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Study on Rheological and Stability of Natural Derived Carbon Nanosphere Nanofluids

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Abstract

In this work, carbon nanosphere (CNS) derived from a waste rice husk (RH) was prepared through chemical treatment and calcination process. Moreover, carbon nanofluids (CNF) were produced using simple chemical treatment assisted by ultrasound technique. Different compositions of the CNS were taken into an experiment to determine the optimum and the best properties. Ultrasound technique was introduced in this study to reduce the agglomeration of the particle. The surface morphology of the CNS was analyzed by Scanning Electron Microscopy (SEM). The sphere shape from the particle/grain was identified from the nanoparticle and proved the term “nanosphere”. The viscosity of the nanofluids was studied by rheological testing (Antoon PAR, MAR 3). The flow curve of the nanofluids improved the stress of the fluid significantly at minimum inclusion of CNS. In addition, the addition of CNS could stabilize the properties of the fluid compared to virgin base fluid, based on the measured dynamic viscosity. The stability of the CNF was investigated using UV-Vis. Findings show that the stability of the nanofluids is maintained starting from 1 week onwards as evidenced by UV-Visible spectrophotometer analysis. Furthermore, little to no precipitation was noticed even after 8 weeks. This work offers a greener approach for nanofluids which are organically derived and environmentally friendly (very low percentage of nanoparticles, 0.02 vol% (equivalent to 0.002 wt %).

Keywords Carbon nanosphere, nanoparticle, nanofluids, ultrasound techniques, rheological study

1.0 INTRODUCTION

Various nanomaterials have been synthesized and the effort to produce new novel nanomaterials is still ongoing. The main motivation is to incorporate better physical properties and chemical functionalities into the nanomaterials to improve their performance in applications. In addition, there is a need to search for new nanomaterials that are more sustainable, which are not only non-toxic, biocompatible, and environmentally friendly, but also the synthesis adopting green production methods and using renewable precursors. Carbon nanospheres (CNS) are one of the alternative nanomaterials that have been discovered and portrayed several advantages over other existing nanoparticles. Similar to the well-known quantum dots, CNS shows bright fluorescence, high photostability, and tunable excitation and emission spectra [1, 2]. In addition, CNS is less-toxic, soluble in water and has good biocompatibility, non-blinking fluorescence, and chemical inertness [3]. Their low molecular weights, as well as small sizes, make them a good candidate for drug delivery [4, 5].

Moreover, a nanofluid is comprised of nanometer-sized particles (nanoparticles) and fluids. Normally, water, engine oil and ethylene glycol etc. are used as base fluids in many industrial sectors, including transportation, energy supply and production, and electronics [6]. Conventional base fluids suffer from low heat transfer performance which limits their application [7]. To overcome the drawbacks, nanosized solid particles act as an additive that suspends the base fluid and can help to improve the heat transfer and rheological properties [8]. The first report on the combination of nanotechnology and fluid in thermal engineering was coined by Choi (1995), where "nanofluid" has been proposed to meet the cooling challenges [9]. In terms of stability, nanofluids become more stable compared to conventional fluids due to the size effect and Brownian motion of particles in the liquid. Ultrafine nanoparticles could probably assist the movement of the particles evenly in a microchannel without clogging and the size of the heat transfer system can be minimized for the use of nanofluids with high heat transfer efficiency [10]. In the past few decades, many reports on nanofluids have been published. In most of the reports, metal oxides such as alumina [11], ZnO [12], TiO_2 [13] and SiO_2 [14] have been used as nanofluids. Alumina nanofluids have been prepared by Beck et al. [15] using ultrasonic mixing to obtain consistent dispersion and reported that the results of the dispersion are still consistent due to surface charges on the particles. According to Raykar and Singh [16], they have prepared ZnO nanofluids by synthesising water-soluble ZnO nanoparticles and found that the nanofluids were stable for 9 months to 1 year. They also discovered that the size of the nanoparticles was reduced from 150 nm to 80 nm due to the occurrence of the reaction. Meanwhile, Longo and Zilio [17] have verified the dispersion of Al_2O_3 – water and TiO_2 – water nanofluids. They proved that ultrasound treatment for that kind of nanofluids showed better dispersion efficiency than mechanical stirring and both nanofluids show high stability for more than one month.

