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Experimental Investigation on Newtonian Behaviour and Viscosity of TiO_2/PVE Nanolubricants for Application in Refrigeration System

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ABSTRACT

The flow characteristics are highly dependent to viscosity of the fluid. For nanolubricant with different concentration, viscosity change is one of important parameter to be measured to evaluate its functional ability as lubricant. This paper studies about the effect of TiO_2 nanoparticle in poly vinyl ether (PVE) at different concentration and temperature. Nanolubricant with volume concentration between 0.01% to 0.1% prepared using two-step method and tested at 40°C, 60°C, and 80°C temperature by using digital rheometer. Beforehand, the colloidal suspension fluid was observed by visual and zeta potential measurement to ensure its stability. The fluid Newtonian behaviour was identified for shear rate up to 1000 rpm. The results shown that dynamic viscosity of 0.01% TiO_2/PVE nanolubricant had decreased up to 11% for all measured temperature. For other samples, viscosity increment does not reach more than 1.5% compared to pure PVE oil. It also observed that viscosity increment by the increasing of volume concentration, but it decreases by the increment of temperature. The finding in this study confirms that viscosity of TiO_2/PVE nanolubricant effected by both temperature and volume concentration to opposite behaviour.

1. Introduction

Viscosity property for compressor lubricant in refrigeration system shall be under its limit so that the system can runs properly. As the compressor lubricant being compressed together with refrigerant in the cycle, lubricant will be forced to change its viscosity depending on temperature at the specific component or area [1]. For instance, inside the compressor the temperature is high that can be reach up to 100°C. At this moment, high viscosity lubricant is required to ensure the compressor remain wet with lubricant for a good tribological affect. However, as usual lubricant viscosity will decrease by the increasing of temperature [2]. With high pressure produced by

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compressor, lubricant easily leaves compressor after mixing with refrigerant through discharge outlet.

The lubricant viscosity also shall have upper limit as the lubricant reached the evaporator, viscosity level will increase by decreasing the temperature. Additionally, phase separation normally occur at this component as refrigerant evaporates while lubricant remain as liquid. This continuous process may result lubricant settlement at evaporator and less lubricant return to compressor. Therefore, lubricant viscosity shall be in specific level so that the refrigerant cycle can operates properly without damaging any component.

The study of compressor lubricant viscosity had been done by several researchers in the past. The founder of ultra-fine particle dispersion in fluids known as nanofluids also had addressed the viscosity concern in their findings [3]. The nanofluid can improve the heat transfer performance of a system [4-6]. In recent nanoparticle dispersion in lubricant, viscosity had become one of major issue to discuss besides thermal conductivity and tribology [7,8]. Azmi *et al.,* [9] had reviewed the effective viscosity of nanofluid. Sharif *et al.,* [10] also discuss about viscosity property when they dispersed Al_2O_3 in PAG lubricant for automotive air conditioning system. It was shown that the viscosity sharply increases after 0.3% nanoparticle dispersed in lubricant. Zawawi *et al.,* [11] studied on hybrid nanoparticle dispersion in PAG lubricant. Maximum viscosity increment recorded at 9% for 0.1% concentration.

The use if TiO_2 nanoparticle in nanofluid studies had proved that a small amount of nanoparticle may increase heat transfer and refrigeration system performance. Azmi *et al.,* [12] uses TiO_2 to increase heat transfer performance. Hamid *et al.,* [13] studied the mixture ratio of TiO_2-SiO_2 to enhance heat transfer performance. Hamisa *et al.,* [14] dispersed TiO_2 in POE lubricant that to be used on hybrid car air conditioning system. Other studies also proved that nanolubricant improved system performance and reduce the energy usage [15-17].

The previous study related to nanolubricant had focus more on other type of lubricant such as mineral oil (MO), Polyalphaolefin (PAO), Polyol ester (POE), Polyalkylene glycol (PAG) [11,14-19,21-27]. However, the studies related to PVE lubricant are quite limited in the literature. Thermo-physical properties specifically on viscosity for PVE nanolubricant is considered new in nanofluid research. Motozawa *et al.,* [28] previously study the thermophysical property of PVE with CuO nanoparticle but only focus on thermal conductivity of the nanolubricant. For TiO_2 nanoparticle in PVE lubricant which usually applied for refrigeration system, it was none previous study found in the literature. Therefore, this paper aims to investigate the Newtonian behaviour a dynamic viscosity for TiO_2/PVE nanolubricant that possible to be use in refrigeration system.

