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Investigation of the Viscosity and Stability of Green Nanofluids from Coconut Fibre Carbon Nanoparticles: Effect of Temperature and Mass Fraction

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Abstract

This study entails the experimental measurements of the viscosity of 60:40% ethylene glycol (EG) and water (W) nanofluids containing nanoparticles obtained from coconut fibre. Furthermore, the effects of temperature and mass fraction of the synthesised nanoparticles on the relative viscosity of the green nanofluid was studied. The morphology of the prepared nanofluids was obtained using transmission electron microscope (TEM) while stability was determined by zeta potential, viscosity and UV spectroscopy measurements of nanofluids for 720 min. The nanofluids prepared were very stable for more than 720 min. The results of characterisation show that the average diameters of the spheres are between 30 nm to 60 nm. Also the results of experiments showed that with increase in temperature, the viscosity decreased. In addition, when the mass fraction was increased, there was an enhancement in viscosity of up to 50%.

Keywords: Coconut Fibre. Viscosity, Green Nanofluid, Green Precursor, Stability.

INTRODUCTION

Fluids with solid nanometer sized particles are called nanofluids and are an innovative class of fluids which have novel characteristics different from the base fluids. The base fluids used are usually conventional heat transfer fluids which are used for heat transfer applications. Nanofluids are becoming popular because they are high energy absorbing materials and they have the ability to skip the intermediate heat transfer state [1]. In addition, they have overall enhanced heat transfer efficiency. Previous base fluids used include: ethylene glycol, water, glycol, propylene glycol and oil. The dispersion of nanoparticles in these base fluids have proven to result in a corresponding improvement in the thermo-physical properties of the fluids [1-8].

The study of viscosity and stability of fluids is important in applications relating to flow of fluids as the knowledge of viscosity is used in determining the pumping power required which can in turn affect the efficiency of the system. A study on the viscosity of MWCNT based high temperature nanofluids shows a significant increase by doping MWCNT in alkali carbonate eutectic. The increase in viscosity was reported to be likely due to the aggregation of the nanotubes [2] which increases the effective volume of the nanotubes [3]. The nanofluids in the study by [3] behaved as a shear thinning material at high particle content and as a Newtonian fluid at lower particle content.

With the on-going studies on nanoparticles and their applications, the issue of their effects on humans, animals and the environment is an issue of concern. Good as they may sound, adverse effects such as the ability to penetrate through skin cells in humans and animals are possible. It can also be absorbed into the lungs through inhalation which can lead to inflammation [9]. Exposure to this class of materials is somewhat unavoidable as they are part of our daily lives. They are present in the atmosphere, creams and liquids. According to a study conducted by Nowack and Bucheli [10], the oxides in metal nanoparticles are able to generate reactive oxygen species and this increases their toxicity. Cytotoxicity and genotoxicity are terms which refer to the death of cells which is also an adverse effect of nanoparticle reaction with human and animal cells [11].

Bio-based nanofluids are beginning to gain research focus because of their low toxicity and availability of the bio-precursors used. They are sourced from nature and are environmental friendly. Recent research has proven that plant and fruit parts after being synthesised can be dispersed in base fluids to produce nanofluids with enhanced thermo-physical properties. A composite containing agricultural waste materials and graphene was synthesised through simultaneous activation and the results yielded high electrical and thermal conductivities of 6.47 % increase at 40 ºC and 787.5 % respectively [12]. Bio-nanofluids were also synthesised by [13, 14] in which clove buds were used to prepare carbon nanotubes and covalently functionalised nanoplatelets based nanofluids. The study was reported to have good potential for heat transfer applications. However, the natural convection heat transfer coefficient of nanofluids obtained from mango bark nanoparticles dispersed in water was found to deteriorate [15]. For the same mango bark nanoparticle based nanofluid, the thermal conductivity measurements showed a minor enhancement with the viscosity results showing an exponentially decreasing trend. Kallamu et al. [16] and Awua et al. [17] conducted an experimental study on the viscosity of nanofluids by using a two-step method that involved the dispersion of banana fibre-based nanoparticles and palm kernel fibre-based nanoparticles respectively obtained from ballmilling into a suitable base fluid. The viscosity obtained from both authors was reported to be higher compared to the base fluid which increased with an increase in the volume fraction.

