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SYNTHESIS AND FLOW BEHAVIOUR OF CARBON NANOTUBES NANOFLUIDS

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Abstract. The purpose of this study is to synthesize samples of Carbon Nanotubes (CNT) nanofluids and investigate its stability, particle structure and flow behaviour characteristics. Carbon nanotubes were dispersed in the base fluids of ethylene glycol (EG) and de-ionized water (DI-water) by the two-step method. Sodium dodecyl sulphate (SDS), a surfactant was used to assist the dispersion of nanoparticles in the fluid. The mixture was then homogenized using an ultrasonic bath. Observations showed that DI-water nanofluids were stable for more than 1 month, while diluted EG nanofluids lasted only 1 week. The SDS surfactant worked better in water-based liquids to reduce agglomeration in nanofluids. Scanning Electron Microscope (SEM) imaging showed the catalyst supports were still attached to the nanotubes, hence reducing its purity. Massive crystallization on the structure of CNT in EG nanofluids also supported the theory that SDS has reduced functionality in EG. For both base fluids, viscosity was shown to increase with particle concentration and decrease with increasing temperature between 30 °C and 60 °C. The magnitude of viscosity increments were underestimated by Einstein's conventional viscosity model.

Keywords: Nanofluids; carbon nanotubes; sodium dodecyl sulphate; viscosity; stability

Abstrak. Ujikaji ini bertujuan untuk menyediakan sampel bendalir-nano dari tiub nano karbon (CNT) dan menguji ciri-ciri kestabilan, struktur zarah dan kelikatannya. Zarah CNT diserakkan di dalam cecair dasar *ethylene glycol* (*EG*) dan air bebas-ion (*DI*) melalui kaedah penyediaan dua-langkah. *Sodium dodecyl sulphate* (*SDS*) yang merupakan suatu bahan penyelerak digunakan untuk membantu penyelerakan zarah di dalam bendalir. Selepas itu, campuran tersebut diadukkan menggunakan takungan ultrasonik. Didapati bahawa bendalir-nano dari air bebas-ion adalah stabil selama 1 bulan, manakala bendalir-nano dari cairan *EG* stabil selama 1 minggu sahaja. *SDS* sebagai penyelerak berfungsi lebih baik di dalam cecair berasaskan air untuk mengurangkan tahap keserabutan zarah. Imej dari imbasan *SEM* menunjukkan bahawa sokongan mangkin masih terlekat pada struktur molekul *CNT*, maka mengurangkan ketulenannya. Struktur kristal yang terlihat pada molekul *CNT* di dalam bendalir-nano *EG* membuktikan bahawa *SDS* kurang berfungsi dalam *EG*. Untuk kedua-dua jenis cecair dasar, kelikatan bertambah dengan kepekatan partikel dan berkurang dengan penambahan suhu antara julat 30 °C hingga 60 °C. Magnitud peningkatan dalam nilai kelikatan terkurang anggar oleh model kelikatan Einstein.

Kata kunci: Bendalir-nano; tiubnano karbon; kelikatan; kestabilan; sodium dodecyl sulphate

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1.0 INTRODUCTION

It has been long recognized that the suspensions of solid particles in fluids provide significant advantages in transport processes, including heat transfer fluids, magnetic fluids and lubricant fluids. However, recently there has been rapid development in the field of nanofluids. Nanofluids consist of solid nanoparticles or nanofibres with sizes typically of 1–100 nm dispersed or suspended in liquid. These nanofluids have been of particular interest lately due to reports of enhanced thermal properties. For example, a small amount of carbon nanotubes (CNT) nanoparticles (1% volume fraction) dispersed in ethylene glycol is reported to increase the thermal conductivity of liquid by 12.4% [1].

The production of carbon nanotubes often result in varying diameters and lengths, maybe physically or chemically entangled, or may have impurities when manufactured. Common techniques to produce carbon nanotubes include arc discharge, laser ablation, high pressure carbon monoxide (HiPCO), and chemical vapour deposition (CVD) [2]. However, production of highly entangled nanotubes will increase difficulty when dispersing these nanoparticles in fluids. Hence, the optimum transport properties such as heat conductivity for these nanofluids cannot be achieved with agglomerates forming within.

Basically, nanofluids are prepared by two techniques: the single-step and the two-step technique. The single-step method produces the nanoparticles and disperses them simultaneously directly into the base fluids. In contrast to this, the two-step method produces the nanoparticles first then only disperses them in the base fluids in another step.

This study focuses on the dispersion process when synthesizing carbon nanotube nanofluids. Due to the intermolecular attractions between the nanotubes itself, the process of producing homogenous solutions of carbon nanotubes is a big challenge. The technique of dispersing the nanotubes in the base fluids using a surfactant and sonicating the mixture was chosen to be the primary method of producing carbon nanotube nanofluids.

