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Performance of an Iso-Butane Driven Domestic refrigerator infused with various concentrations of Graphene based Nanolubricants

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Abstract

In this work, the performance of a slightly modified domestic refrigerator infused with various concentrations (0, 0.2, 0.4 and 0.6 g/L) of graphene based nanolubricants and selected mass charges (40, 50, 60 and 70g) of R600a refrigerant was studied. The steady state energetic performance of the domestic refrigerator was evaluated with test parameters including cabinet temperature, compressor power consumption, power per ton of refrigeration (PPTR) and coefficient of performance (COP). Findings showed that the lowest compressor power consumption and cabinet temperature observed within the system were 65 W and -12°C when infused with either 40g and 0 g/L or 60g and 0.2 g/L nanofluid mixtures. In addition, the utilization of 60 g and 0.2 g/L mixtures gave the highest PPTR value of 5.22 while the maximum COP value of 0.76 was seen with 70 g and 0 g/L respectively. In conclusion, the application of graphene based nanolubricants within the system significantly improved the performance.

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Keywords: Domestic refrigerator; Graphene; Nanolubricants; R600a.

1. Introduction

Drive for improved safety and performance of hydrocarbon based refrigerants in place of conventional refrigerants (such as chlorofluorocarbons, hydro-chlorofluorocarbons and hydro-fluorocarbons) within domestic

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vapor compression refrigerators (HVCRs) have revealed several deficiencies (such as flammability, high operating pressures, lower cooling capacity and coefficient of performance etc.) [1]. Thus, justifying increasing adoption of nanofluids (i.e. a homogenous mixture of nanoparticles of known maximum external diameter of 1-100nm within its base fluid) in recent refrigeration applications [2]. So far, nanofluids in form of nanorefrigerants (mixture of nanoparticles and refrigerant) or nanolubricants (mixture of nanoparticles and lubricants) in domestic refrigerators have considerably enhanced their energy- exergy characteristics [3], thermo-physical characteristics [4], system performance [5] and fire hazard resistance. In the work of Gill et al. [6], liquefied petroleum gas (LPG) and selected concentrations of Al_2O_3, SiO_2 and TiO_2 nanolubricants were successfully retrofitted in a domestic refrigerator using R134a. Similar energetic property improvements was seen in a domestic refrigerator using LPG and the same nanoparticles by Ohunakin et al. [7]. The infusion of TiO_2 and Al_2O_3 nanoparticles in a domestic refrigerator R600a/mineral oil mixtures significantly decreased the mixtures surface tension and increased the solubility and viscosity [8]. In another work by Bobbo et al. [9], inferences from an experimental addition of a single wall carbon nanohorn (SWCNH) and TiO_2 nanoparticles in R134a/POE oil mixtures showed that the mixtures impacted negligibly on solubility and either improved or decreased the tribological characteristics depending on the investigated property (i.e. anti-wear or extreme pressure behaviour). Improvements in the coefficient of performance of R600a driven compressors infused with $3gL^{-1}$ concentration of fullerene C_{60} nanolubricant was seen in Xing et al. [10].

In spite of graphene nanoparticle commercial availability and excellent performances highlighted by Rasheed et al. [11]; authors have found scanty application of graphene nanolubricants in domestic refrigerators. This work therefore experimentally investigate the potential of using selected concentrations of graphene based nanolubricants in R600a driven domestic refrigerator.

Nomenclature

h	refrigerant enthalpy (kJ/kg)
VRC	Volumetric refrigerating capacity (kJ/m^3)
$\dot{m}$	refrigerant mass flow rate (kg/s)
PPTR	Power per ton refrigeration
P	Pressure (kPa)
T	Temperature (°C)
COP	Coefficient of performance
Q_e	Refrigerating effect (kJ/kg)
W_c	Specific compressor workdone (kJ/kg)

2. Methodology

2.1. Experimental set-up

The experimental rig (consists of a domestic refrigerator that is made up of a scroll compressor, 1m capillary tube tube, plate type evaporator and air cooled condenser design), was integrated with valves required for charging and discharging of spent refrigerant within the compressor. It was designed to attain at least -3°C based on ISO 8187 requirement for domestic refrigerator in line with the work of Adelekan et al. [12]. Digital thermocouples K, pressure gauges and a watt meter were also incorporated on the test rig to measure temperature and pressure of the refrigerant; and the power consumption of the refrigerator.

2.2. Instrumentation of the rig

The setup of the refrigeration cycle is shown in Fig 1. The thermocouples measure refrigerant suction (T_1), discharge (T_2), condensing (T_3), and cabinet temperatures for every trial. The test environment is a tropical region (Nigeria) with an ambient air temperature of 29°C and relative humidity of 51% throughout the experiment. The room temperature was captured using Rototherm surface temperature thermometers (Model BL301), having a scale range of 0 to 400°C. An air-conditioner was employed to control the room temperature.

