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Thermal conductivity enhancement of Al_2O_3 and SiO_2 nanolubricants for application in automotive air conditioning (AAC) system

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Abstract. Nanolubricant been introduced in compressor might improve the performance of automotive air conditioning system. Prior testing of the nanolubricant enhancement performance, thermal conductivity of Al_2O_3/PAG and SiO_2/PAG nanolubricants has to be investigated and compared. Al_2O_3 and SiO_2 nanoparticles first been dispersed in Polyalkylene Glycol (PAG) for different volume concentrations. KD2 Pro was used in determining the thermal conductivity of the nanolubricant. The experimental results showed that the thermal conductivity of the Al_2O_3/PAG and SiO_2/PAG nanolubricants increased by volume concentration but decreased by temperature. The highest thermal conductivity was observed to be 0.153 W.(m·K)-1 and enhancement of 1.04 times higher than the base lubricant for Al_2O_3 with 1.0 volume concentration. Finally regression equations were developed in order to estimate the thermal conductivity for these nanolubricants.

1 Introduction

Nanolubricant was produced when nanoparticles were been dispersed in refrigerant/lubricant based. Nanolubricant intended to be put in compressor might improve the performance of automotive air conditioning system. Bi et al. [1] concluded three main bonus obtained when nanoparticles were emlpoyed in refrigerant/lubricant; (1) adding nanoparticle could enhance the solvability between the lubricant and refrigerant. (2) Thermal conductivity and heat transfer characteristics of the refrigerant could be increased. (3) Nanoparticles dispersion into lubricant might reduce the friction coefficient and wear rate. The studies on mixture of nanolubricants and nanorefrigerants have shown enhanced performance compared to their based fluid. For example, Kedzierski [2] studied the influence of Al_2O_3 nanoparticles and R134a/polyolester mixtures on the pool boiling performance on a rectangular finned surface. He found that the boiling performance enhanced up to 113% on a rectangular finned surface.

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Judging by the potential of nanolubricants in improving the efficiency of air conditioning and refrigeration systems, thermal conductivity measurement of potential nanolubricants is necessary not only on the fundamental research but also to the design consideration. But to the best of authors' knowledge, there are only few literatures which are available for the experimental works on thermal conductivity of nanolubricant. For example, Kedzeisky et al [3] investigated the thermal conductivity of Al_2O_3 and ZnO dispersed in polyolester based lubricant. They also summarized that thermal conductivities of nanolubricants were increased with the increased of nanoparticle mass fraction.

Contradict to the research on Al_2O_3 nanolubricant, not much research work was done on SiO_2 nanoparticle. Through literature review, it was found out only one research was done on this particular nanoparticle. R134a refrigerant was used by Henderson, et al. [4] in intention to study the effect of SiO_2 and CuO nanoparticles on the flow-boiling of R-134a and R-134a/polyolester mixtures. It is observed that the heat transfer coefficient decreases by 55 % when SiO_2 nanoparticles were directly dispersed in R134a refrigerant. The decrement of the enhancement is due to difficulties in attaining a stable dispersion. It is noticeable that conclusion made by this research make SiO_2 nanoparticle is less desirable to be explored by other scholars. If further investigation was done in showing or producing more stable SiO_2 nanolubricant/nanorefrigerant, it might open a new sub area of nanorefrigerant research.

As different base fluids have different thermal conductivity properties, the model implemented may not suit for PAG base nanolubricants purposes. Therefore if experimental data of the thermal conductivity properties of the nanolubricants are obtained, it would be used for better understanding on the enhancement of heat transfer, coefficient of performance (COP), energy saving and others.