To the best of the author's knowledge, green-derived carbon nanospheres as nanofluids have not been reported elsewhere. In this context, CNS derived from rice husks has been prepared using a chemical treatment-assisted ultrasound technique. The physical properties including rheology and stability of the nanofluid have been investigated. The suitability of CNS nanofluid as a cooling system has been elucidated.

2.0 METHODOLOGY

2.1 Materials

Rice husks (RH) were supplied by local industry and possess 32.67% cellulose, 31.68% hemicellulose, 18.81% lignin, and 11.88% ash of composition respectively based on wt%. NaOH pellets and 99.7% absolute ethylene glycol were purchased from PERMULA Chemicals Sdn. Bhd, Kuantan.

2.2 Preparation of CNS from waste rice husks

The RH was dried under the sunlight to reduce the moisture content, with drying time between 2 to 8 h depending on ambient temperature and humidity. After drying, the RH weight was 800 g and prepared for the carbonization process. For the carbonization process, the RH was heated using a furnace with a temperature controller. The thermal decomposition temperature was below 300°C. This value was selected to minimize energy consumption in the carbonization process and due to the range of temperature where the hemicellulose and lignin thermal decomposition mainly happened. The carbonized rice husk (CRH) that was obtained from the carbonization processes was further treated using NaOH to obtain a high surface area and remove the impurities. For this purpose, 100 ml of 0.5 M NaOH solution was added to 10 g of the CRH, and the mixture was stirred for 24 h. After being treated with NaOH 0.5 M, the CRH was filtered, washed with DI water until the filtrate was neutral, and dried at 60°C for 10 h. The samples were further calcined in a tubular furnace under constant nitrogen flow at 900°C for 2 h with a heating rate of 150°C/h and finally, obtained CNS.

2.3 Characterization of CNS surface morphology

The surface morphology of the CNS was verified using Scanning Electron Microscopy (SEM) (ZEISS, EVO 50, Germany). The reason for using SEM is to obtain details about internal composition and show many characteristics of the sample such as morphology and crystallization. Before observation under the SEM instrument, samples were coated with platinum using a sputter-coater.

2.4 Preparation of CNS nanofluids

The CNS nanofluids samples were prepared by using the two-step method. This method was based on the dispersion of prepared nanoparticles in a base fluid. As a base fluid, ethylene glycol (POCH, Avantor Performance Materials Poland, Gliwice, Poland) and water were used with the composition of 50:50. The density of ethylene glycol is 1113.7 kgm^{-3} at 293.15 K [18], and the heat capacity is 2384.9 $Jkg^{-1}K^{-1}$ at 298.15 K as reported by Nan et al. [19]. The samples were prepared with different concentrations (vol%) from 0.02% to 0.10%. The uncertainty of volume and mass fraction was calculated as a complex uncertainty, considering the accuracy of the used analytical balance, the uncertainty of density of buoyancy corrections, nanofluids and base fluid are found to be less than 1%. For reducing the agglomeration, sonication for 60 min was performed using GT-SONIC professional ultrasonic cleaner at room temperature. The device's operating frequency was 40 kHz, and the output power was 180 W.

2.5 Characterization of CNS nanofluids

The viscosity measurements were performed using the Anton Paar MCR 302 rheometer and the Peltier system coupled to the Phoenix 2 thermostat (Thermo Electron Corporation, Karlsruhe, Germany). This equipment can measure the viscosity with 5% relative standard uncertainty. The 60 mm diameter and cone angle 1° double cone measurement geometry was used. The dynamic viscosity at a constant temperature of 298.15 K was measured in a shear rate range from 100 to 1000 s^{-1}. Measuring geometry was isolated from the environment with the glass rings. The value of viscosity of the pure ethylene glycol measured in this system was 16.9 mPas as presented by Żyła [20]. It corresponds to the value presented by Bohne [21] (16.63 mPas at 298.15 K with 5% uncertainty). The prepared nanofluids were further characterized using the SHIMADZU UV SPECTROPHOTOMETER UV – 1800 with different weeks (week 1 – week 8).

