INTERNATIONAL JOURNAL OF AUTOMOTIVE AND MECHANICAL ENGINEERING (IJAME)
ISSN: 2229-8649 e-ISSN: 2180-1606
VOL. 17, ISSUE 3, 8224 – 8233
DOI: https://doi.org/10.15282/ijame.17.3.2020.16.0620

ORIGINAL ARTICLE

An Experimental Investigation on Thermal Conductivity and Viscosity of Graphene Doped CNTs /TiO_2 Nanofluid

A.M. Zetty Akhtar [1], M.M. Rahman [1,2*], K. Kadirgama[2] and M.A. Maleque[3]

[1]Department of Mechanical Engineering, College of Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
[2]Automotive Engineering Centre, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
[3]Department of Manufacturing and Materials Engineering, International Islamic University Malaysia, Kulliyah of Engineering, Jalan Gombak, 53100 Kuala Lumpur, Malaysia

ABSTRACT – This paper presents the findings of the stability, thermal conductivity and viscosity of CNTs (doped with 10 wt% graphene)- TiO_2 hybrid nanofluids under various concentrations. While the usage of cutting fluid in machining operation is necessary for removing the heat generated at the cutting zone, the excessive use of it could lead to environmental and health issue to the operators. Therefore, the minimum quantity lubrication (MQL) to replace the conventional flooding was introduced. The MQL method minimises the usage of cutting fluid as a step to achieve a cleaner environment and sustainable machining. However, the low thermal conductivity of the base fluid in the MQL system caused the insufficient removal of heat generated in the cutting zone. Addition of nanoparticles to the base fluid was then introduced to enhance the performance of cutting fluids. The ethylene glycol used as the base fluid, titanium dioxide (TiO_2) and carbon nanotubes (CNTs) nanoparticle mixed to produce nanofluids with concentrations of 0.02 to 0.1 wt.% with an interval of 0.02 wt%. The mixing ratio of TiO_2: CNTs was 90:10 and ratio of SDBS (surfactant): CNTs was 10:1. The stability of nanofluid checked using observation method and zeta potential analysis. The thermal conductivity and viscosity of suspension were measured at a temperature range between 30˚C to 70˚C (with increment of 10˚C) to determine the relationship between concentration and temperature on nanofluid's thermal physical properties. Based on the results obtained, zeta potential value for nanofluid range from -50 to -70 mV indicates a good stability of the suspension. Thermal conductivity of nanofluid increases as an increase of temperature and enhancement ratio is within the range of 1.51 to 4.53 compared to the base fluid. Meanwhile, the viscosity of nanofluid shows decrements with an increase of the temperature remarks significant advantage in pumping power. The developed nanofluid in this study found to be stable with enhanced thermal conductivity and decrease in viscosity, which at once make it possible to be use as nanolubricant in machining operation.

ARTICLE HISTORY
Revised: 26th Sept 2020
Accepted: 6th Oct 2020

KEYWORDS
Hybrid nanofluid; Thermal conductivity; Viscosity; Temperature; Concentration

INTRODUCTION

In a certain application where the heat transfer systems are required, the performance of heat transfer fluids has become a significant concern. Such as conventionally used fluids including the water, ethylene glycol and mineral oil have low thermal conductivity, the modification needed in efforts to enhance the efficiency of the heat transfer fluid (HTF) [1, 2]. One of the effective methods introduced by Choi and Eastman [3] where the nanosized particle (with size less than 100 nm) suspended in conventional HTF. The additions of nanoparticle have been proven by several researchers [4-8] to enhance HTF's thermophysical properties. Therefore, the gaining interest to investigate the effect and performance of adding nanoparticle in conventional base fluids. The machining process is one of the various applications that require the heat transfer system to cool down the heat generated at the cutting zone [9, 10]. The conventional cutting fluid practice, however, was only able to reduce certain part of the heat in the cutting zone due to high pressure in the contact interface between tool and workpiece [11]. Thus, the new effective method introduced in order to utilise the cooling/lubrication fluids in minimal quantities fully, such as minimum quantity lubrication (MQL) [10, 12]. Realising the potential outcome of nanofluid in the heat transfer system, several researchers [13-18] have to focus their study on developing types of nanocoolant/nanolubricant for MQL. However, it is essential to study these two attributes before it can be applied in machining operation since thermo-physical properties such as thermal conductivity and viscosity affected the overall performance of nanofluid.

Thermal conductivity is an essential variable for enhancing the heat transfer performance of the fluid. Nanoparticle, being an additive to nanofluids, plays a vital role in changing the thermal transport properties of nanofluids suspension [19]. Enhancement of thermal conductivity is affected by a few factors such as temperature condition [20], the shape of nanoparticles [21], size of nanoparticles, type of nanoparticles [22] and type of base fluids. By mixing nanoparticles with base fluid, the thermo-physical properties of the fluid may change as the nanoparticles have higher thermal conductivity

*CORRESPONDING AUTHOR | M.M Rahman | ✉ mustafizur@ump.edu.my

compared to base fluid [3, 23]. A significant improvement in the thermal behaviour of nanofluid as it enhanced the thermal conductivity as the concentration of nanoparticles increased [24-26]. The capability of carbon nanotubes in enhancing the thermal-physical properties of nanofluids also discussed and investigated by a few researchers. For example, Munkhbayar, Tanshen [27] was able to achieve 14.5% enhancement in MWCNTs-Ag nanofluid at low concentration (0.05 wt.%). The influence of temperature on thermal conductivity of MWCNTs-water nanofluid and found that thermal conductivity enhanced as temperature increases [28]. The viscosity of nanofluids is also an essential factor in ensuring the overall effectiveness of nanofluids in heat transfer applications besides the enhancement of the thermal conductivity. Theoretically, the viscosity is a measure of fluid's resistance to flow.

The possible issue regarding the viscosity of nanofluids is that addition of nanoparticle may enhance the viscosity under certain conditions and give significant disadvantages due to rise in pumping power [23]. The increment in viscosity ratio (nanofluid to base fluid) is more than four times compared to increment in thermal conductivity ratio (nanofluid to base fluid) [24]. However, the contradicting results as the viscosity of nanofluids decrease with increased temperature and particle size of the nanoparticle [28-31]. The viscosity of nanofluids depends on many factors such as temperature, particle size and shape, surfactants used, dispersion technique, volume concentration and so on. Thus, these criteria need to be considered for validating the experimental results.

