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COMPARATIVE PERFORMANCE OF R600A-Al_2O_3-MO NANOFLUIDS IN A DOMESTIC REFRIGERATOR USING R134a WORKING FLUID

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ABSTRACT
In this study, the energetic performance of a slightly modified R134a domestic refrigerator using a limited mass charge (30g) of R600a refrigerant and various concentrations (0, 0.2, 0.4 and 0.6 g/L) of Al_2O_3-Mineral oil lubricants was evaluated. Performance evaluated include: cabinet temperature, refrigeration capacity, power consumption and coefficient of performance. Results showed that the application of the Al_2O_3 based nanolubricants gave lower steady state cabinet temperature, coefficient of performance and refrigeration capacity in comparison to the baseline (0 g/L) lubricant. The energy consumption of the system decreased by 0.7 % for 0.6 g/L concentration and increased by 15-24 % for 0.2 and 0.4 g/L nanolubricant concentrations in comparison to the baseline system. In conclusion, 0.6g/L concentration of Al_2O_3 based nanolubricants could be used as a substitute within the system.

Keywords: Domestic refrigerator, Al_2O_3 nanolubricant, nanoparticle.

NONMENCLATURE

Abbreviations	
MO	Mineral Oil
Symbols	
h	Enthalpy

1. INTRODUCTION

Increasing consensus is calling for the replacement of conventional refrigerants [such as chlorofluorocarbons (CFCs), hydro-chlorofluorocarbons (HCFCs) and hydro-fluorocarbons (HFCs)] used in domestic refrigerators. Some of the notable justifications for this replacement include, (i) climate change contributions (through Ozone depletion and high global warming) [1], (ii) high energy consumptions and low exergy efficiencies [2], (iii) impracticability of compact refrigerator designs [3], and (iv) high refrigerant charge utilization [4]. Thus renewed interests in hydrocarbons based refrigerants are being witnessed in spite of their flammability concerns [5]. Studies have reported hydrocarbon based refrigerants to be safe and efficient for domestic refrigerators [4]. Besides, hydrocarbons have low global warming effect and neutral reaction to Ozone layer [5]. In the work of Corberan et al. [6], the safety of hydrocarbon-based refrigerants with charges lesser than or equal to 150g within any domestic location was guaranteed, on the basis of their operating temperature, pressure and ventilation/airflow conditions. Rasti et al. [7] established direct correlation between the mass charge and flammability limit of hydrocarbon based refrigerants. Thus, studies abound on the performance of hydrocarbons based refrigerant within domestic refrigerators recently. An attempt to improve the performance of a deliberately lowered liquefied petroleum gas (LPG) refrigerant charge (40g) in a domestic refrigerator infused with TiO_2 based nano lubricants was effective in the work of Adelekan et al. [4]. An updated overview on hydrocarbons based refrigerants used in heating, ventilation and air conditioning systems (HVAC) by Harby [5], showed that hydrocarbons are suitable retrofits to conventional refrigerants. Identified reasons include enhancements in environmental efficiency, energy efficiency, coefficient of performance, refrigerant mass charge reduction, and compressor discharge temperature reduction. However, the work of Mohamed and Fatouh [8], presented shortcomings when domestic refrigerators were retrofitted experimentally and theoretically with LPG and R600a refrigerants.

Recently, the application of nanofluids in domestic refrigerators is a promising prospect [9]. Numerous enhancements have been reported with the application nanofluids within domestic refrigeration systems [10]. Nanofluids are simply homogenously dispersed nanoparticles within suitable base fluids (like engine oil, compressor lubricants, engine oil, ethylene glycol, water, refrigerant, etc.). Solids with a maximum size range of 1-100nm are referred to as nanoparticles, and their small dimensions and large specific surface areas within

