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VISCOSITY CHARACTERISTIC OF CARBON NANOTUBE BASED NANOFLUIDS AT ROOM TEMPERATURE

Kin Yuen Leong[1], N. M. Fadhillahanafi[1] and Sue Ping Chew[2]
[1]Department of Mechanical Engineering, Universiti Pertahanan Nasional Malaysia, Kem Sungai Besi, Kuala Lumpur, Malaysia
[2]Department of Electrical and Electronics Engineering, Univeristi Pertahanan Nasional Malaysia, Kuala Lumpur, Malaysia
E-Mail: leongkinyuen@gmail.com

ABSTRACT

Nanofluid is defined as suspension of nanoparticles in the base fluid. Researchers found that nanofluid improves thermophysical properties of base fluid such as thermal conductivity. However, with the addition of nanoparticles into base fluid also increases its viscosity which leads to augmentation of pumping power. Therefore, better understanding on nanofluid's viscosity characteristic is essential in order to minimize this drawback. This paper presents the investigations on the viscosity characteristic of carbon nanotube based nanofluids. The weight percentage of nanoparticles were varied from 0.01 to 0.5%. Various surfactants such as polyvinylpyrrolidone (PVP), Gum Arabic (GA) and hexadecyltrimethylammoniumbromide (CTAB) were also included in the present study. R/S plus Brookfield rheometer was used to measure viscosity of the samples. Study revealed that nanofluids added with surfactant exhibited lower viscosity compared to nanofluids without surfactant. The viscosity also found increases with the increasing of nanoparticles' weight percentage. Overall, carbon nanotube (0.5 weight %) based nanofluids added with gum arabic has highest viscosity value compared to other samples.

Keywords: carbon nanotube, nanofluids, viscosity, weight percentage, surfactant.

INTRODUCTION

Addition of nanoparticles such as carbon nanotube into base fluid increases its thermal conductivity as well as its viscosity. Augmentation of thermal conductivity is preferable since it will improve the effectiveness of thermal system. However, viscosity increment should maintained as low as possible. Viscosity is expressed as resistance of fluid to flow. Higher viscosity increases pumping power of the system. Therefore, better understanding on nanofluid's viscosity characteristic is essential in order to obtain higher thermal conductivity with minimal viscosity increment.

Garg *et al.* (2009) implied that viscosity of multiwalled carbon nanotube-based aqueous nanofluids increases with sonication time. It will decrease once the viscosity reaches maximum. Authors explained that initial increase is due to declustering of CNT bundles where later decrease is resulted from high breakage rate of CNTs. Phuoc *et al.* (2011) indicated that multiwalled carbon nanotube can be used to enhance or reduce the base fluid's viscosity through its volume fraction. Chitosan was used as surfactant in their study.

Mahbubul *et al.* (2012) in their review articles concluded that nanofluid's viscosity is influenced by particles' content, shape and operating temperature. Halelfadl *et al.* (2013) investigated effect of particles concentration and temperature on viscosity of carbon nanotube based water nanofluids. Sodium dodecyl benzene sulfonate (SDBS) was used as surfactant in that study and particles' volume fraction was varied from 0.0055% and 0.55%. Study implied that nanofluids behave as Newtonian fluid at lower particle's content. At higher content, it shows shear thinning behaviour. In addition, temperature affects nanofluid's viscosity, however relative viscosity at high shear rate is not temperature dependent. Li *et al.* (2013) used viscoelastic-fluid as base fluid in their experiment study. Similar with previous researchers, they added multiwalled carbon nanotube (MWCNT) into the base fluid. Acid treatment was performed to introduce hydrophilic surface on the MWCNTin order to have better dispersion of nanoparticles in the base fluid. Results showed that the nanofluids behave non-Newtonian feature which is similar to its viscoelastic base fluid.

Halelfadl *et al.* (2014) experimentally studied the efficiency of carbon nanotube based water nanofluids as coolant. In this study, they also used SDBS as surfactant, similar to their study published in 2013. Particles volume fractions considered were 0.0055 % to 0.278 %. They found that, the relative viscosity of nanofluids is influenced by shear rate and nanoparticles' volume fraction. Jo and Banerjee (2014) measured viscosity of molten salts nanofluids containing MWCNT which its viscosity enhancement was achieved up to 93% for samples with 2 wt. % of nanoparticles. In another study conducted by Estellé *et al.* (2014), lignin was used as surfactant to assist dispersion of MWCNT in water base fluid. The experiment was performed at 20oC where nanoparticles' volume fraction ranges from 0.0055% to 0.55%. Authors stated that lignin surfactant reduces viscosity and shear thinning character of nanofluids at high particles' content. Recently, Xing *et al.* (2015) used single walled carbon nanotube (SWCNT) instead of MWCNT nanofluid. Based on their observation, viscosity of SWCNT based nanofluids increases with particles' loading but decreases with the increment of operating temperature. In the present study, viscosity characteristic of water containing MWCNT and surfactant was investigated. Surfactant is added to ensure better dispersion of nanoparticles in the base fluid. Comparison between samples with and without surfactants was also performed. Particles' weight percentage ranges from 0.01 to 0.5 were used to prepare the samples.