2 Methodology

2.1 Material preparation

Nanoparticles used are Al_2O_3 and SiO_2. Al_2O_3 with 99.8 % purity and 13 nm in size while SiO_2 nanoparticles with 99.5 % purity and 30 nm in size. Both nanoparticles are procured from Sigma-Aldrich. The characterizations of these nanoparticles are obtained by the field emission scanning electron microscopy (FESEM) technique. The images of FESEM at magnification of 300,000 and 200,000 are shown in Figure 1. From the FESEM image it has been observed that both nanoparticles are in nearly spherical shape and the sizes are about 13 nm and 30 nm respectively. The properties of Al_2O_3 and SiO_2 are shown in Table 1. The properties of these particles are important to be known in order to estimate the model of physical properties such as thermal conductivity. Polyalkylene gycol (PAG) lubricant was intended to be tested in automotive air conditioning system. PAG have been used mainly in automotive air-conditioning systems due to the compatibility characteristic with most of elastomers [5]. Table 2 shows the properties of the PAG 46 lubricant at atmospheric pressure [6, 7].

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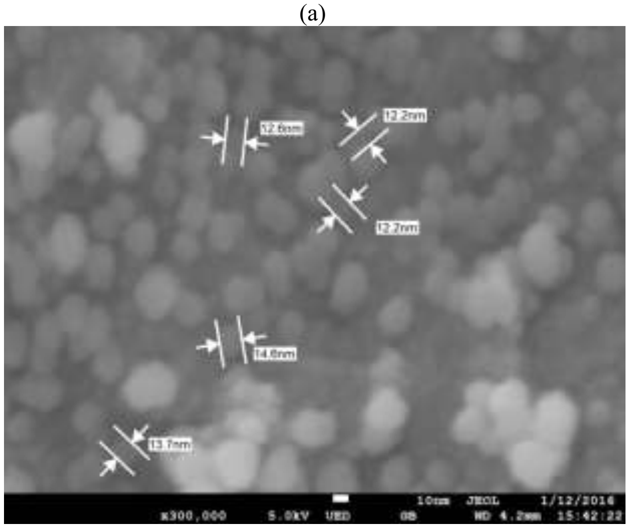
(a)



(b)

Fig. 1. Fesem image of dry nanoparticles (a) SiO_2 at 200,000 (b) Al_2O_3 and 300,000 magnification respectively.

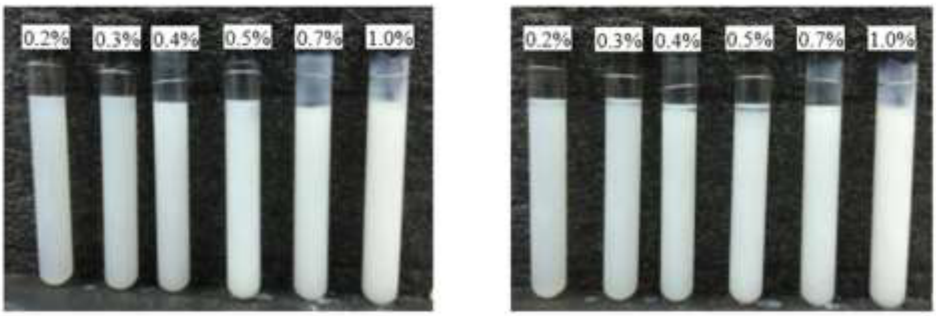
Table 1. Properties of Al_2O_3 and SiO_2 nanoparticles.

Property	Al_2O_3	SiO_2
Molecular mass (g mol^{-1})	101.96	60.08
Average Particle diameter (nm)	13	30
Density (kg m^{-3})	4000	2220
Thermal Conductivity (W m^{-1} K^{-1})	36	1.4
Specific heat (J kg^{-1} K^{-1})	773	745

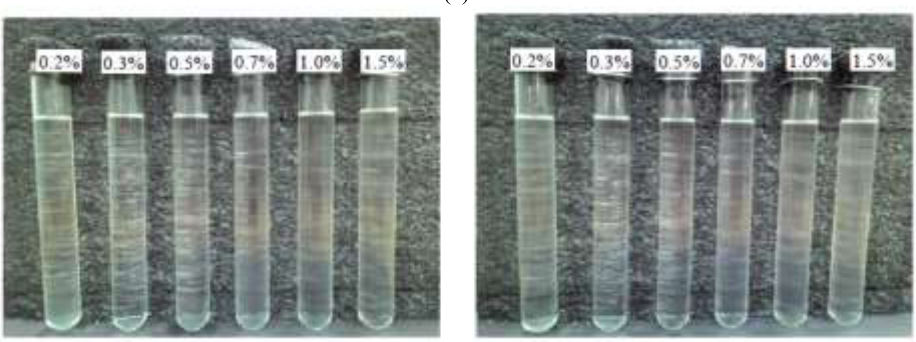
Table 2. Properties of Polyalkylene Glycol (PAG).