2. Methodology

2.1 Preparation of Nanolubricant

The FVC68D is part of PVE family commonly used as compressor lubricant was used in this study as lubricant base. By using two-step method, TiO_2 nanoparticle was initially weighed by five decimal digital scale [29]. Four samples were prepared in this study where one pure PVE lubricant also being measured as reference. Other three samples are 0.01%, 0.05% and 0.1% of TiO_2 nanoparticle concentration with the amount calculated using Eq. (1).

$$\phi = \frac{\left[\frac{m_{TiO_2}}{\rho_{TiO_2}}\right]}{\left[\frac{m_{TiO_2}}{\rho_{TiO_2}}\right]+\left[\frac{m_{PVE}}{\rho_{PVE}}\right]} \times 100\% \qquad (1)$$

The lubricant was measured using measuring cylinder with accuracy of 0.1 ml and poured into 250 ml glass beaker. For each sample, 200 ml TiO_2/PVE nanolubricant was stirred using magnetic stirrer for 0.5 hour before further homogenizing process using ultrasonication bath for 7 hours. After preparation, 20 ml of nanolubricants were poured into test tube for visual stability evaluation and another 5 ml each were taken for zeta potential stability measurement. Figure 1 shows the prepared nanolubricant in comparison with pure PVE lubricant. Noted that there is no surfactant used in this research.

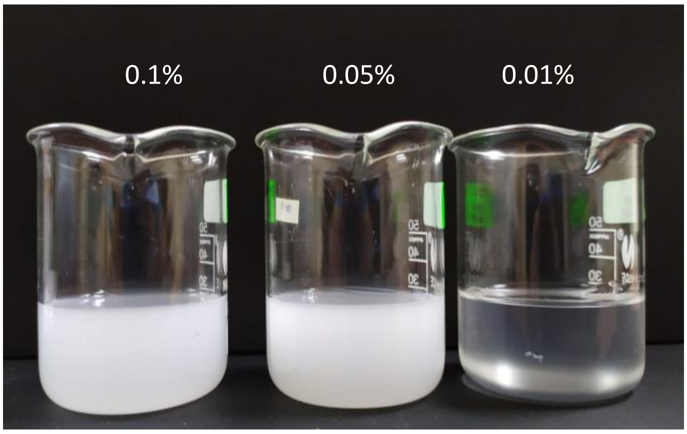


Fig. 1. PVE lubricant and prepared TiO_2/PVE nanolubricant at different concentration (vol. %)

The prepared nanolubricant were characterized by two different methods, Transmission Electron Microscopy (TEM) and Field Emission Scanning Electron Microscope with Energy Dispersive X-Ray (FESEM-EDX). Figure 2 shows the image of TiO_2/PVE nanolubricant that confirmed the average size of 50nm TiO_2 nanoparticles with spherical shape. This result also confirms by FESEM-EDX image in Figure 3 where the composition of titanium and oxygen presents in the energy spectrum. Table 1 gives the PVE lubricant properties at atmosphere condition provided by its manufacturer.

