

Performance Analysis of TiO₂ and SiO₂ Nano-lubricant in Domestic Refrigeration

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Abstract— The transportation industry is no doubt a fast growing industry globally. In the recent years, the use of nano fluids have been proposed in the refrigeration and air-conditioning system as primary, secondary fluids and lubricants to enhance the performance of the system. This present study focuses on the use of TiO₂ and SiO₂ nano lubricants to improve the performance of the vapour compression system. Pure mineral oil was used as the base fluid and the performances were compared with that of the TiO₂ and SiO₂ nano lubricant using R600a refrigerant as the working fluids in the system. The result showed that R600a performed better in the nano lubricant compared to the base lubricant in terms of coefficient of performance, power consumption and the cooling capacity of the system.

Keywords- Automobile Industry, Composite material, Epoxy resin, Thermoplastic Polymer.

I. Introduction

Energy consumption is one the major consideration the refrigerator consumers consider in choosing the choice of the refrigerator. In homes and industries refrigeration systems consume considerable amount energy. The use of Nanotechnologies by introducing Nano fluid into refrigeration system is capable of providing solution to the high energy consumption associated with refrigeration systems. The use of Nano fluid in cooling applications such as refrigeration systems is gaining attention. Nanoparticles when dispersed in the based fluids are capable of enhancing the heat transfer performance of the fluid. The performance of nanoparticles in the based fluids depend on size, shape, surface area and concentration of the Nano fluids [1]–[4].

There have been numerous efforts to improve the performance of refrigeration system through the use of Nano fluids in refrigeration systems. Nano fluids have been used by some researchers to enhance the performance of refrigeration systems. Nabil et al. [5] carried a research on heat transfer of water-ethylene glycol using TiO₂ nanoparticles within 30°C – 80°C. The result showed 15% enhancement in the heat transfer and 22.8% to 28.95 increase in the Nusselt number.

Wang et al. [6] conducted research experiment on the performance of fullerene (70) and NiFe₂O₄ Nano lubricant and compared with the based lubricant in a VCRS. The result showed that the coefficient of performance of the system increase up to 23%. Maheshwary et al. [7] investigated the influence of Nano particles shapes on the heat transfer of ZnO/R134a and compared it with R13a in vapour compression system. The result showed ZnO/R134a increases with 42.5% compared to R134a. Zawawi et al. [8] conducted experiment on PAG oil using hydride nanoparticles (Al₂O₃- TiO₂, Al₂O₃-SiO₂ and TiO₂-SiO₂), KD2Pro was used as the measuring instrument. The result showed 20% increment in viscosity for Al₂O₃-TiO₂/PAG oil and 2.4% rise in the thermal conductivity for Al₂O₃-SiO₂/PAG oil. In another related research Redhwan et al. [9] also investigated Al₂O₃/PAG as a substitute for PAG oil in air-conditioning system, the result showed increase in thermal conductivity and viscosity of Al₂O₃/PAG Nano lubricant.

Nowadays R600a is the commonly used hydrocarbon refrigerant in domestic vapor compression systems. Therefore, this work studies focus on the use of TiO₂ and SiO₂ Nano lubricant as a substitute for the based lubricant (mineral oil) in domestic refrigerator working with R600a. R600a is a hydrocarbon refrigerant which has zero ozone depleting potentials (ODP) and very low global warming potentials (GWP), cheaper and available especially in major oil producing nations.

II. Experimental Method and Procedure

The test rig used for this experiment was a domestic refrigerator. The system was evacuated with the aid of vacuum flusher. The TiO₂ and SiO₂ nanoparticles were measured using a digital scale; the TiO₂ and SiO₂ Nanoparticles were dispersed in the mineral oil, and two samples (0.6g/L TiO₂ and SiO₂ Nano-concentration) were prepared for a 60g mass charge of R600a refrigerant. The R600a refrigerant was charged into the system with the aid of digital charging system. Each TiO₂ and SiO₂ Nano lubricant sample was agitated using an ultrasonic oscillator. The temperatures were taken at inlet and outlet of different components (compressor, evaporator, condenser and capillary tube) of the system with four K-type thermocouples were used to measure the temperature at the inlet and outlet of each component. Also, two pressure gauges were connected to suction and discharge of the compressor to measure the suction and discharge pressure of the compressor. The measurement of the uncertainty of measuring instruments and

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the experimental test rig and condition are shown in Figure 1-2 and Table 1-2. The temperature and pressure readings were taken and repeated for five times at intervals of 30 minutes. The uncertainties of the measuring instruments used are shown in Table 1. The outputs of temperature and pressure readings were used to determine the enthalpy and entropy of the refrigerant using the Ref-prop, version 9.0. These results were used to evaluate the coefficient of performance (COP), cooling capacity, power consumption, thermal conductivity and viscosity of the system. The performance evaluation for the experimental result was calculated by the following equations [1-3].

