Thermo-Physical Properties Of Metal Oxides Composite Nanolubricants

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ABSTRACT

Thermal conductivity and viscosity of the different combination of composite nanolubricants for 0.02% volume concentrations at a temperature range of 30 to 80 ^{o}C were investigated. Al_2O_3, SiO_2 and TiO_2 nanoparticles were dispersed in the Polyalkylene Glycol (PAG 46) lubricant using the two-step method of preparation. Thermal conductivity and viscosity were measured using KD2 Pro Thermal Properties Analyzer and LVDV-III Rheometer, respectively. The result shows that the thermal conductivity and viscosity of composite nanolubricants decrease with temperature. Composite nanolubricants behaved as Newtonian in the range of the temperatures studied. The most optimum combination of composite nanolubricant is Al_2O_3-SiO_2/PAG as it yields higher enhancement in thermal conductivity but lower in viscosity.

Keywords: *composite nanolubricant; thermal conductivity; viscosity*

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Introduction

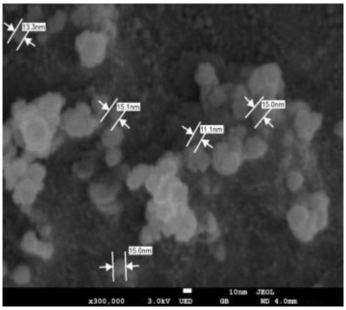
A new concept has been introduced by nanoparticles dispersion in lubricant-mixed refrigerant in the refrigeration system. Thermal conductivity improvement for refrigerant based nanolubricants will gained more potential in the system especially in the automobile air-conditioning system. Heat transfer properties can be enhanced by increasing the thermo-physical properties using refrigerants. Thus, heat transfer behavior studies for nanolubricant are significant to enhance the efficiency and reliability of refrigeration and air conditioning system [1]. From literature, a few scientists focused on the thermo-physical properties of composite nanolubricants with engine oil based only [2-6].

According to previous works, scientists have discussed on using composite nanofluids as an extension on nanofluids research [7-9]. Composite nanofluids are the new current trend in nanofluids research. Composite nanofluids are formulated by dispersing two or more of different nanoparticles in mixture or composite form in the base fluids and are able to improve the working fluids thermo-physical properties. Composite nanofluids yield a significant result in thermal conductivity enhancement and also heat transfer coefficient [10].

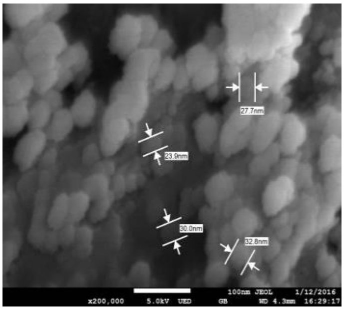
However, none effort has been done to investigate the composite nanolubricant in automotive air-conditioning system. So, in this present study, thermal conductivity and viscosity enhancement of two different combination of composite nanolubricants (Al_2O_3-SiO_2/PAG and Al_2O_3-TiO_2/PAG) for 0.02% volume concentration have been studied at a temperature range of 30 to 80^oC. Lastly, the optimum combination between both of the composite nanolubricant is suggested for further investigations.

Methodology

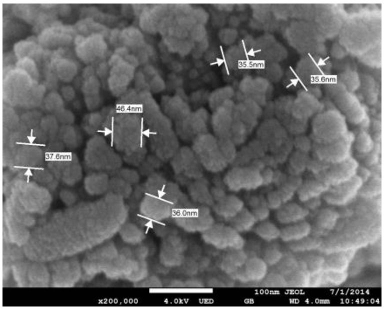
In preparation of nanolubricants, different metal oxides nanoparticles are used namely Al_2O_3, SiO_2 and TiO_2.Al_2O_3 (99.8% purity) with 13 nm in size, SiO_2 (99.5% purity) with 30 nm in size and TiO_2 (97% purity) with less 100nm in size. These nanoparticles are procured from Sigma-Aldrich. The properties of the nanoparticles are given in Table 1**.** The characterizations of these nanoparticles are obtained by the field emission scanning electron microscopy (FESEM) technique. The images of FESEM are shown in Figure 1. PAG 46 lubricant properties at the atmospheric pressure is given in Table 2.