Several of the bio-nanofluids reviewed showed an enhancement in viscosity when compared to the base fluid which is not a good property in nanofluid flow and heat transfer applications. Viscosity is a crucial parameter in fluid flow which determines pumping power and pressure. Therefore, an ideal heat transfer fluid should possess lower viscosity and an increased thermal conductivity. The method of synthesis of these nanoparticles could be a contributing factor to their ineffective viscosity for heat transfer application. However, they may be ideal in applications relating to lubrication.

The present study aimed to investigate the influence of temperature and mass concentration on the viscosity of a new class of green nanofluids in which carbon nanospheres synthesised from a bio-based source, namely, coconut fibre was dispersed in 60:40 EG/W. The stability at different mass fractions was also studied.

MATERIALS AND METHODS

Carbon nanosphere synthesis from coconut fibre and its characterisation

Coconut fibre (CF) was obtained from local farmers in Oyo State, Nigeria. It was cleaned, cut into small sizes and dried in air for over three months. The CF was inserted into a heat resistant quartz tube and placed in a horizontal tube furnace (model MTF 12/38/400). Aerosol was generated from ethanol using an ultrasonic air humidifier (Model GMH-200) operating at 50 Hz. Nitrogen gas was passed through the aerosol mist at a flow rate of 200 mL/min; its function was to create an inert atmosphere for the reaction and to transport the aerosol droplets into the reactor chamber. The exhaust from the reactor was vented directly into the extraction system of the fume cupboard. The aerosol line was closed at the desired temperature, and the nitrogen gas was allowed to flow thereby cooling the system. The experimental procedure and characterisation has been described in our previous study [18] and the setup is presented in Fig. 1.

Figure 1. Experimental setup

Nanofluid preparation

The nanofluid was prepared by using a two-step method which involves the direct dispersal of nanoparticles in a suitable base fluid. A pre-calculated mass of the nanospheres corresponding to the desired weight fraction was weighed using a digital weighing balance (Highland HCB 1002, maximum 1000g, precision 0.001g from Adam equipment). The mixture of the nanospheres, gum arabic (GA) and 60:40 ethylene glycol/water (EG/W) was magnetically stirred using a hotplate stirrer (Lasec from Benchmark Scientific Inc., model-H4000-HSE) and sonicated with a 20 kHz, 700 Watts, QSonica ultrasonic processor. The nanofluid was kept in a programmable temperature bath (LAUDA ECO RE1225 Silver temperature bath) the whole time during sonication and the temperature was maintained at 15 °C.

Dry carbon nanospheres obtained from the synthesis of CF, ethylene glycol (Merck (Pty) Ltd), GA acquired from Fluka Analytical and deionised water was used for the nanofluid preparation. The nanotubes were dispersed in a base fluid consisting of 60:40% EG/DW in the weight concentration of 0.04 wt%, 0.08 wt% and 0.5wt% and 1 wt%. It was stirred with a magnetic stirrer for 2 h after which it was ultrasonicated for another 2 h. The diameters of the nanospheres are between 30 nm and 65 nm with the highest occurrence between 45 nm and 50 nm (Fig. 2).