Property	**PAG**
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

Two step method recommended by Yu et al. [8] is used in preparation of nanolubricants. The preparation of nanolubricant was according to Sharif et al. [9]. The mixing started with magnetic stirrer process for half an hour. Prior mixing, the required mass of the Al_2O_3 and SiO_2 nanoparticles to be dispersed in lubricant was measured using high accuracy electronic balance. The mixtures then are subjected to ultrasonic homogenization for specific hour(s) according to nanoparticles to ensure good dispersions of nanolubricants. Dispersion stability is observed visually after a month of preparation and found that no sedimentations were occurred in the samples as shown in Figure 2. No surfactant is been added in this experiment.



(a)



(b)

Fig. 2. (a) Al_2O_3/PAG (b) SiO_2/PAG nanolubricants at different concentrations after a month of preparation

2.2 Thermal conductivity measurement

As shown in Figure 3, KD2 Pro thermal property analyzer was used in measuring thermal conductivity. This apparatus uses the transient line heat source to establish the thermal properties of liquids and solids. The apparatus meets the standards of both ASTM D5334 and IEEE 442-1981. Single needle sensor (KS-1) in the range of 0.002 to 2.00 W.$(m \cdot K)^{-1}$ is used. A water bath of WNB7L1 model, is been used to maintain a constant temperature of the sample with accuracy of 0.1 °C [10]. The thermal conductivity of 0.2 to 1.0% volume concentrations of nanolubricants were measured for temperature range of 30 to 80 °C. The sensor was validated by measuring the thermal conductivity of the verification liquid (glycerin) given by the supplier. The measured value of glycerin at 25 °C is 0.286 W$(m \cdot K)^{-1}$, which is in accord with the calibrated data of 0.285 W$(m \cdot K)^{-1}$ and within ± 0.35 % accuracy. The validation process was done each time before the thermal conductivity measurement was taken. In order to ensure the consistency of data measurement, minimum five data were taken for every concentration at a specific temperature. Two thermal conductivity models, Maxwell [11] and Yu and Choi [12] in equations 1 and 2 were used to verify the results of nanolubricants thermal conductivity.

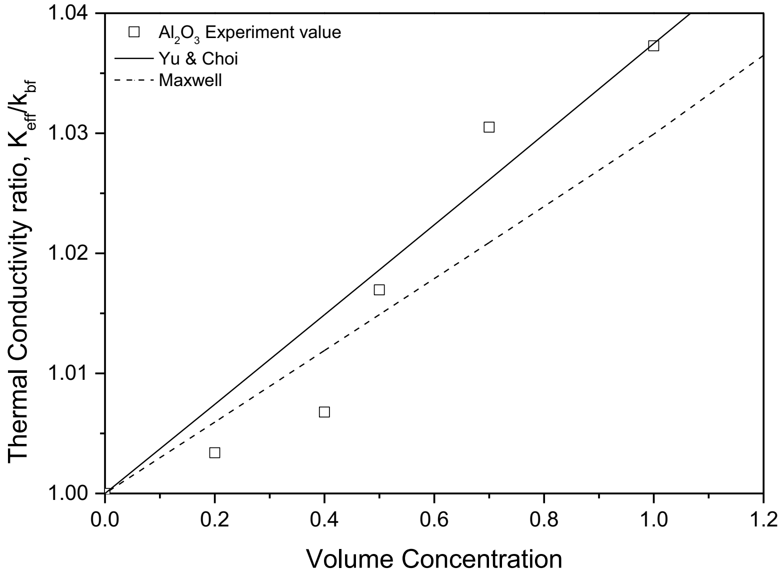
$$k_r = \frac{k_{eff}}{k_{bf}} = \left[\frac{k_p + 2\,k_{bf} + 2\left(k_p - k_{bf}\right)\varphi}{k_p + 2\,k_{bf} - 2\left(k_p - k_{bf}\right)\varphi} \right] \tag{1}$$