Liquids containing nanoparticles with higher thermal conductivities usually exhibit enhancement in heat transfer capabilities compared with the base liquid itself. Compared with millimeter or micrometer sized particles suspensions, nanofluids possess better long-term stability and rheological properties, and can have higher thermal conductivities [1]. Various investigations have been conducted on nanofluids containing carbon nanotubes due to its outstanding heat transfer properties. These nanofluids show great potential in increasing the efficiency of thermal transport. However, the dynamic viscosity has been found to generally increase with particle concentration in the nanofluids. This factor could cause numerous side effects in heat transfer systems especially in cases where nanofluids with high particle loading are used as heat transfer fluids. A built-up in resistance due to the possible high viscous nature of nanofluids could damage the internals of the system. Such enhancement of viscosity could significantly reduce the potential use of nanofluids as heat transfer fluids.

This study was conducted to meet the following objectives: Firstly, to synthesize a sample of carbon nanotubes nanofluids through dispersion of carbon nanotubes in base fluids of ethylene glycol (EG) and de-ionized water (DI water) using Sodium Dodecyl Sulphate (SDS) as a surfactant and sonicating the mixture. Next, to characterize the viscosity and stability of the nanofluids prepared. Particularly, the viscosity of the nanofluids was measured at different temperatures and different particle loadings to observe the effect of nanoparticles when they are present in fluids. A high resolution Scanning Electron Microscope (SEM) imaging was done to ascertain the structure of nanoparticles in the fluid.

This paper is arranged in the following manner. Section 2 describes the details of experimental systems and materials used. Experimental results are presented and discussed in Section 3. Section 4 summarises the main conclusions.

2.0 MATERIALS AND METHODS

2.1 Synthesis of CNT Nanofluids

CNT in raw powder form was obtained from the Advance Membrane Technology Research Centre in Faculty of Chemical and Natural Resources Engineering of Universiti Teknologi Malaysia (UTM), Skudai. The CNT was produced via the chemical vapour deposition (CVD) technique, using a catalyst support to grow the CNTs.

In this study, the two-step preparation method of nanofluids was employed. Carbon nanotubes particles were dispersed accordingly in the base liquids with different particle loadings. Ethylene glycol (99.5% Purity; QReC Chemicals, Grade AR), and DI water were used as the respective base fluids. For both base fluids, 4 samples of CNT nanofluids were produced; all 4 samples with different CNT concentrations. SDS (90% Purity; GCE Laboratory Chemicals) was used to assist the dispersion of the carbon nanotubes. The mixture was homogenized using an ultrasonic bath (Branson Ultrasonic Cleaner 5510E-DTH). A constant sonication frequency of 40 kHz was employed for this equipment.

The procedure for synthesis is as follows: Firstly, an optimum value of SDS concentration was determined for both base fluids. Using varying SDS concentrations and a constant CNT concentration of 0.1 wt%, the most stable nanofluid sample was the sample with the least agglomeration of particles over time. The raw CNT nanoparticles were sonicated for 15 minutes individually beforehand. To ensure that the base fluids containing SDS are dispersed evenly, the solutions are heated on a heater plate and stirred using a magnetic stirrer. Following this, the CNTs were added to the mixtures and were sonicated using an ultrasonic bath for 90 minutes. This was the standard procedure to prepare a nanofluid sample.

For the EG base fluid, the function of SDS as a surfactant was found to have decreased effect compared to DI water. Hence, a mixture of 3:1 EG to DI water volumetric ratio was formulated to replace the pure EG base fluid. This mixture will be referred as EG-solution for this point forward.

After the optimum SDS concentration for each base fluid was known, preparation of the main 8 samples of CNT nanofluids can proceed. CNT nanoparticles of weight fractions of 0%, 0.2%, 0.5% and 1.0% CNTs were used together with the optimum SDS concentration for each base fluid. This step will produce 4 samples of different CNT concentrations for each base fluid (total of 8 samples). Following the normal formulation procedure described above, the glass jars containing the nanofluids prepared were covered and stored in a cool, shaded area for further experimentation.

2.2 Stability, SEM and Viscosity Characterization

The main characteristics of the nanofluids prepared were investigated; that are their stability and also the viscosity behaviour over various temperatures and particle loadings. In addition to that, a SEM analysis was conducted to investigate the molecular characteristics of the nanotubes that are present in the nanofluids themselves.

Stability of the nanofluids was observed by eye to see the sedimentation of suspensions over time. If the suspensions did not agglomerate and still disperse well over a long period of time, preferably over the whole duration of this experiment, then the nanofluid was high in stability. A background light was used to identify the suspensions and the degree of dispersion of CNT particles in the supernatant.