2.3. Refrigerant and Nanolubricant

R600a refrigerant used for the study was obtained locally and has a purity of 99.7%. The Graphene nanoparticle (5-15nm) has 99.5% purity and obtained from Aldrich Chemistry. The characteristics of the lubricating oil for the compressor is shown in Table 1. The nanoparticles were measured on a digital weighing balance (OHAUS Pioneer TM PA114) with measuring range of 0.0001 to 110g, while the R600a refrigerant was measured using a digital weighing balance (CAMRY ACS-30-ZC41) with measuring range of 5 to 30000g. Furthermore, the graphene nanoparticle and mineral oil mixture was sonicated using Branson M2800H ultra-sonicator to ensure proper homogenisation of the mixture and to prevent sedimentation and agglomeration of the nanoparticle within the mixture. A vacuum pump was adopted for extracting spent refrigerant after each trial and the compressor was thoroughly flushed with fresh compressor oil until clear solution is obtained before infusing the required concentration in preparation for another experiment. All experimental trials were repeated three times to ensure repeatability of experiment.

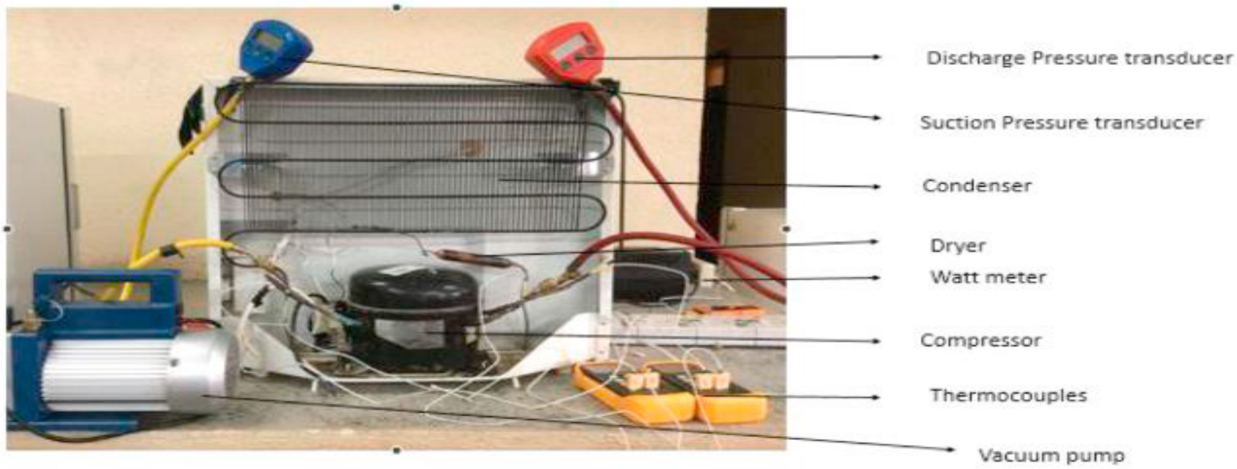

Fig 1: Experimental setup

Table 1: Characteristics of the lubricating oil

S/N	Lubricating Oil characteristics	Units
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 100°C	6.8
7	Viscosity index	22
8	Code	41562

2.4 Governing equations and assumptions

The steady state energetic performance in terms of cabinet air temperature, volumetric refrigeration capacity (VRC), power per ton of refrigeration (PPTR), Power consumption (W) and coefficient of performance (COP) within the test rig were computed equations of described in Bolaji et al.[13];

2.4.1. Equations;

The estimated performance characteristics at steady state were determined as;

$$VRC = \rho Q_{evap} \quad (1)$$

Where VRC is the cooling capacity per unit volume (kJ/m^3), $\rho, kg/m^3$ is the suction refrigerant density (kg/m^3), $Q_{evap,}$ is the refrigeration effect (kJ/kg), W_c kJ/kg is the compressor work input and PPTR was derived as;

$$PPTR = \frac{3.5W_c}{Q_{evap}} \quad 2$$

$$COP = \frac{Q_{evap}}{W_c} = \frac{h_1 - h_3}{h_2 - h_1} \quad 3$$

Where, h_1 (kJ/kg) is the refrigerant saturated vapour enthalpy at the inlet of the compressor, h_2 (kJ/kg) is the refrigerant superheated vapour enthalpy at the discharge of the compressor, h_3 (kJ/kg) is the refrigerant saturated liquid enthalpy at the condenser outlet.