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nanofluids have been linked to efficiency improvements in engineering systems[11]. The observed enhancements in thermo-physical properties (especially thermal conductivities) of nanofluids have been linked to inducements of thermophoresis and Brownian motion effects, which improves heat transfer characteristics of thermal systems [11]. Generally, dispersed solids' (i.e. nanoparticles) have higher thermal conductivities than base liquids/fluids. Thus, nanofluids have thermal conductivities higher than their corresponding base fluids. In addition, nanoparticles induces rolling friction effects at molecular level within compressors using nanolubricants (a homogenized mixture of compressor lubricant and nanoparticles). In the work of Ohunakin et al. [12], the energetic performance of a domestic refrigerator infused with SiO_2 based nanolubricants considerably improved. Domestic refrigerators can be infused of nanofluids in form of either nano lubricants (a homogenous mixture of nanoparticles in suitable compressor lubricant) or nano refrigerants (a homogenous mixture of nanoparticles in suitable refrigerant). The application nanofluids in domestic refrigerators have improved their energetic and exergetic performances of refrigerators [13]; refrigerants forced boiling and convective heat transfer [14]; discharge temperature reduction [4], compressor lubricant tribology characteristics [15]; compressor oil recovery [14]; total equivalent warming impact (TEWI) reduction [7]; and refrigerant charge reduction [4]. In the work of Gill et al. [13], an experimental substitution of R134a working fluid with LPG refrigerant and TiO_2 Al_2O_3 and SiO_2 nanolubricants in a domestic refrigerator improved the energetic and exergetic performance of the system. Similarly, the application of selected concentrations of TiO_2 nano lubricant in a domestic refrigerator using R600a refrigerant worked safely and enhanced the energetic performance of the system in an experimental investigation carried out by Bi et al. [16]. A comprehensive review of applications of nanofluids in domestic refrigerators showed prospects of improved performance and durability in the work of Azmi et al. [17].

In spite of available studies on the effect of nanoparticle concentrations on energetic performance of domestic refrigerators within recent literatures, authors have found scanty work investigating the potential of commercially available Al_2O_3 nanoparticles within domestic refrigerators using R600a refrigerant. This study investigates the energetic potential of selected concentrations of Al_2O_3 based nanolubricant within a domestic refrigerator using R600a working fluid.

2. MATERIALS AND METHOD

2.1 Test rig and Instrumentation

In this work, a 100g R134a domestic refrigerator was modified with valves along the compressor suction and discharge lines and fitted with appropriate digital pressure gauges, thermocouples and a watt meter (See fig 1 for experimental setup). The incorporated valves enabled the fitting of the digital pressure gauges, and charging and discharging spent refrigerant within the system. The digital pressure gauges measured the refrigerant suction and discharge pressures, while the installed thermocouples monitored the suction, discharge, condensing and cabinet air temperatures of the refrigerant. The instantaneous energy consumption of the system was obtained from affixed watt meter (See Table 1 for test rig description and measuring instrument details).

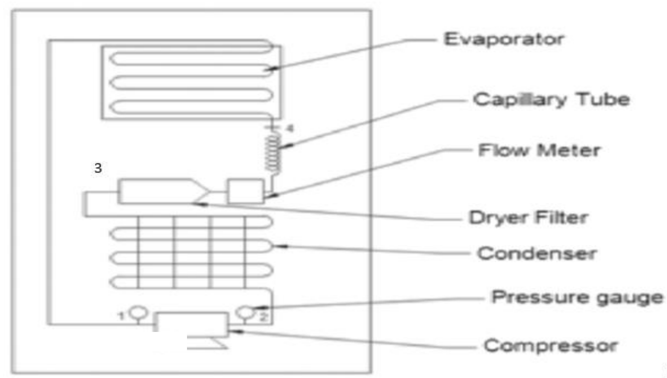

Fig 1: Schematic Diagram of the Test Rig

Table 1: Test Rig Description and Measuring Instrument Details

	S/N	Description	Specification	Type
Test rig details	1	Compressor	150 W	scroll type
	2	Condenser	Fin on tube	Air cooled
	3	Capillary tube	2 m	Copper
	4	Dryer	Adiabatic	Copper
	5	Evaporator	Plate type	Aluminum
Measuring Instrument details	1	Pressure	5-5000 Pa	Digital
	2	Thermocouple	-50 / +750 ^oC	Digital
	3	Watt meter	1-3000 W	Digital

2.2 Nanolubricant Preparation

The nanoparticle sample utilized for this investigation was Al_2O_3 based nanoparticle having 99.8 % purity, 13nm size and procured from Aldrich chemistry.