Further works with different material are required to determined and understand the effect of nanoparticles on the viscosity of nanofluids. The present work focuses on to investigate the stability of TiO_2-CNTs nanofluid with a different concentration in ethylene glycol as base fluid. This work aims to evaluate the thermo-physical properties of nanofluids in terms of thermal conductivity and viscosity. The stable and efficient nanofluid would lead to enhanced heat transfer performance before deemed to be suitable to be suspended as a lubricant in machining operation.

METHODS AND MATERIALS

Nanofluids Preparation

Ethylene glycol, TiO_2 and CNTs were used in this research to prepare hybrid nanofluids. TiO_2 and CNTs nanoparticle selected due to its excellent performance in terms of reducing the coefficient of friction [32, 33], improved surface roughness [34] and increased tool life [35]. The TiO_2 nanoparticles obtained in powder form purchased from U.S. Nanomaterials with an average size between 5-10 nm. Meanwhile, the CNTs used multi-walled carbon nanotubes (MWCNTs) type, doped with 10 wt% graphene. The outer and inner diameters of particles are 30 nm and 12 nm, respectively, with the length range from 10-30 µm. The properties of TiO_2 and MWCNTs nanoparticle is presented in Table 1. Ethylene glycol with purity ≥ 99.75% and sodium dodecylbenzene sulfonate (SDBS), both purchased from Sigma Aldrich used as base fluid and surfactant respectively. Figure 1 shows the morphology (TEM image) of (a) MWCNTs-doped with 10 wt.% graphene nanoparticles and (b) TiO_2 nanoparticles. Based on TEM image, MWCNTs depict the cylindrical shape with multiple SWCNT nested inside one another, while TiO_2 particles were roughly spherically shaped with some appear to be faceted and visibly arranged chain-like configuration.

Table 1. The properties of TiO_2 and MWCNTs nanoparticles.

Properties	Titanium dioxide (TiO_2)	Multi-walled carbon nanotubes (MWCNTs)
Shape	Spherical (faceted)	Cylindrical
Size (nm)	5-10	Outer diameter: 30 Inner diameter: 12
Density, $\boldsymbol{\rho}$ (g/cm^3)	4.23	2.1
Molar mass (g/mol)	79.86	181.2
Colour	White	Black
Purity (%)	≥ 99	> 97

The preparation of stable nanofluid in this study is based on the two-step method, direct mixing technique. Nanofluids prepared with different concentrations, ranging from 0.02 to 0.1wt% with 0.02 increments. The ratio of TiO_2 particle to CNTs particles used was 90:10. The required amount of nanoparticle to be dispersed in a base fluid is calculated using Eq. (1).

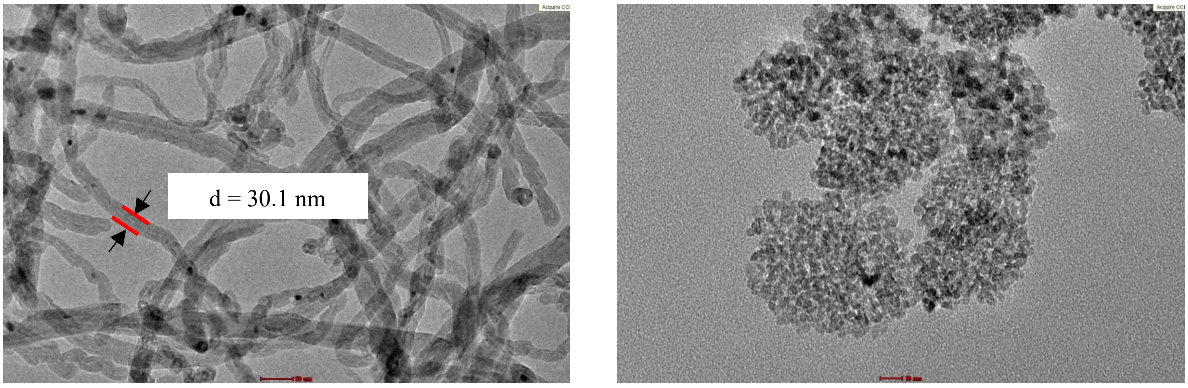
$$\varphi = \frac{\frac{m_{np}}{\rho_{np}}}{\frac{m_{np}}{\rho_{np}} + \frac{m_{bf}}{\rho_{bf}}} \tag{1}$$

where *np* indicates nanoparticle, *bf* represents the base fluid, φ is volume concentration, and ρ is density.

In order to assure the nanoparticles are well dispersed in base fluid and leave no settling particle, the mixing and sonication timing maintained. During the preparation of nanofluid, the nanoparticles were first added into base fluid and mixed using magnetic hotplate stirrer for 2 hours. The mixed solutions were then going through sonication process using the ultrasonic processor for another 4 hours. Surfactant also used in this suspension in order to avoid agglomeration of nanoparticles and obtained more stable suspensions. Sodium dodecylbenzene sulfonate (SDBS) was chosen due to its ability to stabilise the hybrid suspension for more than two weeks. The ratio of surfactant to CNTs used was 10:1 in terms of weight of the particle.

Stability Test

The analysis of the stability of nanofluids was produced in this study using zeta potential analysis and observation methods. Particle analyser (model Litesizer 500 from Anton Paar) used to record the value of zeta potential. The desired nanofluid to be measured first injected into the omega cuvette, that has an inverted omega-shaped capillary tube with capacity 50 µL. Then, it placed in the robust casing of Litesizer Particle Analyzer before the zeta potential measured by electrophoretic light scattering at targeted temperature 20˚C. The speed of particle measured in the presence of the electrical field. Thus, the faster the particle moves, the higher the zeta potential value and indicates more stable suspensions. Typically accepted zeta-potential values for the nanofluid suspension stability is presented in Table 2 [36]. Meanwhile, in the observation method, the photo of nanofluids was captured every day for two months duration. The height of sedimentation that occurs at the bottom of nanofluid also measured throughout the process.