Two samples of nanofluids (each from both types of base fluid which contains the optimum dosage of SDS concentration) and a dry carbon nanotube sample were sent for microscopic imaging. The dry nanotube sample was sent first for SEM imaging to ascertain the conditions of the CNT fibres purchased. The SEM (JEOL JSM-6390LV), from the Ibnu Sina Institute in UTM was used to identify and study the suspensions of nanofibres in the liquids after the CNTs were dispersed in their respective fluids.

To observe the behaviour of viscosity of the nanofluids, an experiment was conducted to determine the viscosity at different temperatures ranging. A direct-flow U-tube viscometer (Rheotek) was employed to measure the viscosity of the nanofluids. A digital stopwatch that possesses accuracy up to 0.01 seconds was used to record the flow time. Before the experiment started, the calibration of the thermostat water bath was done using a thermometer. It was found that temperature deviation was at maximum +/– 0.1 °C.

The main nanofluids samples that were tested for their viscosity were sonicated separately for 30 minutes prior to any testing. The samples were inserted in the thermostat water bath and tested for their viscosities at 10 °C increments from 30 °C to 60 °C. The effect of particle weight fraction, w and temperature on the viscosity of CNT nanofluids could then be studied. The relative viscosity that is the ratio of the viscosity of the CNT nanofluid to the corresponding value of the base fluid was also calculated. The relative viscosity values obtained experimentally were compared with Einstein's model [3] for effective viscosity of very dilute suspensions. This formula relates the relative viscosity to its particle volume fraction and is as shown:

$$\frac{\mu_{eff}}{\mu_{base}} = 1 + 2.5f \tag{1}$$

μ_{eff} is the effective viscosity, μ_{base} is the viscosity of the base fluid and f is the particle volume fraction.

3.0 RESULTS AND DISCUSSION

3.1 Synthesis of CNT Nanofluids

Firstly, the experiment to find the optimum SDS concentration for both base fluids was done. This optimum value is crucial for minimizing the agglomeration and sedimentation of nanoparticles in the fluids in the samples prepared later. Basically, the sample with the least sedimentation after time contains the best SDS concentration.

For DI-water based nanofluids, the sample that contained 0.5 wt% SDS was the most stable nanofluid. The backlight is not detectable for this sample, but visible for the rest of the samples. Increasing the SDS concentration over this limit does little to increase the stability effect but instead demolishes the function of dispersant of the SDS. As the SDS concentration increases over this limit, the sedimentation rate of CNTs also increases proportionally. The function of SDS is to change the surface properties of the particles so that it results in electrostatic repulsion, and hence less particle agglomeration and a slower sedimentation rate. Additional SDS will slowly convert the repulsion forces back into attractive forces, due to increased coating of SDS on the particle surface. This results in faster agglomeration of the particles, which we do not want. Meanwhile, the pH for all the samples does not deviate much from the pH of pure DI-water that is pH 7. It could be concluded that the optimum pH value for a stable CNT nanofluid mixture is around pH 7-8.

For pure EG based nanofluids, all of the samples had the same degree of sedimentation and nearly all the CNT particles have already settled to the base of the bottle only after 2 days. With this, it could be concluded that either the SDS did not function properly with EG, or EG do not have the capability to be used as a base fluid to produce stable CNT nanofluids.

An appropriate ratio of 3:1 EG to DI-water volumetric ratio was used next for any EG-solutions fabricated. The EG-solution with 2.0 wt% SDS was deemed to be the most stable nanofluids sample. This conclusion was drawn only after a period of 24 hours after synthesis. However, it was later observed that this EG-solution sample lasted stable until a maximum of 7 days. After this the particles formed a clear sediment base but the supernatant was still black in colour. A possible explanation behind this occurrence is either because the SDS does not function well with EG, or the water layer is not fully miscible with EG. Another reason is due to the impure nature of the CNT particles that still have the catalyst support attached. It is possible that these properties of CNTs cause progressive agglomeration when dispersed in EG solutions.

Chen *et al.* [4] showed the difference in stability when using pristine/raw CNTs compared to those treated chemically. Pristine CNTs are prone to aggregate and precipitate to the bottom when dispersed in many types of fluids even after long periods of intensive sonication if no surfactant is added. However, treated CNTs can be dispersed in various types of polar fluids and remain stable for many months without any surfactant. Perhaps further modifications on the CNT molecule structure to remove the catalyst support will shed light on different findings. Meanwhile, the pH of the EG-solution samples is around pH 7-8, just as seen for the DI-water samples. It can be concluded that neutral pH conditions are best for EG-solutions to achieve maximum stability and least agglomeration for CNT nanofluids.

The next step was the formulation of the main samples of CNT nanofluids. Using the optimum SDS concentration values, the nanofluids produced should exhibit stable behaviour over time. This is because the use of surfactant decreases the tendency of particles to cluster, while the sonication of the nanofluids should fully homogenize the CNTs in the fluids.