METHODOLOGY

Nanoparticles, base fluid and surfactant

Mixture of 40% ethylene glycol (EG) and 60% distilled water (DW) was used as base fluid in the present study. Ethylene glycol was purchased from Sigma Aldrich (M) Sdn Bhd where it can lower the freezing point of the base fluid. Carbon nanotube (CNT) was procured from Chengdu Organic Chemicals Co., Ltd, Chinese Academy of Sciences. Multi-walled carbon nanotube (MWCNT) is chosen instead of single walled carbon nanotube attributed to its lower cost. It is known that carbon nanotubes are tend to agglomerate due to its hydrophobic in nature. This will affect nanofluid's stability. Therefore, surfactant was added into the base fluid. The surfactants considered are polyvinylpyrrolidone (PVP, non-ionic), Gum Arabic (GA- anionic)or hexadecyltrimethylammoniumbromide (CTAB- cationic). Addition of these surfactants will modify the nanoparticles' surface from hydrophobic to hydrophilic. Nanoparticles with hydrophilic surface have better dispersion in the base fluid. Outer diameter of the selected MWCNT is < 30 nm, length (10-30 nm), purity (95%) and density (2.1 g/cm^3).

Preparation of Nanofluids

Nanofluids were prepared via two-step method. This method is inexpensive compared to that of single-step method. Firstly, surfactant was added into base and stirred by using a magnetic stirrer (Figure-1) to ensure they are mixed perfectly.

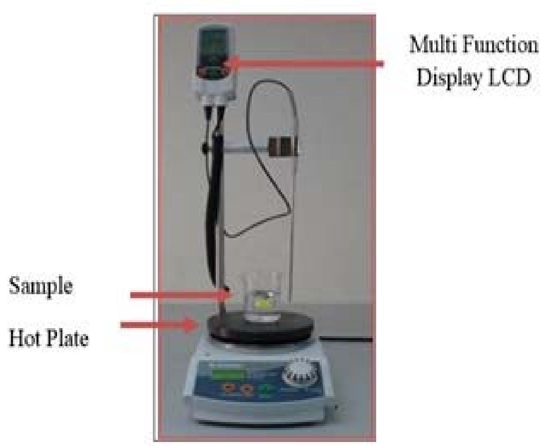

Figure-1. Magnetic stirrer.

Then, MWCNTs were added into the base fluid and subjected to ultrasonication (QSONICA Q700) process as shown in Figure-2. The sonication duration was about 10 minutes with 10% amplitude.

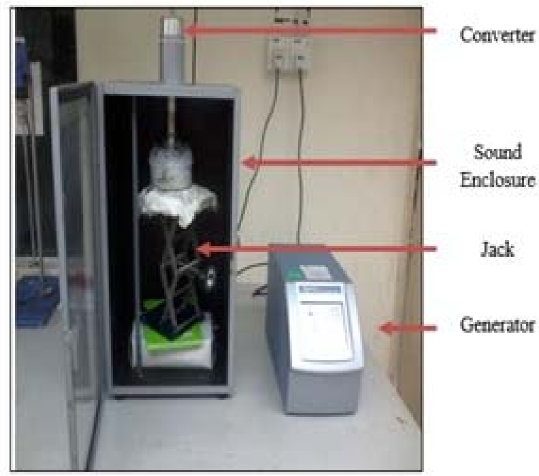

Figure-2. Ultrasonicator (QSONICA Q700).

ON/OFF pulse sonication method (2 seconds "ON" and 5 seconds "OFF") was applied to prevent overheating of the sample. Similar method was performed to prepare samples without addition of surfactant. Table-1 shows concentration of MWCNT used in the present study. Generally, the tested samples are divided into two categories namely samples with and without surfactant. The weight percentage of surfactant is similar with the amount of MWCNT added into base fluid. For example, the sample with 0.01 weight % of MWCNT was also added with 0.01 weight % of surfactant.