3.0 Results and Discussion

The steady state cabinet air temperatures of the selected mixtures are shown in fig 2. The application of 0.2, 0.4 and 0.6 g/L graphene based nanolubricant concentrations within the rig decreased and increased the cabinet air temperature with increasing R600a refrigerant mass charge. Although, an increasing cabinet air temperature was seen with increasing refrigerant mass charge for 0 g/L lubricant; the lowest cabinet air temperature observed was -12ºC when either 40g using 0g/L or 60g using 0.2g/L nanofluid mixtures were infused to the system. The highest cabinet air temperature value of 0ºC was attained with 70g R600a-0 g/L mixture. The infusion of 0.2. 0.4 and 0.6 g/L nanolubricants within the system significantly reduced the cabinet air temperatures for refrigerant charges beyond 40g in comparison with 0 g/L lubricant.

Fig 3 shows the influence of increasing nanolubricant concentrations and refrigerant mass charges on the suction volumetric refrigeration capacity (or cooling capacity per unit volume) of the test refrigerator. As seen in the figure, increasing the concentration of graphene nanoparticles increased and reduced the VRC value of the system with

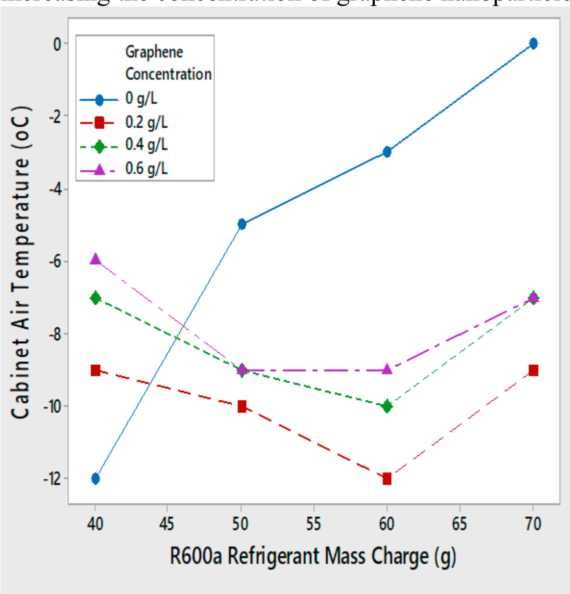

Fig 2: Cabinet air temperature Variation

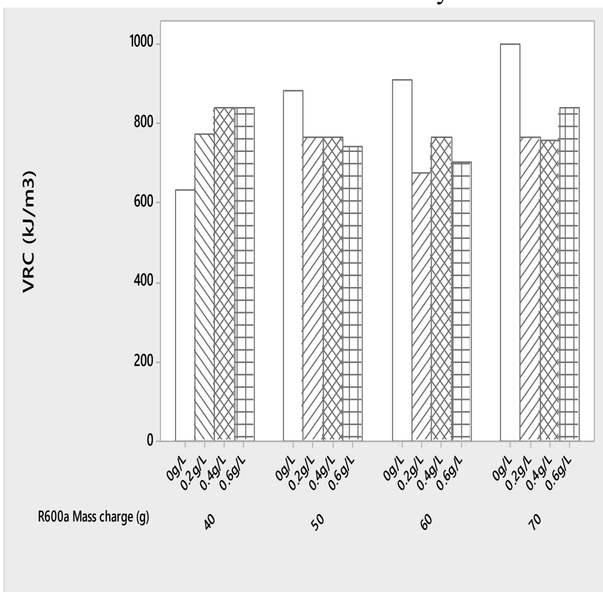

Fig 3: Volumetric Refrigeration Capacity Variation

increasing refrigerant mass charge in comparison to 0 g/L lubricant. Initial increase seen within 0.2, 0.4 and 0.6 g/L nano-lubricants at 40g were due to high suction refrigerant densities. The lowest and highest VRC values within the system were 613.58 and 987.31 kJ/m^3 attained with 40 and 70g R600a in 0g/L compressor lubricant. Improved VRC performance can be seen with the adoption of 0.2, 0.4 and 0.6g/L nanolubricant and 40g of R600a refrigerant in comparison to 0g/L lubricant.

The power per ton refrigeration (PPTR) variation within the rig is shown in fig 4. It is seen that the use of 0g/L lubricant in increasing mass charge of R600a gave reduction in PPTR values of the rig. Also, improvements in PPTR values were observed in concentrations greater than 0g/L and 40g mass charge of R600a refrigerant. In addition, the PPTR range observed within the test rig was 4.49-5.21 for 70g and 40g R600a using 0g/L lubricant.

The power consumption variation within the domestic refrigerator is illustrated in fig 5. Lower power consumptions were observed across all refrigerant mass charge within the test rig. The range of compressor power consumptions observed within the system was 65-86 W for 60g utilizing 0.2g/L nano oil and 70g using 0g/L compressor lubricant. The obtained results are in agreement with Alawi et al., [2] assertions that considerable energy conservation can be achieved in domestic refrigerators utilizing nanolubricants. Similar deductions were achieved in a similar recent work by Gill et al., [14] and Adelekan et al. [15].

