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THERMAL CONDUCTIVITY OF NANOFLUIDS PREPARED FROM BIOBASED NANOMATERIALS DISPERSED IN 60:40 ETHYLENE GLYCOL/WATER BASE FLUID

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ABSTRACT

In the present study, experimental investigation on thermal conductivity of green nanofluids prepared from coconut fibre-based nanoparticles and suspended in 60:40 ethylene glycol (EG) water (W) mixture was carried out. The measurement of thermal conductivity was conducted at 15 °C to 60 °C at mass fractions of 0.04 wt%, 0.08 wt%, 0.5 wt% and 1 wt%. The results show deterioration in thermal conductivity with an increasing temperature. Also the deterioration increased as the mass fraction increased.

Key words: Thermal Conductivity; Green Nanofluids; Mass Fraction; Bio-based nanomaterials

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1. INTRODUCTION

Cooling and heat addition are two processes that must occur in industrial applications, therefore methods to meet these needs must be addressed. The conventional methods for heat removal include the use of conventional solid-liquid suspensions and use of extended surfaces. These methods however have some limitations which are listed as follows:

- Rapid settling of particles;
- Non-applicability in microsystems due to channel clogging; and
- Drop in pressure and pumping power.

With the advent of miniaturization, micro-scale devices such as heat exchangers used in microchannels and micropumps have emerged bringing forth new requirements for more advanced fluids for heat transfer [1]. Nanofluids are suspensions containing nano-metered particles suspended in known heat transfer fluids like ethylene glycol, water, propylene glycol and oil. Dispersion of these particles in the base fluids has been reported to reduce pumping power and prevent channel clogging [2].

Since the discovery of nanofluids by Choi at Argonne Lab [2], new developments in the field of nanofluids preparation and enhancements have been made in proposing new mechanisms behind enhanced thermal properties of nanofluids. A linear rise in thermal conductivity of ethylene glycol/water (EG/W) base fluids have been observed with the addition of carbon nanotubes (CNT) in increasing concentrations [3-5]. TiO_2 nanoparticles were also dispersed in EG/W base fluids and an increase in thermal conductivity was reported with an increase in concentration [6]. A similar pattern of linear increase was observed for CNT/Water nanofluids [7-9]. The effect of volume fraction and temperature on nanofluid thermal conductivity has been studied by several authors [5, 9, 10] in order to know their behaviour when subjected to various temperatures. A general trend was noted in their results which demonstrates an increase in thermal conductivity when temperature is increased [10] which was attributed to the increase in Brownian motion [5, 9].

Recently, the research community has drawn attention to the safety of nanomaterials in relation to humans who are in contact with them, and their impact on the environment. Due to the small size of nanoparticles, which is similar to biological proteins, they are easily adsorbed into the surface of tissues and blood in the human body. Even though this can be an advantage during drug delivery, they can also pass to the lungs when inhaled and may lead to lung inflammation and heart problems [11]. An extensive study on the pros and cons of nanoparticles has been published by [12] where it was established that nanoparticles behaved in a similar manner to ultrafine particles and may have similar side effects as ultrafine particles when inhaled. During synthesis of nanomaterials, the various precursors used may contain or release some toxic chemicals which may be deposited on human skin both intentionally and unintentionally. Through their disposal, they can also be deposited in water and land, and can also come in contact with the environment through transportation from production facilities to other locations where they will be used for research and other applications. In light of these safety concerns, more research focus should be channelled into the synthesis of nanomaterials which have lower risks of toxicity for humans and the environment.

In this study, the thermal conductivity of a new class of green nanofluids prepared from coconut fibre bio-based precursors suspended in 60:40 EG/W base fluid and 1:3.5 nanoparticle to gum arabic as surfactant has been investigated considering the effect of volume fraction and temperature. The results from this study will be applicable in thermal management and in heat transfer applications.

