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*Original Research Article*

# Experimental investigation of vapour compression refrigeration systems using 0.4 g 13 nm $Al_2O_3$-lubricant based LPG refrigerant as working fluid

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## ABSTRACT

Application of nanoparticles has been proven to aid heat transfer in engineering systems. This work experimentally investigated the performance of a domestic refrigerator under the influence of $Al_2O_3$ nanoparticles dispersed in mineral oil based lubricant at different charges (40, 60 and 80 g) of LPG refrigerant. The performance of the system was then investigated using test parameters including: power consumption, evaporator air temperature (pull-down time), to attain the specified International Standard Organisation (ISO) requirement for standard evaporator air temperature with small refrigerator size. Results showed improved pull down time and steady state evaporator air temperatures for the nano-lubricant based LPG. Improvement of about 11.79% in coefficient of performance (COP) was obtained with $Al_2O_3$-lubricant based LPG at 40 g charge on the refrigerator system, while reduction of about 2.08% and 4.41% in COP were observed at 60 and 80 g charge of LPG based on $Al_2O_3$-lubricant respectively. Furthermore, reduction of about 13.4% and 19.53% in the power consumption of the system were observed at 40 and 60g charges of $Al_2O_3$-lubricant based LPG, whereas at 80 g, an increase of about 1.28% was recorded. Using $Al_2O_3$-LPG nano-refrigerant in domestic refrigerators is economical and also a better alternative to pure LPG.

***Keywords:*** Refrigerants; LPG; Nanoparticle; $Al_2O_3$; Lubricant

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## 1. Introduction

Literature works on nanoparticle application in domestic vapour compression refrigeration system (DVCRs) are enormous. The concept of nanoparticle dispersed in working fluids called 'nanofluids' was first introduced by Choi[1]; and he reported improved fluid characterisitics and linked factors to increased heat transfer surface area of base fluids by included nano range size (1-100 nm) solids. Similarly, application of nanoparticles in DVCRs showed improved thermophysical parameters[2,3]. Application of nano particles in DVCRs working fluids called refrigerant (nanorefrigerant) or in lubricant (nanolubricant) enhances their overall heat transfer rate and system efficiency[3-6]. An instance of experimental work by Segio *et al.*[7] investigating tribological properties and solubility of R134a in a single wall carbon nanohorn (SWCNH) and titanium dioxide ($TiO_2$) nanoparticles dispersed in POE base oil (SW32) showed the performance of using the nanolubricants either better or worsened the tribological property(extreme pressure behaviour and anti wear properties) of SW32 base oil and had insignificant effect on solubility. Furthermore, the influence of nanoparticle fullerene $C_{60}$ in R600a domestic refrigerator compressors achieved reduced power consumption of 4.58 and 4.52% which invariably improved COP by 5.6 and 5.3% with decreased friction coefficient and enhanced stability was reported by Meibo *et al.*[8].

Most conventional refrigerant (chlorofluoro-carbons (CFCs), hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbon HFCs) employed in domestic refrigerators contain flourine or/and chlorine base compounds which act harshly on the environment by depleting the Ozone layer and contribute immersely to global warming thus; phaseout/restricted usage are ongoing[9,10]. Recently, UNEP 2012 emission gap report[11] gave insight of adverse deficit in emission data from earlier proposed safe targets (44 gigatonne of $CO_2$ and 1.5-2.0 °C global temperature by year 2020) and recommended urgent correction strategies be employed. Researches on conventional refrigerants environmental hazards and retrofit methodologies in literature have increased with factors like total equivalent warming impact (TEWI), ozone depletion potential (ODP) and global warming potential (GWP) emerging as key selection factors justifying the adoption of 1st generation class refrigerants like pure and blended hydrocarbons having excellent environmental characteristics inspite of their flammability[12]. Mehdi *et al.*[13], reported 18.7% and 14.6% reduction in energy consumption for 55 g and 60 g optimum gram charges of R600a and R436a used as replacement of R134a (105 g). The substituted hydrocarbons also had 16% and 21% lower total equivalent warming impact (TEWI) to R134a. They concluded the tested hydrocarbons were economical, energetically efficient and eco-friendly.

