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Overall heat transfer coefficient improvement of an automobile radiator with graphene based suspensions

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ABSTRACT

In the present work, we report the enhancement in overall heat transfer coefficient of an automobile radiator using graphene nanoplatelets based nanofluid as the coolant. Water-ethylene glycol mixture (70:30 by volume) was used as the base fluid and stable nanofluids were synthesized by non-covalent functionalization method with volume concentrations of graphene nanoplatelets varying from 0.1% to 0.5%. Experiments were performed in an automobile radiator for varying nanofluid mass flow rates viz. 12.5 g/s, 25 g/s, 37.5 g/s, 50 g/s, 62.5 g/s and two nanofluid inlet temperatures viz. 35 °C, 45 °C and air velocity. For each condition the ambient air velocity was varied from 1 m/s to 5 m/s in steps of 1 m/s. The convective heat transfer coefficient of nanofluid and overall heat transfer coefficient are found to increase with respect to mass flow rate, inlet temperature of nanofluid and graphene nanoplatelets loading. The improvement in convective heat transfer coefficient of nanofluid play a significant role in the enhancement of overall heat transfer coefficient. The maximum enhancement in OHTC with respect to concentration is found to be ~104% at 35 °C while it is found to be ~81% at 45 °C for 0.5 vol%, 62.5 g/s flow rate and 5 m/s air velocity. Further, the pressure drop of nanofluids increases with increase in mass flow rate and graphene loading. The increase in pressure drop is significantly influenced by the mass flow rate than by graphene nanoplatelets loading.

1. Introduction

Radiators are used in automobiles to transfer heat from the engine coolant to ambient air. Despite the name, most radiators transfer bulk of their heat via convection. The demand to enhance the heat transfer rate can be addressed either by increasing the surface area or by increasing the convective heat transfer coefficient (CHTC). With regard to higher surface area many types of compact heat exchangers have been proposed. In order to increase the CHTC innovative heat transfer fluids are required in which conventional heat transfer fluids have lower thermal conductivity. In this regard, Choi et al. [1] coined a new class of heat transfer fluid named 'nanofluid' in which solid nano-sized (<100 nm) materials are seeded in the conventional heat transfer fluids. Nanofluids show an enhanced thermal conductivity than that of the conventional heat transfer fluids which yields a higher CHTC [2–5].

Over the past few decades, carbon based nano materials such as carbon nanotubes (CNTs), graphene nanoplatelets (GnP), graphene oxide, nano diamond were utilized in order to increase the thermal conductivity of conventional heat transfer fluids due to their high intrinsic thermal conductivity [6–9]. Recently many research works have been performed with graphene based nanofluids due to its low interfacial thermal resistance and high aspect ratio resulting in higher thermal conductivity enhancement of nanofluids [10–12]. Several researchers have conducted experiments on convective heat transfer coefficient of nanofluids seeded with GnP in various types of heat exchangers [13–19]. The published literature reveals that the GnP nanofluids significantly increases the CHTC as compared to other nanofluids. The experiments on CHTC and overall heat transfer coefficient (OHTC) of an automobile radiator using various nanofluids as a coolant are reported by several researchers [20–29].

Vermahmoudi et al. [24] studied the OHTC of an automobile radiator using Fe_2O_3/water (φ = 0.15%, 0.4% & 0.65%) nanofluid as the coolant for the flow rate ranging from 0.2 to 0.5 m^3/h. The enhancement in OHTC was reported to be 13% at 0.65 vol% of Fe_2O_3. Amiri et al. [25,26] performed the experiments on CHTC of GnP/H_2O-EG (H_2O-EG = 40:60 by volume) nanofluid as a coolant (w = 0.01%, 0.05%, 0.1%, and 0.2%) in an automobile radiator for the flow rate ranging from 3 to 7 LPM. The highest enhancement in CHTC was reported to be 130% for 0.2 wt% at 7 LPM. It is also

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Nomenclature

Symbols

Cp	specific heat capacity (kJ/kg·K)
D_h	hydraulic diameter (m)
h	convective heat transfer coefficient (W/m^2 K)
k	thermal conductivity (W/m·K)
L	length (m)
$\dot{m}$	mass flow rate (kg/s)
Q	heat transfer rate (W)
T	temperature (°C)
V	velocity (m/s)
U	overall heat transfer coefficient (W/m^2 K)
w	weight fraction of the nanoparticles (%)

Greek symbols

η	efficiency
δ	uncertainty
ν	kinematic viscosity (cSt)
φ	volume fraction of nanoparticles (%)

Subscript

a	air
bf	basefluid
b	bulk mean
nf	nanofluid
N1	nanofluid inlet
N2	nanofluid outlet
W	wall