Table-1. Concentration of MWCNT.

No.	Weight % of MWCNT
1	0.01
2	0.05
3	0.1
4	0.3
5	0.5

*surfactants considered are GA, PVP and CTAB

Viscosity measurement of Nanofluids

Brookfield R/S Plus rheometer was used to investigate viscosity characteristic of carbon nanotube based nanofluids. This is a rotational type of viscometer where the viscosity is translated from the force required to rotate a spindle in the fluid. The measurement can be done under controlled shear stress and shear rate. This instrument consists of main unit, coaxial spindle (DG3-Din) and chamber. Figure-3 illustrates R/S Plus rheometer used in this experiment while DG 3 Din spindle and chamber is depicted in Figure-4

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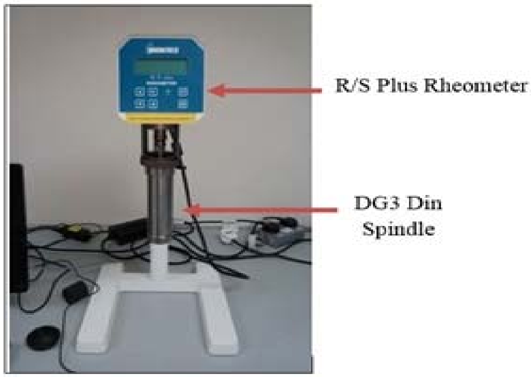

Figure-3. R/S plus rheometer.

In the present study, the shear rate was varied from 100 – 500 s^{-1} where the measurements were done at room temperature (~25 ^{o}C)

Figure-4. DG3-DIN spindle and chamber.

RESULTS AND DISCUSSION

Figure-5 compares viscosity of DW/EG mixture measured from this experiment and reference value from Ashrae handbook (Ashrae, 2002). From the experiment, it is observed that the measured viscosity is 2.399 mPa.s while ASHRAE's value is about 2.57. This represents deviation of 6.65% which is less than 10% and proves that this instrument is reliable.

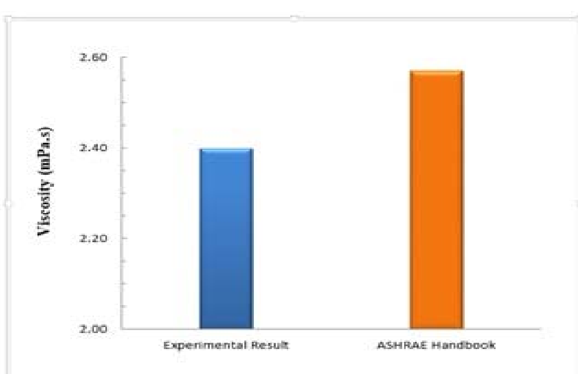

Figure-5. Comparison of experiment and reference values.

Figure-6 depicts viscosity of EG/DW and carbon nanotube based nanofluids.

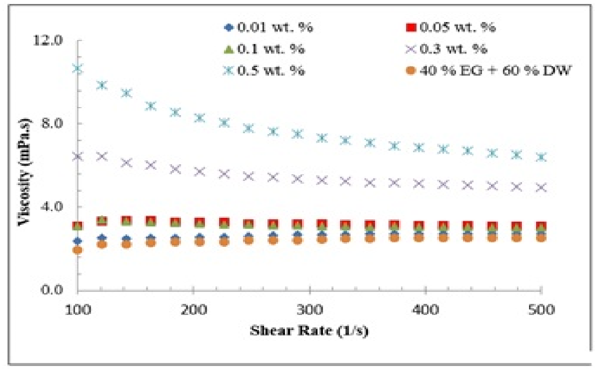

Figure-6. Viscosity characteristic of EG/DW and carbon nanotube based nanofluids without surfactant.

Based on Figure-6, it is found that viscosity of nanofluids is proportional to weight percentage of nanoparticles. Addition of nanoparticles creates additional resistance on fluid to flow. Most of the investigations reported in the literature which related to nanofluid's viscosity concur that viscosity increases with the increasing of nanoparticles' loading (Mahbubul *et al*. 2012).

Generally, EG/DW, 0.01 wt %, 0.05 wt. %, 0.1 wt % nanofluids show Newtonian characteristic since viscosity remains constant within the experimented shear rate. As for 0.3 and 0.5 wt. % samples, the viscosity decreases with the increase of applied shear rate. It can be deduced that these two fluids are categorized as non-Newtonian fluid (shear thinning). Halelfadl *et al*. (2013) revealed that nanofluids tend to exhibit shear thinning characteristic for nanofluid with high nanoparticles' content. At lower particles' content, Newtonian behaviour existed.