$$k_r = \frac{k_{eff}}{k_{bf}} = \left[\frac{k_p + 2k_{bf} + 2\left(k_p - k_{bf}\right)\left(1+\beta\right)^3 \varphi}{k_p + 2k_{bf} - \left(k_p - k_{bf}\right)\left(1+\beta\right)^3 \varphi} \right] \tag{2}$$

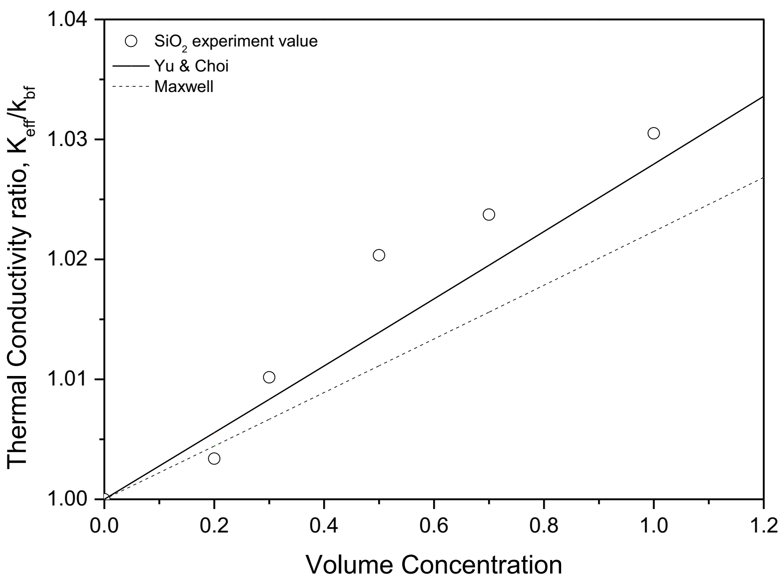
Fig. 1. KD2 Pro Thermal properties analyzer with water bath.

4 Results and discussion

Figure 4(a) and (b) show the thermal conductivity of the Al_2O_3/PAG and SiO_2/PAG nanolubricants at 30 °C for 0.2 to 1.0% volume concentrations. The figure shows that the thermal conductivity of the nanolubricant increases with volume concentration. The experimental data were also been compared to the estimated values obtained from earlier published model in literature. The experimental values for these study were found to be slightly higher than the Maxwell [11] model. However, the model by Yu and Choi [12] seem agreed with the experimental value in some extent. The mean and maximum deviation of the experimental values of Al_2O_3/PAG nanolubricant compared to Yu and Choi [12] as depicted in Figure 4(a) is 0.36 and 0.80 %, respectively. While for SiO_2/PAG nanolubricant, the mean and maximum deviation compared to the same model as shown in Figure 4(b) is 0.34 and 0.63 %, respectively. Mahbubul et al. [13] on the hand have compared their thermal conductivity experimental value of Al_2O_3-R141b nanorefrigerant with Maxwell [11]. The results showed that their experimental data also is much higher compared to Maxwell [11] by 34% deviation. By comparing with other researcher result, the thermal conductivity result in this study is found to be in a good agreement with these two models.



(a)



(b)

Fig. 4. Variations of thermal conductivity ratio as a function of volume concentration at 30^{o}C (a) Al_2O_3 nanolubricant (b) SiO_2 nanolubricant.

