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Study of Rheological Behavior of Water-Ethylene Glycol /Nano Al2O3 –Nano Graphene Hybrid Nanofluid at Low Temperatures

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ABSTRACT: Nanofluids are a new generation of fluids with very high potential in industrial applications. In this study, the effect of temperature and concentration of nanoparticles consisting of Al2O3 nanoparticles and graphene nanoplates on the rheological behavior of the base fluid consisting of water and ethylene glycol was studied. Also, 0.2%vol. of oleic acid and 0.2%wt. of sodium dodecyl sulfonate were added to the base fluid as a surfactant to disperse the nanoparticles. The volume fraction of nanoparticles in this study was considered 0.05, 0.1, 0.5, 1, 1.5, 2, and 2.5% by volume, and also to investigate the effect of temperature, the tested temperatures were selected in the temperature range of 263-293K. The morphology and microstructure of the nanoparticles were investigated by scanning and transmission electron microscopy. Detection of phases in nanoparticles was performed by X-Ray Diffraction analysis. Also, the specific area and porosity of nanoparticles were determined. The dynamic viscosity of hybrid nanofluids was measured and compared with the base fluid. The results showed that the rheological properties of nanofluid were dependent on temperature and nanoparticle concentration, especially at sub-zero temperatures. Hybrid nanofluid samples with solid volume fraction less than 0.5% showed Newtonian behavior, while samples with higher solid volume fractions showed non-Newtonian shear thinning behavior.

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1- Introduction

Nanofluid is a colloidal suspension which consists of nanoparticles and a base liquid. The nanoparticles used in nanofluids are typically made of metals(Cu, Ni, Al, etc.), oxides(Al_2O_3, TiO_2, CuO, SiO_2, Fe_2O_3, Fe3O4, $BaTiO_3$, etc.), carbides(SiC, TiC, etc.), or some other compounds (AlN, $CaCO_3$, graphene, carbon nanotubes, etc.) while the base fluids basically include water, ethylene glycol, propylene glycol, engine oil, etc. Hybrid nanofluids are the next generation of nanofluids which are made of a combination of more than one type of nanoparticles suspended in a base fluid. The thermophysical and rheological properties of hybrid nanofluids, such as thermal conductivity and viscosity values are higher than those for single nanofluids, which recommended that hybrid nanofluids have great potential in thermodynamic applications. Hybrid nanofluids may be prepared via single or two-step methods. The most commonly used method for the preparation of hybrid nanofluid is the two-step method. Previous research has revealed that nanofluids have superior thermophysical properties such as thermal conductivity, thermal diffusivity, viscosity, and convective heat transfer coefficients when compared to base fluids such as oil or water. These unique properties provide a wide range of applications for nanofluids, such as: Automobile applications, Solar energy applications, Mechanical applications, Reactor-heat exchange, Optical applications, Biomedical applications, and Electronics cooling. There are many experimental studies to investigate the thermal conductivity and viscosity behavior of nanofluids with different nanoparticles. These researches lead to the development of nanofluids in various industrial applications.

2- Methodology

The used Al_2O_3 nanoparticles and graphene nanoplatelets were obtained from US research nanomaterials. Ethylene glycol with purity ≥99% and distilled water were used for preparing the base fluid. The X-Ray Diffraction (XRD) studies were carried out by a Philips PW1730 X-ray diffractometer using Cu ($K\alpha$ =1.54060 A°) radiation for 2θ (20° to 80°) in steps of 0.03° with a step scan time of 0.6s. The test was performed to identify the phase and crystal structure of nanoparticles. The size and morphology of nanoparticles were analyzed by Transmission Electron Microscopy (TEM) using the Philips CM120 instrument. To be able to investigate the surface morphology of the nanoparticles, TESCANMIRA3 Scanning Electron Microscopy (SEM) was used. Before the

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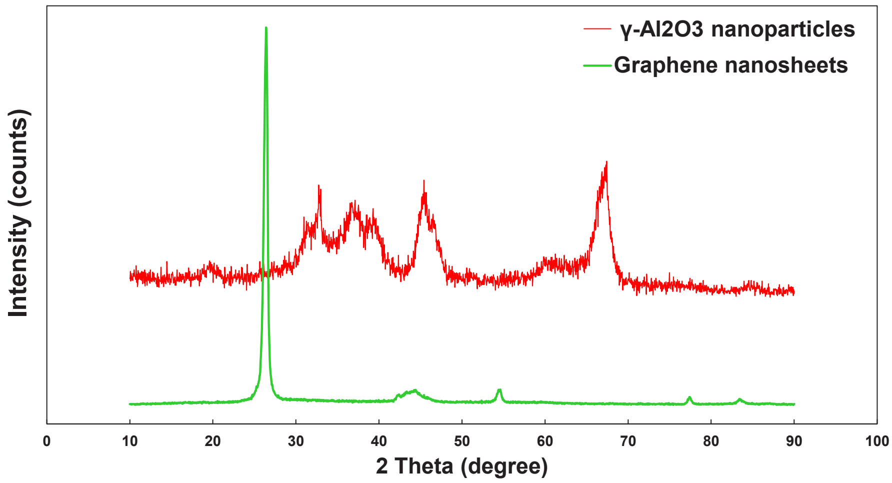