2. THEORY

The phenomena of heat conduction deals with the transfer of heat arising from vibration of molecules which occurs even when the fluid is at equilibrium. The effective thermal conductivity k_{eff} can generally be expressed as a function of the base fluid thermal conductivity k_{bf}, nanoparticles thermal conductivity k_p and nanoparticle volume concentration φ. This can be written mathematically as [1]:

$$k_{eff} = f(k_{bf}, k_p, \varphi) \quad (1)$$

The Maxwell equation for thermal conductivity of fluid mixtures with low particle-volume concentrations effectively models equation (1) and is given as [1]:

$$k_{eff} = k_{bf} + 3\varphi \frac{k_p - k_{bf}}{2k_{bf} + k_p} k_{bf} \quad (2)$$

From Maxwell's' equation, particle interactions due to their shape was neglected and the study focused on dilute suspension of spherical particles. This model under-predicts the thermal conductivity of nanofluids because it does not take into consideration geometry, temperature and surface area of nanoparticles. This limitation led to a model by Hamilton and Crosser [13] in which particle shape was considered:

$$k_{eff} = k_f \left(\frac{k_f + (n-1)k_f + (n-1)\varphi(k_p - k_f)}{k_p + (n-1)k_f - \varphi(k_p - k_f)} \right) \quad (3)$$

Where the empirical shape factor is denoted as n. This model also had limitations due to its lack of consideration of temperature and particle size on the nanofluids thermal conductivity. Maxwell's model was modified by Mehta et al. [14] by including the effect of particle size and temperature on the thermal conductivity of nanofluids through incorporation of the influence of Brownian motion and micro-convection heat transfer:

$$\frac{q_{eff}}{q_f} = \left[\frac{k_p + 2k_f + 2(k_p - k_f)\varphi}{k_p + 2k_f - (k_p - k_f)\varphi} \right] + \frac{k_p k_p}{k_f \alpha_m \mu d_p \left(\frac{6\varphi}{\pi}\right)^{1/3}} \quad (4)$$

Where q_{eff} is the effective heat flux, q_f is the nanofluids heat flux, α_m is the thermal diffusivity, $d_p$is the average particle diffusivity and μ is the dynamic viscosity.

Another model considering the impact of Brownian motion on thermal conductivity was studied by [15]. The result is an equation for thermal conductivity in nanofluid suspension containing some modes of energy transportation such as: thermal diffusion of nanoparticles in fluids, thermal interactions of dynamic nanoparticles, base fluid molecules and the thermal conductivity of the base fluid [15]. The effective thermal conductivity is [15]:

$$k_{eff} = k_{bf}(1 - \varphi) + k_p \varphi + h\delta_T \quad (5)$$

Where δ_T and h is the boundary layer thickness and heat transfer coefficient respectively for a flow past of nanoparticles.

In general, transfer of heat in nanofluids results from two prominent factors, namely, conduction in base fluids and nanoparticles, and micro-convection from Brownian motion of nanoparticles.

3. EXPERIMENTAL

3.1. Preparation of Stable Nanofluids

Nanoparticles prepared from the ethanol treatment of coconut fibre activated carbon were used for the preparation of the nanofluids. The process of carbon nanosphere synthesis has been reported in our previous study [16, 17]. From the synthesis, a spherical morphology was obtained (Fig. 1) which was suspended in a base fluid containing 60:40 ethylene glycol/water base fluid using the conventional two-step method. A known weight of the nanoparticles corresponding to 0.04 wt%, 0.08 wt%, 0.5 wt% and 1 wt% was measured using a digital weighing balance. In order to get a stable nanofluid, gum arabic was used as surfactant which was based on the study by Sadri et al. [9]. The mixture was stirred using a magnetic hotplate stirrer (Lasec from Benchmark Scientific Inc., model-H4000-HSE). After stirring the mixture was then vibrated using a 20 kHz, 700 Watts, QSonica ultrasonic processor. Sonication took place in a constant temperature water bath (LAUDA ECO RE1225 Silver temperature bath) at 15 °C to maintain the temperature of sonication.

3.2. Thermal Conductivity Measurements

KD2 Pro (Decagon, USA) makes use of the transient hot-wire method to measure the thermal conductivity of nanofluids. Calibration of the thermal conductivity meter was carried out using standard glycerine with known thermal conductivity of 0.282 W/m.K at 20 °C. A KS-1 sensor probe of 60 mm in length was used for measurement of nanofluids enclosed in insulation with a read time of 10 minutes which was aimed at lowering errors from contact resistance. Also, free convection errors were reduced by the low heat of the KS-1 needle. Changes in temperature while taking measurements were corrected by means of a linear drift term. To optimise measurement precision, readings were taken eight times at each mass concentration to ensure accuracy in measurement within 5 %. Repeatability of measurements was ensured by taking thermal conductivity of 60:40 EG/W) at 15 °C to 60 °C and the results obtained were compared with ASHRAE [24]. The error in the setup was established by comparing the experimental value of thermal conductivity of distilled water with its standard value. The experiments with distilled water were conducted three times to check the repeatability of the results, and the accuracy of the measurement is found to be within 10 mW/m.K.

