INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
G. Adewumi and F. Inambao, Vol.10, No.3, September, 2020

An Experimental Study on the Effect of Particle Morphology, Temperature and Mass Fraction on the Density of Biomass-based Green Nanofluid

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Received: 05.08.2020 Accepted:07.09.2020

Abstract- A novel class of fluids called nanofluids have been used for several applications among which is applications relating to heat transfer. Studying the thermo-physical properties of nanofluids will go a long way in designing nanofluids that will suit the desired application. In light of this, the present study presents the results obtained from the measurement of density from coconut fibre (CF) nanosphere-based nanofluids and CF nanotube-based nanofluids which were obtained from the dispersion of CF nanospere and CF nanotubes in 60:40 ethylene glycol/water (EG/W) in a ratio of 1:3.5. The temperature range was 15 ^{o}C to 60 ^{o}C at 15 ^{o}C intervals. The results obtained show a decrease in nanofluid density as temperature increased. On the other hand, the effect of nanoparticle morphology on the density of the nanofluids indicate that the nanofluids that contained CF nanotube had a higher density compared to the nanofluid containg CF nanosphere. A maximum density of 27.3% and 26.4% has been observed for CF nanotube-based nanofluid and CF nanosphere-based nanofluid respectively.

Keywords Density, Nanofluids, Nanoparticles, Green bio-precursor.

1. Introduction

Transfer of heat energy is quite inevitable in many industrial processes. The control of the removal and addition is vital as this can result in energy savings and longer life of machines alongside, saving cost through reduced process time and increasing the equipment's working life. The principle of heat transfer generally centres on reducing thermal resistance by increasing the effective heat transfer surface area or by generating turbulence in the fluid flow [1].

Nanofluids are a novel class of fluids with particles in the nanometer scale dispersed and suspended in suitable base fluids in order to improve their heat transfer properties for a desired application. They can also be described as colloidal suspensions containing nanoparticles. Nanofluids possess thermophysical properties which include viscosity, electrical conductivity, thermal conductivity, specific heat capacity and density. These have been revealed to change under varying temperature, particle loading, morphology and particle geometry; with these variations originating from the changes in its internal structure and flow hydrodynamic properties. In order to use nanofluids in applications relating to heat transfer, the thermo-physical properties it possesses have to be understood. When thermo-physical properties are inefficient, it can lead to inefficient ultrahigh cooling devices. Nanofluids have been reported to have enhanced thermo-physical properties and lead to an astonishing decrease in pumping power used in heat exchangers. Choi [2] and his team had established that the thermal conductivity of copper nanoparticles dispersed in water had improved and their pumping power reduced which is an important advantage in heat exchangers. They are also believed to reduce clogging and erosion seen in micro particles and lead to major savings in energy.

The density of a nanofluid is one the very important thermophysical property which needs to be focused upon because the Reynolds number, pressure loss, friction factor, Mouromtseff number and Nusselt number [3] all depend on the density of the fluid. The classical formulas for a two phase mixture [4] previously used in the determination of the density of nanofluids have not been very reliable as this approach does not take into consideration the effect of temperature, surfactant and morphology of the nanoparticles. This knowledge has led to several studies on the densities of various nanofluids [3, 5-9]. Halefadl et al [9] derived an equation for density of a nanofluid, taking into consideration the effect of surfactant:

$$\rho_f = (1 - \emptyset - \emptyset_s)\rho_w + \emptyset\rho_p + \emptyset_s\rho_s \qquad (1)$$

Where ρ, f, w, s and p denotes density, nanofluid, de-ionised water, surfactant and nanoparticles respectively. The authors went on to report a linear increase in density with a corresponding increase in nanoparticle volume fractions.

The pressure loss in a tube flow is given as:

$$\Delta p = (f\rho LV^2)(2d) \qquad (2)$$

Where f is the friction factor, ρ is the density, L is the tube length and d is the diameter of the tube.

Recent studies on nanofluids densities places a large focus on metallic nanofluids with a lack of information on other types of nanofluids like biomass-based nanofluids. Studies by [10] have focused on the conversion of green waste to useful energy. This study therefore presents experimental results of the density of nanofluids prepared from CF nanospheres and nanotubes with varying temperatures, mass fractions and morphology. This study was carried out to investigate the effect of mass fraction, particle morphology and temperature on the density of as prepared green nanofluids from coconut fibre nanoparticles dispersed in 60:40 ethylene glycol-water nanofluids (60:40 EG/W)

2. Materials and Methods

2.1 Material Characterization and Preparation of nanofluid

The nanomaterials used in this article were prepared using from CF. The process which has been described in our previous study [11] yielded carbon nanotubes and nanospheres (Fig 1). Measured weights corresponding to mass fractions of 0.04 wt%, 0.08 wt%, 0.5 wt% and 1 wt% respectively for both CF nanospheres and nanotubes were