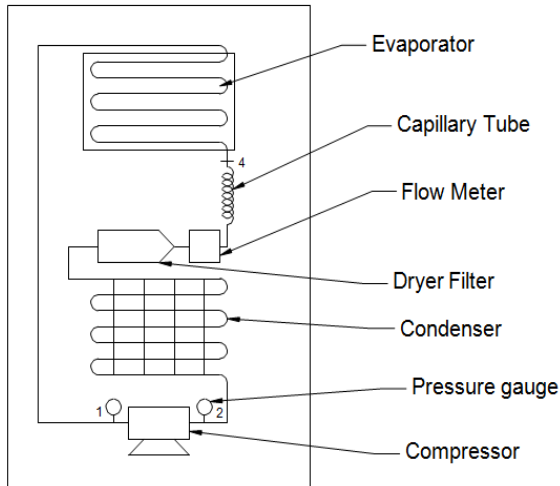


Figure.1 Schematic diagram of the experimental test rig

TABLE 1. SPECIFICATIONS OF THE MEASURING INSTRUMENT AND UNCERTAINTY

S/N	Parameter	Specification	Range	Uncertainty
1	Temperature	Thermocouple K	-50°C - 700°C	±3°C
2	Pressure	pressure gauge	5 - 4000 Pa	±1%
3	Power consumption	Wattmeter	1- 2000W (0.0001- 999.9 kWh)	±1%

TABLE 2. CHARACTERISTICS OF THE LUBRICANT

S/N	Pure lubricant characteristics	Unit
1	Oil type	Capella mineral oil
2	ISO viscosity grade	68
3	Flash point	-36°C
4	Density at 15°C kg/L	0.91
5	Kinematic viscosity (mm ² /s) at 40°C	68
6	Kinematic viscosity (mm ² /s) at 40°C	6.8
7	Viscosity index	22
8	Code	041562

TABLE 3. RANGE AND CONDITIONS OF THE EXPERIMENT

S/N	Parameters	Range of Experiment
1	Refrigerant mass charge	60g
2	Refrigerant	R600a
3	Compressor lubricant	Pure lubricant, TiO ₂ and SiO ₂ Nano-lubricants
4	TiO ₂ Nanoparticles SiO ₂ Nanoparticles	15nm 5-15nm
5	Nano-lubricant concentration	0.6g/L
6	Test environment temperature	27°C
7	Capillary tube length	1.5m
8	Condenser type	Air cooled
9	Evaporator size	70litres

The system performance of the system was evaluated using the equation 1-3

Cooling capacity (Q_{evap}) is capacity given by

$$Q_{evap} = m(h_4 - h_1) \quad (\text{kW}) \quad (1)$$

The compressor power input is given by

$$W_c = m(h_2 - h_1) \quad (\text{kW}) \quad (2)$$

Coefficient of performance

$$COP = \frac{Q_{evap}}{W_c} \quad (3)$$

III. Experimental Result and Discussion

Figure 2- 7 illustrate the effect of TiO₂ and a SiO₂ Nano lubricant concentration on the system pull-down time, COP,

power consumption, discharge thermal conductivity and viscosity of R600a in the based lubricant and the Nano lubricant in the system.

Fig. 2 shows the pull-down time of the R600a refrigerant in the based lubricant, TiO₂ and SiO₂ Nano lubricant concentration. The Evaporator air temperature of -5, -10, -11°C were attained at the pull-down time of 210, 210 and 240 minutes for R600a in the based lubricant, TiO₂ and SiO₂ Nano lubricant concentration respectively in the system. This is corroborate with the work of Anish et al. [10] and Hussain et al. [11] where a shorter pull down time was achieved as a result of enhancement in heat transfer rate performance due to application nanoparticles into the based lubricant.