Abbreviation

CHTC	convective heat transfer coefficient
EG	ethylene glycol
H_2O	water
H_2O-EG	water-ethylene glycol mixture
GnP/H_2O-EG	graphene/water-ethylene glycol mixture nanofluid
GnP	graphene nanoplatelets
OHTC	overall heat transfer coefficient
vol%	volume fraction of the nanoparticles

reported that the increase in pressure drop is not too high with respect to concentration of GnP. Ali et al. [27] studied the heat transfer characteristics of ZnO-water (φ = 0.01%, 0.08%, 0.2% and 0.3%) nanofluids in an automobile radiator for the flow rates ranging from 7 to 11 LPM. They reported that the heat transfer rate increases by 46% up to 0.2 vol% then it is decreases beyond 0.2 vol%. Sandhya et al. [28] investigated the CHTC of TiO_2/H_2O-EG (H_2O-EG = 60:40 by volume) nanofluid (φ = 0.1%, 0.3% and 0.5%) in automobile radiator for the Reynolds number ranging from 4000 to 15,000. The highest increase in CHTC is reported to be 37% at 0.5 vol%. Selvam et al. [29] studied the CHTC of GnP/H_2O-EG (H_2O-EG = 70:30 by volume) in an automotive radiator for the mass flow rate ranging from 10 to 100 g/s. The enhancement in CHTC of GnP nanofluid for the highest mass flow rate was reported to be ~51% at 0.5 vol% and 3 m/s air velocity.

Thus, it is inferred that nanofluids significantly enhances the CHTC and OHTC of an automobile radiator and limited works have been carried out with GnP nanofluids. From the above literature, the higher improvement of CHTC in automobile radiator is found with the GnP based nanofluids at ultra-low concentration. The nanofluids containing spherical nanoparticles shows higher increase in pressure drop than that of carbon based nanostructures (ie. GnP and CNT) due to its higher density. Nowadays anti-freeze fluids (ethylene glycol and water-ethylene glycol mixture) are widely used in automobile radiators in order to avoid freezing during winter. The general recommendation is water-ethylene glycol mixture containing 30% (by volume) of ethylene glycol [30]. Till now no work has been reported using GnP dispersed in water-ethylene glycol mixture at this concentration. Lack of experimentation using specific appliances has lead to the manufacturers being skeptical about the performance of such heat transfer fluids in real time scenarios. The improvement in OHTC of an automobile radiator using GnP nanofluid has not been reported even though a few papers on CHTC are published. Thus this study has significance in the context of considering GnP/H_2O-EG nanofluid as a futuristic coolant for automotive applications.

In the present work, H_2O-EG (70:30 by volume) seeded with GnP was used as the coolant. Few-layered GnP with an average thickness of 4–8 nm was selected due to the (1) high intrinsic thermal conductivity (2) high surface area (3) 2D structure (4) low interfacial thermal resistance (5) lower size nanoplatelets can carry more atoms in their surface which in turn higher heat transfer rate. In this work CHTC and OHTC of an automobile radiator were investigated experimentally by varying mass flow rates, GnP loading and air velocity.

2. Materials and methods

2.1. Nanofluid preparation

In the present work, graphene nanoplatelets (XG sciences, USA, Grade M) and water-ethylene glycol mixture (70:30 by volume) were used as the nanoparticle and basefluid respectively. Scanning (SEM) electron microscope visualization of few-layered graphene nanoplatelets (GnP) is shown in Fig. 1. In this study, the non-covalent functionalization method was used to synthesize of nanofluids. To synthesize stable nanofluid dispersions, the sodium deoxycholate (SDC) surfactant was added in the basefluid due to the hydrophobic nature of GnP. The SDC surfactant (0.75 vol%) was added to the basefluid and stirred well by magnetic stirrer for 30 min. The basefluid along with 0.75 vol% SDC was considered as the 0 vol% fluid in the convection experiments. GnPs were dispersed in the 0 vol% fluid by intensive ultrasonication (QSonica, USA, Power Rating: 700 W, Frequency: 20 kHz) for 2 h. The GnP/H_2O-EG nanofluids with volume concentrations of 0.1%, 0.2%, 0.3%, 0.4% and 0.5% were synthesized. There was no particle sedimentation observable during visual inspection of the nanofluid

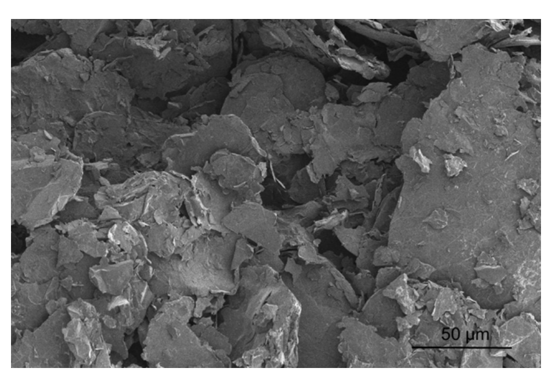

Fig. 1. SEM visualization of GnP.