3.0 RESULTS AND DISCUSSION

3.1 CNS surface morphology

The surface morphology of the CNS is given in Figure 1. It could be observed that the CNS is presented in a conglomeration of spheres. This study was in line with research from Nieto-Márquez [22]. It can be observed that the CNS appeared in irregular spheroidal shapes with different sizes. The diameter of the CNS calculated has a range of 84.04 – 834.86 nm with an average diameter of 315.52 nm. Furthermore, Figure 1 shows that the CNS tend to agglomerate when their diameters are less than 1000 nm to form bead, necklace-like structures [23].

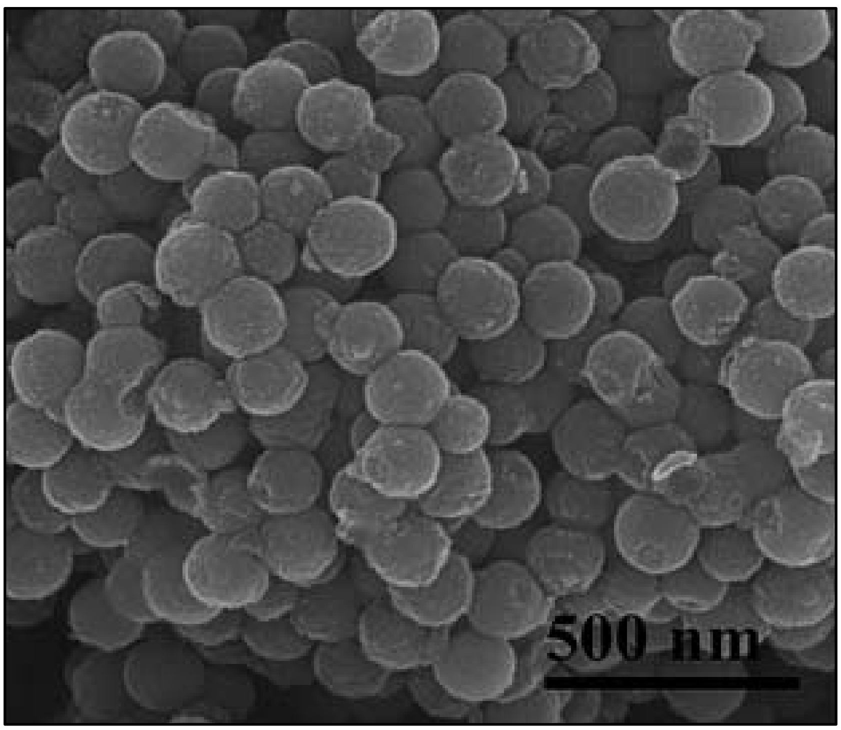

Figure 1 SEM images of CNS.

3.2 Rheological study of CNS nanofluids

A total of five samples were prepared from different concentrations ranging from 0.02 vol% to 0.10 vol%. The nanoparticles were dispersed in ethylene glycol and water (binary mixture). The visual images of these samples are shown in Figure 2.

Figure 3a presents the flow curves of CNS in binary mixture nanofluids with variance volume fractions of particles at constant temperature 298.15 K. It can be seen that with the shear rate, the shear stress improves linearly. The results also verified that the binary mixture itself already shows the improvement of fluids and it is significantly increased with the addition of carbon nanoparticles with only a small portion which is 0.02 vol % equal to 0.048 g. The higher the concentration of the CNS in the nanofluids, the higher the viscosity.

Meanwhile, Figure 3b shows the dependence of viscosity against shear rate based on different CNS concentrations. The results show that the viscosity increases with increasing concentrations of nanoparticles in the suspension. Small concentrations of CNS can contribute to an increase in performance in terms of dynamic viscosity. The liquids which have such a characteristic of the flow are called Newtonian fluids. The Newtonian model assumes that the shear stress is proportional to the shear rate, and the proportionality factor is the viscosity of the liquid [24]. The liquids which are classified into this group do not change their viscosity with the change in shear rate. Thus, this will improve the properties of the base fluid with minimal inclusion of CNS nanoparticles.