Figure 5 shows the thermal conductivity of the nanolubricants as a function of temperature. The highest thermal conductivity is 0.153 W.(m $\cdot$ K)$^{-1}$ achieved by Al_2O_3/PAG at 1.0% volume concentration and temperature of 30 ^{o}C. In addition, the enhancement ratio of Al_2O_3/PAG nanolubricant is 1.04 higher when compared to pure PAG under the same volume concentration and temperature. While for SiO_2/PAG nanolubricant, the maximum thermal conductivity achieved is 0.152 W.(m·K)$^{-1}$, slightly lower compared to Al_2O_3/PAG under the same condition. This is reasonable because the thermal conductivity of SiO_2 nanoparticle is 1.4 W.(m·K)$^{-1}$ lower compared to 36 W.(m·K)$^{-1}$ by Al_2O_3 nanoparticle. The enhancement ratio is 1.03, just slightly lower to Al_2O_3/PAG. This result is supported by Jiang et al. [14] when they concluded that thermal conductivities of nanorefrigerants with various types of nanoparticles are quite similar to one another if the nanoparticle volume fractions are similar.

Figure 5 also depicted that the measured thermal conductivity for all volume concentrations decreased with the increasing of temperature. The pattern is well agreed with the pure PAG behaviour as plotted using the data from Booser [15] which presented by the solid straight line in Figure 5. This behavior could be explained when liquid is heated, the molecules of the liquid move apart, hence increase the mean path. Consequently the probability of collision of molecules will be reduced. As the result, thermal conductivity decrease with increase in temperature.

Consequently, Eq. (3) is developed to estimate the thermal conductivity of nanolubricants for different volume concentrations and wide range of temperature. The correlation has an average deviation of 0.34% and standard deviation of 0.26%. The equation is in good agreement within ± 1.5% deviation compared to the experimental data and applicable for $0 \le \phi \le 1.0\ \%$ and $30 \le T \le 80$ °C.

$$k_r = \frac{k_{NL}}{k_L} = 0.15\left(1+\frac{\phi}{100}\right)^4\left(1+\frac{T}{80}\right)^{-0.05} \qquad (3)$$

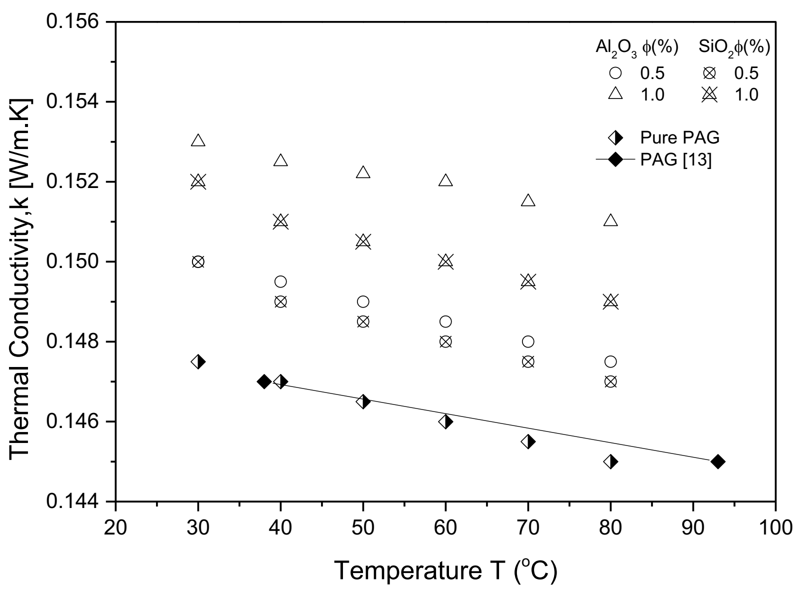


Fig. 5. Thermal conductivity of nanolubricants as a function of temperature at different volume concentration.

5 Conclusions

Thermal conductivity of nanolubricants has been studied. The experimental investigation found that the thermal conductivity of the nanolubricants increases with volume concentration, but decreases with the increase of the temperature.