4. RESULTS AND DISCUSSION

4.1. Morphology and Stability of Nanofluids

Fig. 1 shows the analysis of the nanoparticles using particle size distribution and transmission electron microscope (TEM). From the figure, the diameters of the particles ranged from about 30 nm to 100 nm with the highest distribution of particles at 75 nm. Figure 2 presents the results of XRD of the carbon nanoparticles. The peaks present correspond to hexagonal graphitic structure of carbon [18] as reported in [16]. There is also the presence of amorphous carbon due to the broadened peaks as shown in the diffractogram.

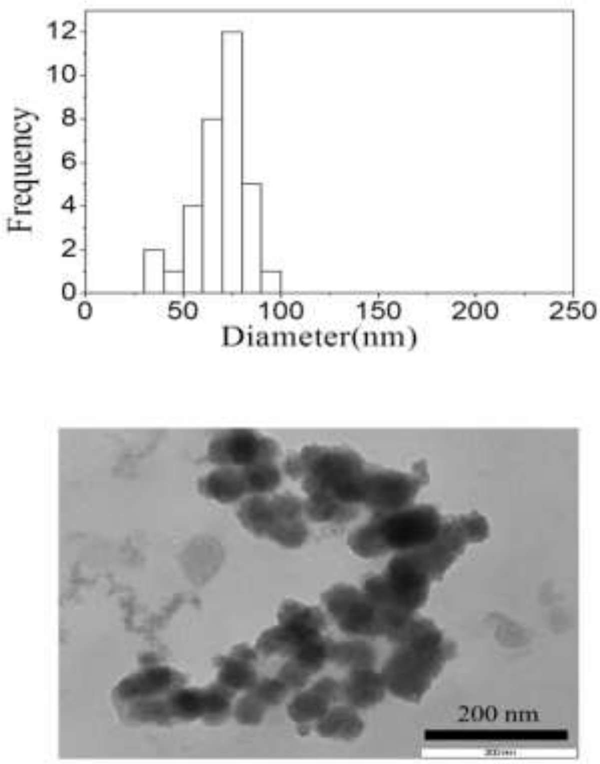

Figure 1 Particle size distribution and TEM image of green nanoparticles synthesized from bio-based precursor and used in the present study

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 nanofluid. The percentage of gum arabic used as surfactant is 3.5 % with respect to the nanoparticles. This ratio brought about an excellent stability in the nanofluids. Recently the use of ultra violet (UV) spectroscopy to study the stability of nanofluids has been studied by several researchers [19-23]. By using this technique, the rate at which incident light is absorbed by nanoparticles is measured. A linear relationship exists between the sedimentation time and absorbance which allows the stability of nanofluids to be determined from the time of sedimentation. This is in accordance with Beer Lamberts law:

$$A = log_2\left[\frac{I_0}{I}\right] = \varepsilon CL \quad (1)$$

Where: I is the final intensity of light; I_0 is the initial intensity of light; ε is the molecular absorptivity; L is the sample path length and C is the concentration.

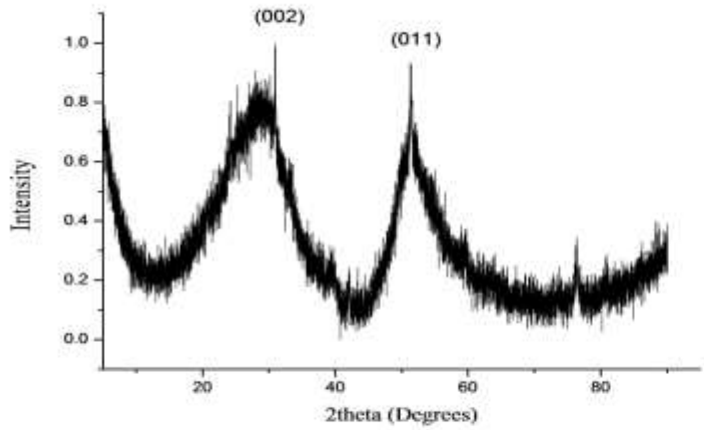

Figure 2 X-ray diffractogram of nanoparticles

Figure 3 shows the UV-Vis spectroscopy indicating the absorbance of the different mass fractions of the nanofluid with a sedimentation time of 800 minutes. The outcomes confirm the stability of the nanofluid for the period of observation. With these results, the thermal conductivity measurements could be carried out with no concerns regarding particle settlement or agglomeration.