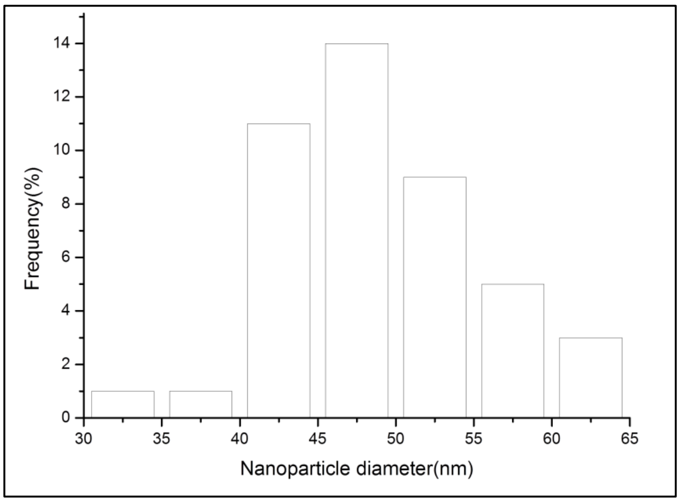


Figure 2. Particle size distribution of CNS

Viscosity and stability measurements

The instrument used for measuring viscosity is a piece of equipment known as a sine-wave vibroviscometer SV–10 from A&D Company Ltd., Japan. The cup used for measurement is connected to an adjustable temperature bath for effective sample temperature control. The viscometer uses a tuning-fork vibration technique to measure viscosity of fluids. The viscometer was calibrated using 99.5 % glycerol with manufacturer-stated viscosity of 1412 mPa.s at 20 °C. The viscosity was measured at a temperature range of 15 °C to 60 °C. The stability of the fluids was carried out by using zeta potential, viscosity measurements at a constant temperature for 700 min, and a UV Spectrometer.

NANOFLUID VISCOSITY

Existing models

Several models and relationships have been proposed to relate viscosity with parameters of nanofluids like mass concentration, temperature and morphology of nanoparticles. Pioneering work on the relationship between the viscosity of nanofluids and base fluids was carried out by Einstein [19]. He proposed a model which took into consideration fluids containing particles with a volume percentage of less than 1%.

$$\mu_{nf} = (1 + 2.5\emptyset)\mu_{bf} \qquad (1)$$

Where: μ_{nf} is the nanofluid viscosity, μ_{bf} is the base fluid viscosity and $\emptyset$ is the volume fraction.

A particle volume fraction of up to 4 % in base fluid was proposed by Brinkman [20]. This was derived from Einstein's model:

$$\mu_{nf} = \mu_{bf}\left(\frac{1}{(1-\emptyset)^{2.5}}\right) \qquad (2)$$

Batchelor [21] studied the effect of Brownian motion on fluids with spherical particles dispersed. His results were:

$$\mu_{nf} = \mu_{bf}\,(1 + 2.5\emptyset + 6.5\emptyset^2) \qquad (3)$$

Selvakumar and Dhinakaran [22] recently developed a model to explain nanofluid viscosity by considering the phenomena of particle clustering and interfacial layer formation. This model is reported to be valid through all volume particle fractions:

$$\mu_{eff} = \mu_{bf}\left(1 - \frac{\emptyset_{ecs}}{\emptyset_m}\right)^{[\eta]\emptyset_m} \qquad (4)$$

Where: μ_{eff} is effective viscosity, μ_{bf} is the base fluid viscosity, $\emptyset_{ecs}$ is the effective volume fraction of cluster spheres and $\emptyset_m$ is the maximum particle volume fraction which is usually taken as 0.605.

A correlation was developed by Sundar et al. [23] from experimental results obtained by putting into consideration the effects of temperature on the viscosity of nanofluids. This was developed to close the gap in the limitation of Einstein model:

$$\mu_{nf} = \mu_{bf}Ae^{B\emptyset} \qquad (5)$$

Where: A = 1.1216 and B = 77.56 (60:40 EG/W nanofluid).

Aberoumand et al. [24] have also considered the effect of temperature and volume fraction in their study.

$$\frac{\mu_{nf}}{\mu_{bf}} = (1.15 + 1.061\varphi - 0.5442\varphi^2 + 0.1181\varphi^3) \qquad (6)$$

RESULTS AND DISCUSSION

XRD and nanofluid stability

Fig. 3 shows the XRD pattern of the nanospheres obtained from CF. It shows two major broad peaks at (002) and (011) which signify a hexagonal graphite structure. The (002) peak is located at $\theta = 30^0$ while the (011) peak is found at $\theta = 51^0$. The d-spacing is calculated as 0.33 nm. The stability of the green nanofluid was determined using zeta potential and viscosity at a constant temperature (20 ^{o}C) for 700 min.