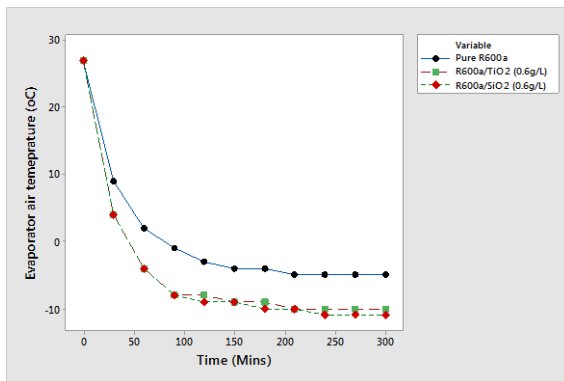


Figure 2. Effect of Nano lubricant concentration on the pull-down time of the system

Fig. 3 depicts the coefficient of performance (COP) of the system. The COP of R600a in the based lubricant, TiO₂ and SiO₂ Nano lubricant are 2.1, 2.6 and 2.51 respectively. The COP of R600a is in TiO₂ and SiO₂ Nano lubricant are 23% and 19.5% greater than R600a in the based lubricant. The result is in line with the work [12], [13].

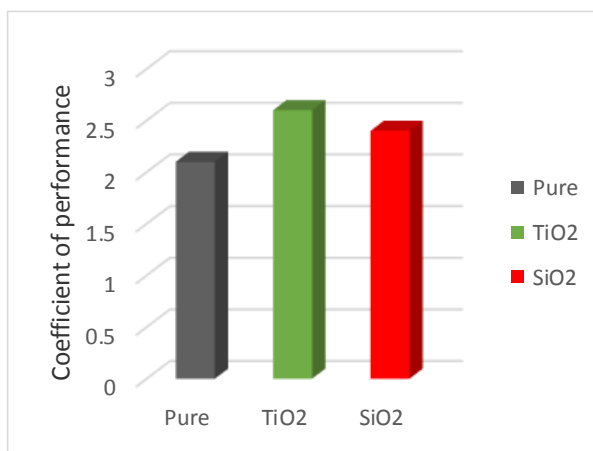


Figure 3. Effect of Nano lubricant concentration on the COP of the system

Fig. 4 shows the cooling capacity R600a in the system. The cooling capacity of the R600a in the pure lubricant, TiO₂ and SiO₂ Nano lubricant are 173.6W, 197.2W and 199.5W respectively. The cooling capacity of TiO₂ and SiO₂ Nano lubricant is higher than the R600a in based lubricant with 13.6% and 14.9% respectively. This is due to enhancement in the heat transfer as a result of increase in the thermal conductivity of the system.

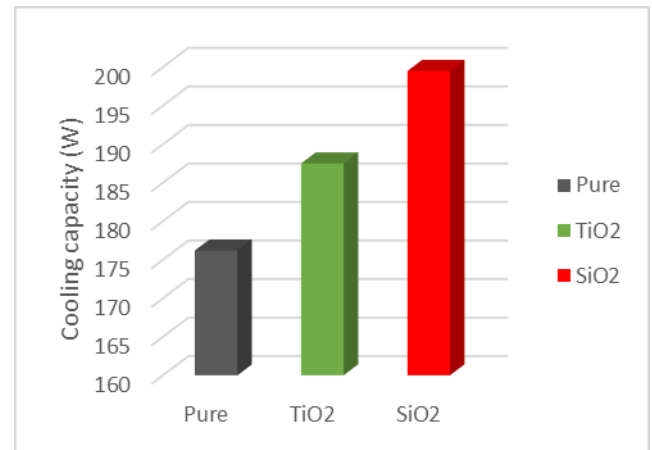


Figure 4. Effect of nanolubricant concentration on the cooling capacity of the system

Fig. 5 shows the power consumption of the system. The power consumption of the R600a in the pure lubricant, TiO₂ and SiO₂ Nano lubricant are 82.1W, 75.2W and 79.5W respectively. The power consumption of TiO₂ and SiO₂ Nano lubricant is lower than the R600a in based lubricant with 8.4% and 3.2% respectively. The reduction in the power consumption can be attached to reduction in the friction force in the compressor system [14], [15].

