

Short communication

# Thermal conductivity enhancement of ethylene glycol and water with graphene nanoplatelets

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## ABSTRACT

In the present work, we report the effective thermal conductivity of ethylene glycol and water with graphene nanoplatelets. Sodium deoxycholate, a bile salt was used as the surfactant to prepare stable nanofluid dispersions. Stability tests were performed using UV–vis absorption spectrometry and zeta potential to monitor the stability of the prepared nanofluids as a function of time. Thermal conductivity measurements were carried out using transient hot wire technique. Thermal conductivity of the nanofluids significantly increases with respect to graphene loading. Maximum thermal conductivity enhancements of ~21% and ~16% at a loading of 0.5 vol% was obtained for the nanofluids with graphene nanoplatelets seeded in ethylene glycol and water respectively. Analysis of experimental results with Maxwell-Garnett type effective medium theory reveal that despite the high thermal conductivity of graphene, interfacial thermal resistance between graphene and the surrounding base fluid limits the thermal conductivity enhancement significantly. The interfacial thermal resistance between graphene sheet and ethylene glycol was found to be  $2.2 \times 10^{-8} \text{ m}^2 \text{ KW}^{-1}$  while between graphene sheet and water was found to be  $1.5 \times 10^{-8} \text{ m}^2 \text{ KW}^{-1}$  respectively for the present nanofluids.

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## 1. Introduction

Thermal conductivity of the heat transfer fluids plays an important role in the energy transfer process for heating and cooling applications. However, thermal conductivity of heat transfer fluids such as ethylene glycol and water are very low resulting in poor convective heat transfer characteristics. Choi et al. [1] developed a new class of heat transfer fluid by seeding nanoparticles to improve the thermal conductivity of such fluids. Several published literature show that the thermal conductivity and convective heat transfer coefficient increases substantially for nanofluid, when compared to their respective base fluids [2–5]. Hence, nanofluids have great potential in the heat transfer enhancement and are highly suited for applications in practical heat transfer processes. Nanoparticles of various metals and metal oxides are considered for the production of nanofluids [4,5] but the enhancements in heat transfer characteristics are limited. Still there is a scope to improve the thermal conductivity of heat transfer fluids which in turn can yield compact thermal systems. Over the past decades many researchers have investigated the thermal conductivity enhancement in nanofluids

with carbon based nanostructure due to its higher thermal conductivity coupled with high aspect ratio and lower density.

In this context, carbon based nanomaterials such as carbon nanotubes (CNTs) [6–19], single-walled carbon nanohorns [20], graphene (graphene oxide, graphene nanoplatelets) [21–33] and nano diamond [34] are used to prepare high conductive nanofluids by several researchers. From the above literature, it is observed that carbon based nanostructures such as carbon nanotubes and graphene nanoplatelets are highly favored due to its high thermal conductivity coupled with high aspect ratio, and lower density as compared to the other nanoparticles [35,36]. The excellent thermal properties of carbon nanostructures play a predominant role in the enhancement of thermal conductivity. The basefluid with carbon nanostructure such as CNT and Graphene with high aspect ratio can efficiently participate in the energy transfer process resulting in higher heat conduction and improved convection characteristics [9,31]. Recent experiments show that particle clustering plays a significant role in thermal conductivity enhancement as compared to the effect of Brownian motion of particles [20,37]. Hence, it is expected that carbon nanotube and graphene nanoplatelets dispersed in the basefluid would show a better enhancement in thermal conductivity as compared to other nanoparticles. When the particle size reaches nanoscale, interfacial thermal resistance between the nanoparticle and the surrounding

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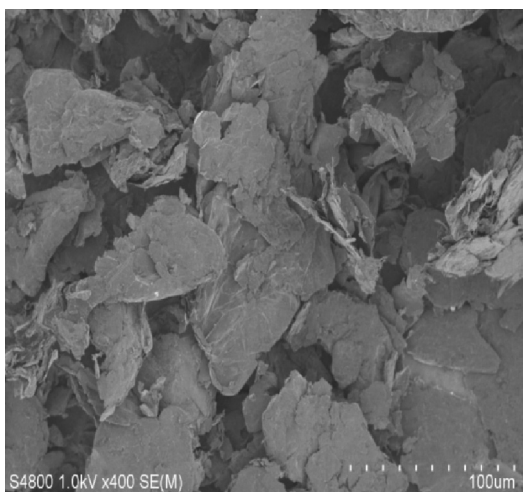


Fig. 1. SEM visualization of Graphene nanoplatelets.

fluid becomes significant. Recent calculations based on effective medium theory (EMT) shows that graphene based nanocomposites show superior performance compared to carbon nanotubes and other nanostructures due to their high thermal transport and low interfacial thermal resistance [38].

From the previous studies it is observed that, limited work has been done on thermal conductivity of graphene nanoplatelets based nanofluids with conventional heat transfer fluids. The comparison of experimental results with EMT prediction considering the role of interfacial thermal resistance is also limited in the previous studies. Further experimental studies are needed to exactly predict the thermal behavior and interfacial thermal resistance of graphene nanoplatelets with different basefluids. In the present work, we report (1) the thermal conductivity enhancement of graphene based nanofluids and a comparison of the results with effective medium theory calculations, (2) the interfacial thermal resistance between graphene and surrounding base fluid, (3) the thermal conductivity enhancement depends on the base fluid thermal conductivity and volume concentration of graphene nanoplatelets.