Observation tells that the CNT-DI Water nanofluids were the most stable nanofluids that were successfully produced during this lab-scale experiment. For EG-solution nanofluids, observation generally showed that EG is not as suitable as a base fluid for CNT nanofluids, if compared to DI-water. More agglomeration and sedimentation were noted in EG-solutions. The stability results for the main nanofluid samples are further discussed in the following sections.

3.2 SEM Analysis

A dry CNT nanoparticle sample was sent for SEM analysis, together with the DI-water nanofluid containing 0.5 wt% SDS and 0.1 wt% CNT, and EG-solution nanofluid with 2.0 wt% SDS and 0.1 wt% CNT. The DI-water nanofluid sample was left to evaporate on the microscopic slide while the EG-solution nanofluid sample was baked in an oven at 110°C to remove all moisture present.

Firstly, the dry nanotube sample was studied under the SEM. Figure 1 shows the dry CNT as received. The average diameter, d of the nanotubes taken at different imaging spots is 40–70 nm. Meanwhile, the average length, l of the tubes is 1–2 μm. Catalyst supports attached to the nanotube fibres are seen throughout the dry CNT sample. This reflects the impurity of CNTs and could lead to reaction with other substances such as the SDS. The multi-walled CNTs are highly entangled before sonication and tends to agglomerate easily if dispersed without any surfactant.

Figure 2 shows the SEM images of the nanotubes contained in DI-water based nanofluids. The SDS surfactant is seen to have coated the nanotubes although the

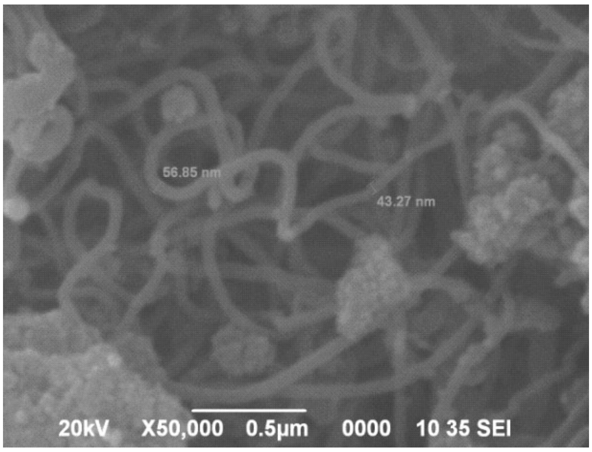

Figure 1 SEM of dry CNT sample as received

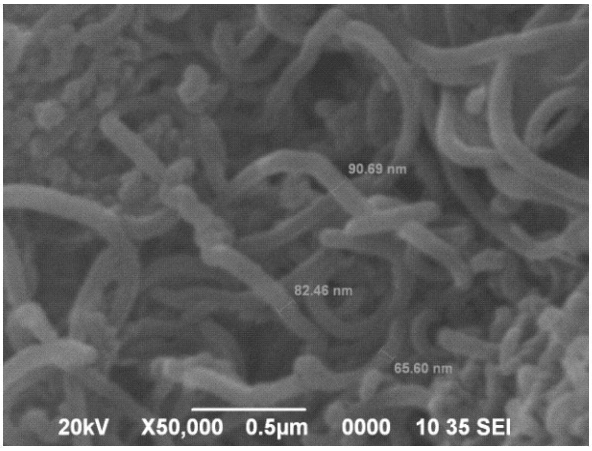

Figure 2 SEM of CNT-DI-water nanofluid sample

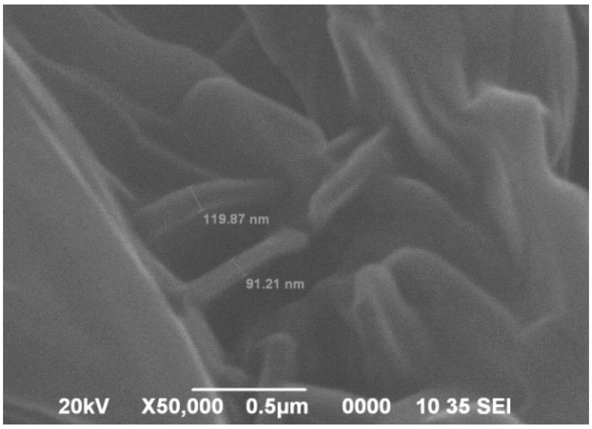

Figure 3 SEM of CNT-EG nanofluid sample

fibres of CNTs are still visible. Basically the SDS modifies the surface properties of the CNTs to reduce the intermolecular Van der Waals attractive forces which result in agglomerated particles. The catalyst supports are still visible throughout the sample. The average diameter of the nanotubes is 60–90 nm.

