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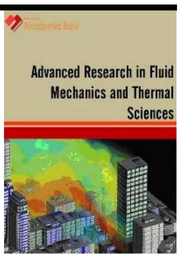

Thermal Conductivity and Viscosity of TiO_2/MWCNTs (doped 10wt% graphene) - Ethylene Glycol Based Nanofluids for Different Ratio of Nanoparticle

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ABSTRACT

The use of nanofluids to boost the thermal performance of conventional work fluids has recently shown considerable interest. This paper aims to analyse the thermal conductivity, viscosity and stability of titanium dioxide (TiO_2)-multi-walled carbon nanotubes (MWCNTs) nanofluid in the presence of sodium dodecyl benzene sulfonate (SDBS) as a surfactant. The enhancement of thermal physical properties of nanofluids in this study investigated under different concentrations and ratios of the nanoparticle. Ethylene glycol (base fluid), TiO_2 and CNTs nanoparticle mixed to produce hybrid nanofluid with concentration 0.02 to 0.1 wt.% with 0.02 wt% interval. The mixing ratio of TiO_2: MWCNTs was 90:10 and 80:20, meanwhile the ratio of SDBS: MWCNTs was 10:1. The stability of nanofluid was confirmed by using the observation method and zeta potential analysis. The thermal conductivity and viscosity of suspension were measured to determine the relationship between concentration on nanofluid and thermal physical properties. Based on results obtained, zeta potential value for both nanofluid with different ratios range from -50 to -70 mV indicates excellent stability of the suspension. Thermal conductivity of nanofluid increase as nanofluid concentration and temperature increase and also shows enhancement compared to the base fluid. However, the increment in thermal conductivity for nanofluid with ratio 90:10 was more stable and higher throughout the increasing temperature compared to nanofluid with ratio 80:20. Meanwhile, the viscosity value of nanofluid shows decrements over increased temperature and increment over increase volume concentration. In conclusion, the developed nanofluid with both ratios in this study found to be stable, with enhanced thermal conductivity and viscosity.

Keywords:
Nanofluids; Carbon nanotubes; Thermal Conductivity; Viscosity; Stability

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1. Introduction

Nanofluids are new kind of heat transfer fluid containing a small quantity of nanosized particles (usually 1 to 100nm) that uniformly and stably suspended in base fluids. Nanofluids were considered as the future of heat transfer fluid in various heat transfer applications. It expected to give better thermal performance than conventional fluids due to the presence of suspended nanoparticle which has higher thermal conductivity. Furthermore, nanofluids do not block flow channels and induce only a tiny pressure drop during flow, which is beneficial for heat transfer applications [1]. There are few criteria to be considered in selecting nanomaterials, including chemical stability, suitability with base fluids, thermophysical properties, its toxicity and availability. The nanoparticle can be dispersed in conventional heat transfer fluids by two methods; single step technique and two steps technique. In a single step method, the nanoparticles simultaneously made and dispersed into base fluids. Meanwhile, in two step methods, the nanoparticles were made in a separate process and then dispersed into base fluids.

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 suspension [2-4]. Enhancement of thermal conductivity was affected by a few factors such as temperature condition, the shape of nanoparticles, size of nanoparticles, type of nanoparticles and type of base fluids [5-9]. By mixing nanoparticles with base fluid, thermo-physical properties of the fluid may change as the nanoparticles have higher thermal conductivity compared to base fluid [10-13]. Researchers in their study have observed significant improvement in the thermal behaviour of nanofluid as it enhanced the thermal conductivity as the concentration of nanoparticles increased [14-18]. More significant enhancement of thermal conductivity was recorded by Vajjha and Das [6], where Al_2O_3, CuO and ZnO nanofluid gave 69%, 60% and 48.5% increment respectively compared to base fluid (Ethylene glycol-water). However, the linearity of relationships still needs further research. Besides nanofluid, the enhancement of thermal conductivity by using graphene or graphite related nanoparticle were also recorded by Mohamad *et al.,* [19] in base phase change material (PCM).

Besides the enhancement of thermal conductivity, viscosity of nanofluids was also an essential factor in ensuring the overall effectiveness of nanofluids in heat transfer applications. Theoretically, viscosity is a measure of fluid's resistance to flow, or also describe as the internal friction of moving fluids. It is the ratio of the shear stress to shear rate. When the viscosity is constant at a different shear rate, the liquid is known as Newtonian, while the viscosity that varies as a function of shear rate was known as non-Newtonian. The possible issue regarding the viscosity of nanofluids was addressed by Khairul *et al.,* [20] as they mentioned that addition of nanoparticle might increased the viscosity under certain conditions and give significant disadvantages due to rise in pumping power. 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) [21]. However, another study conducted by other researchers [22-25], contradict results as the viscosity of nanofluids decrease with increased temperature and particle size of the nanoparticle. It shows that 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 criterions need to be considered in validating experimental results. Further works with different material are required to determined and understand the effect of nanoparticles on the viscosity of nanofluids.