(a) (b)

Figure 1. TEM images of (a) MWCNTs-doped 10 wt% graphene nanoparticles and (b) TiO_2 nanoparticles.

Table 2. Zeta potential values and nanofluid suspension stability [36].

Zeta potential value (±mV)	Stability
0	Little or no stability
15	Some stability but settling lightly
30	Moderate stability
45	Good stability, possible settling
60	Excellent stability, little settling likely

Thermal Conductivity Measurement

Thermal conductivity of TiO_2-CNTs hybrid nanofluid was measured by using Thempos thermal analyser. Hybrid nanofluid was placed in the test tube before immersed in a water bath at an initial temperature of 30 °C. Needle (sensor) inserted into the test solution and adjusted to fits at the centre of the test tube. Good thermal contact between the sensor and hybrid nanofluid is critical for the accurate measurement of thermal conductivity. The thermal conductivity values were measured at the main menu in SI unit; watt per meter Celsius (W/m˚C). The error value of reading was considered less than ± 0.01. The temperatures of the water bath were then gradually increased to 40 C, 50 C, 60 C, and 70 C. The average readings were taken five times for each solution concentration and temperature, respectively.

Viscosity Measurement

The viscosity of hybrid nanofluids suspension was measured using MCR 92 Anton Paar Rheometer. The temperature of 25 C, up to 100 C and spindle speed of 1000 rpm were considered during the measurement of the viscosity. The measurement of viscosity appears in units of miliPascal per second (mPa/s) while the shear stress reading was recorded in units of Pascal (Pa). The average readings were taken five times for each solution concentrations and temperature.

RESULTS AND DISCUSSION

Stability of Nanofluid

Preparation methods, nanoparticle characteristics, type of base fluid, surfactant, pH of the solution and ultra-sonication time were some of the factors that affected the stability of nanofluids. The unstable nanofluid happens mainly due to proneness of the nanoparticle to aggregate, from the presence of high surface charge on them [37]. Stability of nanofluids is crucial as it can alter the thermophysical properties such as thermal conductivity, viscosity, and density, with time. Thus, unstable nanofluid would result in depreciation of the potential benefit of nanoparticle in heat transfer. Many methods were available nowadays to evaluate the stability of nanofluids. The simplest method is sedimentation photograph of nanofluids in test tubes. Nanofluids were left to observe in a certain period of times to ensure there is no or minimal sedimentation settling at the bottom of the solution. Minimal or no sedimentation observed indicates that nanoparticles are well dispersed, and nanofluids are stable enough. Figure 2 shows the sedimentation observation of hybrid nanofluid solution for 24 hours and after two months, respectively. There is no sedimentation spotted at the bottom of nanofluids for all concentration after 24 hours, and all the suspensions were black. However, after two months of observation, the suspension with a concentration of 0.08 wt.% and 0.1 wt.% changed into slightly greyish colour, with a height of sedimentation less than 1 mm and most of the black particles stick to the surface of the test tubes. The other suspension with concentration 0.02, 0.04 and 0.06 wt.% maintained in black colour and no sedimentations observed.