Figure 3 shows the SEM imaging on the CNTs in the EG-solutions. The images produced did not show any fibres of CNTs at all. It shows crystalline structures that have similar tubing shapes that appear throughout the sample. These crystalline structures were not noticeable in the DI-water base nanofluids before. In addition to this, EG-solution nanofluids agglomerate easily and settle faster compared to DI-water nanofluids. There are two possibilities behind these occurrences. Firstly, the highly agglomerated CNTs in EG based solutions were caused by some form of reaction between the impure CNTs and EG. It is known that EG is more polar and possess higher cohesive energies, dielectric constants and hydrogen bonding ability than water. This factor could cause the massive crystallization over the CNT's surface, and obscured the fibres of CNT from view. Furthermore, this type of formation promoted agglomeration and higher sedimentation rates in the nanofluids. This theory is also backed up by the fact that CNTs dispersed in pure EG containing SDS agglomerated easily after sonication and lasted only up to 2 days. The addition of DI-water to dilute the pure EG managed to assist the dispersant effect of SDS and decrease the agglomeration rate modestly.

Another reason is that SDS does not work well in EG solutions compared with DI-water. From the experimental procedure earlier, it was noted that CNT in DI-water and pure EG based nanofluids both agglomerate easily and settle within one day if no SDS is applied. However, with only 0.5 wt% SDS used, the amount of sedimentation for DI-water nanofluids decreased tremendously while there was no appreciable change for pure EG nanofluids. The dilution of EG also decreased the agglomeration rate. This shows that SDS works best in water-based fluids.

3.3 Viscosity Characterization

The viscosities of the DI-water based nanofluids and EG-solution based nanofluids were measured at temperatures ranging from 30 °C to 60 °C using a U-tube viscometer.

For DI-water based nanofluids, viscosity increased with particle concentration in a non-linear fashion with higher viscosity values for lower temperatures. As particle concentration increases, the internal viscous shear stresses increases which results in higher fluid viscosity. Ko *et al.* [5] found that the nanotubes are highly entangled when dispersed in fluids and this contributed to the highly viscous behaviour of nanofluids at rest or under weak shear stress. When shear stress is increased, the tubes arrange themselves along the flow direction and the viscosity is reduced. On the other hand, increasing the temperature weakens the intermolecular forces of the particles and fluid itself, hence decreasing viscosity. At low concentrations of CNT nanoparticles, the increments in viscosity are nearly negligible. The changes in viscosity are more

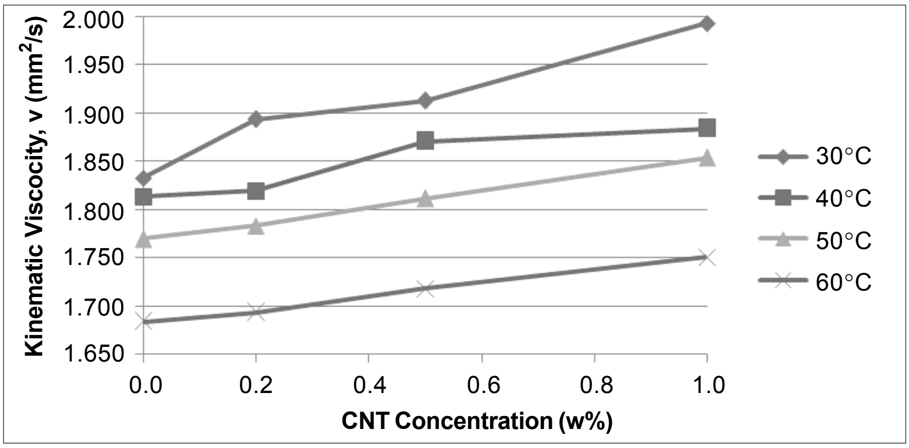

Figure 4 Viscosity versus CNT concentration for DI-water based nanofluids

dependent on temperature for low particle loadings. Figure 4 shows the relationship between viscosity and CNT particle concentration at various temperatures.

EG-solution based CNT nanofluids basically showed similar results and trends as DI-water based nanofluids. Viscosity for these nanofluids also increased with particle concentration and decreased with temperature. There are similar increases in shear stresses between the layers of the base fluid due to higher nanoparticle concentration. As the number of nanoparticles that congregate into a specific volume increases, there is a build-up of the internal stresses in the fluid. In general, for any fluid flow, layers move at different velocities and the fluid's viscosity arises from the shear stress between the layers that oppose any applied force. Therefore, an increase in particle concentration will lead to higher viscosities for the base fluid involved. Figure 5 shows the respective connections between viscosity, CNT concentration and temperature.