This study aimed to employ this hybrid nanofluid as a cutting fluid in minimum quantity lubrication (MQL) method during the machining process realising the advantages of nanofluid in the heat transfer system. Thus, the current work focuses on investigating the stability of TiO_2-MWCNTs nanofluid with different concentration and ratio of nanoparticles in ethylene glycol as base fluid. Furthermore, this work aims to evaluate the thermophysical properties of nanofluids in terms of thermal conductivity and viscosity. The stable and efficient nanofluid would lead to enhanced thermal conductivity and viscosity, thus eventually improve the heat transfer performance of cutting fluid during machining process.

2. Methodology

2.1 Materials and Nanofluid Preparation

Ethylene glycol as base fluid, titanium dioxide (TiO_2) nanoparticle, multi-walled carbon nanotubes (MWCNTs)-doped with 10wt% graphene nanoparticle, and sodium dodecyl benzene sulfonate (SDBS) surfactants were used in preparing the TiO_2-MWCNTs nanofluid. TiO_2 and MWCNTs (doped with 10wt% graphene) nanoparticle was purchased from U.S Nanomaterial, obtained in powder form. Ethylene glycol (with purity ≥99.75%) and SDBS surfactant were sourced from Sigma Aldrich. The properties of TiO_2, and MWCNTs nanoparticle and used in this experiment are presented in Table 1 below. The TEM image presented in Figure 1 shows the morphology of (a) MWCNTs-doped with 10wt% graphene nanoparticles and (b) mixture of MWCNTs and TiO_2 nanoparticles. Based on TEM image, MWCNTs depict the cylindrical shape with multiple SWCNT nested inside one another. The outer and inner diameter of particles also confirmed to be 30nm and 12nm respectively, with length range from 10-30µm. The TiO_2 nanoparticle on the other hand, were roughly spherically shaped with some appear to be faceted and visibly arranged like chain-like configuration, with average diameter 5-10nm.

Table 1
The properties of TiO_2 nanoparticles and MWCNTs nanoparticles

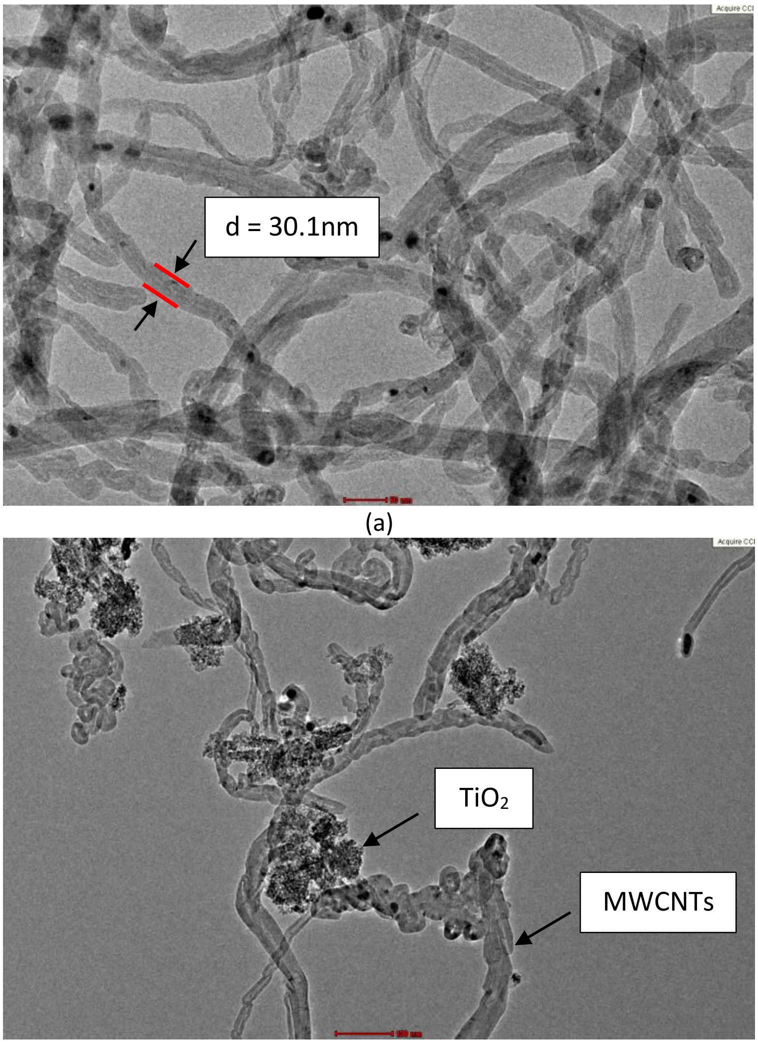
Properties	Titanium Dioxide (TiO_2)	Multi-Walled Carbon Nanotubes (MWCNTs)
Shape	Spherical (faceted)	Cylindrical
Size (nm)	5-10	Outer diameter: 30nm Inner diameter: 12nm
Density, $\boldsymbol{\rho}$ (g/cm^3)	4.23	2.1
Molar mass (g/mol)	79.86	181.2
Colour	White	Black
Purity (%)	≥ 99	> 97