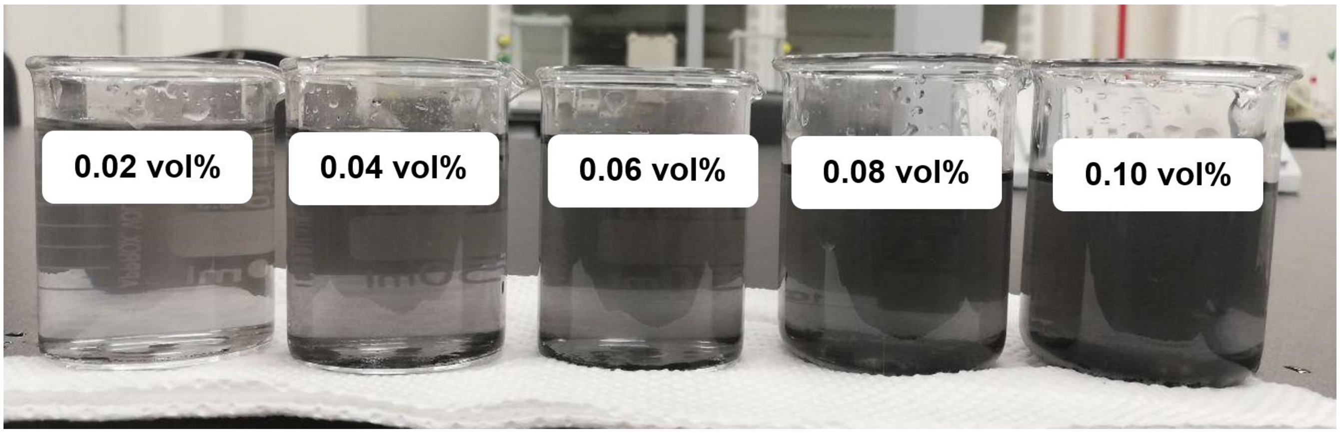

Figure 2 Binary mixture with different concentration of CNS.

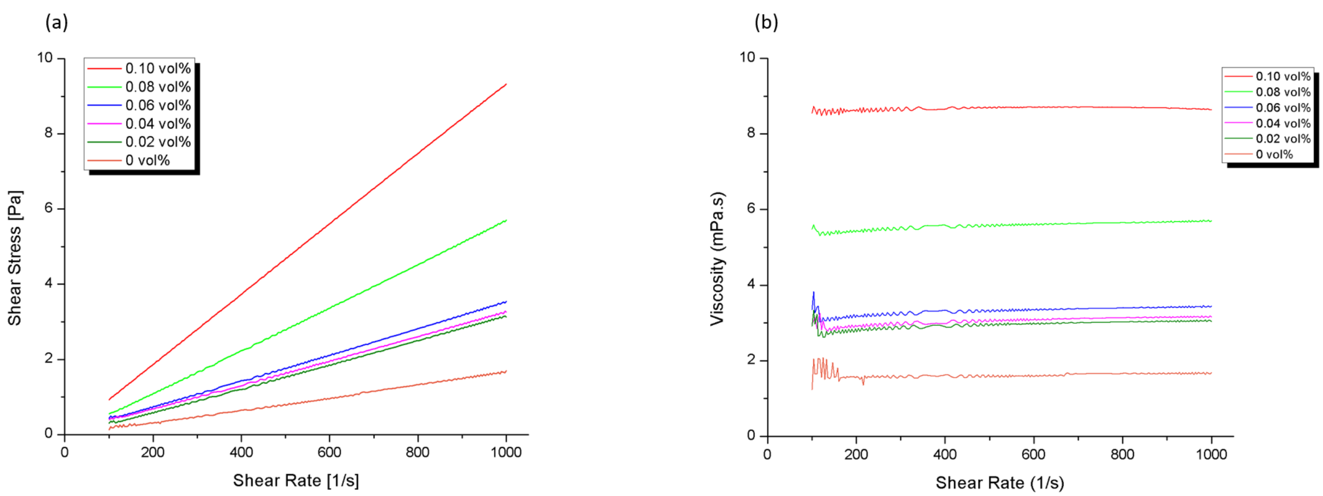

Figure 3 (a) Flow curve graph of different concentrations of CNS nanofluids; (b) Dynamic viscosity curves graph on various concentrations of CNS nanofluids.