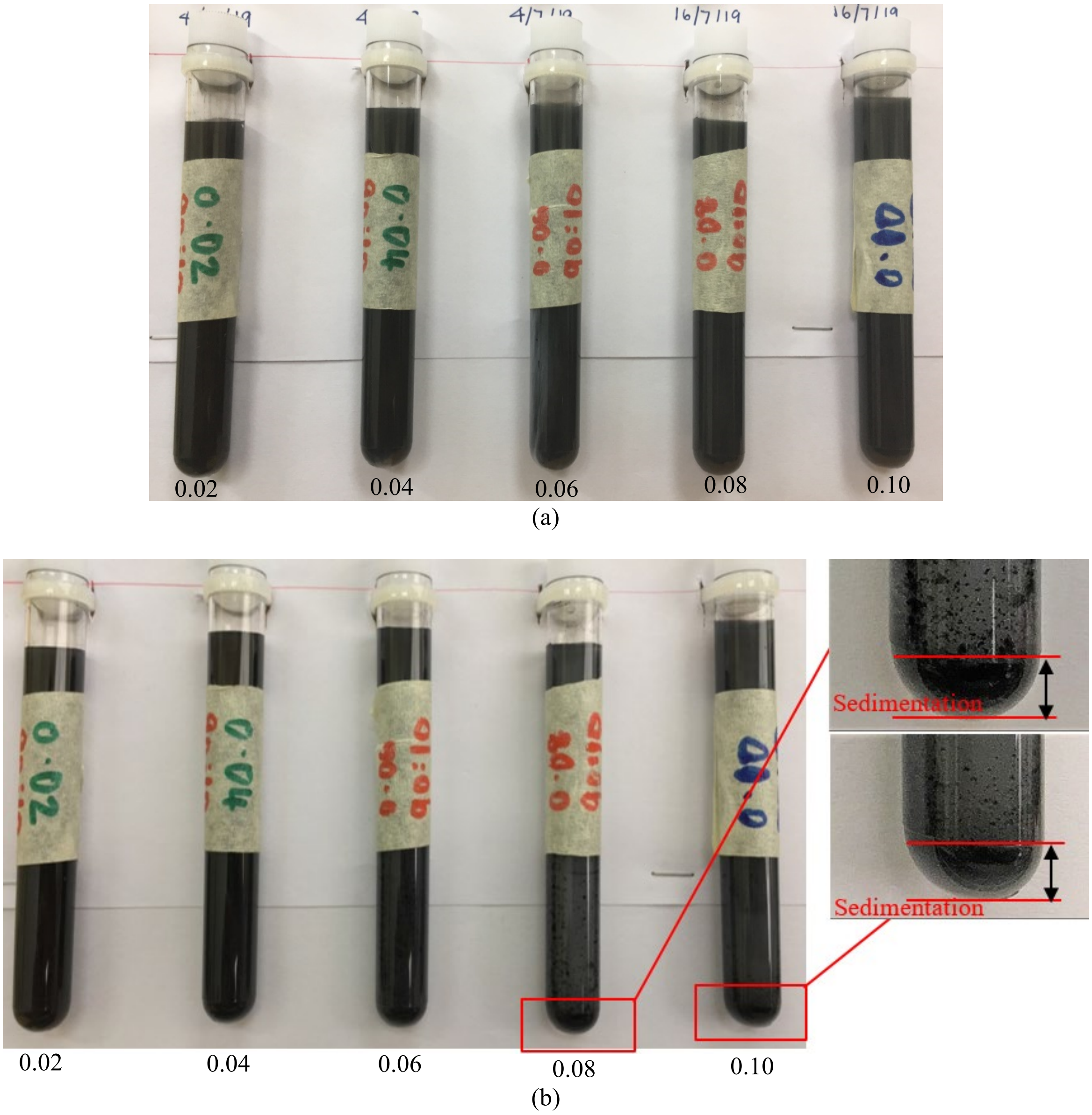


Figure 2. Sedimentation observation of TiO_2-CNT nanofluids with concentration 0.02-0.10wt.% for (a) 24 hours and (b) after two months**.**

Besides observation methods, the long term colloidal stability of hybrid nanofluids was measured using zeta potential. It is the qualitative observation of the hybrid nanofluids in static conditions. The relationship between nanofluids stability and zeta potential values arises from mutual repulsion that occurs between like-charged particles. Particles with high surface charge tend not to agglomerate since contact is opposed, which then leads to good stability of the suspensions. Table 3 shows zeta potential value for TiO_2-CNTs hybrid nanofluids with a concentration of 0.02 wt.% up to 0.1 wt.%, measured after mixing suspensions. The zeta values for all hybrid nanofluid concentration were above 30mV (±), indicates to have excellent stability. A negative value of zeta potential resulted from the use of surfactant in a nanofluid. Surfactants were categorised depending on the charge of the head group of surfactants. It can be anionic (negatively charged), cationic (positively charged), non-ionic (neutral) or amphoteric (both negative and positive charge). Sodium dodecylbenzene sulphonate (SDBS) that been used in this study fall into the anionic group. Thus, the addition of SDBS in suspension altered the surface charge of nanoparticles that high in positive charge initially to negative charge. The separation of

SDBS in the suspension to produce phenyl sulfonic group which adsorbed on the nanoparticle, successively increasing the net negative charge on nanoparticle surface [38].

Table 3. Measured zeta potential value for TiO_2-CNTs hybrid nanofluid.

Base fluid	Concentration (wt%)	Ratio of TiO_2-CNTs	Zeta potential value (mV)
Ethylene glycol	0.02	90:10	- 65.48
	0.04	90:10	- 70.97
	0.06	90:10	- 57.65
	0.08	90:10	- 65.76
	0.10	90:10	- 74.22

Thermal Conductivity Enhancement

The evaluation of thermophysical properties of hybrid nanofluid such as pH and zeta potential, thermal conductivity, viscosity and particle size distribution was analysed in order to implement nanofluid in practical applications. Moreover, the overall effectiveness of hybrid nanofluids in the heat transfer system can be evaluated when the enhancements of thermal conductivity and viscosity considered at the same time. By adding the nanoparticles in the base fluid, the thermal conductivity is expected to improve since nanoparticles have higher thermal properties when compared to base fluid [3, 23]. The thermal conductivity of TiO_2-CNTs nanofluid was measured using Thempos thermal analysis at the temperature of 30 °C to 70 °C (with an increment of 10 °C) for every concentration. Figure 3 shows the thermal conductivity of TiO_2-CNTs hybrid nanofluids as a function of temperature and volume concentrations, compared to ethylene glycol (base fluid). It can be seen that an increment in thermal conductivity value for all concentration as temperature increased (up to 60 °C); therefore, remarks on the improvement of the heat transfer system were due to more collisions between particle and increasing Brownian motions [39]. However, the thermal conductivity values recorded for hybrid nanofluid solution with a concentration of 0.02% to 0.06% are higher than 0.08% and 0.10% for all over the temperature.

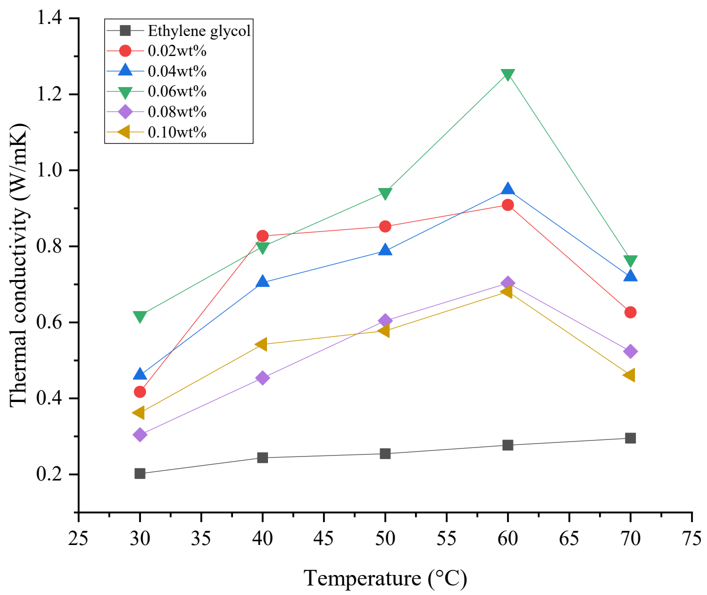


Figure 3. Thermal conductivity of TiO_2-CNTs hybrid nanofluids as a function of temperature and volume fractions, compared to base fluid (ethylene glycol).