The preparation of stable nanofluid in this study was based on two step method, direct mixing technique, as shown in Figure 2. Nanofluids were prepared with different concentrations, ranging from 0.02 to 0.1wt% with 0.02 increments. Furthermore, there are two different ratios of TiO_2: MWCNTs used in this experiment which is 90:10 and 80:20 ratio. In this paper, solutions with ratio 90:10 were referred as Solution A. Meanwhile solution with ratio 80:20 referred as Solution B. The required weight of nanoparticle to be dispersed in the base fluid was calculated using Eq. (1) below, with pre-calculated density value using Eq. (2):

$$\emptyset = \frac{{}^{mnp}/_{\rho np}}{{}^{mnp}/_{\rho np} + {}^{mbf}/_{\rho bf}} \times 100 \tag{1}$$

$$\rho_{np} = \frac{\phi_1 \rho_1 + \phi_2 \rho_2}{\phi} \tag{2}$$

where ‘np’ indicate nanoparticle, ‘bf’ represent base fluid, $\emptyset$ is volume concentration, ρ_1 is density for nanoparticle 1 and ρ_2 is density for nanoparticle 2. The suspension of TiO_2, CNTs, SDBS and ethylene glycol were first mixed using stirrer for 1 hour. Then, the high pressure ultrasonic homogeniser was used for another 4 hours to sonicate the suspension. Ultrasonic process is most frequently used method to overcome the strong cohesion forces between nanotubes, avoiding agglomeration.



(a)

(b)

Fig. 1. TEM images of (a) MWCNTs-doped 10wt% graphene nanoparticles and (b) CNT-TiO_2 mixed nanoparticles (at 90:10 ratio and 0.02wt% concentration)

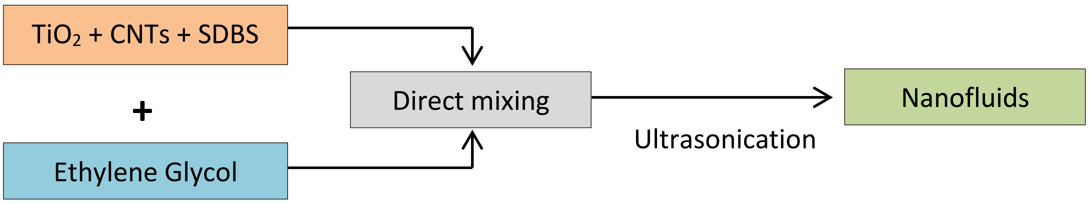


Fig. 2. Two step preparation process of nanofluids (direct mixing method)

2.2 Stability Test

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

Table 2
Zeta potential values and suspension stability [26]

Zeta potential value, ±mV	Stability
0 to 5	Little or no stability
10 to 30	Some stability but settling lightly
30 to 40	Moderate stability
40 to 60	Good stability, possible settling
Greater than 60	Very good stability, little settling likely

2.3 Thermal Conductivity Measurement

Thermal conductivity of nanofluid was measured by using KD2 Pro Thermal Analyzer. The nanofluid was placed in the test tube before immersed in a water bath at an initial temperature 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 measured medium is critical for accurate measurement. The thermal conductivity reading value then can be collected at the main menu in SI unit; Watt per meter Kelvin (W/mK). The error value of reading should be less than err = ±0.01. The temperatures of the water bath were then gradually increased from 30˚C, up to 60˚C with increment of 10˚C. Averages reading were taken 5 times for each solution concentration and temperature respectively.

2.4 Viscosity Measurement

The viscosity of nanofluids suspension was measured using MCR 92 Anton Paar Rheometer. The condition during measuring viscosity includes temperature 25˚C, up to 60˚C and spindle speed 1000rpm. The measurement of viscosity appears in units of miliPascal per second (mPa/s) on display. The shear stress reading also recorded in units of Pascal (Pa). Average readings were taken 50 times for each solution concentrations and temperature.

3. Results

3.1 Stability of Nanofluids

Stability is one of the major concern in preparing nanofluids since nanoparticle tends to agglomerate due to van der Waals force and prone to sedimentation caused by the density difference between nanoparticle and base fluids. Stability of nanofluids is crucial as it can alter the thermo physical properties such as thermal conductivity, viscosity, density and so forth with time. Thus, unstable nanofluid would result in depreciation of the potential benefit of nanoparticle in heat transfer. There are several methods to evaluate nanofluid stability with time. The simplest method is sedimentation where the volume or mass of sediment is an indication of the stability of nanofluids [27,28]. 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 visible to eyes indicates that nanoparticles are well dispersed and nanofluids are stable enough.