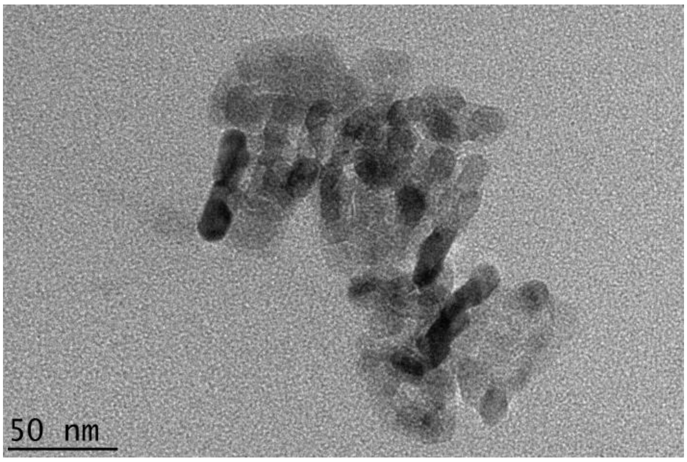
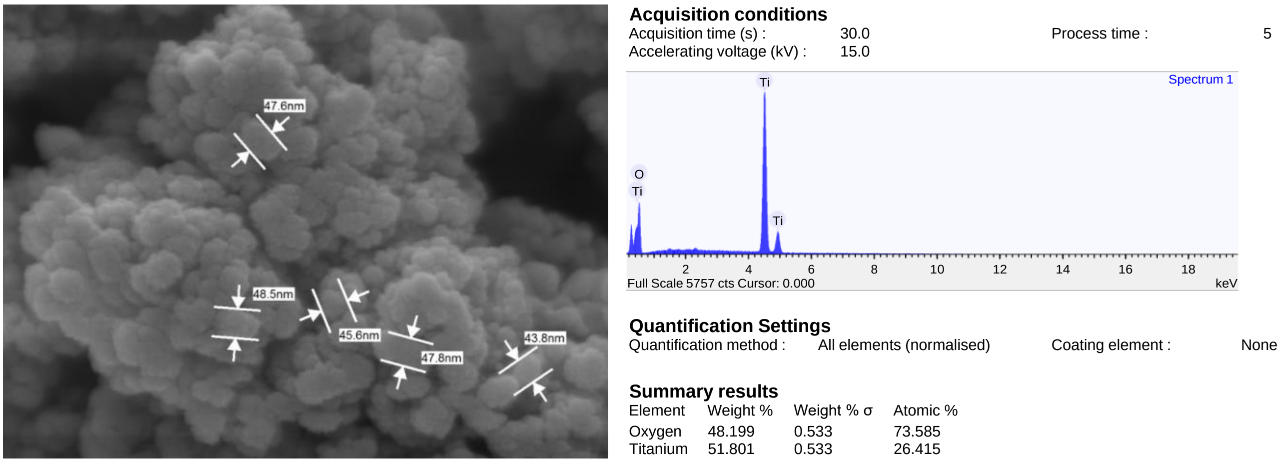


Fig. 2. TEM image of TiO_2/PVE nanolubricant



(a) FESEM (b) EDX results

Fig. 3. FESEM-EDX image of TiO_2 nanolubricant

Table 1
Properties of PVE oil [30]

Property	PVE
Density, g/cm^3(@15°C)	0.9369
Dynamic Viscosity, Pa.s (@40°C)	62.37x10^{-3}
Pour Point, °C	-37.5
Flash point, °C	204

Zeta potential is one of the methods to measure the stability of colloidal dispersion fluid. In this study, Melvern Zetasizer ZS was used. Few material parameters shall be input to the machine as part of calculation such as dielectric constant, viscosity at dedicated temperature, and reflective index. As zeta potential value does not affected by nanolubricant concentration, only 0.01% concentration was tested. Figure 4 shows zeta potential results for the current study. The zeta potential was found at 115.8 mV. Ghadimi *et al.,* [31] in their review had categorized zeta potential value to five level where above 60 mV was identified as excellent stability, 45 mV to 60 mV as good stability, 30 mV to 45 mV as moderate stability, 15 mV to 30 mV as limited stability and zeta potential below 15 mV is categorized as no stability. Comparing the present results with previous, it was shown that TiO_2/PVE has higher stability. After the nanolubricant had been confirm with its stability, the samples were proceeded with viscosity measurement.