(a) Al_2O_3



(b) SiO_2



(c) TiO_2

Figure 1: FESEM image of dry nanoparticles

Table 1: Properties of nanoparticles [11-15]

Properties	Al_2O_3	SiO_2	TiO_2
Molecular mass (g/mol)	101.96	60.08	79.87
Average particle diameter (nm)	13	30	≤100
Density (kg/m^3)	4000	2220	4260
Thermal Conductivity (W/m.k)	36	1.4	-
Specific Heat (J/kg.K)	773	745	692

Table 2: Properties of polyalkylene glycol (PAG 46)

Properties	PAG 46
Density (g/cm^3) @ 20 °C	0.9954
Flash Point (°C)	174
Kinematic viscosity (cSt) @ 40°C	41.4-50.6
Pour Point (°C)	-51

The two-step method was used in the preparation of the different combination composite nanolubricant for 0.02% volume concentration. At first, all nanolubricants used in the experiment; Al_2O_3/PAG nanolubricant, SiO_2/PAG nanolubricants and TiO_2/PAG nanolubricant were prepared separately. Two combinations between composite nanolubricants (Al_2O_3-SiO_2 and Al_2O_3-TiO_2) were homogenized together by a 50:50 mixture ratio for each sample. The volume concentrations of the composite nanolubricant were calculated using Eq. (1).

$$\phi = \frac{m_p / \rho_p}{m_p / \rho_p + m_l / \rho_l} \times 100 \tag{1}$$

KD2 Pro thermal property analyzer as shown in Figure 2 was used to measure the thermal conductivity of the different combination composite nanolubricant samples. The thermal conductivity of 0.02% volume concentrations of composite nanolubricants were measured at temperature range of 30 to 80^{o}C after homogenization. An average of five values of thermal conductivity for each volume concentrations at different range of temperature were taken for data collection and analyzed.

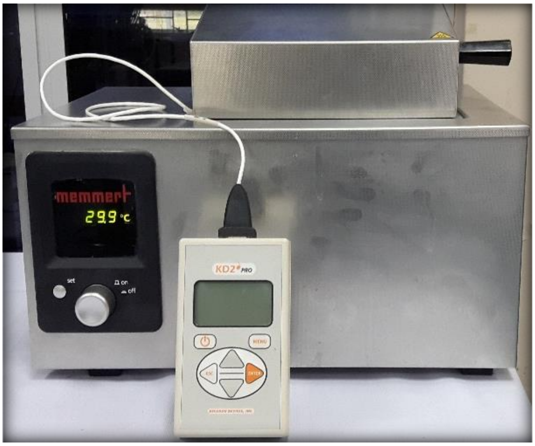


Figure 2: KD2 pro thermal property analyzer and water bath

As shown in Figure 3, LVDV-III (low viscosity digital viscometer) Ultra Programmable Rheometer was used to measure viscosity of the different combination of composite nanolubricant samples within different temperatures between 30 to 80^{o}C for 0.02% volume concentrations. Data measurement was carried out within the equivalent percentage of torque range from 10 to 100 % and within the range of 1.0 to 6,000,000 mPa. Viscosity measurement was repeated three times for each temperature in order to obtain reliable data and the mean value from the three sets of data was attained for further analysis.