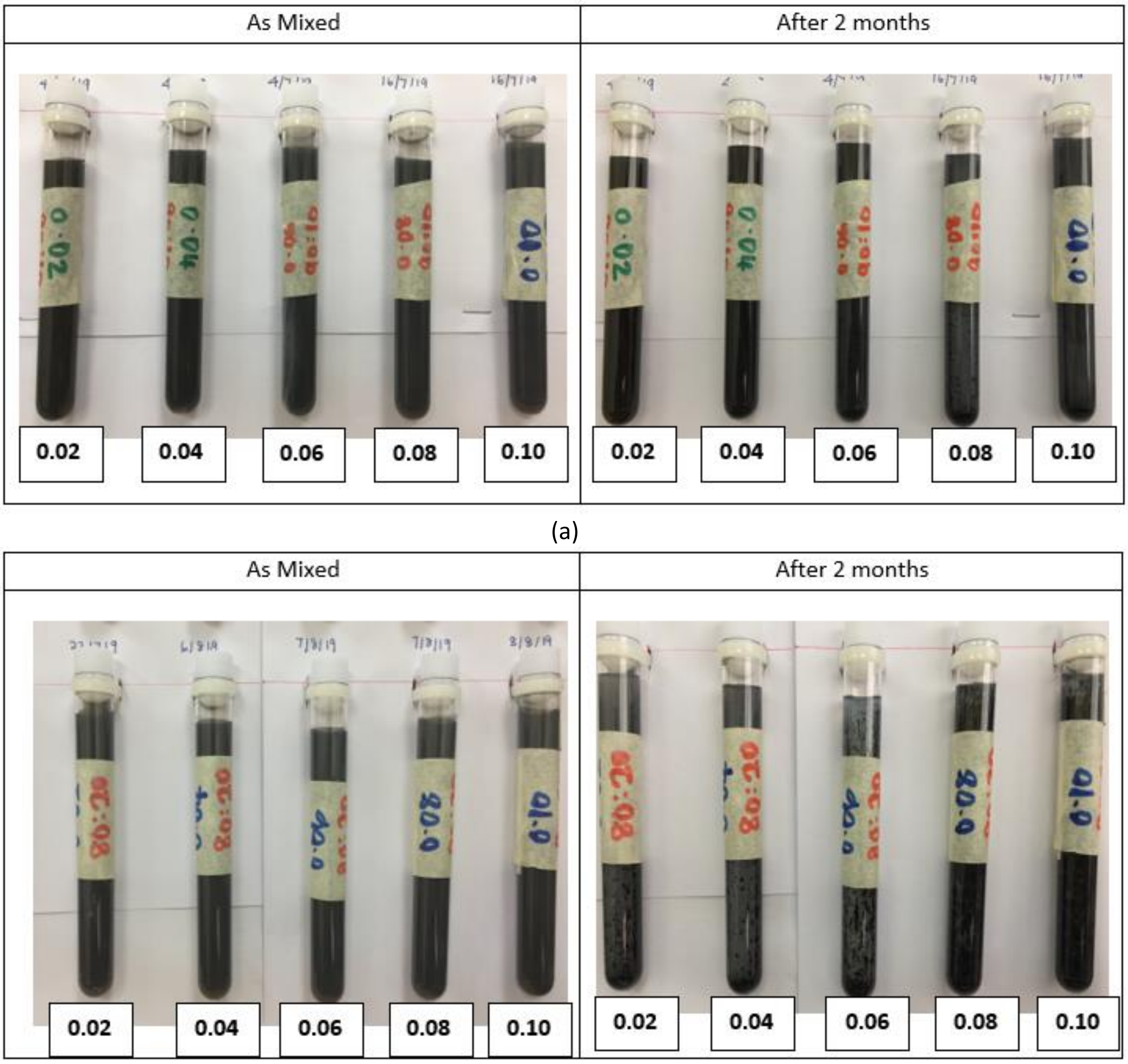
Figure 3 shows comparison of observation; as mixed and after two months for TiO_2-MWCNTs nanofluids with different ratios and concentration. There is no sedimentation (visible with eyes) spotted at the bottom of both Solution A and B for all concentrations. After two weeks, Solution B slightly turns into greyish colour especially for 0.08 and 0.1% wt.% concentration, with sedimentation less than 2mm. The other concentrations remain black in colour with no sedimentation. Similar results were observed for Solution A in all concentrations. However, after two months of observation, all Solution B turned into greyish colour with most particle sediment at the bottom of suspensions and separation between particles and base fluid can be seen. Solution A remained black in colour and no sedimentation occurred for 0.02, 0.04 and 0.06wt.% concentration, while for 0.08 and 0.10% wt.% concentration, sediment occurred less than 1 mm. The visual observation findings were summarized in Table 3.