The thermal conductivity value for hybrid nanofluid suspension with a concentration of 0.06% is 0.6183 W/mK, significantly higher than the 0.10% concentration (of 0.3621 W/mK) at 30 °C. The similar trend also observed the highest thermal conductivity value of 1.2549 W/mK for 0.06% concentration at 60 °C. While the lowest thermal conductivity of 0.6809 W/mK was observed for 0.10% concentration. Even though the dependence of thermal conductivity value to the nanofluid concentration, it is almost difficult to compare the results with previously studied due to few factors [40]. Even the same concentration used, factors such as particle morphology and size, surfactant quality and quantity, the quantity of nanoparticle dispersing in base fluid make significant changes on the overall results obtained. However, the possible explanation on higher concentration nanofluid in this study has lower thermal conductivity value was because of aggregation of the nanoparticle. Since the concentration increase, the chances of aggregation of particle increase, thus hindering the enhancement benefit of adding nanoparticles [41-43]. The contradicting results on thermal conductivity enhancement for the same particle size found that the thermal conductivity value decreases as concentration increases [42]; however, the thermal conductivity enhanced as concentration increases [41]. After 60 °C, the thermal conductivity for all concentration decreased due to the usage of surfactants. Although using surfactant as nanofluid stabiliser gave few advantages, it also has a downside as surfactant is sensitive to hot temperature. The rise in temperature causes the bonds between surfactant and particle to break, thus creating instability of the nanofluid and affecting thermal conductivity measurement [43].

Thermal conductivity ratio is defined as the ratio of thermal conductivity of nanofluid to the base fluid and deemed as good approach to determine the effect of nanoparticle on thermal conductivity enhancement [44]. Table 4 shows the thermal conductivity enhancement ratio (k_{nf}/k_{bf}) determined at temperatures of 30 °C and 60 °C. It was found that the thermal conductivity ratio is dependent to the concentration of nanofluids at the temperature of 30 °C, as the ratio value increased with larger concentration (for 0.02 to 0.06% concentration) but slightly decrease for 0.08 and 0.10% concentration. Meanwhile, increasing trend of ratio was seen to be the same until 0.06% concentration, and start to decrease at 0.08% until 0.1wt.% concentration at 60 °C temperature. Increased thermal conductivity of nanofluid, when compared to the base fluid, can be explained through several mechanisms. Brownian motion of nanoparticle was slow to transport the significant amount of heat through nanofluid, thus influenced the particle clustering and eventually affected the enhancement of thermal conductivity [45, 46]. Besides that, it is known that layer structured would be formed on particle surfaces by liquid molecules in base fluid-nanoparticles mixture. This layer is important in the heat transfer process of a solid to adjacent liquid. Since the specific surface area (SSA) of nanoparticles is large compared to micron-sized particles, the effect of heat transfer across the interface was more significant. However, it is not a dominating factor that led to an increase in thermal conductivity.

Table 4. Thermal conductivity ratio of TiO_2-CNTs hybrid nanofluids at 30 °C.

Temperature (°C)	Concentration (%)	k_{nf} (W/mK)	k_{bf} (W/mK)	k_{nf}/k_{bf}
30	0.02	0.4172	0.2022	2.06
	0.04	0.4610	0.2022	2.28
	0.06	0.6183	0.2022	3.06
	0.08	0.3046	0.2022	1.51
	0.10	0.3621	0.2022	1.79
60	0.02	0.9089	0.2771	3.28
	0.04	0.9487	0.2771	3.42
	0.06	1.2549	0.2771	4.53
	0.08	0.7031	0.2771	2.54
	0.10	0.6809	0.2771	2.46

Another mechanism that related to the enhancement of thermal conductivity is the clustering of nanoparticles. This phenomenon creates paths of lower thermal resistance and eventually increased the thermal conductivity significantly. When the larger cluster settles down in base fluid, the physical volume of particles is much smaller compared to the effective volume of cluster. Thus, the heat can move very rapidly within such cluster, and contribute to the increase in thermal conductivity. However, as the concentration of nanoparticles increase, the effective volume of cluster decreased, thus resulting in a decreased trend of thermal conductivity values. For example, from the results obtained through this study, the increment of thermal conductivity values for nanofluid with 0.02%, 0.04% and 0.06% concentration was found higher throughout the increasing temperature, compared to 0.08% and 0.10% concentration because of the effective volume larger for loosely packed cluster than the closely packed cluster [45]. Nevertheless, the clustering of nanoparticles also resulted in decreased thermal conductivity value due to the settling particles in the base fluid. This settling particle would create larger regions of particle-free liquid with high thermal resistance and high particle arrangement at the bottom of the fluid.

Variation of Viscosity with Temperature

The study of viscosity is a significant concern in connection to lubrication of suspensions [47]. In the machining process, the developed heat from the friction of tool-workpiece surfaces reduced by the presence of a suitable film liquid created by cutting fluids between the moving surface. The least viscous lubricant still forces the two moving surface apart to achieve fluid bearing to desired. Lubricant that is too viscous need more considerable energy to move, and when it is too thin, the surface comes in contact and increases the friction. Thus, it is crucial to ensure that the addition of nanoparticles to the base fluid improved the viscosity properties of nanofluids, that leads to better heat transfer performance.

Figure 4 shows the viscosity of TiO_2-CNTs hybrid nanofluids as a function of temperature and volume fractions compared to base fluid (ethylene glycol). The viscosity of hybrid nanofluids for all concentration was higher than the base fluid throughout the temperature rise. With the addition of nanoparticle to the base fluid, the fluid resistance against movement increased thus explained the rise in dynamic viscosity values. Meanwhile, the viscosity of nanofluids decreased with increasing temperature for all concentrations, thus remarks almost dependent relationship between viscosity and temperature. The highest viscosity of 15.82 mPa/s was recorded at 25 °C by 0.10% concentration, while the lowest (of 13.882 mPa/s) by 0.02% concentration. The viscosity keeps reducing as temperature increases, and at 70 °C, 0.02% nanofluid still recorded the lowest viscosity of 4.1484 mPa/s compared to other concentrations. However, higher concentration nanofluid gave higher viscosity value compared to the lower concentrations due to the dynamic viscosity increase as concentration increase [48]. This discovery can be explained by particle theory in liquid, where molecules loosely packed and intermolecular attraction is strong [49]. When the temperature increases, the energy level of liquid molecules increases and the distance between molecule increases. The relative motion of molecules become easier, as the intermolecular attraction between molecules decreases, resulting in reduced viscosity [50]. The addition of nanoparticle to base fluid improve the viscosity of suspension in the function of temperature [29, 51-54]. However, findings by Chen, Xie [55] slightly contradict to the data obtained, as they measured the temperature effect of multi-walled carbon nanotubes nanofluid at temperatures of 5 °C to 65 °C. The results indicated that the relative viscosity increases significantly with temperature after 55 °C. Thus, as many factors influence the viscosity of nanofluid, the contradict various variables may have caused value.