Figure 3: Viscometer

Results and Discussion

Thermal Conductivity

Thermal conductivity values of composite nanolubricant for 0.02% volume concentration at different temperatures are shown in Figure 5. According to the figure, thermal conductivity of composite nanolubricant decreases along with temperature increment. Thermal conductivities measurement of the composite nanolubricant are comparatively higher compared to the PAG based fluid. Liquid molecules when heated moving apart from each other results in increasing their mean path[13]. This behaviour aids in decreasing the molecules collision probability. Thermal conductivity according to Agarwal et al[16], can be efficiently increased due to increment of surface-to-volume ratio of particles by dispersing smaller size particles. CRC Handbook of Lubrication and Tribology[17] is used to validate experiment data and is represented by solid straight line in Figure 4. Particles random distribution due to dispersion of nanoparticles in a matrix material ensured good material properties because it is closely related to the thermal and mechanical performance of composites[18]. Furthermore, the smaller size nanoparticles filled the gaps in between more larger nanoparticles size and both nanoparticles were randomly distributed in the base lubricant. Thus, increased the contact area between the nanoparticles. Therefore, the thermal conductivity of composite nanolubricants was more enhanced. The highest achievable enhancement ratio of composite nanolubricant is 1.010 or 1.035% for Al_2O_3-SiO_2/PAG composite nanolubricant at 80°C when compared to pure PAG and temperature as shown in Figure 5. Meanwhile the lowest is observed at 1.007 or 0.68% for Al_2O_3-TiO_2/PAG composite nanolubricant at 30°C.

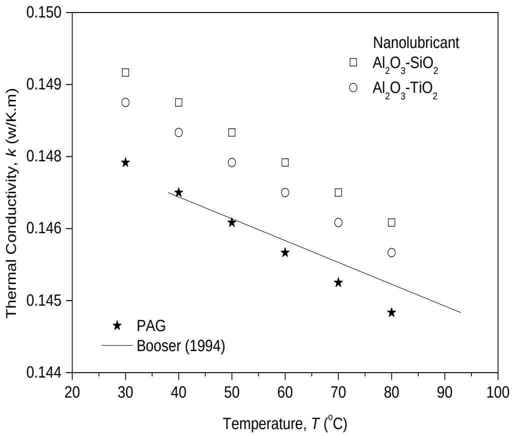


Figure 4: Thermal conductivity of composite nanolubricants at different temperatures

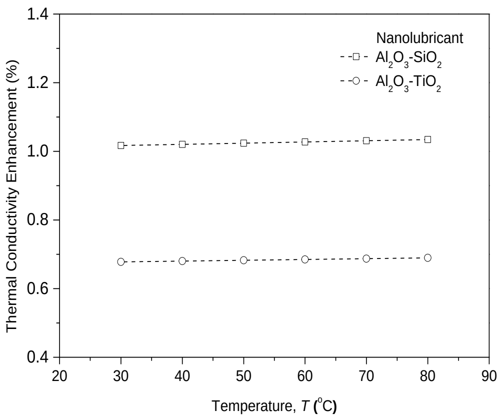


Figure 5: Thermal conductivity enhancement with respect to temperatures

Viscosity

Figure 6 depicts the variation of dynamic viscosity versus shear rate at 0.02% volume concentration for composite nanolubricant. A slight increase in dynamic viscosity is clearly observed with the increasing shear rate. This behaviour is independent to shear rate. When relationship between shear rate and shear stress are linear and also viscosity remains constant with shear rate, the behaviour of the fluid can be considered as Newtonian [19]. Therefore, the sample can be considered as Newtonian fluid under these conditions. This behaviour can be explained by considering the occurring shear heating in high shear rates[20]. According to Asadi et al[2], Newtanion behaviour is shown at volume concentration for 0.75% MWCNT-MgO/engine oil composite nanolubricant at 25 to 50°C.

Viscosity variation of Al_2O_3-SiO_2/PAG and Al_2O_3-TiO_2/PAG composite nanolubricant at different temperature of 30 to 80°C for 0.02% volume concentrations is shown in Figure 7. It is clearly observed in the graph that viscosity of composite nanolubricant decreases with temperature increment. The increasing of nanoparticles and engine oil molecules interactions by nanoparticles and nanotubes addition in engine oil and the volume concentration increment lead to viscosity increment. This was probably due to restriction of oil layers' movement and van der Waals forces between the molecules [4, 21, 22]. RC Handbook of Lubrication and Tribology[17] is used to validate data and represented by solid straight line in Figure 7. Viscosity measurement of composite nanolubricant for different combination of metal oxides are relatively higher compared to the PAG based fluid. The maximun viscosity enhancement ratio of composite nanolubricant is 1.098 or 9.79% for Al_2O_3-TiO_2/PAG composite nanolubricant at 80°C when compared to pure PAG under the same volume concentration and temperature as shown in Figure 8. Meanwhile the lowest enhancement is observed at 1.012 or 1.19% for Al_2O_3-SiO_2/PAG composite nanolubricant at 50°C.