Fig. 1. XRD patterns of nanosized γ-Al_2O_3 and graphene nanoplatelets.

analysis, samples were covered by gold coating using an IB-3 ionic sputter coater. Brunauer-Emmett-Teller (BELSORB MINI II, BEL, JAPAN) N2-adsorption at 77 K was conducted to determine the Molecular sieve surface area, porosity, and specific surface area (SSA) of Al_2O_3 nanoparticles and graphene nanoplatelets using a five-point BET isotherm ((TriStar II Plus, Micromeritics) after degassing the samples for ≥1 h at 140 °C). The BET equation was used to calculate the specific surface area. In the present research, the hybrid nanofluids were prepared using a two-step method. The base fluid was a combination of distilled water and ethylene glycol (W:EG/50:50 concentrations in Volume Percent at 298.15 K) and the amount of 0.2 volume percentage oleic acid (OA) and 0.2 weight percentage sodium dodecyl sulfonate (SDS) as surfactants to stabilize and disperse the nanoparticles. Nanoparticles were dispersed in ethylene glycol /water with solid volume fractions of 0.05, 0.1, 0.5, 1, 1.5, 2 and 2.5 %. Equal volumes of Al_2O_3 nanoparticles and graphene nanoplatelets have been dispersed in the base fluid. The viscosity of Al_2O_3 - graphene/ ethylene glycol -water nanofluids with solid volume fractions ranging from 0.05% to 2.5% were measured in a temperature range from 263.15K to 303.15K. A Brookfield viscometer with a temperature bath was used to measure the viscosities of Al2O3 - graphene/ ethylene glycol -water nanofluids in the shear rate range of 0.3 RPM – 70 RPM. The ranges of repeatability and accuracy of the viscometer are, respectively, ±0.2% and ±1.0%. The viscometer was tested with a mixture of pure water and ethylene glycol (50:50) at different temperatures before being used to measure the dynamic viscosity of the hybrid nanofluids.

3- Results and Discussion

The XRD patterns of Al_2O_3 nanoparticles and graphene nanoplatelets are presented in Fig. 2. The XRD pattern of the nano size γ-alumina. Diffraction peaks of the nano γ-alumina are indicated at 32.81°, 36.72°, 45.38°, 66.59°, and 67.24° at d-spacings of 2.726, 2.446, 1.996, 1.403 and 1.391 Å respectively. For Graphene, a sharp and tight peak at 26.42° and some short peaks at 43.348°, 54.484°, 77.421° and 83.478° could be seen in the XRD output of the graphene nanoplates; the strong peak at $2\theta = 26.42$ with d-spacing of 3.370 Å attributed to the (002) crystalline plane.Fig. 2 shows the dynamic viscosity and shear stress values as a function of shear rate at different temperatures for different solid volume fractions. As can be seen, the shear stress is dependent on the shear rate for hybrid nanofluids with solid volume fractions ranging from 0.5 to 2.5% by volume. For these samples, increasing the shear rate at constant temperature leads to a nonlinear decrease in viscosity, indicating non-Newtonian behavior at all temperatures studied. It can also be observed that the n values are less than 1, indicating that the hybrid nanofluids exhibit shear thinning behavior at high concentrations. The samples with a solid volume fraction less than 0.1 vol% ($\varphi \leq 0.1$ vol%) show different rheological behavior. For solid volume fractions of 0.05 and 0.1 vol%, the variation in viscosity versus shear rate is insignificant and the viscosity values remain approximately constant as the shear rate increases, indicating that the hybrid nanofluid approximates Newtonian behavior. This is confirmed by the nearly linear relationship between shear stress and the shear rate at these temperatures.

