water-ethylene glycol (H_2O-EG) based nanofluid seeded with nitrogen doped graphene in an automobile radiator. They reported that the improvement in thermal conductivity and heat transfer coefficient were found to be 19.4% and 83% respectively.

Present day automobiles use H_2O-EG mixtures rather than pure H_2O because of the phase change associated with the latter at temperatures above 100 °C and below 0 °C. It is generally recommended [18] to have at least 30% volume concentration of ethylene glycol in automobile radiators for fast motorway driving in winter. Research work on automotive radiators with carbon nanostructures based nanofluids in EG or H_2O-EG mixtures are limited. A comprehensive review of existing literature show that no study was performed in an automobile radiator with H_2O-EG (70:30 volume ratio) as basefluid and GnP seeded in it. In this paper, we report the convective heat transfer and pressure drop characteristics of H_2O-EG mixture with GnP in an automobile radiator.

2. Materials and methods

2.1. Preparation of nanofluids

Graphene nanoplatelets (GnP) were obtained from a commercial source (XG Sciences, USA) with thickness of (t) = 5–10 nm and diameter (d) = 15 μm. Scanning electron microscopy and transmission electron microscopy visualization of GnP is shown in Fig. 1. Covalent or non-covalent functionalization method is widely adopted to prepare stable carbon based nanofluid dispersions. Covalent functionalization technique often employs strong acids which introduces structural defects in the planar structure of GnP. The intrinsic thermal conductivity of GnP will be decreased due to enhanced phonon scattering under such circumstances. Hence in the present work, we used non-covalent functionalization approach to prepare stable dispersions. Sodium deoxycholate (SDC, Molecular formula: $C_{24}H_{39}NaO_4$) surfactant was used as the surfactant (0.75 vol%) in present experiments. De-ionized water (70 vol%) and ethylene glycol (30 vol%) mixture was used as the basefluid. The basefluid with 0.75 vol% of SDC will be further referred as 0 vol% fluid. The graphene nanoplatelets were added directly to the H_2O-EG mixture by intensive ultrasonic vibration for 2 h using