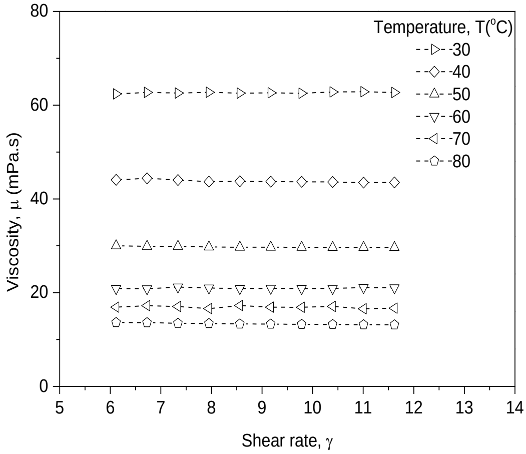


Figure 6: Variations of viscosity with 0.02% volume concentration at different temperatures

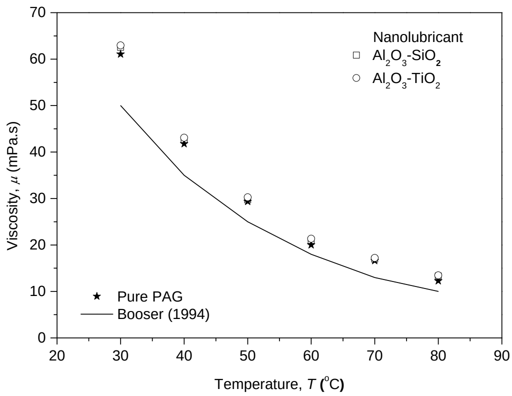


Figure 7: Viscosity of composite nanolubricants at different temperatures

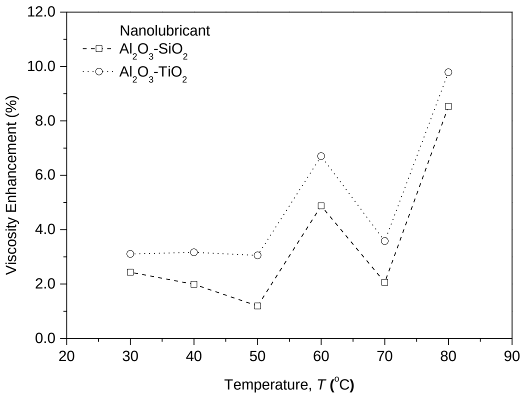


Figure 8: Viscosity enhancement with respect to temperatures

Conclusions

Thermal conductivity and viscosity of different combination composite nanolubricant were determined at 0.02% and various temperatures from 30 to 80°C. The composite nanolubricants behaved as Newtonian fluid in the range used in the experiment. The highest achievable enhancement ratio of composite nanolubricant is 1.010 or 1.035% for Al_2O_3-SiO_2/PAG composite nanolubricant at 80°C meanwhile the lowest is observed at 1.007 or 0.68% for Al_2O_3-TiO_2/PAG composite nanolubricant at 30°C. The maximum dynamic viscosity increments of 1.098 or 9.79% for Al_2O_3-TiO_2/PAG composite nanolubricant at 80°C were obtained meanwhile the lowest enhancement is observed at 1.012 or 1.19% for Al_2O_3-SiO_2/PAG composite nanolubricant at 50°C. The present composite nanolubricant was intended to be tested in automotive air conditioning systems that use compressors and lubricated by polyalkylene glycol (PAG). Therefore, it is recommended to use the Al_2O_3-SiO_2/PAG composite nanolubricants for application in refrigeration systems as it yielded higher enhancement in thermal conductivity but lower enhancement in viscosity which were important in systems efficiency. Further investigations on the performance of refrigeration system using the Al_2O_3-SiO_2/PAG composite nanolubricants are required to extend the present work.

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