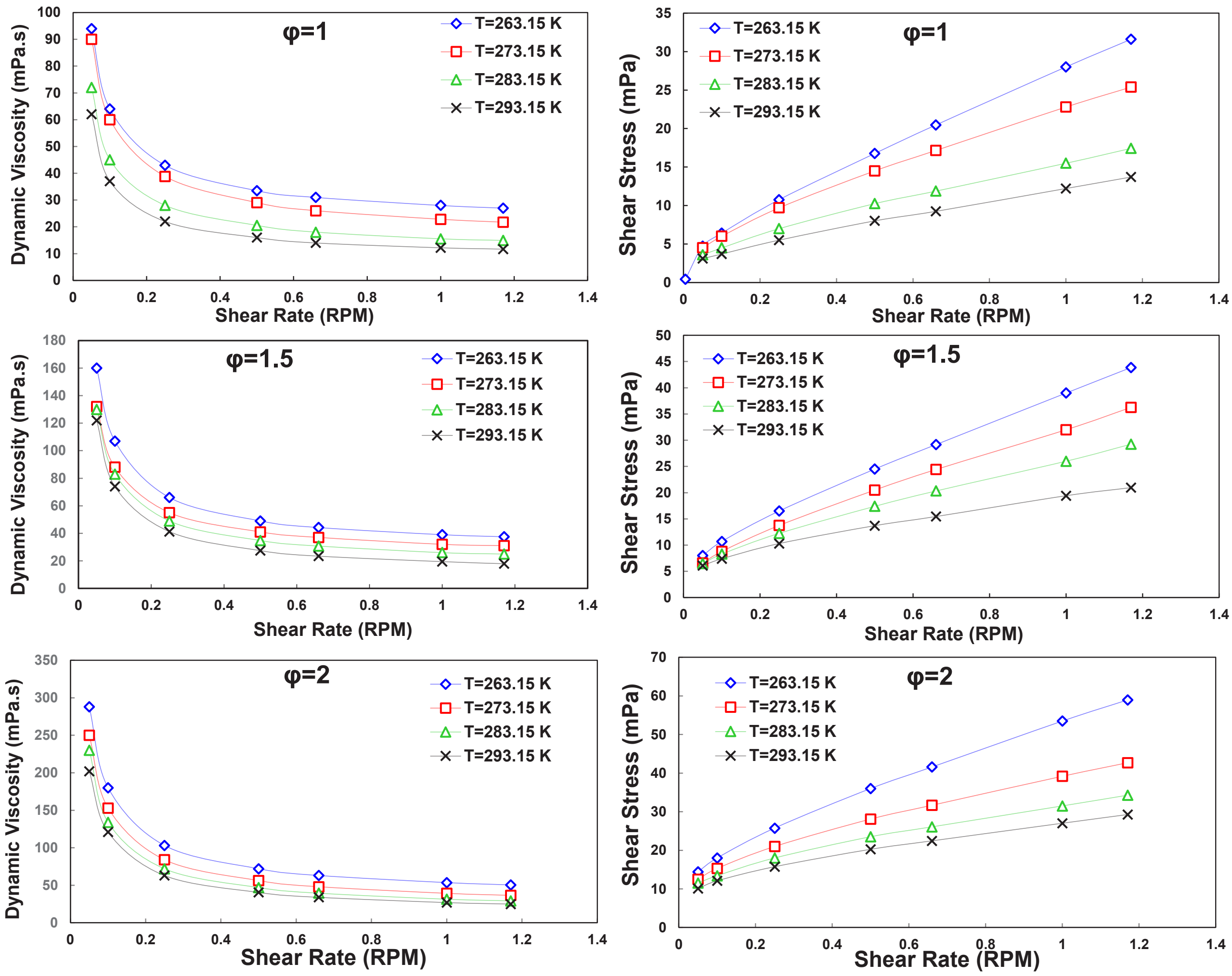

Fig. 2. Viscosity (left) and shear stress (right) of nanofluid against the shear rate for solid volume fractions of 1, 1.5, and 2 at different temperatures.

4- Conclusions

The effect of nanoparticle concentration and temperature on the rheological properties of graphene-Al_2O_3/ethylene glycol-water hybrid nanofluid at low temperatures was studied. The hybrid nanofluids were prepared using a combination of water-ethylene glycol (W: EG/50:50 concentrations in volume percent at 298.15 K) and surfactants containing oleic acid and sodium dodecyl sulfonate. The dynamic viscosity of the hybrid nanofluids were determined experimentally for temperatures between 263.15 K and 303.15K. The main results of the current work are summarized below:

1. Experiments show that the rheological properties of hybrid nanofluids are strongly affected by the concentration of nanoparticles and temperature, especially at sub-zero temperatures.

2. The measurement results of dynamic viscosity of nanofluids showed that the hybrid nanofluid of samples with solid volume fraction less than 0.5% had Newtonian behavior, while those with higher solid volume fraction (0.5%-2.5%) had non-Newtonian behavior and followed the power-law model.

3. Hybrid nanofluids show surprising rheological behavior at sub-zero temperatures and low concentrations which can be attributed to the existence of oleic acid and graphene nanoplatelets.

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