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Experimental study on thermal conductivity and electrical conductivity of diesel oil-based nanofluids of graphene nanoplatelets and carbon nanotubes

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ABSTRACT

In this study the performance of diesel oil using carbon-based nano additives evaluated. Since carbon nanostructures are unstable in diesel oil (DO), covalent and noncovalent bonds can solve this challenge to a large extent. Here, nanoparticles containing graphene nanoplatelets (GNP) as well as multi-walled carbon nanotubes (MWCNT) in the form of non-covalent with surfactant oleic acid (OA) and covalent with hexylamine (HA) have been synthesized and their thermal and electrical conductivity have investigated in the laboratory. For this purpose, individually, GNP and MWCNT are functionalized with hexylamine. Then, nanofluids include HA-GNP/DO, HA-MWCNT/DO, OA-GNP/DO, OA-MWCNT/DO and a hybrid of OA-GNP and MWCNT/DO at weight concentrations of 0.05%, 0.1%, 0.2%, and 0.5% were synthesized. The thermal conductivity and electrical conductivity of above suspensions, were studied at temperatures of 5 °C to 100 °C. The results showed increasing in thermal conductivity and electrical conductivity of all nanofluids in all weight concentrations compared to the pure diesel oil at the constant temperature. In addition, with increasing temperature, thermal conductivity and electrical conductivity increased for all weight concentrations.

1. Introduction

Nanofluids are homogeneous mixtures of solids and liquids when these solid particles are smaller than 100 nm and uniformly and stably suspended in a fluid. These added solid particles are supposed to improve thermo-physical properties and heat transfer behavior of their base fluid. According to the literature, nanofluids dramatically have better thermophysical properties and might achieve better Heating performance compared to conventional liquids. Choi [1] coined the term “nanofluids” for this new type of heat transfer fluids.

Numerous review articles provide discussion on synthesis, investigation of thermophysical properties, mechanism of heat transfer in nanofluids, challenges and applications in heat transfer. Aberoumand et al. [2] studied thermophysical properties of Cu–engine oil nanofluids. The results reveal that for weight fraction of 0.2% and 1%, the increase in thermal conductivity was from 27% to 49%. Amiri et al. [3] used graphene quantum dot (GQD) as additive to water to investigate the thermophysical properties of water-based GQD suspensions. The results showed that by adding very low amount of GQD, thermal conductivity of nanofluid increased exceedingly in comparison with water.

Zeinali Heris et al. [4] studied the effect of TiO_2 nanoparticle on heat transfer properties of turbine oil. Results cleared that heat transfer coefficient and pressure drop of turbine oil increased and quality of turbine oil was improved. Yu et al. [5] observed that the enhancement in thermal conductivity of ZnO-EG nanofluids depended on the temperature. The thermal conductivity increased with the increase in temperature. Sundar et al. [6] used the Fe_3O_4 nanofluids for investigation the thermal conductivity. They performed experiments with considering the temperature and volume concentration. The results showed that the thermal conductivity was plainly dependent on the temperature and particle volume concentration and increased with an increase in the particle volume concentration. Also a maximum enhancement was observed of 48% with 0.2% volume. Zeinali Heris et al. [7] investigated heat transfer properties of turbine oil-based nanofluids inside a circular tube. Results showed using TiO_2 and CuO as nanoparticles leads to improve the performance indexes of CuO and TiO_2/turbine oil and consequently heat quality of turbine oil. Yeganeh et al. [8] measured the thermal conductivity augmentation of Nanodiamond particles suspended in pure deionized water with different volume concentration. In this investigation, the thermal conductivity improvement of 7.2% was obtained with 3 vol%. At higher temperature, thermal conductivity showed more improvement. Gandhi et al. [9] investigated the thermal conductivity of graphene for different concentrations of 0.01–0.2 vol% at different temperatures. The thermal

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conductivity was found to improve with the increase in the concentration of graphene and maximum enhancement of 27% was observed at 0.2 vol% concentration. Zeinali Heris et al. [10] studied on turbine oil with a mixture of nanoparticles include Al_2O_3, TiO_2, and CuO with different weight concentration of nanoparticles in a natural convection flow to improve heat transfer. The results revealed that nanofluids with lower weight percent had higher result in Nusselt number compared to the base fluids.

Singh et al. [11] synthesized nano diamond-water nanofluids and estimated thermophysical properties such as thermal conductivity, viscosity and estimated their potential use in various heat transfer applications. Their experimental results showed enhancement in thermal conductivity of 12.7% and 22.8% at 1.0 vol%. Samani et al. [12] investigated the thermal conductivity of individual multi-walled carbon nanotubes using a pulsed photothermal reflectance technique. Liu et al. [13] considered the thermal conductivity improvement of synthetic engine oil based multi-walled carbon nanotubes and ethylene glycol based MWCNTs with an increase in volume concentration of the nanoparticles. For the 1% volume concentration for the MWCNTs–ethylene glycol, the increase in thermal conductivity was up to 12.4%, while for the MWCNTs–synthetic engine oil suspension, the increase of thermal conductivity at the volume concentration of 2% was up to 30%. Jiang et al. [14] measured the effect of different CNT volume concentrations and temperatures on thermal conductivity of CNT-water nanofluid.by increasing in CNT volume concentration, thermal conductivity enhanced nonlinearly. The enhancement of thermal conductivity by increasing the temperature is constant. Kumar et al. [15] investigated thermal conductivity and rheological properties of Cu-Zn hybrid as nanoparticle in various base fluids such as SAE oil. In all type of oils, thermal conductivity of the hybrid nanofluids increased by increasing in volume concentration of Cu-Zn hybrid. Pourhoseini et al. [16] experimented the effect of different concentrations in the range of 0–0.125 wt%. Results revealed that in all concentration of nanoparticles, thermal conductivity increased in comparison with base fluid and in 0.03 wt% the thermal conductivity was in its maximum amount. Kole et al. [17] investigated thermal and electrical conductivity of graphene-based nanofluids and their results showed increasing of thermal conductivity of both the base fluid and nanofluids with temperature. Also Electrical conductivity of the nanofluids increased linearly with concentration.

