An experimental evaluation on thermophysical properties of functionalized graphene nanoplatelets ionanofluids

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ABSTRACT

Ionanofluids (ionic liquid-based nanofluids) as newly introduced types of nanofluids with promising potential for heat transfer and thermal storage applications are created through complex dispersion of ultrafine nanometer-sized particles in ionic liquids. As innovative agents for development of energy sustainability, ionanofluids are widely employed in some applications, i.e., solar panels, catalysts, heat insulators and so forth. Non-flammability and non-volatility features of ionic liquids, make them applicable as green working fluids for any chemical processes. In the present paper, an experimental investigation was conducted on some thermophysical properties (viscosity, electrical conductivity and surface tension) of graphene based ionanofluid as main effective parameters in performance analysis. For this purpose, ionanofluid was prepared at three levels of weight fractions (1%, 2% and 3%) by adding and dispersing polycarboxylate functionalized graphene nanoplatelets (GNPs) in BMIM-PF_6 (1-Butyl-3-methylimidazolium hexafluorophosphate) with 98 + % purity as the base fluid. The experimental data was acquired within the temperature range of 293.15 to 333.15 K and at atmospheric pressure (~101 kPa). The results show that the viscosity of ionanofluid decreases with enhancement of temperature and nanoparticle concentration. On the other hand, electrical conductivity of ionanofluid augments as temperature and particle loading increase. For instance, EC at 1% wt. nanoparticles and 303.15 K enhances around 64% compared to the pure IL. Surface tension of the ionanofluids was also determined experimentally as a function of temperature for different mass loadings of nanoparticles. The results reveal that surface tension of ionanofluids decreases slightly as temperature enhances and it reduces with enhancement of nanoparticle fraction as well.

1. Introduction

Introduction of nanofluids as a new generation of industrial working fluids with superior capability of heat transfer augmentation goes back to near two decades. Nanofluids are produced by adding and suspending nanoscale (1–100 nm) metallic, metallic oxide, carbon or composite particles in conventional fluids such as water, ethylene glycol, mineral oils etc. Offering nanofluids for the first time in 1995, Choi [1] could made an evolutionary change to heat exchange within fluids. In fact, a new perspective was introduced on suspensions of solid particles of nanometer dimensions in liquids. Due to the small size of suspended particles, some problems in system i.e., corrosion, impurity and pressure loss have been substantially diminished and stability of suspensions against sedimentation has been improved as well [2].

Vast number of investigations have been carried out on the evaluation of nanofluids with water [3–10], ethylene glycol (EG) [11,12] and oil [13,14] as base fluid experimentally and numerically. Since water and ethylene glycol are more proper for use at low temperature

ranges and also oils possess relatively lower thermal stabilities and higher vapor pressure compared to other frequently used working fluids, it is needed to fabricate novel nanofluids with another types of base fluid, i.e., ionic liquids, to be employed in wide range of thermal conditions. Ionic liquids (electrolytes) are the center of attention in materials research since the 21st century [15]. Indeed, they are mineral salts with low melting point (below 100 °C) in the liquid state which can be utilized in higher temperature ranges (up to about 200 °C). With higher electrical conductivity (EC) and thermal stability as well as lower vapor pressure compared to the common liquids, ILs can be alternatively used in a wide variety of industrial applications where using working fluids with limited thermophysical and chemical properties is not a feasible option. As a green chemical solvent, they have an effectual role in decrement of using hazardous substances to the environment. In spite of such interesting advantages, the number of investigations on the combination of ionic liquids and different nanoparticles (ionanofluids) [16–18] is extremely lower than ordinary nanofluids.

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On the other hand, graphene nanoparticles as one of the most promising candidate for thermal conductivity enhancement have attracted tremendous interest among researchers, insofar as the number of investigations on nanofluids containing graphene nano-additive [19–24] has redoubled in the recent years. Also in order to make graphene-based nanofluids more stable and soluble, some practical measures such as chemical functionalization of graphene nanoparticles and using surfactants have been so far taken by investigators [25,26].

Performing an experimental study, Liu et al. [17] reported 22.9% increment in thermal conductivity of HMIM-BF$_4$ (1-Hexyl-3-methylimidazolium tetrafluoroborate) through dispersing 0.06% weight concentration of graphene nanoparticles at temperature ranging from 25 to 200 °C. They also observed that viscosity of the ionanofluid decreased around 6.3 cP (0.0063 Pa.s) by enhancement of temperature up to 210 °C in comparison with the base liquid.

In another research, the colloidal stabilities of dispersions of surface-functionalized and unmodified SiO$_2$ nanoparticles in hydrophobic and hydrophilic imidazolium-based ILs were investigated by Wittmar et al. [27]. They observed that the unmodified hydrophilic nanoparticles are more compatible with the hydrophilic IL. Also they reported that the colloidal stability of the dispersions in the hydrophobic IL improves with the surface functionalization of SiO$_2$ with hydrophobic groups.