Thermal conductivity of Al_2O_3/PAG and SiO_2/PAG nanolubricants also has been compared. It is found that the thermal conductivity of Al_2O_3/PAG nanolubricant is slightly higher but not significant compared to SiO_2/PAG nanolubricant. The highest value of experimental reading is recorded by Al_2O_3/PAG nanolubricant with value of 0.153 W.(m·K)$^{-1}$ with enhancement of 1.04. Referring to thermal conductivity result, the Al_2O_3/PAG nanolubricant is suggested to be used as nanolubricant in compressor because its thermal conductivity is superior compared to SiO_2/PAG nanolubricant. Further thermo-physical investigation is needed to be done in order to achieve concrete conclusion of better enhancement between these two nanolubricant. Therefore, it is recommended to further investigate the thermo-physical of these nanolubricants especially their viscosity behavior towards the increment of volume concentrations and temperature.

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References

1. S. Bi, K. Guo, Z. Liu, and J. Wu, "Performance of a domestic refrigerator using TiO_2-R600a nano-refrigerant as working fluid," *Energy Conversion and Management,* vol. 52, pp. 733-737, 2011.
2. M. A. Kedzierski, "R134a/Al_2O_3 nanolubricant mixture pool boiling on a rectangular finned surface," *Journal of Heat Transfer,* vol. 134, p. 121501, 2012.
3. M. A. Kedzierski, R. Brignoli, K. T. Quine, and J. S. Brown, "Viscosity, Density, And Thermal Conductivity Of Aluminum Oxide And Zinc Oxide Nanolubricants," *International Journal of Refrigeration*.
4. K. Henderson, Y.-G. Park, L. Liu, and A. M. Jacobi, "Flow-boiling heat transfer of R-134a-based nanofluids in a horizontal tube," *International Journal of Heat and Mass Transfer,* vol. 53, pp. 944-951, 2010.
5. P. L. Matlock, W. L. Brown, and N. A. Clinton, "Polyalkylene glycols," *Chemical Industries-New York-Marcel Dekker,* pp. 159-194, 1999.
6. W. L. Brown, "Polyalkylene glycols," *CRC Handbook of Lubrication and Tribology,* vol. 3, pp. 253-267, 1993.
7. Dow, "Material Safety Data Sheet," *Ucon Refrigerant Lubricant 213,* 2013.
8. W. Yu and H. Xie, "A review on nanofluids: preparation, stability mechanisms, and applications," *Journal of Nanomaterials,* vol. 2012, p. 1, 2012.
9. M. Z. Sharif, W. H. Azmi, A. A. M. Redhwan, and R. Mamat, "Investigation of thermal conductivity and viscosity of Al2O3/PAG nanolubricant for application in automotive air conditioning system," *International Journal of Refrigeration,* vol. 70, pp. 93-102, 10// 2016.
10. I. Zakaria, W. H. Azmi, W. A. N. W. Mohamed, R. Mamat, and G. Najafi, "Experimental investigation of thermal conductivity and electrical conductivity of Al_2O_3 nanofluid in water-ethylene glycol mixture for proton exchange membrane fuel cell application," *International Communications in Heat and Mass Transfer,* vol. 61, pp. 61-68, 2015.

11. J. C. Maxwell, *A Treatise on Electricity and Magnetism*, 2nd ed. Cambridge, U.K.: Oxford University Press, 1904.
12. W. Yu and U. S. Choi, "The role of interfacial layers in the enhanced thermal conductivity of nanofluids: A renovated Maxwell model," *Journal of Nanoparticle Research,* vol. 5, pp. 167-171, 2003.
13. I. M. Mahbubul, R. Saidur, and M. A. Amalina, "Influence of particle concentration and temperature on thermal conductivity and viscosity of Al_2O_3/R141b nanorefrigerant," *International Communications in Heat and Mass Transfer,* vol. 43, pp. 100-104, 2013.
14. W. Jiang, G. Ding, H. Peng, Y. Gao, and K. Wang, "Experimental and model research on nanorefrigerant thermal conductivity," *HVAC&R Research,* vol. 15, pp. 651-669, 2009.
15. E. R. Booser, *CRC Handbook of Lubrication and Tribology, Volume III: Monitoring, Materials, Synthetic Lubricants and Applications* vol. 3. USA: CRC Press LLC, 1994.