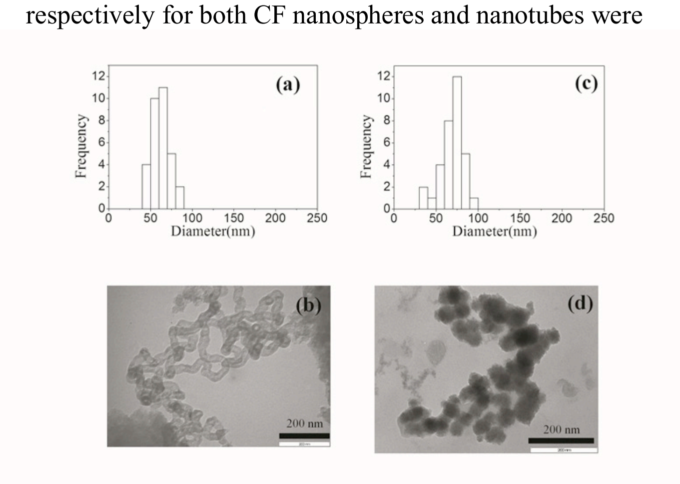

Fig. 1. Particle size distribution and TEM images of CF (a) carbon nanotubes and (b) carbon nanospheres

measured with a digital weight balance (model: AS 220.R2 Max: 220g Min: 10mg). The nanoparticles were dispersed in basefluid comprising 60:40 ethylene glycol/water (Merck (Pty) Ltd) and gum arabic (GA) (Fluka Analytical) in a ratio of 1:3.5. The mixture was stirred magnetically using a hotplate stirrer (Lasec from Benchmark Scientific Inc., model-H4000-HSE) and ultrasonicated with a 20 kHz, 700 Watts, QSonica ultrasonic processor. During sonication, the system temperature was kept constant at 15 ºC with a temperature bath which was programmable (LAUDA ECO RE1225 Silver temperature bath). The diameters of the synthesized green nanotubes are between 50 nm and 90 nm with the highest diameter between 50 nm and 60 nm. On the other hand, the synthesized nanospheres have diameters between 40 nm and 100 nm with the highest diameter at 80 nm.

2.2 Density measurements and stability of nanofluids

An instrument known as Anton Paar Density and Sound Velocity Meter (model number: 3SA 5000M) was used to measure the density of the nanofluids in this study. Deionised water at 25 ºC was used for calibration and the measured density of water was 0.99706 g/cm^3. The density was measured at a temperature range of 15 ºC to 60 ºC, while the stability was measured using a UV Jenway spectrometer (model no: 7315). The stability was measured by putting some nanofluid sample into a cuvette cell having two highly polished surfaces after which electromagnetic radiation was passed. The purpose of the polished surfaces is to minimize reflection and scatter losses while the other sides of the cuvette are transparent, for the purpose of absorbing incident light beam. For this study, each sample of the prepared nanofluids were poured into the cuvette for testing the stability.

3. Results and Discussion

3.1 Nanofluid Stability

The stability of nanofluids is essential for their effective use in heat transfer applications. An unstable nanofluid will result in clogged pipes and an overall inefficient fluid. Recently the use of ultra violet (UV) spectroscopy to study the stability of nanofluids has been studied by several researchers [5, 12]. A linear relationship exists between the sedimentation time and absorbance which allows the stability of nanofluids to be determined from the time of sedimentation. In order to study the stability of the nanofluids using UV spectroscopy, the absorbance of nanofluids prepared were compared with the absorbance of the base fluid (60:40) ethylene glycol/water. The difference in absorbance was observed to be directly related to the nanoparticle concentration and a fall in absorbance will indicate agglomeration in the nanoparticles present in the basefluid.

Fig. 2 and Fig. 3 shows results of absorbance in relation to time for a period of 600 minutes for nanofluid from CF nanospheres and nanofluid from CF nanotubes respectively. The results indicate that the nanofluids are stable for the time studied. This gave a degree of confidence on the stability of the fluid thereby allowing for the density to be measured.