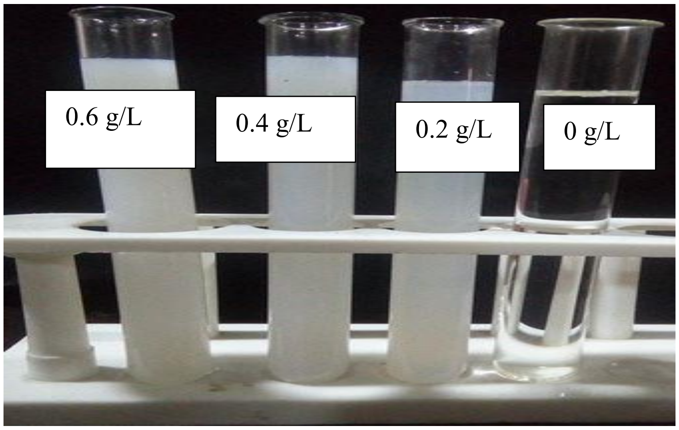

Fig 2: Image of 24 hrs Ultrasonificated nanolubricants.

The required nanolubricant concentrations were obtained by weighing the nanoparticles on a digital balance (Ohaus Pioneer TM PA114) and separately mixing and homogenized them within a locally procured mineral oil based compressor lubricant. A Branson M2800H ultrasonic vibrator was used to achieve homogenization within the respective nanolubricants. According to Fuskele and Sarviya [18], stability of nanolubricants are required for improved performance within thermal systems. Thus, the prepared nanolubricants were monitored for sedimentation after 24 hrs of preparation (See fig 2). Results showed that the nanolubricant were stable.

2.3 Theory/calculation

$$Refrigeration\ capacity = Q_e = (h_1 - h_3)$$

$$Coefficient\ of\ Performance = \frac{\dot{m}(h_1-h_3)}{\dot{m}(h_2-h_1)} = \frac{(h_1-h_3)}{(h_2-h_1)}$$

Where h_1 is saturated vapor enthalpy, h_2 is superheated vapor enthalpy, h_3 is saturated liquid enthalpy and $\dot{m}$ is the refrigerant mass flow rate.

2.4 Results

This section presents results of investigated energetic characteristics of within the test rig.