Figure-7 illustrates viscosity of EG/DW and carbon nanotube (0.5 wt. %) based nanofluids added with surfactant. Viscosity of samples with surfactant only (without MWCNT) also included is this figure.

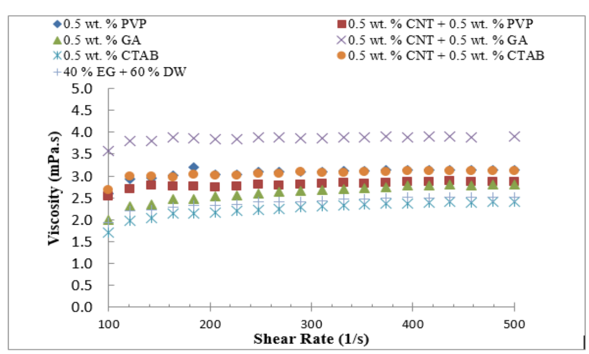

Figure-7. Viscosity characteristic of EG/DW and carbon nanotube (0.5 wt %) based nanofluids with surfactant.

Study reveals that the viscosity of nanofluids added with surfactant is lower that nanofluids without surfactant at the same concentration. This is due to better dispersion of MWCNT in the base fluid. Particles agglomeration that exists in the samples without surfactant resists fluid to flow, thus increases fluid's viscosity. However, this problem is addressed when surfactant is added into the base fluid. Leong *et al.* (2014) stated that particles agglomeration can be reduced by the addition of surfactant. Surfactant capable of modifying nanotube's surface from hydrophobic to hydrophilic. Thus, repulsive force among the nanoparticles is increased.

Contrary with results shown in Figure-6, all the tested carbon nanotube (0.5 wt. %) based nanofluid added with surfactant exhibit Newtonian characteristic. The measured viscosity is remained constant despite the increase of shear rate. Similar results were also obtained for base fluid added with surfactant only.

When compare the viscosity of nanofluids added with surfactant, study implies that nanofluids added with gum arabic possess highest viscosity followed by nanofluids added with CTAB and PVP. Addition of surfactant into base fluid (without MWCNT) also affects the base fluid's viscosity. This is observed at the base fluids added with GA and PVP which have higher viscosity compared to that of base fluid. In contrast base fluid added with CTAB has slightly lower viscosity than base fluid. Mingzheng *et al.* (2012) also revealed that type of surfactants have substantial effect on base fluid's viscosity. The concentration of surfactant was varied in their study.

Figure-8 illustrates the effect of sonication time to the viscosity of carbon nanotube (0.5 wt. %) based nanofluids added with surfactant.

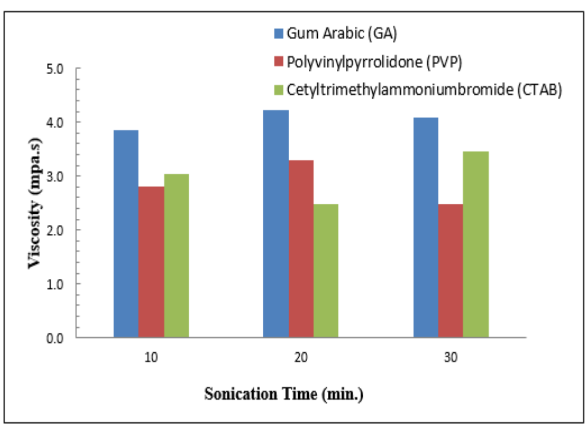

Figure-8. Effect of sonication time to viscosity carbon nanotube (0.5 wt %) based nanofluids with surfactant.

Sonication duration between 10 to 30 minutes were applied during nanofluids' preparation. Figure-8, shows that the viscosity of nanofluid added with GA register highest viscosity value regardless its sonication time (10, 20 and 30 minutes)

CONCLUSIONS

The viscosity characteristic of nanofluids containing carbon nanotubes and surfactant was investigated in the present study. The conclusions that can be drawn are as follows:

- Viscosity of carbon nanotube (0.5 wt.%) based nanofluid added with surfactant is lower than samples without surfactant at the same particles' loading.
- Viscosity of nanofluids is proportional with nanoparticles' weight percentage.
- Carbon nanotube (0.5 wt. %) based nanofluids added with gum Arabic exhibit the highest viscosity compared to that of other types of surfactants.
- Addition of surfactant into base fluid can affect the base fluid's viscosity.

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