3.3 Stability study of CNS nanofluids

The stability of nanoparticles is one of the most important characteristics of therapeutic applications. In this study, the UV-Vis spectrum was used to evaluate the nanofluid stability. The samples of nanofluids were prepared from fresh samples until week 7. Moreover, there is no precipitation detected on each sample along the ongoing study which shows good stability of the nanofluids were observed within 7 weeks. The samples for this stability study were taken from samples that used 0.1 vol% of CNS nanofluids starting from fresh samples until week 7 were recorded. Figure 4a shows the graph of absorbance against wavelength from the UV-Vis. The absorbance peak at 225 nm represents the existence of CNS. The peak of the CNS nanoparticle was in agreement with Farvod et al. [25], indicating that the peak appears in the range of 200-300 nm and corresponds to the CNS nanoparticle. The absorbance at peak 225 nm has been recorded for the stability study. Referring to Figure 4b, the nanofluids become stable starting from week 1 onwards. This proved that the CNS nanofluids become stable and improve the properties of the base fluids. Similar trends have been found in several previous studies [26-28].

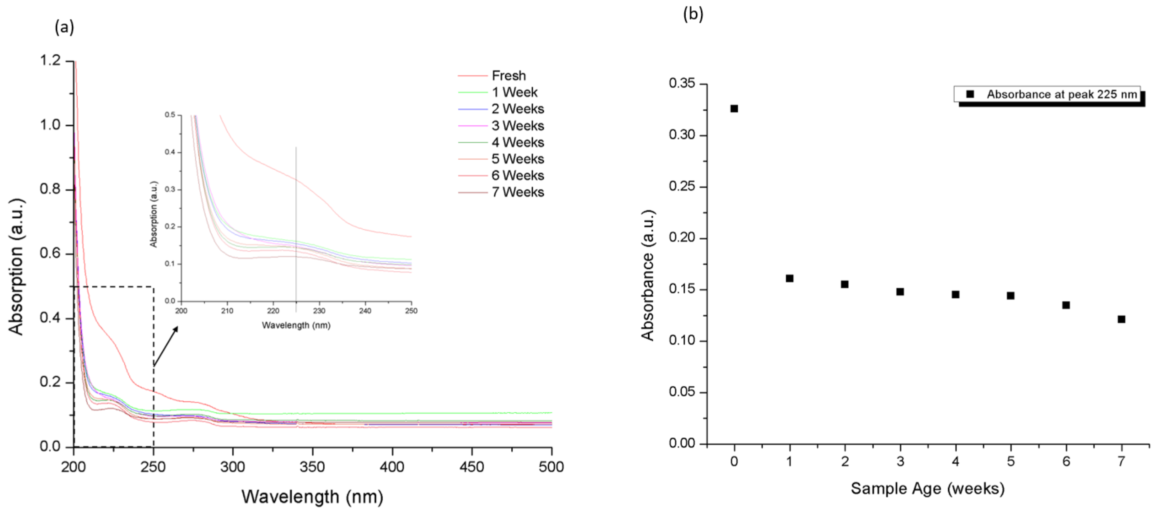

Figure 4 (a) Stability study of carbon nanopowder nanofluids (UV-Visible measurement); (b) Absorbance at peak 225 nm plotted for 8 weeks.

4.0 CONCLUSION

This study highlights the outcomes of the experimental research of CNS surface morphology and the properties of CNS nanofluid on viscosity and stability in the binary combination of ethylene glycol and water with different volume fraction suspensions. The carbon was successfully derived from waste rice husk which is considered green biomass via the carbonization method. Simple chemical treatment with safe calcination was introduced to produce the CNS. Experimentally, findings on the surface morphology of CNS visualize the spherical shape of the nanoparticle with the average size of 315.52 nm. Moreover, it is shown that the CNS–binary mixture improves the base fluid characteristics in which the viscosity increases with the suspension fraction of particles. It is shown that viscosity improvement was linear with increasing particle concentration in the measured volume fraction range. The UV-Vis stabilization study demonstrated that the nanofluids start to stabilize starting from week 1 to week 7. The compatibility and suitability of nanofluids based on CNS nanofluid as a nano coolant will be a great opportunity to reduce waste and improve the coolant properties.

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