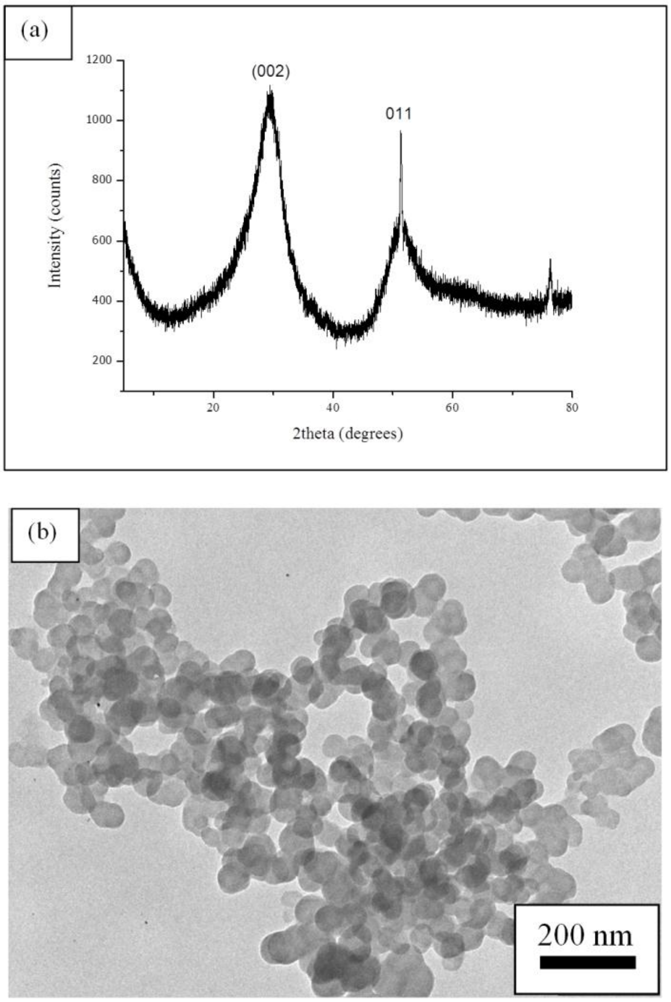


Figure 3. (a) XRD pattern. (b) TEM results

Nanofluid stability is a key parameter in nanofluid preparation and its subsequent application. A nanofluid with poor stability cannot be utilised in heat transfer applications and applications involving fluid flow. The stability of a nanofluid is affected by the surface charge present in the nanoparticles, while the index of the surface charge present is referred to as zeta potential. Fig. 4 shows a photograph of the nanofluids taken after one week. From Fig. 4(a), it is evident that there were complete sedimentations and the nanofluids displayed poor stability when the nanofluids were kept for one week for nanofluids with 1:1, 1:2, 1:2.5, and 1:3 of CNS/GA. However a good stability can be seen for nanofluid containing 1:3.5 CNS/GA. The zeta potential was measured for 0.04 wt%, 0.08 wt%, 0.5 wt% and 1 wt% dispersed in 60:40 EG/W and the obtained values were 84.8 mV, 130 mV, 126 mV and 120 mV respectively.