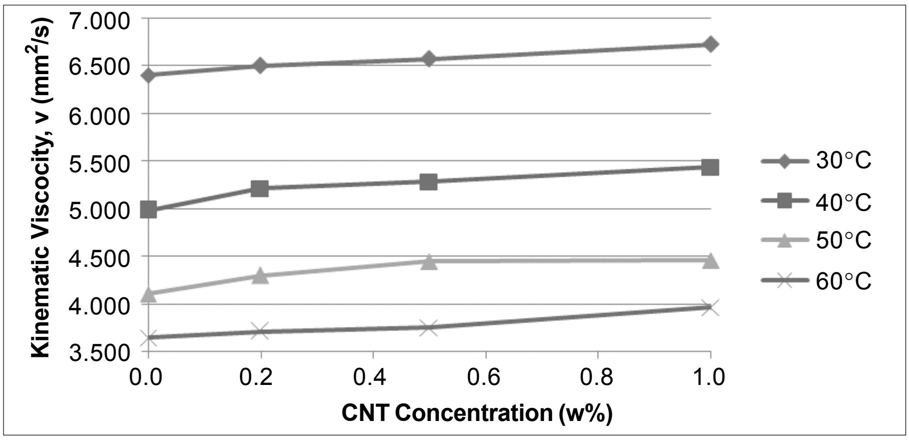

Figure 5 Viscosity versus CNT concentration for EG-solution based nanofluids

Figure 6 compares the relative viscosity with increasing CNT concentration for DI-water nanofluids. Generally, the relative viscosity increases with CNT concentration at a constant temperature. This increase is in a non-linear fashion and is observed to be unaffected by the temperature. Viscosity increases with particle loading due to higher internal shear stresses as discussed before. This directly increases the relative viscosity value. The Einstein model used to predict the relative viscosity is seen to underestimate its magnitude of increment. Also, there is no obvious dependence of relative viscosity on the nanofluid temperature. Theoretically, there should be no visible connection between these two variables. The decrease in viscosity with temperature for all nanofluids should be within the same order of magnitude irrespective of particle loading. However, there are slight variations as due to the unpredictable behaviour of nanofluids as temperature changes.

Experimental data from Chen *et al.* [4] who studied CNT nanofluids, and Chen *et al.* [6] who did research on titania nanofluids; both using DI-water as base fluid, are inserted in Figure 6 for comparison. Viscosity data for the CNT nanofluids was shown to decrease for very low particle concentrations and increase further on with particle loading. This event was said to be due to the lubricative effect of nanoparticles that occurs for volume fractions less than 0.004. However, this effect was not seen in this study on CNT nanofluids. Higher relative viscosities were achieved by Chen *et al.* [4] for higher particle fractions. This could be the results of different particle morphologies and formulation techniques. Besides that, titanate nanofluids from Chen *et al.* [6] were

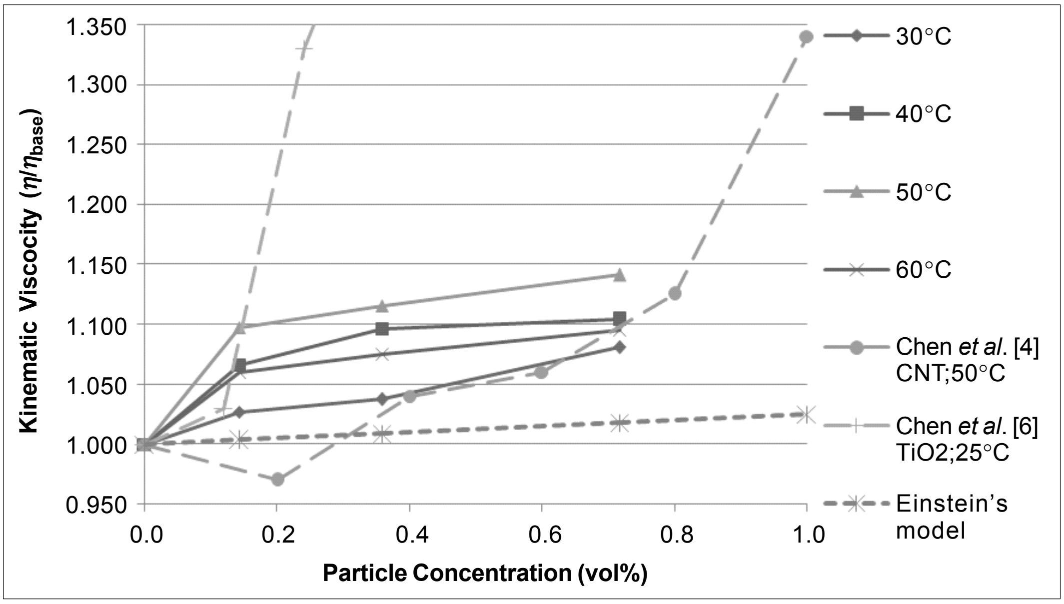

Figure 6 Relative viscosity versus particle concentration for DI-water nanofluids