Rashidi et al. [18,19] studied the thermal conductivity of nanofluids based on Graphene. Their result suggested that thermal conductivity improves by increasing Graphene concentration. Ahmadi et al. [20] Investigated the behavior of engine oil based nanofluid from multi-walled carbon nanotubes and showed that thermal conductivity of nano-fluid, improved with respect to the base oil. Hajjar et al. [21] studied on GO/water nanofluid and indicated that the thermal conductivity of nanofluid is substantially higher than the base fluid.

In this study, thermal conductivity and electrical conductivity of 5 nanofluids based on diesel oil (DO) were investigated. For the evaluation of above-mentioned properties, nanomaterials such as multi-walled carbon nanotubes (MWCNT), graphene nanoplatelets (GNP), functionalized GNP and MWCNT with Hexylamine (HA), and hybrid of MWCNT and GNP with the ratio of 1:1 were used. All of them dispersed separately in diesel oil as the base fluid. For evaluation and comparison of the effect of above nanomaterials on the behavior of thermal conductivity and electrical conductivity, several nanofluids by changing the weight percent of nanomaterial (0.05%, 0.1%, 0.2%, and 0.5%) were prepared and thermal conductivity and electrical conductivity were measured in each nanofluid. Moreover, temperature effect on thermal conductivity and electrical conductivity has been studied as well in the range of 5 °C to 100 °C. Nanofluids stability was assured by using ultrasonic probes to prepare stable nanofluids and to avoid of agglomeration of nanomaterials in nanofluids.

2. Experiment

2.1. Materials and methods

Pristine Graphene nanoplatelets (GNP) (1–20 μm in diameter, < 40 nm in length and purity of 99.5%) and multi-walled carbon nanotubes (MWCNT) (20–30 nm in diameter, 5–10 μm in length and purity of +95%) were obtained from VCN Materials Co. Dimethylformamide (DMF), tetrahydrofuran (THF), methanol, hexylamine (HA), sodium nitrite ($NaNO_2$), and sulfuric acid (H_2SO_4,98%), all with analytical grade were purchased from Sigma–Aldrich Co. Also, oleic acid (OA) was obtained from Merck Inc. diesel oil (DO) was prepared by Iranol Company.

Recently, the new mechanism for the functionalization of GNP and MWCNT with amine groups was suggested by Amiri et al. [22]. Regarding HA-treated GNP and HA-treated MWCNT, the pristine GNP and MWCNT (200 mg) were sonicated with HA (20 ml) and $NaNO_2$ (200 mg) for 2 h at 50 °C, separately, until a uniform suspension was provided. During sonication time, 0.5 ml of H_2SO_4 was dropped to the suspension to complete diazonium reaction. The mixture was subsequently poured into a Teflon reaction vessel (100 ml), placed into the microwave (Milestone Micro SYNTH programmable microwave system) and continuous microwave irradiation was carried out with simultaneous monitoring of power and temperature. The suspension was irradiated for 30 min at 120 °C power of 700 W. After being cooled at room temperature, the mixture was filtrated on a polytetrafluoroethylene(PTFE) membrane. Then, the resulting product was washed with DMF, THF, and methanol to remove any unreacted HA and then dried for 72 h at 40 °C.

2.2. Preparation of the nanofluids

GNP and MWCNT were used for the synthesis of surfactant–GNP, surfactant–MWCNT and surfactant-GNP/MWCNT oil suspension. Then, above-mentioned suspensions were synthesized in the ratios of 1–1 (OA-GNP and OA-MWCNT), respectively. For suspension stability, the ultrasonic probe with the power of 750 W and 20 kHz was used for 15 min.

In order to prepare HA-GNP/DO and HA-MWCNT/DO, the functionalized GNP and MWCNT with HA in a known amount of DO as a base fluid sonicated for nearly 15 min using the ultrasonic probe. HA-GNP/DO and HA-MWCNT/DO with weight concentration of 0.05%, 0.1%, 0.2%, and 0.5% were synthesized.

2.3. Instrumentation

Regarding characterization, the infrared spectra of samples are studied by a Fourier transform infrared spectroscopy (Nicolet 470) in the region 400–4000 cm^{-1}. Raman spectroscopy.

(Renishaw confocal spectrometer at 514 nm), and high-resolution transmission electron microscopy, HRTEM (HT7700, Fi Instruments, High-Contrast/High-Resolution Digital TEM) were employed to analyze samples.

The electrical conductivity of the resulting suspension was measured using an electrical property analyzer. The thermal conductivity of samples was measured with a KD2 Pro thermal analyzer. The thermal conductivity of all samples has been measured four times and the average amount of results is reported.

The HA-GNP, HA–MWCNT, OA-GNP, OA-MWCNT and OA-GNP/MWCNT were first dispersed in pure DO by the ultrasonic probe with the power of 750 Wand 20 kHz (Sonics & Materials, Inc., USA). Next, the suspensions were prepared for measurement of the thermal conductivity and electrical conductivity.