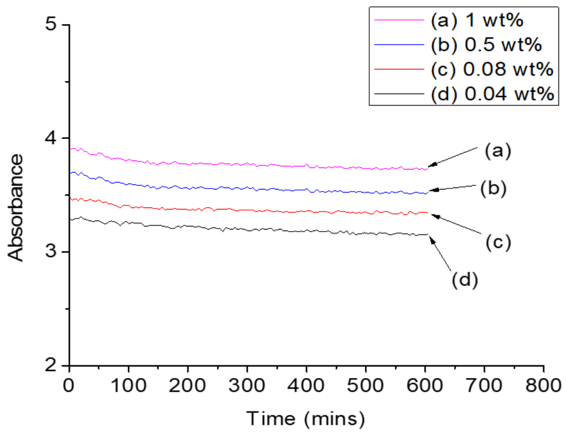

Fig. 1. Stability test for CF based nanosphere-nanofluid using UV Spectroscopy at a constant temperature for 700 minutes

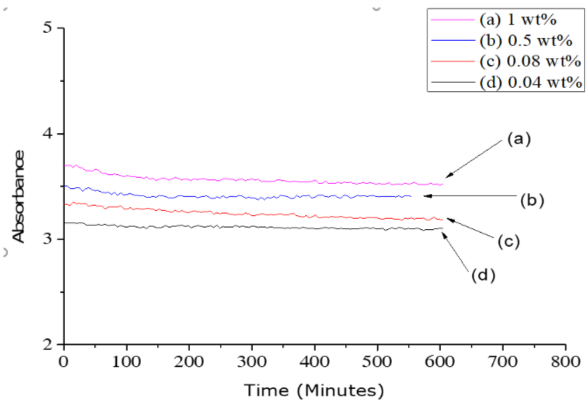

Fig. 2. Stability test for CF based nanotubes-nanofluids using UV Spectroscopy at a constant temperature for 700 minutes

3.2 XRD Analysis

Fig. 4 presents the results of XRD of the carbon nanotubes and carbon nanospheres. 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.as reported in [11]. There is also the presence of amorphous carbon due to the broadened peaks as shown in the diffractogram.

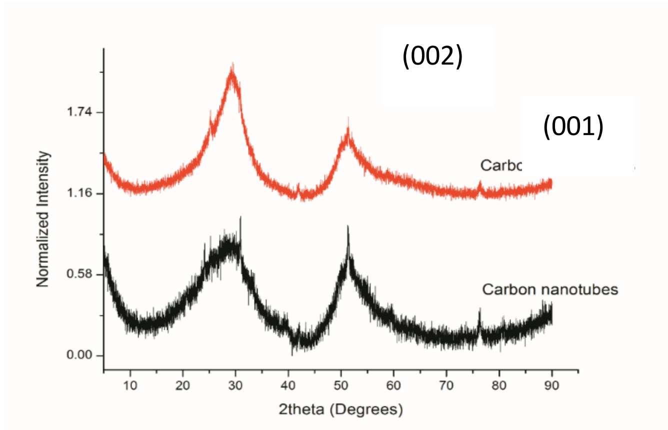

Fig. 3. X-ray Diffractogram of CF carbon nanosphere CF carbon nanotubes

4. Nanofluid Density

4.1 Effect of temperature on the density of nanofluids

Density is an important thermo-physical property that affects the pumping power of nanofluids. The measured value of the basefluid (60:40 EG/W) compared to the values given in ASHRAE is given in Fig. 5. The relative deviation is 0.09 % which is of the same order as the degree of data uncertainty.

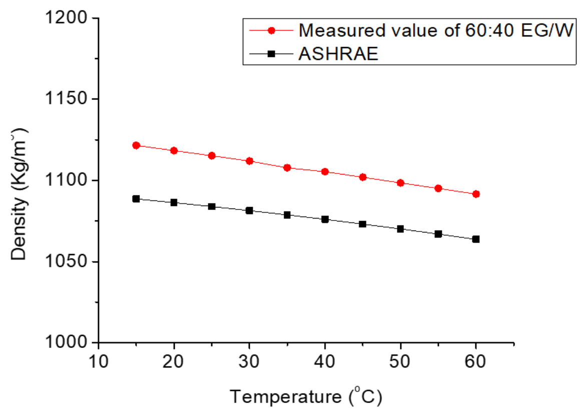

Fig. 4. Measured value of 60:40 EG/W and ASHRAE value of 60:40 EG/W

The variation of density with temperature for different concentration is shown in Fig. 6 and 7 respectively. The graphs show a decrease in density when the temperature increases for both nanofluids tested. This can be attributed to a change in volume with temperature. The volume of a fluid increases when temperature is increased because the more mobile molecules have moved further apart. Similar results have been obtained in the studies by [13] where three types of base fluid with addition of 15%, 35% and 35% of ethylene glycol and propylene glycol to water were studied. [7, 13, 14] also obtained results where the density decreased with an increase in temperature. Comparing both nanomaterials studied, the results show a very similar pattern in the density decrease of nanofluids. The highest density of nanofluids was observed in nanofluids with 1 wt% for both CF-nanosphere and CF nanotubes respectively, while nanofluid with 0.04 wt% had the least density. This indicates that the nanofluids with 0.04 wt% will need the least pumping power while nanofluids with 1 wt% will require the greatest pumping power.