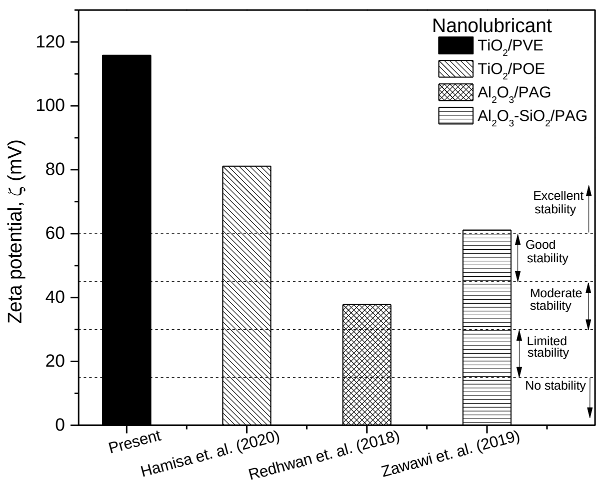


Fig. 4. Zeta potential results of present study in comparison with previous findings

2.2 Viscosity Measurement

The viscosity measurement in this study was measured using Digital viscometer RheolabQC by Anton-Paar. The samples were tested at different rotational speed between 0.01 1/min to 1000 1/min. Each sample were measured at three dedicated temperatures at 40°C, 60°C and 80°C. The dynamic viscosity measurement was repeated three times for each sample to ensure the measurement consistency, repeatability, and reliability.

3. Results

This section divided to two sections which the first part will discuss about the nanolubricant behaviour at different concentration and temperature. The second part will discuss about the dynamic viscosity behaviour of the same nanolubricant comparing to pure lubricant.

3.1 Nanolubricant Behaviour

Figure 5 depicted the dynamic viscosity of TiO_2/PVE nanolubricant at different shear rate and temperature in comparison with pure PVE lubricant. The results show dynamic viscosity remain constant at all range of shear rate from 0 to 100 rpm. By the increasing of temperature, dynamic viscosity dropped for all concentration of nanolubricant. It is also shown that the 0.01% volume concentration nanolubricant is the lowest viscosity at all different range of temperature while the other concentrations show higher viscosity comparing to pure lubricant.

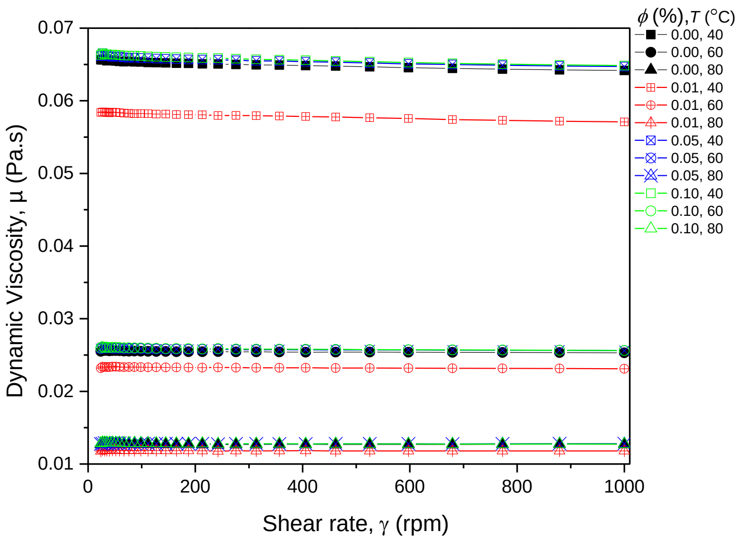
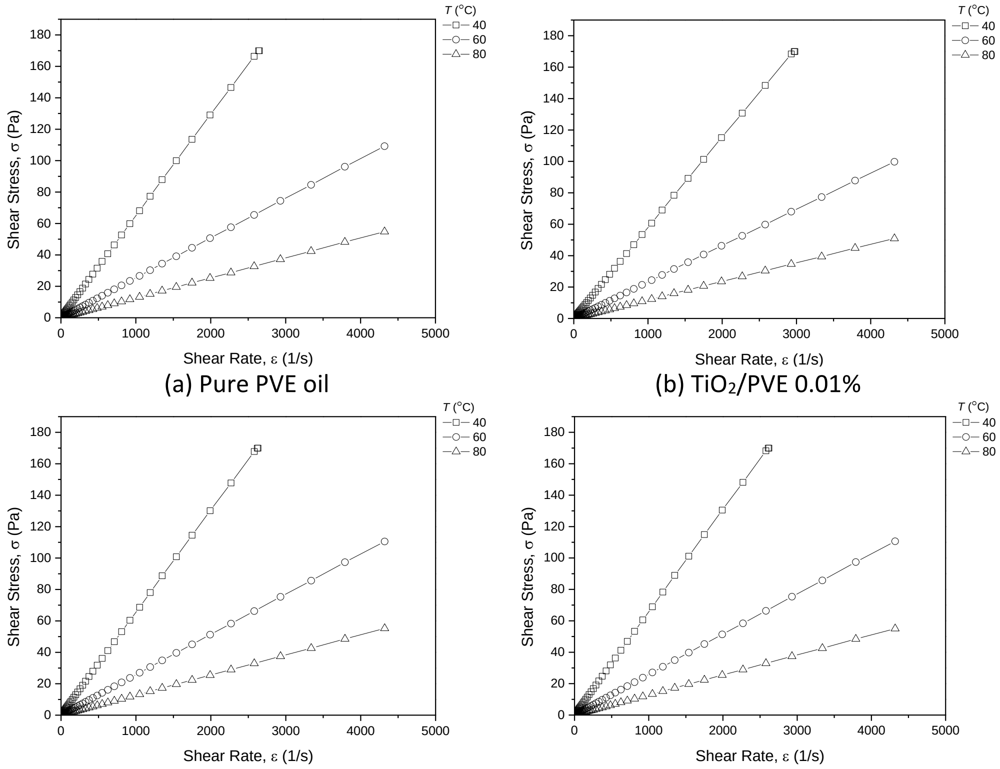