Table 3
Nanofluids stability (N: No sedimentation, MS: Minor sedimentationand S: Separation)

Duration (days)	Nanofluid stability									
	Solution A					Solution B				
	0.02	0.04	0.06	0.08	0.10	0.02	0.04	0.06	0.08	0.10
0	N	N	N	N	N	N	N	N	N	N
14	N	N	N	N	N	N	N	N	MS	MS
30	N	N	N	N	N	MS	MS	MS	S	S
60	N	N	N	MS	MS	S	S	S	S	S

Besides observation methods, the stability of nanofluids also measured using zeta potential, which is the qualitative observation of the nanofluids in static conditions. The relationship between nanofluids stability and zeta potential values arises from mutual repulsion that occurs between like charge particles. Particles with high surface charge tend not to agglomorate since contact is opposed, which then leads to the good stability of the suspensions. Nanofluids with high zeta potential value (positive or negative charge within range 40-60mV), are considered as stabilised, while suspension with low zeta potential tends to agglomerate and sedimentation proned to occurred [29,30].

Table 4 shows the zeta potential value of Solution A and B for all concentrations. The zeta values for all hybrid nanofluid concentration were above 40mV (±), indicates that suspensions have good stability. A negative value of zeta potential resulted from the use of surfactant in a nanofluid. Surfactants were catogerized depending on the charge of the head group of surfactants. It can be anionic (negatively charge), cationic (positively charge), non-ionic (neutral) or amphotenic (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 ananoparticles that high in positive charge initially to negative charge. The dispersion of SDBS in the suspension to produce phenyl sulfanic group which adsorbed on the nanoparticle, successively increasing the net negative charge on nanoparticle surface [20]. These findings also supported by [31,32], were they concluded that pH value and used of SDBS as surfactant influenced the stability of water-based nanofluids. As mentioned before, nanoparticle tends to agglomerate which resulted in sedimentation and phase separation due to van der Waals force between particles. However, the surfactant is usually used to increase the stability by lowering the surface tension of the base fluid and increase the wetting of nanoparticles. Surfactants tend to locate at the interface between nanoparticle and base fluid, thus creating continuity between nanoparticle and fluids.



(a)

(b)

Fig. 3. As mixed and after 2 months observation of TiO_2-MWCNTs nanofluid for different ratios and concentrations; (a) ratio 90:10, (b) ratio 80:20

Table 4
Zeta potential values for TiO2-MWCNTs nanofluids

Concentration (%)	Zeta potential value (mV)	
	Ratio 90:10	Ratio 80:20
0.02	- 65.48	- 60.48
0.04	- 70.97	- 62.99
0.06	- 57.65	- 67.26
0.08	- 65.76	- 70.97
0.10	- 74.22	- 51.21

3.2 Thermal Conductivity Enhancement

The evaluation of thermo-physical properties of nanofluids is important, in order to implement nanofluid in practical applications. Moreover, the overall effectiveness of nanofluids in the heat transfer system can be best evaluated if the enhancements of thermal conductivity and viscosity are considered at the same time. By adding the nanoparticles in the base fluid, the thermal conductivity was expected to improve since nanoparticles have higher thermal properties compared to base fluid [10,11].

Figure 4 and 5 show the thermal conductivity (*k*) value of TiO_2-MWCNTs nanofluids as a function of temperature and volume concentrations for Solution A and Solution B respectively. Both graphs shows increment in thermal conductivity value for all concentration as temperature increase compared to base flluid, thus remarks the improvement of the heat transfer system. The increase trend of *k* values for both solutions can be explained by Brownian motion of nanoparticles which increase the chaos in the fluid [33]. The kinetic energy of the particle can describe the increasing thermal conductivity with increasing temperature. As the temperature increase, the motion of particle also increases and contact between nanoparticle and fluid occuring in less time, so the heat transfer rate increase. This finding supports the conclusions made by previous researchers that thermal conductivity increase with temperature rise due to more collusions between particle and increasing Brownian motions [34]. Besides that, in base fluid-nanoparticles mixture, it is known that layer structured would be formed on particle surfaces by liquid molecules. This layer is vital in the heat transfer process from 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, Solution A with higher concentration (0.08wt% and 0.10wt%) show less enhancement of *k* value compared to lower concentration. Similar trend were observed with Solution B, with its *k* value for 0.10wt% concentration were even lower than 0.02wt% concentration at 40˚C onwards. This findings can be reasoned out by another mechanism that related to the enhancement of thermal conductivity, which is clustering of the nanoparticle. This phenomenon creates paths of lower thermal resistance and eventually increase the *k* value significantly. When the cluster settles down in base fluid, the physical volume of particles is much smaller compared to the adequate volume of cluster. Thus, the heat can move very rapidly within such cluster, and contribute to an increase in thermal conductivity. However, as the concentration of nanoparticles increase, the effective volume of cluster decrease, thus resulting in a decreased trend of *k* values.