Nanofluids are homogenous suspensions containing nanometer-sized particles which possess great potential to enhance thermal conductivity, viscosity, electrical conductivity and surface tension of base liquids. These thermophysical properties play a significant role in improvement of heat exchange, pumping power effect and convective heat transfer coefficients of fluids. With regard to the close relation between viscosity, shear rate, pumping power and friction factor in a system, an extensive survey on nanofluids thermophysical behavior has a particular significance. Numerous research papers have characterized thermophysical properties of different nanofluids including graphene nanoparticles and carbon nanotubes (CNTs) [28–31] while few experimental studies have been concerned about those of graphene-based ionanofluids. One of the common observations in the previous investigations is changing the viscosity of fluid with increment of nanoparticles loading as well as temperature.

In fluids with the suspension of nanoparticles, improvement of EC could be attributed to the charge transfer kinetics enhancement which is significantly affected by EDL (electrical double layer) effect in solution [32]. Particles size, nanoparticle concentration, and reference electrolyte are some important factors affecting electrical conductivity of suspensions directly. Electrical conductivity of fluids has diverse industrial and technological usages such as electric-field formation in colloidal dispersions, sensors, electrically conductive adhesive, etc. In some original research studies, electrical conduction capability of metals, metal oxides and CNTs has been carefully studied [32,33].

So far a few studies have been accomplished on the electrical conductivity of graphene nanofluids compared to their thermal conductivity [34–36] which all represent remarkable increase in electrical conductivity of the base fluids with the addition and dispersion of graphene nanoparticles to them.

In an experimental study, electrical conductivity of aqueous graphene based nanofluid at various volume loadings of nanoparticles (% vol.) and temperatures was measured by Baby and Ramaprabhu [34]. They reported an enhancement of about 1400% in electrical conduction of the solution at 0.03% vol. and 25 °C.

Aravind and Ramaprabhu [37] in a research determined the electrical conductivity of graphene nanosheets (GNs) nanofluids. According to their comparative outcomes at room temperature, electrical conductivity of GNs nanofluid with EG as base fluid enhances around 81 and 190% at 0.008 and 0.14% vol. respectively. Also this parameter augments about 33% at 0.008% vol. and 55% at 0.14% vol. for the solution with de-ionized (DI) water as the base fluid.

The interesting features of ILs as well as the significance of

Table 1
Physical properties of the GNPs.

Nanoparticles	Appearance (color)	Molecular weight (gr/mol.)	Chemical composition
Polycarboxylate functionalized graphene nanoplatelets	Faint grey to black	12.01	Carbon, > 85% wt. Oxygen, > 3% wt.

examining thermophysical characteristics of working fluids for optimized use in energy transport processes specifically thermal and electrical energies, has acted as a keen motivator for the current research authors to experimentally evaluate the consequence of dispersing functionalized GNPs at three mass fraction levels (1, 2 and 3%) on viscosity, electrical conductivity and surface tension of BMIM-PF$_6$ as the base liquid in the temperature range 293.15 to 333.15 K.

2. Preparation of ionanofluid

Despite inefficiency of the two-step method for preparation of well dispersed nanofluids with high stability, due to some benefits such as simplicity, quickness and low cost [38], it is becoming more and more popular among scholars.

Polycarboxylate functionalized graphene nanoplatelets (GNPs) was used to create the ionanofluids with BMIM-PF$_6$ (98 + % purity) as the base liquid at 1, 2 and 3% (by weight) nanoparticle loadings by the two-step procedure. Both the nanoparticles and the ionic liquid were manufactured by American chemicals company (Sigma-Aldrich). Some physical properties of the GNPs have been presented in Table 1.

In order to obtain a morphological viewpoint, the X-ray diffraction (XRD) pattern and SEM (scanning electron microscope) images of the Polycarboxylate functionalized GNPs at two different magnifications have been represented in Fig. 1(a), (b) and (c) respectively. Since the ionanofluids should be more stable and well dispersed for a long period without any agglomeration, sodium dodecyl sulfate (SDS) was used as a surfactant to deduct the base liquid adhesion. For preferable dispersion, after mixing GNPs, the IL and SDS together by a mechanical mixer, the solution was homogenized in an ultrasonic probe sonicator (Hielscher-UP200S) for around 90 min. A digital photograph of prepared ionanofluid (at 2% wt.) right after ultrasonically dispersion as well as the base ionic liquid sample (BMIM-PF$_6$) are illustrated in Fig. 2. According to the observations, stability of the ionanofluid decreases as the nanoparticles fraction rises, so that the prepared ionanofluid at 3% loading (by weight) was not sufficiently stable and showed the least resistance against sedimentation compared to other concentrations.

3. Experimental measurements

3.1. Viscosity of ionanofluids

In general, viscosity is defined as a measure of the resistance to flow of a fluid. Viscosity of the ionanofluids at 1, 2 and 3% wt. was measured right after preparation by a programmable viscometer (Brookfield-DV-II + Pro, Fig. 3) with ± 1% accuracy and ± 0.2% repeatability which was properly connected to a computer for recording the data. For controlling the temperature or keeping it fixed during the tests, a temperature control water bath was used. To sense and read the temperatures during the trials PT100 type sensors with ± 0.1 K precision and a digital k-type thermometer were utilized in the system. To minimize possible errors and obtain reliable results, prior to the experiments, the viscometer was intently checked and calibrated on the basis of test results for the standard fluid of known viscosity within a specified temperature range and accordingly the maximum deviation of < 0.9% was detected. Under steady-state conditions, the data was