Fig. 5. Dynamic viscosity at different shear rate and temperature

One of the methods to identify the behaviour of a fluid is by plotting its shear stress (s) and shear rate (ε) as shown in Figure 6. These figures compare the shear stress vs shear rate for pure lubricant with nanolubricant at different concentration. In each figure, three different temperatures were plotted for shear rate between 0 to 4500 s^{-1}. The results of all samples show straight line at its own gradient. Gradient for 40°C shows the highest value followed by 60°C and 80°C. From Figure 4 and Figure 5, it can be concluded that the PVE lubricant and all prepared nanolubricant has shown Newtonian behaviour constantly at all selected temperature.



(a) Pure PVE oil

(b) TiO_2/PVE 0.01%

(c) TiO_2/PVE 0.05%

(d) TiO_2/PVE 0.10%

Fig. 6. Shear stress vs strain at different temperature

3.2 Dynamic Viscosity of Nanolubricant

Further investigation on rheological behaviour of the nanolubricant is the value of dynamic viscosity. The dynamic viscosity of all samples is shown in Figure 7. At 40°C, the dynamic viscosity fall between 0.055 to 0.065 Pa.s, while for 60°C, the dynamic viscosity fall between 0.02 to 0.025 Pa.s and for 80°C, dynamic viscosity fall between 0.01 to 0.015 Pa.s. Comparing the viscosity at different concentration, it is shown that 0.01% drastically drop while 0.05% and 0.1% shown a small increment compared to pure lubricant at all temperature.