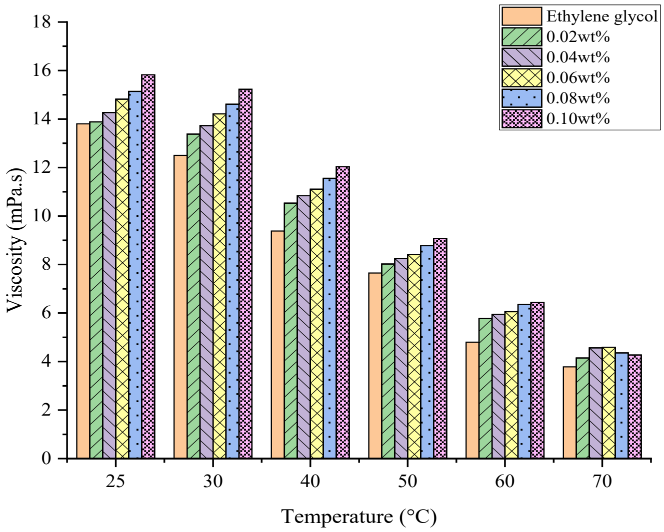


Figure 4. Viscosity of TiO_2-CNTs nanofluids as a function of temperature at different volume fractions, compared to base fluid (ethylene glycol).

Figure 5 shows the variation of shear stress against shear strain curves for TiO_2-CNTs hybrid nanofluids at a concentration of 0.02%. Eventually, all concentrations showing the same trend of curves which indicates that nanofluids fall into category shear thickening fluid. The shear-thickening material is the viscosity increase with the rate of shear strain, related to change in lubrication regimes between particles. Shear thickening fluid is non-Newtonian fluids. This peculiar effect usually occurs with suspensions of small particle, where it has first observed as a liquid of low viscosity and reacts like a liquid of very high viscosity when mixed more rapidly [56]. The employment of non-ionic dispersant in nanofluid contributes to shear thickening behaviour [56]. However, the relations between surfactant existence to the viscosity of nanofluids need further experimental investigations.

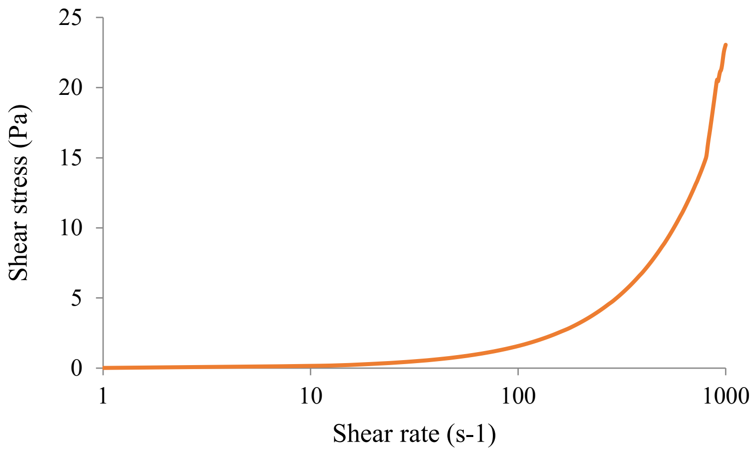


Figure 5: Shear stress vs shear strain curves for TiO_2-CNTs nanofluid with a concentration of 0.02%.

CONCLUSION

In this paper, TiO_2-CNTs nanofluid with the addition of SDBS as surfactant prepared by concentration ranging from 0.02% to 0.1%, and at 90:10 ratio. The stability of nanofluids observed using sedimentation photo capturing method and zeta potential analysis. Thermo-physical properties of nanofluids, including thermal conductivity and viscosity, also measured for temperature between 30-70 °C and 25-70 °C, respectively. Based on the results obtained, there are few conclusion drawn as follows:

i. The nanofluids were stable enough for all concentration, with little sedimentation spotted after two weeks for 0.0.8% and 0.1% concentration. The best stabilisation of nanofluid observed in 0.02-0.06% concentration, where the zeta potential analysis recorded at the range of -57 mV to -70 mV and no sedimentation occurred for at least two months.
ii. Thermal conductivity of nanofluid increase as temperature increase, for all concentration, thus remarks an enhancement on the heat transfer system. However, after 60 °C, the *k* value for nanofluid decreased, as results of breaking bonds between surfactant and nanoparticle. The thermal conductivity enhancement also found not dependent on the volume concentration, as *k* value for higher concentration nanofluid lower compared to lower concentration nanofluid.
iii. The viscosity of nanofluid found to decrease linearly with increasing temperature. Meanwhile, the addition of nanoparticle increased the viscosity of suspension when compared to the base fluid, and continues to increase as volume concentration increases.
iv. From the results obtained, a TiO_2-CNTs nanofluid with 0.02%, 0.04% and 0.06 wt.% concentration shows the most effective enhancement in terms of stability, thermal conductivity and viscosity.

ACKNOWLEDGEMENT

The authors would like to thank University Malaysia Pahang for providing the laboratories facilities and the financial support under the University LEAP-3 FLAGSHIP Research Grant (No. RDU172203), University Internal Fundamental Research Grant No. RDU190367 and Postgraduate Research Grant scheme (PGRS1903152).

REFERENCES

[1] Akhtar AZ, Rahman M, Kadirgama K, Maleque M. Effect of TiO_2 and Al_2O_3-ethylene glycol-based nanofluids on cutting temperature and surface roughness during turning process of AISI 1018. In: IOP Conference Series: Materials Science and Engineering, pp. 052033; 2020.

[2] Najiha MS, Rahman M. Experimental investigation of flank wear in end milling of aluminum alloy with water-based TiO_2 nanofluid lubricant in minimum quantity lubrication technique. The International Journal of Advanced Manufacturing Technology 2016;86:2527-37.