## 2. Materials and methods

### 2.1. Preparation and characterization of nanofluids

The graphene nanoplatelets (GnP) were purchased from XG Sciences with an average thickness of 5–10 nm and mean particle diameter of 15  $\mu\text{m}$  (Grade M). The SEM visualization of GnP nanoplatelets is shown in Fig. 1. The hydrophobic nature of GnP makes it very difficult to disperse them in a basefluid directly. Covalent or non-covalent treatment is often followed to create stable dispersions of graphene nanoplatelets. Covalent treatment often damages the planar structure and introduce structural defects of the 2D structure. This results in the reduction of intrinsic thermal conductivity of GnP due to increased phonon scattering. To avoid this, we have made use of non-covalent treatment in this work.

Ethylene glycol and water were used as basefluids in this study. Graphene nanoplatelets were mixed with the basefluid under ultrasonic vibration for 2 h using the Digital Sonicator (QSonica, USA) with 0.75 vol% sodium deoxycholate (DOC) as a surfactant. Hence, 0 vol% fluid actually refers to 0.75 vol% of DOC added to the basefluids namely ethylene glycol and water. The thermophysical properties and purity of materials and basefluids are listed in Table 1. The volume percent of the graphene nanoplatelets loading considered were viz. 0.001%, 0.01%, 0.1%, 0.2%, 0.3%, 0.4% and 0.5% with the

surfactant. Stability test was performed by taking small samples of nanofluid and visually inspecting it for occurrence of any settlement. There was no sedimentation in the prepared sample kept undisturbed for even more than 15 days. The photographic views of the prepared nanofluids after 5 min and after 15 days are shown in Fig. 2(a) and (b). The prepared nanofluids were further characterized using the UV–vis absorption spectrum (PG instruments, UK) and zeta potential distribution (Malvern Instruments, UK).

### 2.2. Measurement of thermal conductivity

Transient hot wire method is the widely used method to measure the thermal conductivity of liquids. In this method, the platinum wire acts as both the heater and an electrical resistance thermometer. The wire is surrounded by the liquid (nanofluid) whose thermal conductivity is to be measured. The wire is then heated by sending electrical current through it. The higher the thermal conductivity of the surrounding liquid, the lower will be the temperature rise of the wire. The relation between thermal conductivity ( $k$ ) and measured temperature ( $T$ ) can be summarized as follows [40] in Eq. (1).

$$k = \frac{q}{4\pi(T_1 - T_2)} \ln \frac{t_1}{t_2} \quad (1)$$

Where, temperature of the hot wire at time instants  $t_1$  and  $t_2$  are  $T_1$  and  $T_2$  respectively.

In this study KD2 Pro thermal properties analyzer (Decagon Devices, Inc, USA) which is based on the transient hot wire measurement technique was used to measure the thermal conductivity of the nanofluids. The design of the instrument is as per ASTM Standard D5334-08 and IEEE Standard 442-1981. The KD2 pro apparatus with a measuring probe (ks-1 sensor) having a maximum uncertainty of  $\pm 5.0\%$  (for 'k' ranges from 0.2 to 2 W/m K) was used. Thermal conductivity measurement was performed at a temperature of 30  $^{\circ}\text{C}$  and pressure of 100.7 kPa ( $\pm 1\%$  standard uncertainty). The pressure was not varied during the experiment.

## 3. Results and discussion

### 3.1. Nanofluid characterization

To quantify the stability of nanofluids, we made use of UV–vis absorption spectrometer to measure the time dependent properties of the prepared nanofluids for a period of 15 days. The absorption spectrums were found from GnP-EG and GnP-water nanofluids as shown in Fig. 3(a) and (d). The absorbance increases with increasing volume concentration of graphene nanoplatelets which indicates the good stability of nanofluid dispersion. The maximum peak of the absorbance spectrum is observed around 270 nm. Long term stability test was performed quantitatively using UV–vis absorption spectrometer. The estimated relative concentrations of GnP-EG and GnP-H<sub>2</sub>O nanofluids with respect to time and different volume percent are shown in Fig. 3(c). The estimated relative concentration by absorbance at a wavelength of 270 nm is drawn for time of 15 days. It is observed that relative concentration of nanofluids decreases over a period of 15 days. The maximum sedimentations are found to be  $\sim 21\%$  and  $\sim 10\%$  for 0.01 vol% of nanoplatelets in water and ethylene glycol respectively. After 15 days (20th day) the prepared nanofluid was again sonicated for 2 h and characterized by UV–vis in order to check whether the particle aggregation is reversible or irreversible as shown in Fig. 3(d). It is clearly seen that the maximum deviations are found to be within 1–2% for 0.01 vol% of GnP in water and ethylene glycol respectively which indicates the particle aggregation is reversible. The deviations can be attributed to the fact that error in the mea-

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