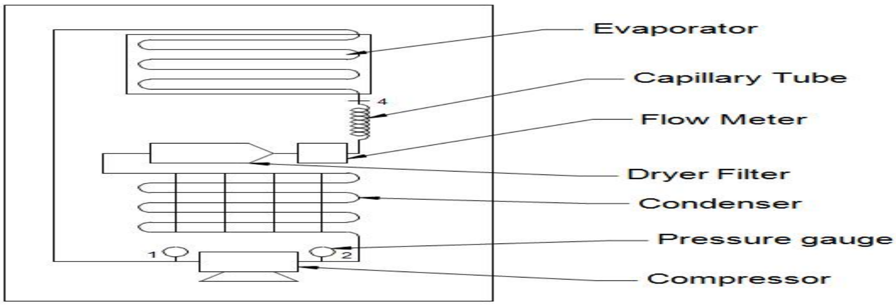


**Figure 1.** Experimental setup.

Liquidified petroleum gas (LPG) refrigerant is a flammable mixture of hydrocarbons. Although LPG composition varies from region to region, it is globally reported to have higher mass fractions of propane (R290) and butane (R600a) irrespective of location[14]. Although LPG large scale utilization catastrophe abounds in literature, utilization below 150g has been reported safe and can be employed in domestic refrigerator sizes[6]. Furthermore, works retrofitting LPG in domestic refrigerators all reported improved system performance indexes but had some system performance compromise issues hence, this justifies the utilization of nanoparticles which have been noted for optimizing refrigerator performances. However the performance of nanoparticle in domestic refrigerators are dependent on factors like (i) concentration, (ii) nanoparticle type, and (iii) application temperature range therefore, this work based on scarce available literature investigating the utilization of $Al_2O_3$ nanoparticle in hydrocarbon based domestic refrigerators experimentally investigates the performance of varied LPG refrigerant mass charges in a domestic refrigerator working with pure and 0.4 g/litre 13 nm $Al_2O_3$ nanoparticle mineral compressor oil.

## 2. Methodology

### 2.1 Materials

The experiment utilized an exisiting modified

R134a domestic refrigerator having built in 100 Watts compressor, 2 mm air cooled fin condenser, 100 grams charge R134a and 1m capillary length [See **Table 1** for rig characterisitics]. The rig was designed to achieve -3 °C evaporator air temperature in accordance to ISO 8187 requirement for domestic small size refrigerator[15]. Thermocouple K was fitted to the rig for measurement of refrigerant temperature at the inlet and oulet of the evaporator and condenser. $T_1$ for compressor suction temperature, $T_2$ for compressor discharge temperature, $T_3$ for condensing temperature, $T_4$ for evaporator inlet temperature and $T_{air}$ for evaporator air temperature. Compressor suction (1) and discharge pressure (2) were recorded using a pressure gauge device [See **Figure 1** for set up]. The nanoparticle was measured using a digital weighing scale (OHAUS PIONEER PA114) while CAMRY weighing scale was employed for charging the required refrigerant gram [See **Table 2** for measuring instrument characterisitics]. The $Al_2O_3$ nanoparticle used was produced by Aldrich chemistry and had 99.8% purity [See **Table 3**] while the compressor lubricant mineral oil and LPG refrigerant was purcharsed locally from Ogun gas limited and had 99% purity [See **Table 4** for lubricating oil characteristics]. The mixture of capella mineral oil (one litre) and 13 nm $Al_2O_3$ (0.4 grams) nanoparticle mixture was homogenised using Bransonic M2800H ultrasonic bath equipment. The mixture was ultrasonicated until a uniform mixture was obtained. A digital watt meter (RoHS) was used to monitor the power consumption of the refrigerator.

**Table 1.** Characteristics of test rig

| S/N | Refrigerator specification | Unit |
|---|---|---|
| 1 | Evaporator size | 62 Litres |
| 2 | Voltage rating | 220-240V |
| 3 | Power rating | 100W |
| 4 | Refrigerant type | R134a |
| 5 | Refigerant charge | 100 grams |
| 6 | Compressor type | HFC |

**Table 2**. Characteristics of Measuring Instruments

| S/N | Measured Data | Specification | Range | Uncertainty |
|---|---|---|---|---|
| 1 | Temperature | Digital Thermocouple K | -50 °C-750 °C | ± 1 °C |
| 2 | Pressure | Digital Pressure gauge | 5-5000 Pa | ± 1% |
| 3 | Power | Digital Watt/Watt-h- Meter Consumption | 1-3000W (0.0001-1-999.9 kWh) | ± 1% |
| 4 | Weight (OHAUS) | Digital Weighing Scale | 0.0001-110 grams | ± 0.0001 g |
| 5 | Weight (CAMRY) | Digital Weighing Scale | 0.0001-110 grams | ± 1 g |