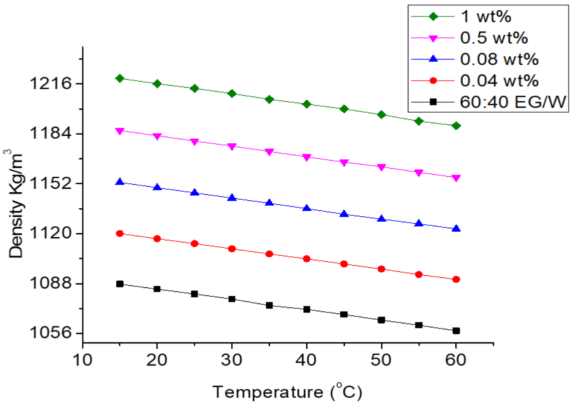

Fig. 5. Density of CF nanosphere-based nanofluid

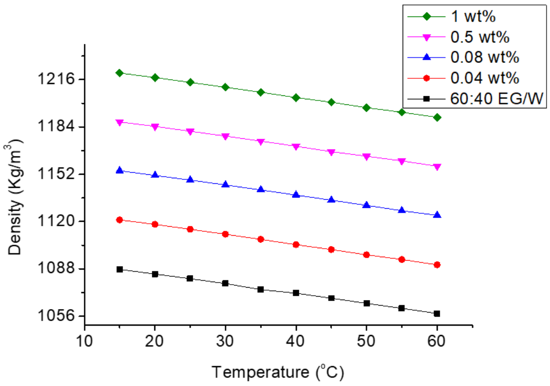

Fig. 6. Density of CF nanotube-based nanofluid

4.2 Effect of Nanoparticle morphology and mass fraction on the density of nanofluids

Fig. 8 shows an increase in the density of the CF nanotube-based nanofluid and CF nanosphere-based nanofluids with a corresponding increase in the mass fraction at atmospheric pressure. However, it has also been observed that the CF nanosphere-based nanofluid has a lower density to the CF nanotube-based nanofluid. A similar result was obtained by Pati et al.[15]; in this study, there was less compactness in nanoparticles between Ag-nanowires nanofluids which resulted in a decrease in the density compared with Ag-nanoplatelets nanofluid. A maximum percentage increment in density of 26.4% at 1 wt% and a minimum increase of 1.01% at 0.04 wt% was observed for CF nanosphere based nanofluid. Similarly, a maximum percentage increament of 27.3% at 1 wt% and a minimum increase of 1.9 wt% at 0.04 wt% was observed for CF nanotube-based nanofluid.

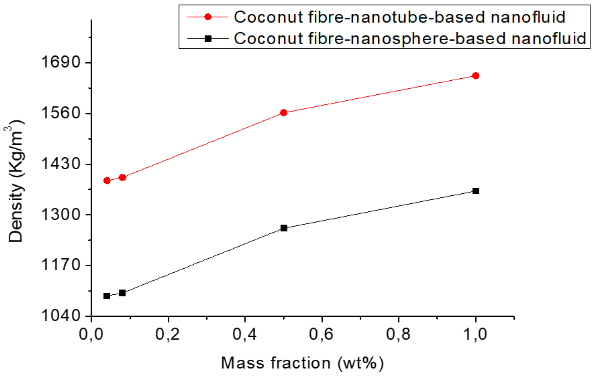

Fig. 8. Weight fraction variation of densities from CF nanotube and CF nanosphere-based nanofluids at 0.04 wt%

4. Conclusion

The present study presents results obtained from the measurement of density of green nanofluids prepared from the dispersion of CF nanospheres and CF nanotubes in 60:40 EG/W nanofluids. The results indicate a decrease in nanofluid density as the temperature increased. A relationship between nanofluid density for the different morphologies were studied at varying mass fraction, and the results show that the density increased as the mass fraction increased for both nanofluids with CF nanotube-based nanofluid having a higher density than CF nanosphere-based nanofluid. A maximum density increase of 27.3% was recorded for CF nanotube-based nanofluid.

Convection heat transfer occurs when a liquid or gas undergoes heat addition which results in a change in density of the fluid. The difference in density with the surrounding fluid leads causes the fluid to flow, carrying thermal energy with it. Therefore, the more the density difference, the greater the amount of thermal energy generated. Therefore, this study will be vital in studying the performance of a system containing nanofluid for convective heat transfer. The more the density of the fluid, the more the pumping power required to pump the fluid.

Future work on this research will focus on the application of the different densities studied in convective heat transfer. There will also be further studies on the comparison of other thermophysical properties of the prepared nanofluids.

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