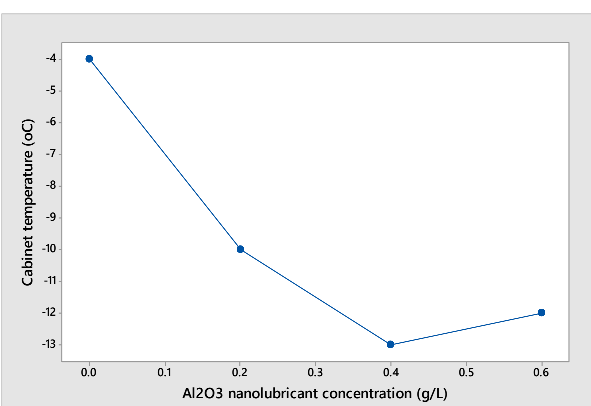

Fig 3: Cabinet temperature variation

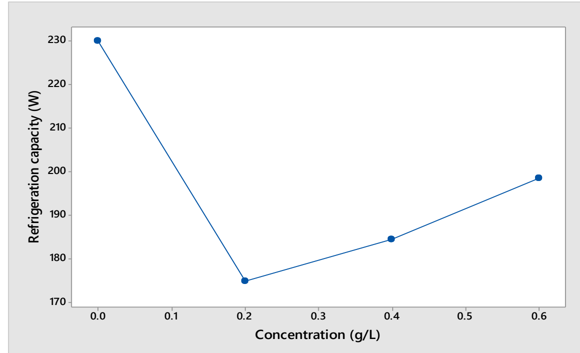

Fig 4: Refrigeration capacity variation

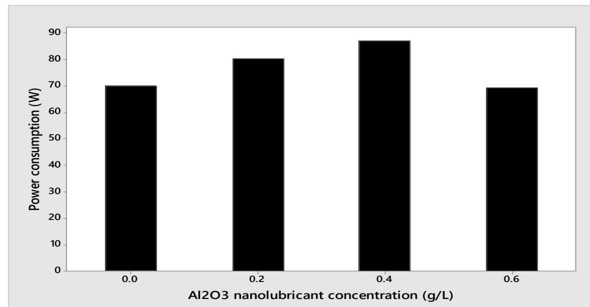

Fig 5: Power consumption variation

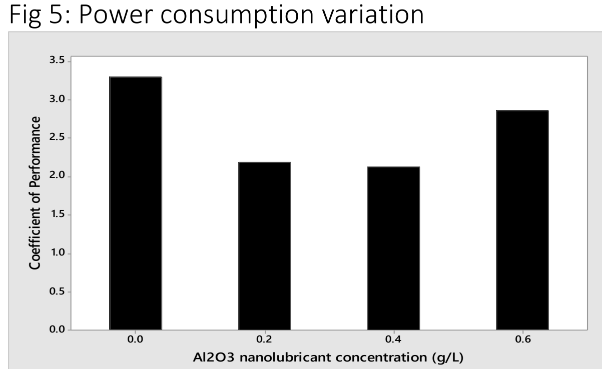

Fig 6: Coefficient of performance variation

2.5 Discussion

Fig 3 described the steady state cabinet temperatures of the various Al_2O_3 nanolubricants concentration infused into the test refrigeration system. It can be seen that the Al_2O_3 nanolubricants gave lower cabinet temperatures in comparison to the baseline lubricant. Furthermore, the cabinet temperatures attained within the system were lower than ISO 8187 recommended cabinet temperature of -3 ^oC.

The refrigeration capacity of the system was reduced and increased with increasing Al_2O_3 nanolubricant concentration (see Fig 4). The refrigeration capacity range obtained within the test rig was 230 W for the baseline lubricant and 175 W for 0.2 g/L Al_2O_3 based nanolubricant concentration.

Fig 5 shows the power consumption variations of the system. It can be seen that the power consumption of the system increased by 15-24 % for 0.2 and 0.4 g/L nanolubricant concentration and decreased by 0.7 % for 0.6 g/L concentration in comparison to the baseline lubricant. The use of 0.6 g/L nanolubricant concentration gave the least power consumption value of 69 W, while the highest power consumption value of 87 W was obtained with the infusion of 0.4 g/L nanolubricant concentration into the system.

Fig 6 illustrates the variations of the coefficient of performance of the system. Increasing the nanolubricant concentration within the test rig reduced and increased the coefficient of performance of the system. In comparison to the baseline lubricant, the coefficient of performance of the system reduced by 13 - 36 %. The minimum coefficient of performance value within the system was 2.12 for 0.4 g/L nanolubricant concentration while the maximum coefficient of performance value was 3.29 for the baseline lubricant.

2.6 Conclusion

The experimental results of the application of Al_2O_3 nanolubricants within the system showed that it is a feasible retrofit option, having considered energetic characteristics including: cabinet air temperature, refrigeration capacity, power consumption and coefficient of performance. It was concluded that the use of 0.6 g/L of Al_2O_3 nanolubricant was the best substitute to the baseline (0 g/L) lubricant within the 30g R600a refrigeration system.

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REFERENCE

[1] Calm JM. The next generation of refrigerants - Historical review, considerations, and outlook. Int J Refrig 2008;31:1123–33. doi:10.1016/j.ijrefrig.2008.01.013.

[2] Bolaji BO, Huan Z. Ozone depletion and global warming: Case for the use of natural refrigerant - A review. Renew Sustain Energy Rev 2013; 18:49–54. doi:10.1016/j.rser.2012.10.008.

[3] Ghadiri F, Rasti M. The effect of selecting proper refrigeration cycle components on optimizing energy consumption of the household refrigerators. Appl Therm Eng 2014; 67:335–40. doi:10.1016/j.applthermaleng.2014.03.024.