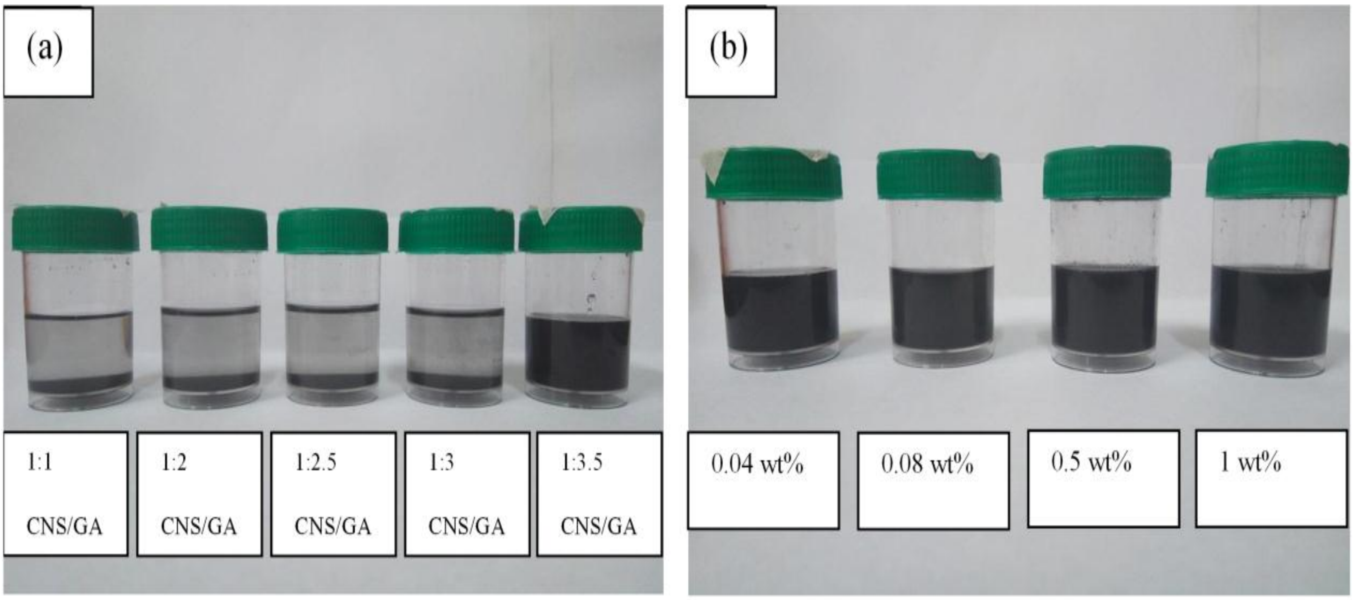


Figure 4. Photos of nanofluid: (a) After one week (b) After one week (1:3.5 CNS/GA)

Colloidal stability of the prepared nanofluids were further tested by measuring the viscosity at 20 ºC for 720 min. Fig. 5 is the result of the observation from nanofluids which shows that the viscosity values were hardly changed for the whole duration. This is an indication that the fluids were stable for more than 720 min which is more than sufficient time to take the viscosity measurements. It was therefore determined that a ratio of 1:3.5 CNS/GA gave a good stability and this ratio was maintained throughout this study.

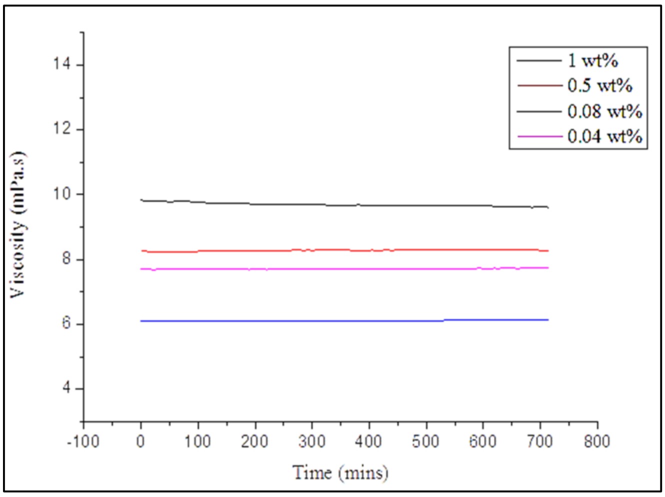


Figure 5 Stability test using viscosity at a constant temperature for 720 min

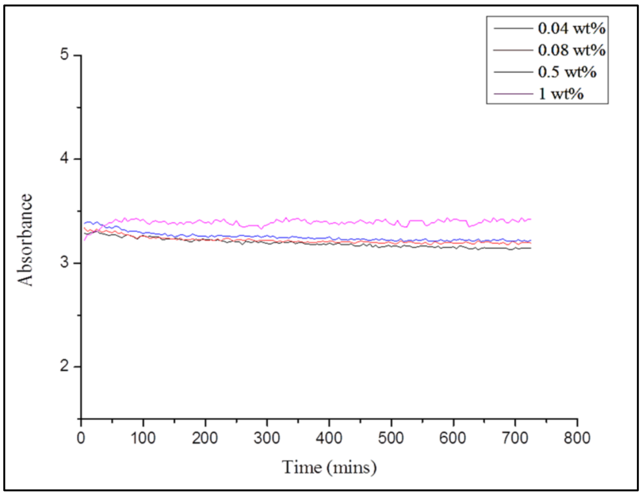
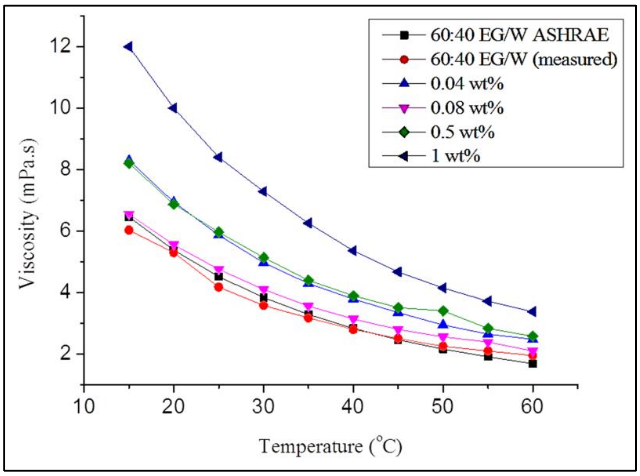