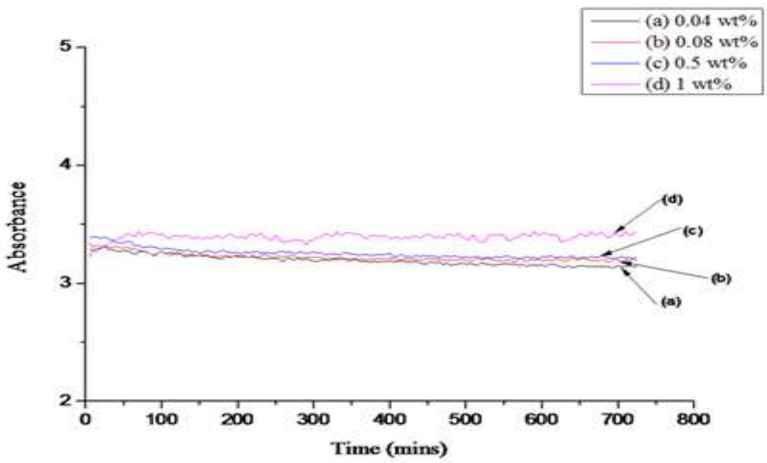

Figure 3. UV-Vis spectroscopy for stability analysis of nanofluids

5. MEASUREMENT OF THERMAL CONDUCTIVITY

To establish and confirm the accuracy of the measuring device, the measured thermal conductivity of the 60:40 EG/W base fluid was compared with results from the ASHRAE handbook [24]. The results are presented in Fig. 4. The results from measurement show good agreement with the ASHRAE values.

Thermal conductivity of the nanofluids was measured at mass fractions of 0.04 wt%, 0.08 wt%, 0.5 wt% and 1 wt% all with a nanoparticle to surfactant ratio of 1:3.5. While past studies have shown an enhancement in thermal conductivity of nanofluids compared to known heat transfer fluids, the results presented in Fig. 5 indicate deterioration in thermal conductivity of the prepared green nanofluids with an increase in temperature for all mass fractions. Therefore, it can be assumed that the thermal conductivity of the nanofluid is inversely proportional to the temperature and directly proportional to the mass fraction as there was an increase in thermal conductivity with an increase in mass fraction at all temperatures. A similar result has been published by Altan et al. [25] where a deterioration in thermal conductivity was observed in aqueous magnetite nanofluids. The deterioration in the study was attributed to an incompatibility between the base fluid and the nanoparticles. In addition, the presence of thermal boundary resistance could be a source of deterioration in thermal conductivity in nanofluids.