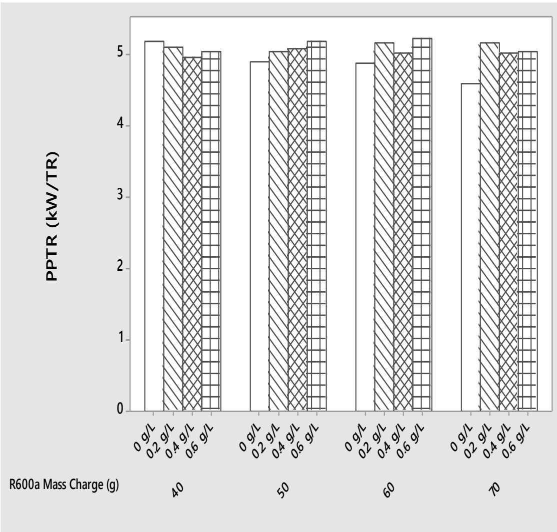

Fig 4: Power Per Ton Refrigeration Variation

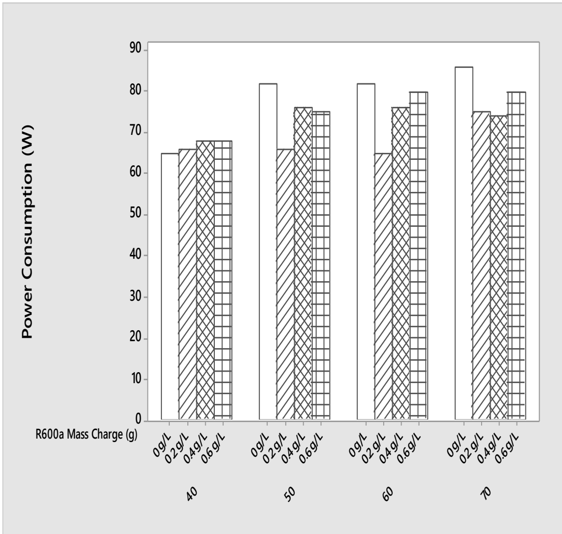

Fig 5: Power Consumption Variation

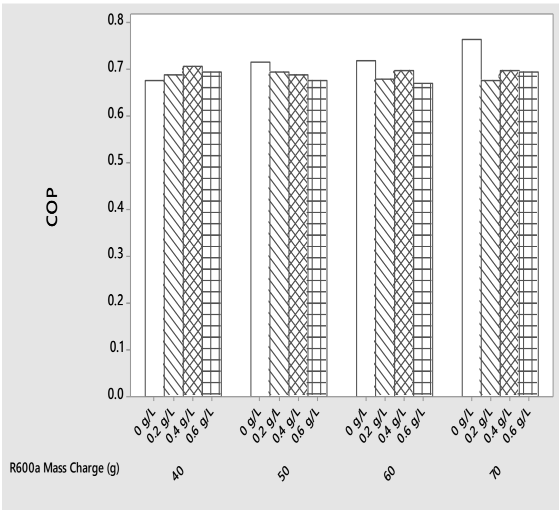

Fig 6: COP Variation

The COP variations can be found in fig. 6. The application of graphene based nanolubricant within the rig followed similar pattern to the power consumption variation. Although the highest COP value of 0.76 was seen with 70g using 0g/L nano-refrigerant mixture while the lowest COP value was 0.61 seen with the infusion of 60g using 0.6g/L in the test rig, 70g using 0g/L nano-refrigerant mixture did not meet the ISO 8187 cabinet air temperature requirement. Overall, the use of 0.2, 0.4 and 0.6 g/L graphene nanolubricant concentrations gave higher COP values in comparison 0 g/L within the system when charged with 40g R600a.

3. Conclusion

The performance of the iso-butane driven domestic refrigerator infused with various concentrations of graphene based nanolubricants showed that the application of graphene based nano-lubricants within the test rig worked safely and significantly improved the investigated energetic performance of the system for only 40g R600a mass charge. Conclusions that were drawn from the results and discussion includes;

- All nanolubricants mixtures infused into the rig attained at least -3°C cabinet at steady state except 70g R600a using 0 g/L blend.
- Improvement in VRC performance with increasing graphene concentrations was seen only at 40g mass charge of R600a.
- The PPTR values for the graphene based nanolubricants were lower at 40g R600a and higher at 50, 60 and 70 g R600a than baseline lubricant. The range of PPTR value seen within the system was 4.59-5.22.
- The power consumption of the system with the selected graphene based nanolubricants was higher at 40g R600a and lower 50, 60 and 70g R600a in comparison with the baseline lubricant.
- The COP range of value seen within the system was 0.61-0.76.

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