Figure 6. Stability test using UV spectroscopy at a constant temperature for 720 min

Nanofluid viscosity

Effect of temperature and mass fraction

In order to ensure minimal error in results, the viscometer was calibrated using deionised water at 25 ºC. The measured value of deionised water at 25 ºC is 0.883 mPa.s, which closely matches that of the theoretical value. The relative deviation is 0.7% which is of the same order as the degree of data uncertainty. Viscosity at various temperatures was measured from 15 ºC to 60 ºC for four different weight fractions (0.04 wt%, 0.08 wt%, 0.5 wt% and 1 wt%). The results are presented in Fig. 6. The results show that an increase or decrease in temperature has a significant impact on the viscosity value. The viscosity is seen to decrease as the temperature increases. This effect has been attributed to a decrease in intermolecular forces arising from micro-convection [24]. This is in agreement with results from Sundar et al. [23] and Singh et al. [8] validating the theory that dispersing nanoparticles in a base fluid leads to a resistance between fluid layers which results in increased viscosity, which occurs in all the fluids at different mass fractions. Results from Fig. 7 indicate that the nanofluid with the mass concentration of 1 wt% had the highest viscosity compared with nanofluids of lower mass fractions. There is a similar trend in viscosity at various mass fractions which indicates a consistency in the obtained values.



Figue 7. Nanofluid viscosity as a function of temperature

The relative viscosity presented in Fig. 8 indicates an almost constant value at all temperatures. These results are in line with those obtained in [3]. However, nanofluids with 1 wt% nanoparticles display a higher viscosity while it is interesting to note that nanofluids with 0.08 wt% have the lowest relative viscosity. The results show an increase in relative viscosity with an increase in nanoparticle concentration which is in contrast with studies carried out by Attari et al. where at the same mass fraction, an increase in temperature reduced the viscosity ratio of the nanofluids prepared.

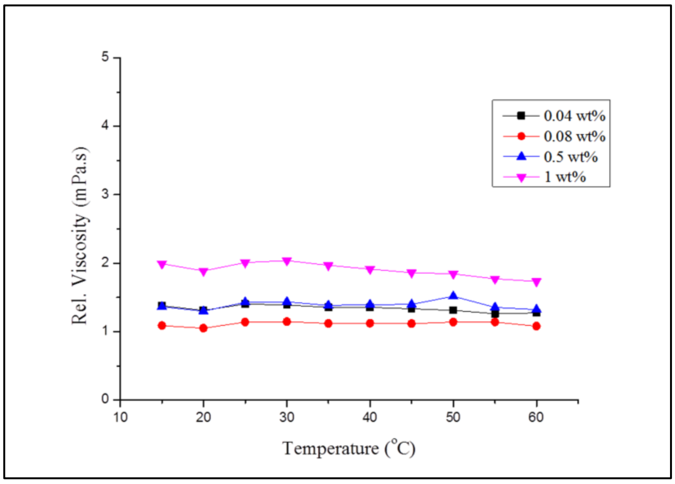


Figure 8. Nanofluid relative viscosity as a function of temperature

From Fig. 8, an enhancement in relative viscosity is observed for increasing mass fraction at all temperatures. At 0.08 wt% there is a drop in viscosity and it begins to improve again at higher mass fractions.