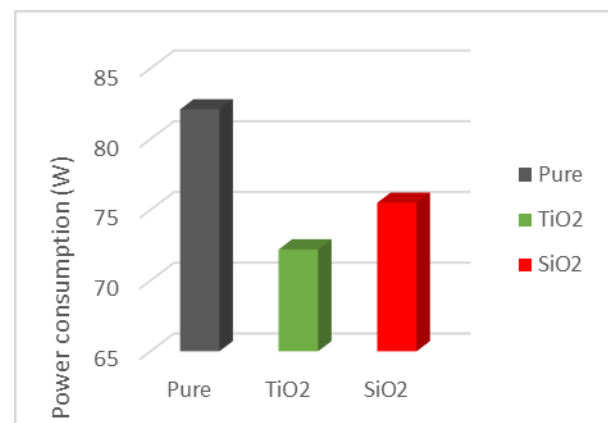


Figure 5. Effect of nanolubricant concentration on the power consumption of the system

Fig. 6 and 7 shows the discharge thermal conductivity and viscosity of the system, the discharge thermal conductivity of R600a in the based lubricant and TiO₂ and SiO₂ Nano lubricant concentration are 21.2 mW/m-k 21.6 mW/m-k and 21.4 mW/m-k respectively. This result is in line with the result of Farshad et al. [2], [16] that the thermal conductivity of R600a in Nano lubricant increased as a result of the larger thermal conductivity of Nanoparticles dispersed in the base lubricant.

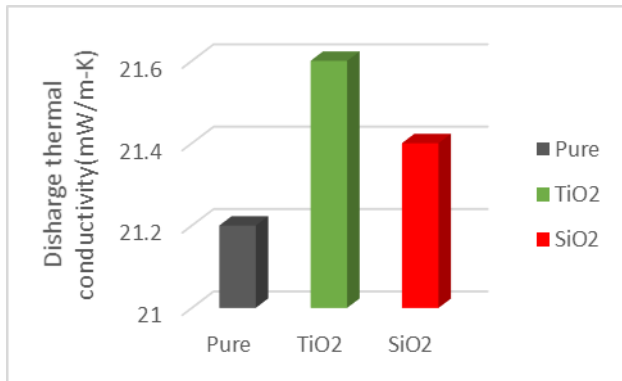


Fig. 6 Effect of nanolubricant concentration on the thermal conductivity of the system

Figure 5 and 6 shows the discharge and suction viscosity of the system, the discharge viscosity of R134a, R600a in the based lubricant, TiO₂ and SiO₂ Nano lubricant concentration are 8.5 μPa-s, 8.6 μPa-s, 8.5 μPa-s respectively. The discharge viscosity of R600a in TiO₂ Nano lubricant concentration increased with 1.8% compared to R600a in the based lubricant and SiO₂ Nano lubricant in the system, this is because of the Newtonian behavior of the Nano lubricant [16].

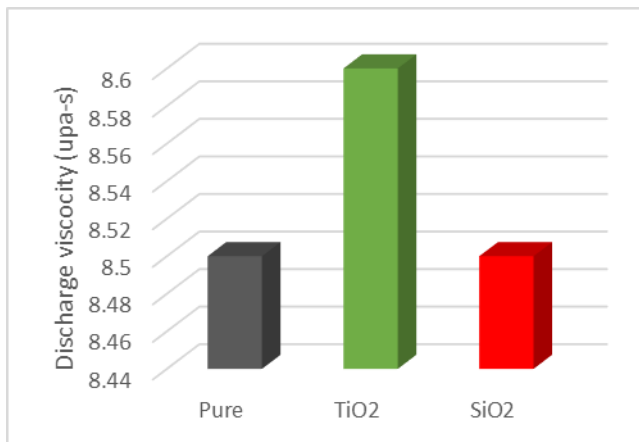


Fig. 7 Effect of nanolubricant concentration on the thermal conductivity of the system

IV. Conclusion

After studying the effect of TiO₂ and SiO₂ Nano lubricant in the vapour compression refrigerator system working with R600a. The following inferences were made;

- Shorter pull down time and lower evaporator air temperature was attained in the system using TiO₂ and SiO₂ Nano lubricant compared to the base fluid with SiO₂ concentration offering the lowest evaporator air temperature.
- Higher COP was attained in R600a of Nano lubricant compared to the R600a in the based lubricant.
- A decrease in power consumption was obtained throughout using TiO₂ and SiO₂ Nano lubricant.
- The thermal conductivity of the system was enhanced with TiO₂ Nano lubricant in the system.
- R600a in TiO₂ Nano lubricant offers a best performance compared to R600a in the based lubricant and SiO₂ Nano lubricant