From the results obtained through this study, the increment of *k* value for nanofluid with lower concentration was found higher throughout the increasing temperature compared to higher concentrations. For example, at 0.02wt% concentration and 30˚C, *k* value for Solution A and B increased 106% and 110% respectively relative to base fluid. Meanwhile at 0.10wt% concentration, the value increased to 79% for Solution A and 100% for Solution B compared to base fluid. It is understandable because the adequate volume will be larger for loosely packed cluster than the closely packed cluster [35]. According to Ghadimi and Metselaar [36], the large enhancement of thermal conductivity can occur in a stable solution if the aggregate is less dense and small enough to stay in solutions.

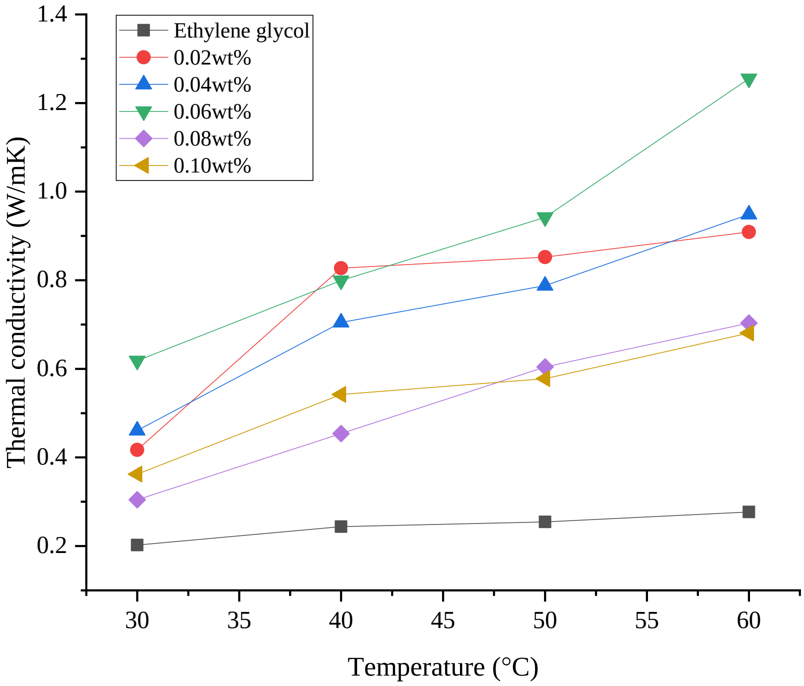


Fig. 4. Thermal conductivity of TiO_2-MWCNTs nanofluid (ratio 90:10) as a function of temperature and concentrations compared to base fluid (ethylene glycol)

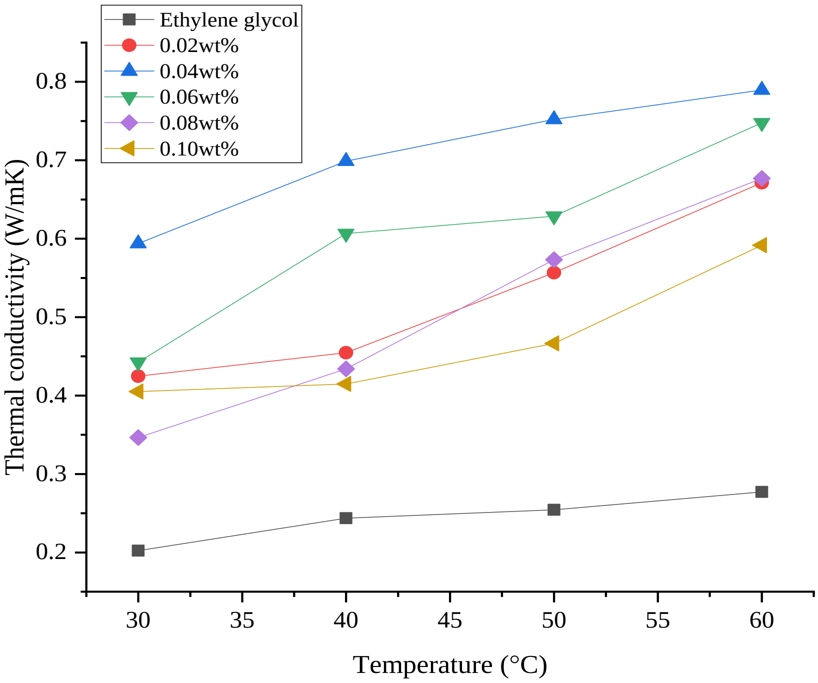


Fig. 5. Thermal conductivity of TiO_2-MWCNTs nanofluid (ratio 80:20) as a function of temperature concentrations compared to base fluid (ethylene glycol)

3.3 Viscosity vs. Temperature

The study of viscosity and its measurement is a major concern in connection to lubrication of suspensions [37]. In the machining process, the developed heat from the friction of tool-workpiece surfaces was reduced by the presence of a suitable film liquid created by cutting fluids between the moving surface. Generally, the least viscous lubricant which still forces the two moving surface apart to achieve ‘fluid bearing’ is desired. Lubricant that is too viscous will need more considerable energy to move, and if it’s too thin, the surface will come in contact and increase the friction. Thus, it is essential to ensure that the addition of nanoparticles to the base fluid did improve the viscosity properties of nanofluids, that lead to better heat transfer performance.