[4] Adelekan DS, Ohunakin S, Gill J, Atayero A, Diarra CD, Asuzu A. Experimental performance of a safe charge of LPG refrigerant enhanced with varying concentrations of TiO2 nano-lubricant in a domestic refrigerator. doi:10.1007/s10973-018-7879-2.

[5] Harby K. Hydrocarbons and their mixtures as alternatives to environmental unfriendly halogenated refrigerants: An updated overview. Renew Sustain Energy Rev 2017; 73:1247–64. doi:10.1016/j.rser.2017.02.039.

[6] Corberán JM, Segurado J, Colbourne D, Gonzálvez J. Review of standards for the use of hydrocarbon refrigerants in A/C, heat pump and refrigeration equipment. Int J Refrig 2008; 31:748–56. doi:10.1016/j.ijrefrig.2007.12.007.

[7] Rasti M, Aghamiri S, Hatamipour MS. Energy efficiency enhancement of a domestic refrigerator using R436A and R600a as alternative refrigerants to R134a. Int J Therm Sci 2013;74:86–94. doi:10.1016/j.ijthermalsci.2013.07.009.

[8] Fatouh M, Kafafy M El. Experimental evaluation of a domestic refrigerator working with LPG. Appl Therm Eng 2006;26:1593–603. doi:10.1016/j.applthermaleng.2005.11.026.

[9] Alawi OA, Sidik NAC, Kherbeet AS. Nanorefrigerant effects in heat transfer performance and energy consumption reduction: A review. Int Commun Heat Mass Transf 2015; 69:76–83. doi:10.1016/j.icheatmasstransfer.2015.10.009.

[10] Saidur R, Kazi SN, Hossain MS, Rahman MM, Mohammed HA. A review on the performance of nanoparticles suspended with refrigerants and lubricating oils in refrigeration systems. Renew Sustain Energy Rev 2011;15:310–23. doi:10.1016/j.rser.2010.08.018.

[11] Malvandi A, Heysiattalab S, Ganji DD. Thermophoresis and Brownian motion effects on heat transfer enhancement at film boiling of nanofluids over a vertical cylinder. J Mol Liq 2016; 216:503–9. doi:10.1016/j.molliq.2016.01.030.

[12] Ohunakin OS, Adelekan DS, Gill J, Atayero AA, Atiba OE, Okokpujie IP, et al. Performance of a hydrocarbon driven domestic refrigerator based on varying concentration of SiO 2 nano-lubricant. Int J Refrig 2018; 94:59–70. doi:10.1016/j.ijrefrig.2018.07.022.

[13] Gill J, Singh J, Ohunakin OS, Adelekan DS. Energetic and exergetic analysis of a domestic refrigerator system with LPG as a replacement for R134a refrigerant , using POE lubricant and mineral oil based TiO 2 - , SiO 2 - and Al 2 O 3 -lubricants. Int J Refrig 2018;91:122–35. doi:10.1016/j.ijrefrig.2018.05.010.

[14] Alawi OA, Sidik NAC, Kherbeet AS. The effects of nanolubricants on boiling and two phase flow phenomena: A review. Int Commun Heat Mass Transf 2016;75:197–205. doi:10.1016/j.icheatmasstransfer.2016.04.001.

[15] Xing M, Wang R, Yu J. Application of fullerene C60 nano-oil for performance enhancement of domestic refrigerator compressors. Int J Refrig 2014; 40:398–403. doi:10.1016/j.ijrefrig.2013.12.004.

[16] Bi S, Guo K, Liu Z, Wu J. Performance of a domestic refrigerator using TiO2-R600a nano-refrigerant as working fluid. Energy Convers Manag 2011; 52:733–7. doi:10.1016/j.enconman.2010.07.052.

[17] Azmi WH, Sharif MZ, Yusof TM, Mamat R, Redhwan AAM. Potential of nanorefrigerant and nanolubricant on energy saving in refrigeration system – A review. Renew Sustain Energy Rev 2017; 69:415–28. doi:10.1016/j.rser.2016.11.207.

[18] Fuskele V, Sarviya RM. Recent developments in Nanoparticles Synthesis , Preparation and Stability of Nanofluids. Mater Today Proc 2017; 4:4049–60. doi:10.1016/j.matpr.2017.02.307.