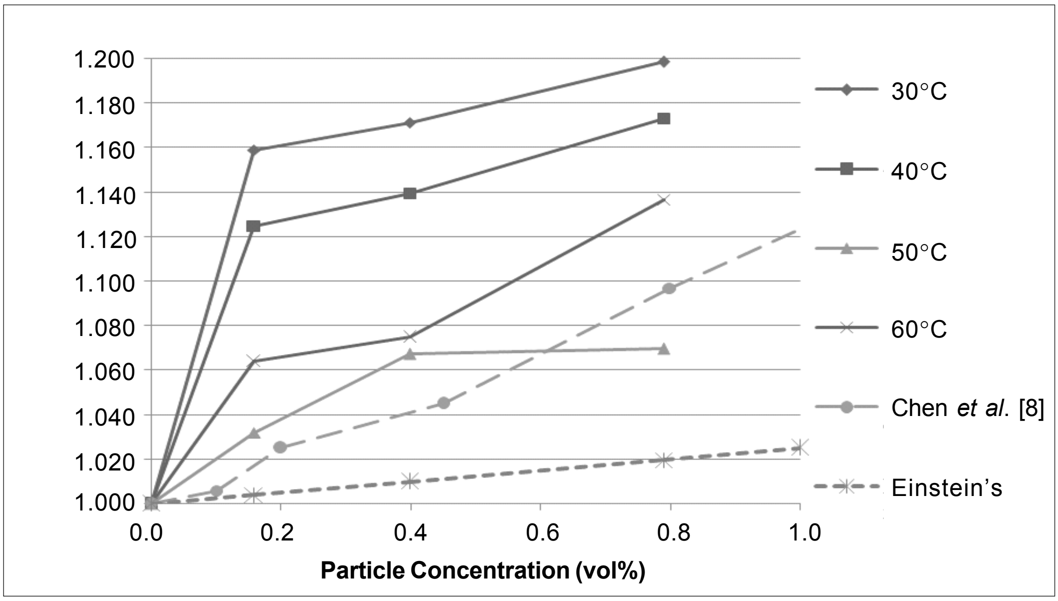

Figure 7 Relative viscosity versus particle concentration for EGsolution nanofluids

also reported to have very high orders of viscosity increments compared to this study. Rod-like shape particles are said to be the cause of the large viscosity increments. Hence, there exists a strong relationship between particle shape and rheological behaviour of nanofluids.

For EG-solution based nanofluids, Figure 7 shows the relationship between relative viscosity, CNT concentration and temperature. Relative viscosity of these nanofluids also increases with particle concentration, also in a non-linear fashion. The Einstein model also under-predicts the magnitude of viscosity enhancement for this case. Perhaps the Einstein model does not takes into account the shape and size of the particles that are so small, on the nanometre scale; and this could somehow change the intermolecular forces that affect the viscosity of the fluid. Nanoparticles in fluids also tend to form clusters and experience surface adsorption. These factors were not considered in the empirical models involved [7]. Further research needs to be conducted to study the effect of particle size, nature of particle surface, ionic strength of base fluid, surfactants, pH values and inter-particle potentials on the viscosity of the base fluid. Similarly, temperature variation has no obvious effect on the relative viscosity for EG-solution nanofluids.

Comparison with experimental data from Chen *et al.* [8] who studied EG based titania nanofluids showed that increments in viscosity were in the same order of magnitude. This confirmed that viscosity of EG based nanofluids do indeed increase with particle concentration but do not follow conventional viscosity models.

3.4 Stability Characterization

The stability of the nanofluids produced was observed over time throughout the experiment conducted. The amount of sedimentation of particles can be seen through the glass jar used and this is a rough measure of the stability of the nanofluid. Figure 8 shows the image capture of the DI-water nanofluid samples one month after synthesis. Figure 9 shows the EG-solution nanofluids after one week.

All of the DI-water nanofluids lasted stable throughout the duration of the experiment of one month. This shows how good the SDS surfactant complements the based fluid of water to steadily disperse the CNT particles and reduce agglomeration for long periods of time. The stability increases with particle loading. This implies that the SDS successfully dispersed the particles even at relatively high weight fraction. Hence, at higher particles loadings the backlight will be less visible.