[3] Choi SU, Eastman JA. Enhancing thermal conductivity of fluids with nanoparticles. In: ASME International Mechanical Engineering Congress & Exposition, San Francisco, California; 12-17 November, 1995.

[4] Salimi-Yasar H, Zeinali Heris S, Shanbedi M. Influence of soluble oil-based TiO_2 nanofluid on heat transfer performance of cutting fluid. Tribology International 2017;112:147-54.

[5] Mao C, Huang Y, Zhou X, Gan H, Zhang J, Zhou Z. The tribological properties of nanofluid used in minimum quantity lubrication grinding. The International Journal of Advanced Manufacturing Technology 2014;71:1221-8.

[6] Uysal A, Demiren F, Altan E. Applying Minimum Quantity Lubrication (MQL) Method on Milling of Martensitic Stainless Steel by Using Nano MoS_2 Reinforced Vegetable Cutting Fluid. Procedia - Social and Behavioral Sciences 2015;195:2742-7.

[7] Kalita P, Malshe AP, Rajurkar KP. Study of tribo-chemical lubricant film formation during application of nanolubricants in minimum quantity lubrication (MQL) grinding. CIRP Annals 2012;61:327-30.

[8] Kalita P, Malshe AP, Arun Kumar S, Yoganath VG, Gurumurthy T. Study of specific energy and friction coefficient in minimum quantity lubrication grinding using oil-based nanolubricants. Journal of Manufacturing Processes 2012;14:160-6.

[9] Puvanesan M, Rahman M, Najiha M, Kadirgama K. Experimental investigation of minimum quantity lubrication on tool wear in aluminum alloy 6061-t6 using different cutting tools. International Journal of Automotive and Mechanical Engineering 2014;9:1538-49.

[10] Najiha M, Rahman M, Kadirgama K. Performance of water-based TiO_2 nanofluid during the minimum quantity lubrication machining of aluminium alloy, AA6061-T6. Journal of cleaner production 2016;s135:1623-36.

[11] Bai X, Li C, Dong L, Yin Q. Experimental evaluation of the lubrication performances of different nanofluids for minimum quantity lubrication (MQL) in milling Ti-6Al-4V. The International Journal of Advanced Manufacturing Technology 2018.

[12] Najiha M, Rahman M. Experimental study on minimum quantity lubrication in end milling of aa6061-t6 using tialn coated carbide tools. International Journal of Automotive & Mechanical Engineering 2015;11:2771-85.

[13] Eltaggaz A, Hegab H, Deiab I, Kishawy HA. Hybrid nano-fluid-minimum quantity lubrication strategy for machining austempered ductile iron (ADI). International Journal on Interactive Design and Manufacturing (IJIDeM) 2018;12:1273-81.

[14] ManojKumar K, Ghosh A. Assessment of cooling-lubrication and wettability characteristics of nano-engineered sunflower oil as cutting fluid and its impact on SQCL grinding performance. Journal of Materials Processing Technology 2016;237:55-64.

[15] Khalil ANM, Ali MAM, Azmi AI. Effect of Al_2O_3 nanolubricant with SDBS on tool wear during turning process of AISI 1050 with minimal quantity lubricant. Procedia Manufacturing 2015;2:130-4.

[16] Sharma AK, Katiyar JK, Bhaumik S, Roy S. Influence of alumina/MWCNT hybrid nanoparticle additives on tribological properties of lubricants in turning operations. Friction 2018.

[17] Hegab H, Kishawy HA, Gadallah MH, Umer U, Deiab I. On machining of Ti-6Al-4V using multi-walled carbon nanotubes-based nano-fluid under minimum quantity lubrication. The International Journal of Advanced Manufacturing Technology 2018.

[18] Najiha M, Rahman M, Kadirgama K. Machining performance of aluminum alloy 6061-t6 on surface finish using minimum quantity lubrication. International Journal of Automotive and Mechanical Engineering 2015;11:2699-712.

[19] Li Y, Zhou Je, Tung S, Schneider E, Xi S. A review on development of nanofluid preparation and characterization. Powder Technology 2009;196:89-101.

[20] Elias MM, Mahbubul IM, Saidur R, Sohel MR, Shahrul IM, Khaleduzzaman SS, et al. Experimental investigation on the thermo-physical properties of Al_2O_3 nanoparticles suspended in car radiator coolant. International Communications in Heat and Mass Transfer 2014;54:48-53.

[21] Vajjha RS, Das DK. Experimental determination of thermal conductivity of three nanofluids and development of new correlations. International Journal of Heat and Mass Transfer 2009;52:4675-82.

[22] Sharma AK, Tiwari AK, Dixit AR. Rheological behaviour of nanofluids: A review. Renewable and Sustainable Energy Reviews 2016;53:779-91.

[23] Wang X-Q, Mujumdar AS. Heat transfer characteristics of nanofluids: a review. International Journal of Thermal Sciences 2007;46:1-19.

[24] Yu W, Xie H, Li Y, Chen L, Wang Q. Experimental investigation on the thermal transport properties of ethylene glycol based nanofluids containing low volume concentration diamond nanoparticles. Colloids and Surfaces A: Physicochemical and Engineering Aspects 2011;380:1-5.

[25] Zeinali Heris S, Nasr Esfahany M, Etemad SG. Experimental investigation of convective heat transfer of Al_2O_3/water nanofluid in circular tube. International Journal of Heat and Fluid Flow 2007;28:203-10.

[26] Pak BC, Cho YI. Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles. Experimental Heat Transfer 1998;11:151-70.

[27] Munkhbayar B, Tanshen MR, Jeoun J, Chung H, Jeong H. Surfactant-free dispersion of silver nanoparticles into MWCNT-aqueous nanofluids prepared by one-step technique and their thermal characteristics. Ceramics International 2013;39:6415-25.

[28] Nguyen CT, Desgranges F, Roy G, Galanis N, Maré T, Boucher S, et al. Temperature and particle-size dependent viscosity data for water-based nanofluids – Hysteresis phenomenon. International Journal of Heat and Fluid Flow 2007;28:1492-506.