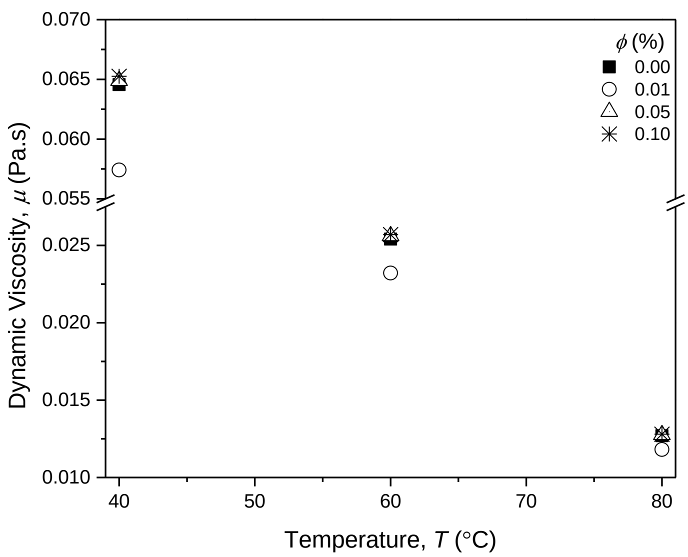
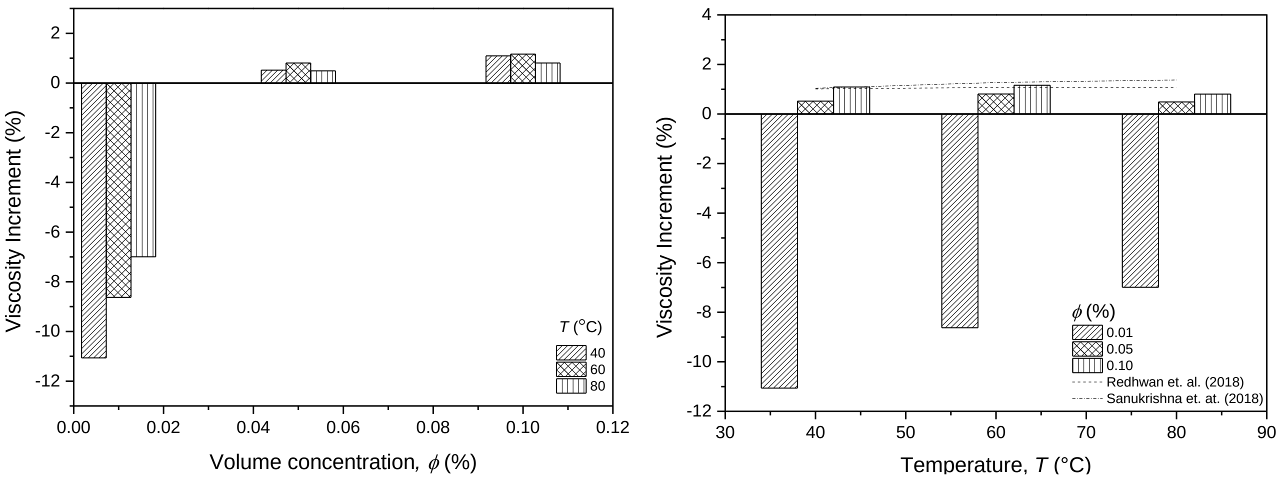


Fig. 7. Dynamic viscosity of PVE nanolubricant at various temperature and concentration

Figure 8(a) shows the comparison of dynamic viscosity increment of nanolubricant to pure PVE lubricant. For concentration between 0.01% to 0.1% at different temperature. For 0.01%, it is shown that decrement occur in dynamic viscosity between -8% to -12%. For 0.05% and 0.1% concentration, dynamic viscosity shows small increment less than 1.5%. Figure 8(b) shows the comparison of dynamic viscosity increment at different temperature. At the increment of temperature, all nanolubricant shows the increment of viscosity even though the 0.01% concentration shows negative value. By comparison to results from the literature, the increment in viscosity in the current study are still lower than selected reference from literature [23,25].



(a) (b)

Fig. 8. Viscosity increment of PVE nanolubricant subject to temperature and concentration

4. Conclusions

The current study investigates the Newtonian behaviour of TiO_2/PVE nanolubricant and the effect of dynamic viscosity for different concentration. Three nanolubricant at concentration 0.01%, 0.05%, and 0.1% were prepared and tested at 40°C, 60°C, and 80°C temperature. From the results, it can be concluded that all samples including pure PVE lubricant shown Newtonian behaviour at all condition. It is good news for material used in refrigeration system as change of pressure does not change the viscosity of the fluid. Dynamic viscosity decreases when 0.01% TiO_2 nanoparticle were dispersed while it increases at higher concentration. The lowest decrement occurs on nanolubricant at 0.01% concentration at 40°C. Highest increment also does not reached more than 1.5%. The current studies show that TiO_2/PVE at concentration less than 0.1% can be use in refrigeration system as the dynamic viscosity does not increase much that exceed the limit set by manufacturer.

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