Meanwhile, for EG-solution based nanofluids, the samples lasted a maximum of 1 week only. Nearly all the particles have settled and the background light is quite visible. All of the solutions remained ink-black in colour for less than 7 days only. Basically, the addition of SDS does not assist in the stabilization of EG-CNT nanofluids

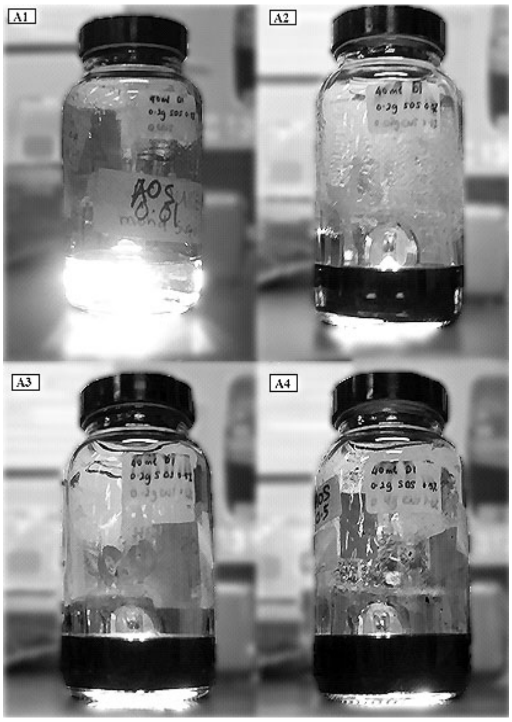

Figure 8 Vials containing DI-water based CNT nanofluids for 0%, 0.2%, 0.5% and 1.0% weight CNT respectively after 1 month of obeservation

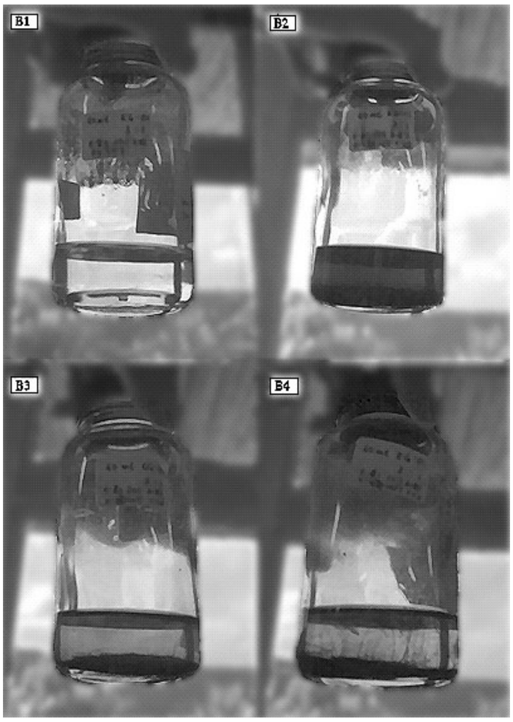

Figure 9 Vials containing EG-solution based CNT nanofluids for 0%, 0.2%, 0.5% and 1.0% weight CNT respectively after 1 week of observation

if water is absent. It is possible that the SDS surfactant does not function well in EG solutions, or there are impure elements in the CNT particles that cause reactions which promote agglomeration and sedimentation. The fact that increasing particle concentration increases the visibility of the backlight hence reducing stability shows that either one or both of the above deductions may be correct. Further experiments to confirm this phenomenon should be done.

4.0 CONCLUSION

In this study, the synthesis of stable CNT nanofluids was successfully conducted for both base fluids of DI-water and EG. Although for the latter, the duration of stability was significantly less than DI-water based nanofluids. Generally, the function of SDS as a surfactant was better in water-based liquids if compared with EG.

From SEM imaging, the raw particles were seen to be entangled in ropes. However, once dispersed with aid of surfactant and sonicated, the CNT particles in DI-water nanofluids were still quite agglomerated but managed to produce homogenous suspensions. From observation, there were many catalyst supports still attached to the raw particles, hence casting a doubt on the CNT purity. This could be the reason why the EG-solution nanofluids did not last as long as the DI-water nanofluids and the formation of crystals on the nanotube structure.

Furthermore, viscosity of the nanofluids increases with particle concentration but decreases with temperature. Conventional viscosity models also underestimate the amount of increment in viscosity. This is because the model does not take into account the particle shape and size, agglomeration, clustering and surface adsorption that happens in nanofluids. Comparison with other works of journals also implied that the increments in viscosity follow similar trends, although generally not in the same order of magnitude. This could be attributed to the different particle morphology, synthesis technique, surfactant used and properties of the base fluid.

The relative viscosity of all the nanofluids produced increased non-linearly with particle concentration. However, its dependence on temperature is still vague and deserves further attention to explain its rather peculiar behaviour.

Overall, this paper mainly focused on the synthesis and viscosity characterization of CNT nanofluids. The outcome of this research can be a good assistance and comparison with other related research into the capabilities that CNT nanofluids can offer to increase the efficiency of heat transfer systems.

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NOMENCLATURE

d - Diameter (nm)
l - Length (μm)
f - particle Volume Fraction
w - Particle Weight Fraction
v - Kinematic Viscosity (mm^2/s)
EG - Ethylene glycol
DI-water - Di-ionized water
CNT - Carbon Nanotubes
SEM - Scanning Electron Microscope
SDS - Sodium Dodecyl Sulphate

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