References

- [1] C. Choi, H. S. Yoo, and J. M. Oh, "Preparation and heat transfer properties of nanoparticle-in-transformer oil dispersions as advanced energy-efficient coolants," *Curr. Appl. Phys.*, vol. 8, no. 6, pp. 710–712, 2008.
- [2] T. O. Babarinde, S. A. Akinlabi, and D. M. Madyira, "Enhancing the Performance of Vapour Compression Refrigeration System using Nano Refrigerants: A review," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 413, p. 012068, 2018.
- [3] S. U. S. Choi, "JAM 11 19s5," 1995.
- [4] W. Yu, D. M. France, J. L. Routbort, and S. U. S. Choi, "Review and comparison of nanofluid thermal conductivity and heat transfer enhancements," *Heat Transf. Eng.*, vol. 29, no. 5, pp. 432–460, 2008.
- [5] M. F. Nabil, W. H. Azmi, K. Abdul Hamid, R. Mamat, and F. Y. Hagos, "An experimental study on the thermal conductivity and dynamic viscosity of TiO₂-SiO₂nanofluids in water: Ethylene glycol mixture," *Int. Commun. Heat Mass Transf.*, vol. 86, pp. 181–189, 2017.
- [6] R. Wang, Y. Zhang, and Y. Liao, "Performance of rolling piston type rotary compressor using fullerenes (C70) and NiFe 2 O 4 nanocomposites as lubricants additives," 2017.
- [7] P. B. Maheshwary, C. C. Handa, and K. R. Nemade, "Effect of Shape on Thermophysical and Heat Transfer Properties of ZnO/R-134a Nanorefrigerant," *Mater. Today Proc.*, vol. 5, no. 1, pp. 1635–1639, 2018.
- [8] N. N. M. Zawawi, W. H. Azmi, A. A. M. Redhwan, M. Z. Sharif, and K. V. Sharma, "Propriétés thermo-physiques du nanolubifiant composite Al₂O₃-SiO₂/PAG pour les systèmes frigorifiques," *Int. J. Refrig.*, vol. 80, pp. 1–10, 2017.
- [9] M. Z. Sharif, W. H. Azmi, A. A. M. Redhwan, and R. Mamat, "Étude de la conductivité thermique et de la viscosité de nanolubifiant Al₂O₃/PAG appliqué au système de conditionnement d'air d'automobile," *Int. J. Refrig.*, vol. 70, pp. 93–102, 2016.
- [10] M. Anish, G. Senthil Kumar, N. Beemkumar, B. Kanimozhi, and T. Arunkumar, "Performance study of a domestic refrigerator using CuO/AL₂O₃-R22 nanorefrigerant as a working fluid," *Int. J. Ambient Energy*, vol. 0750, 2018.
- [11] Z. Hussain, T. Hayat, A. Alsaedi, and B. Ahmad, "Three-dimensional convective flow of CNTs nanofluids with heat generation/absorption effect: A numerical study," *Comput. Methods Appl. Mech. Eng.*, vol. 329, pp. 40–54, 2018.
- [12] T. O. Babarinde, S. A. Akinlabi, D. M. Madyira, O. S. Ohunakin, D. S. Adelekan, and S. O. Oyedepo, "Comparative analysis of the exergetic performance of a household refrigerator using R134a and R600a," *Int. J. Energy a Clean Environ.*, vol. 19, no. 1–2, pp. 37–48, 2018.

- [13] W. Zhang *et al.*, “Research on the flammability hazards of an air conditioner using refrigerant R-290” d ’ un Recherches sur les risques d ’ inflammabilite conditionneur d ’ air fonctionnant au R-290,” *Int. J. Refrig.*, vol. 36, no. 5, pp. 1483–1494, 2013.
- [14] C.-S. Jwo, L.-Y. Jeng, T.-P. Teng, and H. Chang, “Effects of nanolubricant on performance of hydrocarbon refrigerant system,” *J. Vac. Sci. Technol. B Microelectron. Nanom. Struct.*, vol. 27, no. 3, p. 1473, 2009.
- [15] N. Subramani and M. Prakash, “Experimental studies on a vapour compression system using nanorefrigerants,” *Int. J. Eng. Sci. Technol.*, vol. 3, no. 9, pp. 95–102, 2012.
- [16] F. Farzin, S. Z. Heris, and S. Rahimi, “Laminar Convective Heat Transfer and Pressure Drop of TiO₂/Turbine Oil Nanofluid,” *J. Thermophys. Heat Transf.*, vol. 27, no. 1, pp. 127–133, 2013.



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