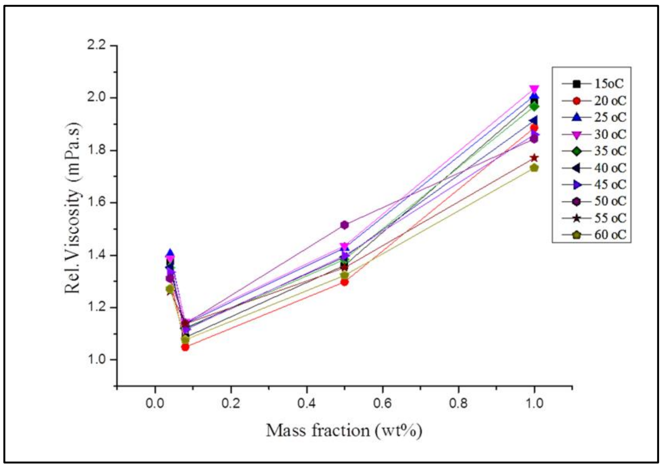


Figure 9. Nanofluid relative viscosity as a function of mass fraction

PROPOSED CORRELATION

A correlation for viscosity was proposed based on forty data points as given in Fig. 9. The various correlations at different mass concentrations are plotted in Fig 10. The figure shows very good relationship between the correlations and the obtained results.

Mass concentration 0.04 wt%,

$$\mu = 6E-08T^5 - 1E-05T^4 + 0.0007T^3 - 0.014T^2 - 0.1798T + 12.43\ (R^2 = 1) \qquad (7)$$

Mass concentration 0.08 wt%,

$$\mu = -5E-08T^5 + 1E-05T^4 - 0.0007T^3 + 0.0262T^2 - 0.6664T + 12.526\ (R^2 = 1) \qquad (8)$$

Mass concentration 0.5 wt%,

$$\mu = -3E-08T^5 + 5E-06T^4 - 0.0003T^3 + 0.0146T^2 - 0.5587T + 14.127\ (R^2 = 0.9983) \qquad (9)$$

Mass concentration 1 wt%

$$\mu = 9E-08T^5 + 2E-05T^4 - 0.0015T^3 + 0.0643T^2 - 1.6087T + 25.961\ (R^2 = 0.9999) \qquad (10)$$

The experimental values obtained from this study can be estimated from the correlations proposed at different mass concentrations. The following correlation can only predict viscosity of CF-based 60:40 EG/W based nanofluids at mass fractions of 0.04 wt%, 0.08 wt%, 0.5 wt% and 1 wt%. The following correlation was also evaluated based on the experimental data for relative viscosity of the prepared nanofluids at 20 °C:

$$\mu_{nf} = 0.2127\varphi^2 - 0.8861\varphi + 1.9561 \qquad (11)$$

With polynomial goodness of fit $R^2 = 0.9961$

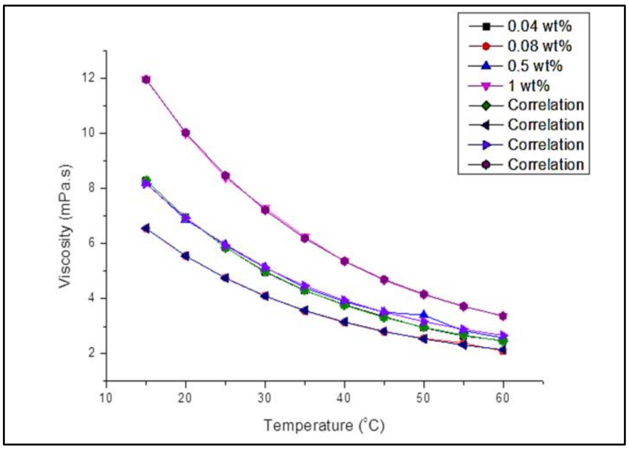


Figure 10. Correlations obtained compared with results

CONCLUSION

In this article, the viscosity and stability of green nanofluids prepared from CF was investigated. The base fluid used was 60:40 ethylene glycol/water and GA was the surfactant used. The results of TEM analysis and particle size distributions show spherical carbon nanoparticles with diameters of between 30 nm and 65 nm. Stability analysis was carried out using visual analysis, zeta potential, viscosity values for a period of 720 min, and UV-Vis spectroscopy. The results indicate a very stable fluid with high zeta potential values. It can also be depicted from the values obtained that addition of these green nanoparticles in 60:40 EG/W have a significant effect on the nanofluids' viscosity which is a function of temperature and nanoparticle mass fraction. The viscosity of the nanofluids at different mass fractions decreases with an increase in temperature, while the relative viscosity remains fairly constant with an increase in temperature. An increase in mass fraction enhances the viscosity of nanofluids at all temperatures under study. Empirical correlations have been developed to predict the viscosity of nanofluids at different temperatures and mass fractions.

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