Figure 6 and 7 show the viscosity of Solution A and B as a function of temperature and volume concentration respectively. The viscosity of both solution decrease with increasing temperature for all concentrations, thus remarks dependent relationship between viscosity and temperature. The viscosity value however, were increased as volume concentration of nanofluid increased, indicates dependent relationship towards concentration. Based on Figure 6, for Solution A, the lowest viscosity (13.82mPa/s) recorded at 25˚C by 0.02 wt.% concentration, while the highest (15.82mPa/s) by 0.10wt.% for the same temperature. The viscosity keeps reducing as temperature increasing, and at 60˚C, the viscosity range around 5.7mPa/s to 6.4mPa/s.

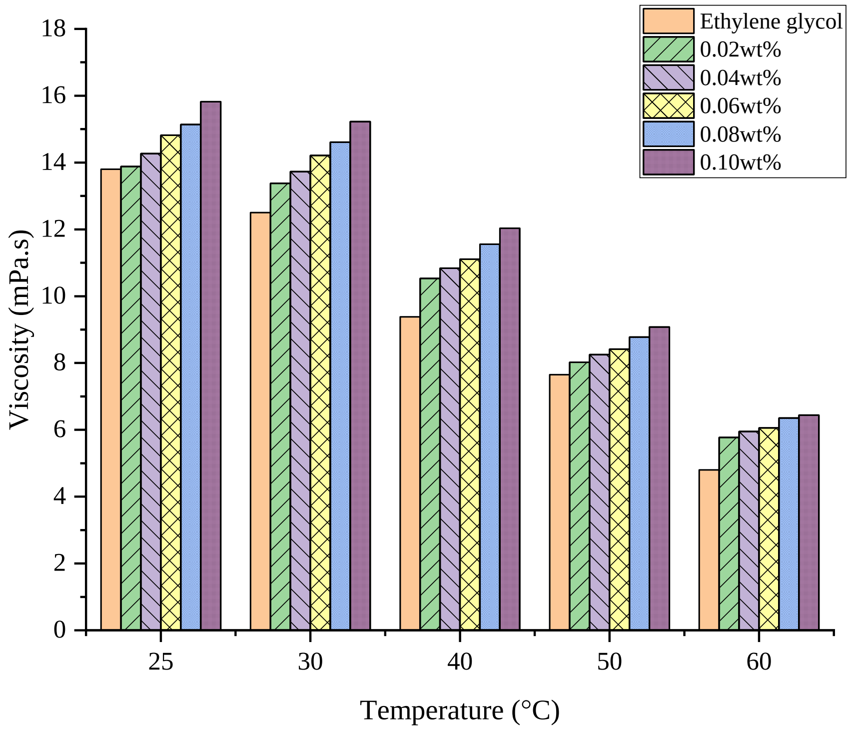


Fig. 6. The viscosity of TiO_2-MWCNTs nanofluid (ratio 90:10) as a function of temperature and concentrations

The viscosity value for Solution B (Figure 7) also showed the same trend as Solution A, showing dependent relationship towards temperatures and volume concentrations. Even so, the viscosity value for Solution B were higher than Solution A for initial temperature (25˚C). The viscosity for Solution B with concentration 0.02wt% start with 17.205mPa/s, about 24.6% higher than base fluid. For concentration 0.10wt%, viscosity value recorded at 19.095mPa/s, which 38.4% relative to base fluid. Nevertheless, the viscosity value at 60˚C shows similar value to Solution A, ranging from 5.39 to 6.78mPa/s.