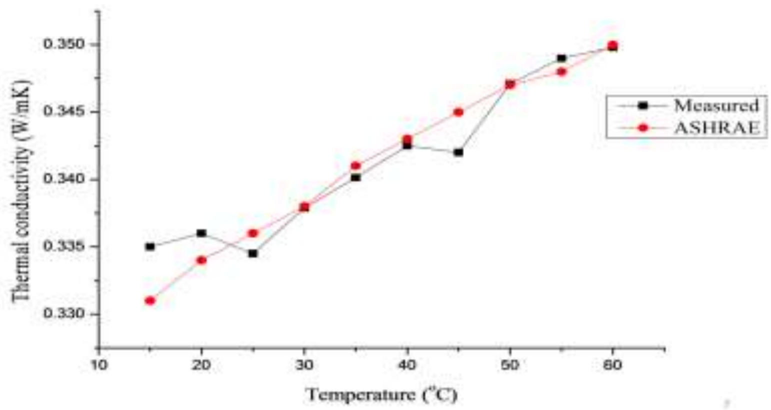

Figure 4 Comparison of measured data and ASHRAE

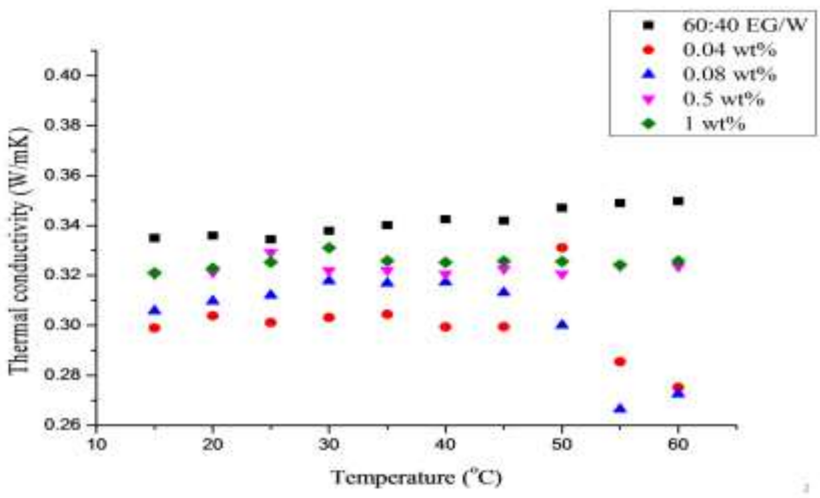

Figure 5. Thermal conductivity at different mass fractions

In the present study, the nanofluid is a composite fluid comprising the green nanoparticles, gum arabic, ethylene glycol and water. An interruption is caused between the particles interface, gum arabic and ethylene glycol/water. Inconsistencies in mass density which occur at the junction between dissimilar materials, creates an impedance mismatch [26]. There is an interruption of phonons between the interface layers of dissimilar mass segments which represents the fundamental reason behind the thermal resistance. An elevated jump takes place when there is an increase in length of the phonons with a denser mass segment thereby resulting in a decrease in thermal conductivity and heat flux.

Based on the above theories, the decline in thermal conductivity cannot only be dependent on the thermal boundary resistance as other factors such as purity of the nanoparticles, inconsistent size of nanoparticles and ratio of surfactant or a combination of all these factors could contribute to the decline.

In summary, the overall decrease in thermal conductivity of the prepared green nanofluids cannot really be explained as other references in literature have reported an enhancement in thermal conductivity of nanofluids relative to the base fluid. These findings show that there is still more research to be carried out in this area. The thermal conductivity of the green nanoparticles dispersed in other base fluids together with the effect of thermal boundary resistance on the thermal conductivity of this new class of nanofluids needs to be studied.

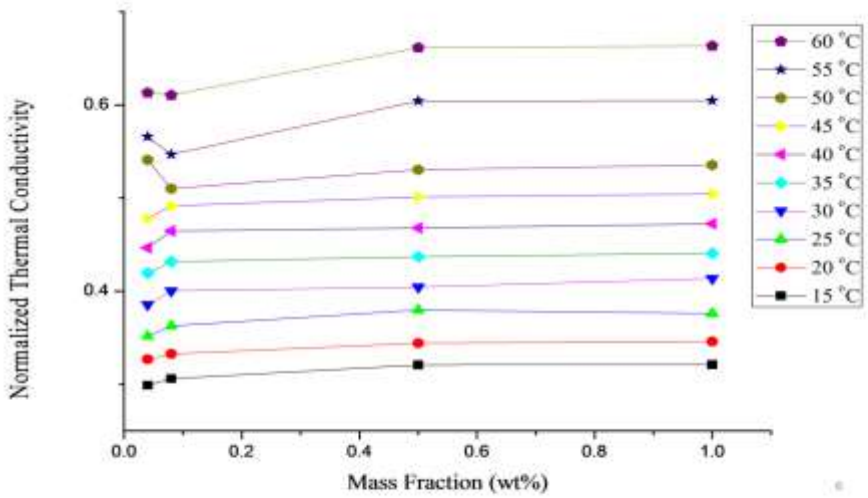

Figure 6 Temperature effect on thermal conductivity of prepared nanofluids

6. CONCLUSION

The effect of temperature and mass fraction on the thermal conductivity of nanospheres synthesized from coconut fibre and suspended in a mixture of 60:40 EG/W nanofluids has been reported. The results show deterioration in thermal conductivity as temperatures increase for all mass fractions and this deterioration increased as the mass fraction increased. This decrease has been attributed to factors such as a high thermal boundary resistance, ratio of surfactant and inconsistent size of the nanoparticles.

In conclusion, the results from the present study point to the fact that a lot of research still has to be carried out in order to tailor this new class of nanofluids to specific applications.

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