[29] Kanjirakat A, Kabelac S, Sundararajan T, Das S. Rheological and flow characteristics of nanofluids: Influence of electroviscous effects and particle agglomeration2009.

[30] Duangthongsuk W, Wongwises S. Measurement of temperature-dependent thermal conductivity and viscosity of TiO_2-water nanofluids. Experimental Thermal and Fluid Science 2009;33:706-14.

[31] Turgut A, Tavman I, Chirtoc M, Schuchmann HP, Sauter C, Tavman S. Thermal Conductivity and Viscosity Measurements of Water-Based TiO_2 Nanofluids. International Journal of Thermophysics 2009;30:1213-26.

[32] Rabiei F, Rahimi AR, Hadad MJ. Performance improvement of eco-friendly MQL technique by using hybrid nanofluid and ultrasonic-assisted grinding. The International Journal of Advanced Manufacturing Technology 2017;93:1001-15.

[33] Zhang D, Li C, Zhang Y, Jia D, Zhang X. Experimental research on the energy ratio coefficient and specific grinding energy in nanoparticle jet MQL grinding. The International Journal of Advanced Manufacturing Technology 2015;78:1275-88.

[34] Sridharan U, Malkin S. Effect of minimum quantity lubrication (MQL) with nanofluid on grinding behavior and thermal distortion. Transactions of NAMRI/SME 2009;37:629-36.

[35] Muthusamy Y, Kadirgama K, Rahman MM, Ramasamy D, Sharma KV. Wear analysis when machining AISI 304 with ethylene glycol/tio_2 nanoparticle-based coolant. The International Journal of Advanced Manufacturing Technology 2016;82:327-40.

[36] Vandsburger L. Synthesis and covalent surface modification of carbon nanotubes for preparation of stabilized nanofluid suspensions: McGill University; 2009.

[37] Ghadimi A, Saidur R, Metselaar HSC. A review of nanofluid stability properties and characterization in stationary conditions. International Journal of Heat and Mass Transfer 2011;54:4051-68.

[38] Khairul MA, Shah K, Doroodchi E, Azizian R, Moghtaderi B. Effects of surfactant on stability and thermo-physical properties of metal oxide nanofluids. International Journal of Heat and Mass Transfer 2016;98:778-87.

[39] Hemmat Esfe M, Karimipour A, Yan W-M, Akbari M, Safaei MR, Dahari M. Experimental study on thermal conductivity of ethylene glycol based nanofluids containing Al2O3 nanoparticles. International Journal of Heat and Mass Transfer 2015;88:728-34.

[40] Lee S-H, Jang S. Do temperature and nanoparticle size affect the thermal conductivity of alumina nanofluids? Applied Physics Letters 2014;104: 161908.

[41] Timofeeva E, Gavrilov A, McCloskey J, Tolmachev Y, Sprunt S, Lopatina L, et al. Thermal conductivity and particle agglomeration in alumina nanofluids: Experiment and theory. Physical review E, Statistical, nonlinear, and soft matter physics 2008;76:061203.

[42] Li CH, Peterson GP. Experimental investigation of temperature and volume fraction variations on the effective thermal conductivity of nanoparticle suspensions (nanofluids). Journal of Applied Physics 2006;99:084314.

[43] Chen L, Xie H, Li Y, Yu W. Nanofluids containing carbon nanotubes treated by mechanochemical reaction. Thermochimica Acta 2008;477:21-4.

[44] Ahmadi MH, Alhuyi Nazari M, Ghasempour R, Madah H, Shafii MB, Ahmadi MA. Thermal conductivity ratio prediction of Al2O3/water nanofluid by applying connectionist methods. Colloids and Surfaces A: Physicochemical and Engineering Aspects 2018;541:154-64.

[45] Keblinski P, Phillpot SR, Choi SUS, Eastman JA. Mechanisms of heat flow in suspensions of nano-sized particles (nanofluids). International Journal of Heat and Mass Transfer 2002;45:855-63.

[46] Angayarkanni SA, Philip J. Review on thermal properties of nanofluids: Recent developments. Advances in Colloid and Interface Science 2015;225:146-76.

[47] Edwards RA. Chapter 3 - Viscosity. In: Edwards RA, editor. Physics for ONC Courses: Pergamon; 1970. p. 41-52.

[48] Baratpour M, Karimipour A, Afrand M, Wongwises S. Effects of temperature and concentration on the viscosity of nanofluids made of single-wall carbon nanotubes in ethylene glycol. International Communications in Heat and Mass Transfer 2016;74:108-13.

[49] Esfe M. The investigation of effects of temperature and nanoparticles volume fraction on the viscosity of copper oxide-ethylene glycol nanofluids. Periodica Polytechnica Chemical Engineering 2017;62.

[50] Landau LD, Akhiezer AI, Lifshitz EM. Chapter XV - Viscosity. In: Landau LD, Akhiezer AI, Lifshitz EM, editors. General Physics. Oxford: Pergamon; 1967. p. 341-66.

[51] Namburu PK, Kulkarni DP, Dandekar A, Das DK. Experimental investigation of viscosity and specific heat of silicon dioxide nanofluids. Micro & Nano Letters 2007;2:67-71.

[52] Namburu PK, Kulkarni DP, Misra D, Das DK. Viscosity of copper oxide nanoparticles dispersed in ethylene glycol and water mixture. Experimental Thermal and Fluid Science 2007;32:397-402.

[53] Zhu H, Li C, Wu D, Zhang C, Yin Y. Preparation, characterization, viscosity and thermal conductivity of $CaCO_3$ aqueous nanofluids. Science China Technological Sciences 2010;53:360-8.

[54] Kole M, Dey TK. Viscosity of alumina nanoparticles dispersed in car engine coolant. Experimental Thermal and Fluid Science 2010;34:677-83.

[55] Chen L, Xie H, Li Y, Yu W. Nanofluids containing carbon nanotubes treated by mechanochemical reaction. Thermochimica Acta 2008;477:21-4.

[56] Coussot P. 1 - Introduction to the rheology of complex fluids. In: Roussel N, editor. Understanding the Rheology of Concrete: Woodhead Publishing; 2012. p. 3-22.