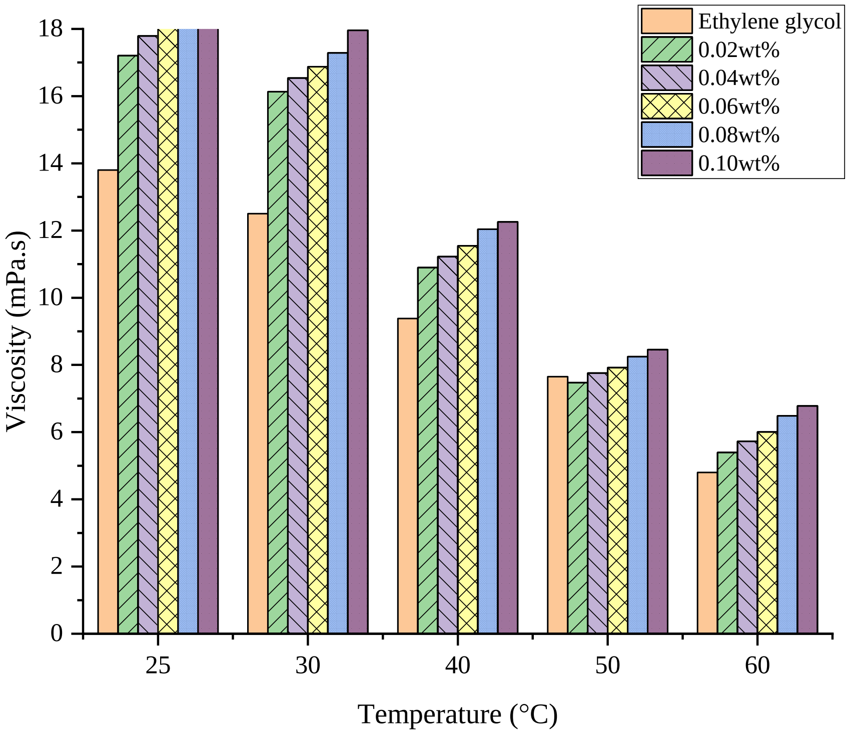


Fig. 7. The viscosity of TiO_2-MWCNTs nanofluid (ratio 80:20) as a function of temperature and concentrations

This decreasing viscosity over increasing temperature can be explained with particle theory in liquid, where molecules are loosely packed, and intermolecular attraction is strong. When the temperature increase, the energy level of liquid molecules increase and distance between molecule increase. The relative motion of molecules become more relaxed, as the intermolecular attraction between molecules decreases, resulting in reduced viscosity [38]. These findings were also supported by previous researchers [23,39-42], where they found that the addition of nanoparticle to the base fluid improve the viscosity of suspension in the function of temperature. However, findings by Chen *et al.,* [43] slightly contradict to the data obtained, as they measured the temperature effect of multi-walled carbon nanotubes nanofluid for temperature 5˚C to 65˚C. The results indicated that the relative viscosity increases significantly with temperature after 55˚C. Thus, as many factors influenced the viscosity of nanofluid, the contradict value may have been caused by various variables.

One of the few factors that significantly affected the value of viscosity was the volume concentration of nanofluids. According to Hemmat Esfe *et al.,* [44], by increasing the volume concentration of nanofluids, the number of nanoparticle that collided with base fluid's molecules increase and lead to higher viscosity value. This statement can be supported by the findings in this study where the viscosity value increased significantly with increment of volume concentration of nanofluid from 0.02wt% to 0.10wt%. This finding were also supported by Sarsam *et al.,* [45], which the viscosity value of 0.1wt% water based-MWCNTs in their study rise up to 25.04% in comparison to water. Another factor that contributed to the increase value of viscosity is the addition of surfactant in nanofluids as been proved by Gao *et al.,* [46] in their study by comparing various surfactant and its effect on viscosity values. Throughout their findings, by adding the surfactants in CNT nanofluid, the viscosity increased to different extents depending on which type of surfactant were used. For example, nanofluid that use SDBS as surfactant have lower viscosity compared to the nanofluid using SDS or CTAB due to its lower hydrophile-lipophile balance (HLB) value compared to the other two. Eventhough the increment in viscosity value were undesirable in some application, slightly viscous nanofluid would resulting in increased lubrication performance, thus become desirable effect in using it as cutting fluid during MQL machining process.

4. Conclusions

The hybrid nanofluid TiO_2-CNTs with the addition of SDBS as a surfactant was prepared by concentration ranging from 0.02% to 0.1% with ratio 90:10 and 80:20. The stability of nanofluids was observed using sedimentation photo capturing method and zeta potential analysis. Thermo-physical properties of nanofluids including thermal conductivity and viscosity, were also measured for temperature between 30˚C-60˚C and 25˚C-60˚C respectively. Based on data obtained, there are few conclusion can be listed as below.

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 0.04% concentration, where the zeta potential analysis recorded at -70.97 mV and no sedimentation occurred for at least two months for Solution A. For Solution B, highest zeta potential recorded at 0.08wt% concentration (-70.97 mV).
ii. Thermal conductivity of nanofluid increase as temperature increase for all concentration, compared to base fluid. However, the *k* value for nanofluid with 0.08 and 0.1 wt.% concentration recorded smaller than nanofluid with lower concentration. The enhancement of thermal conductivity value calculated at 30˚C for 0.02wt.% concentration for Solution A and B were 52.67% and 11.04% respectively compared to the base fluid.
iii. The viscosity of nanofluid increase linearly with increasing volume concentration and decrease with increasing temperature. Addition of both nanoparticle and surfactant did slightly increase the viscosity of suspension compared to the base fluid, resulting in increased lubrication performance.
iv. From the results obtained, a TiO_2-CNTs nanofluid (ratio 90:10) with 0.02 to 0.06 wt.% concentration shows the most effective enhancement in terms of stability, thermal conductivity and viscosity. Nanofluid with ratio 80:20, despite gave a positive enhancement on thermal conductivity and viscosity, but only stable for two weeks thus giving disadvantages on long term use as cutting fluids.

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