**Table 3.** The Characteristics of nanoparticle selected

| Particle type | Particle size (nm) | Purity (%) | Manufacturer |
|---|---|---|---|
| Aluminium Oxide ($Al_2O_3$) | 13 nm | 99.8 | Aldrich Chemistry |

**Table 4.** The Characteristics of the lubricating oil

| S/N | The characteristics of lubricating oil | 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 |

## 2.2 Method

The experimental analysis of the test rig was based on steady state variation analysis. The temperature and pressure variations in the test rig (refrigerator) were monitored for each mass charge of LPG refrigerant. The refrigerant was defined as a 50/50 propane/butane mixture in RefProp 9.0 NIST software for the determination of its corresponding saturated vapour enthalpy $h_1$, superheated vapour enthalpy $h_2$, saturated liquid enthalpy $h_3$, and their respective entropy values using Microsoft Excel look up command. The performance of the pure mineral compressor oil and ultra-sonicated homogenized 0.4 g/litre $Al_2O_3$ nanoparticle containing compressor oil for 40, 60 and 80 varied grams charges of LPG refrigerant in the rig was recorded and compared. The experiment was repeated three times to ensure repeatability of collected data for each gram investigation and evacuated using a vacuum pump for a new gram test trial. The experiment was carried out in a conditioned environment of ambient temperature range of 29-32 °C. Under listed are equation and assumptions were employed in the test.

### 2.2.1. Equation

$$Coefficient\ of\ Performance\ (COP) = \frac{Q}{W} = \frac{\dot{m}(h_1 - h_4)\ (Watts)}{\dot{m}(h_2 - h_1)\ (Watts)} \quad (1)$$

Where m is mass flow rate (Kg/s), Q is refrigeration effect (Watts), W is the power consumption (Watts).

### 2.2.2. Assumptions

The under-listed assumptions were employed for this study;

- Steady state performance.
- No pressure drop through the pipe line of the test rig.
- Sub cooling and super heating do not takes place.
- $h_3$ is equal to $h_4$.
- The outlet and Inlet pressures of the evaporator are equal.
- The outlet and Inlet pressures of the condenser are equal.

## 3. Results and discussion

### 3.1 Pull down time variation

**Figure 2** showed the pull down time characteristics of varied gram charges of pure LPG (40, 60, 80 g) using pure mineral oil and 0.4 g/litre $Al_2O_3$ nano-lubricant. A decreasing evaporator air temperature with time performance for all investigated charges was observed. It can be seen in **Figure 2**, that only 40 g charge pure LPG achieved ISO 8187 evaporator air temperature of -3 °C at 180 minutes, while 60 and 80 g charge had 2 and 5 °C respectively unlike, varied gram charges of LPG using 0.4 g/litre nano-lubricant that achieved -5 °C for 40 g, -10 °C for 60 g and -5 °C for 80 g charge. Furthermore, the time taken to achieve -3 °C evaporator air temperatures for all nano-lubricant charges was shorter (i.e. 40 g LPG 0.4 g/litre = 80 minutes; 60 g LPG 0.4 g/litre = 56 minutes and 80 g LPG 0.4 g/litre = 80 minutes).

### 3.2 Coefficient of performance variation

The COP variation of optimized pure 40 g LPG and varied gram charges LPG using 0.4 g/litre $Al_2O_3$ nano-lubricant is as illustrated in **Figure 3**. The result showed 40 g LPG nano-lubricant COP was 11.79% better than 40 g pure LPG while 60 and 80 g LPG nano-lubricants had 2.08 and 4.41% reduction. COP values obtained at steady state were 2.67, 2.98, 2.61 and 2.55 for optimized refrigerant using pure compressor lubricant mixture and 40, 60 and 80 g LPG using 0.4 g/L nano-lubricants respectively. Performance revealed that the optimum concentration of $Al_2O_3$-LPG nano-fluid mixture was obtained using 40 g LPG-0.4 g/litre $Al_2O_3$ nano-lubricant mixture while higher concentrations within the rig resulted in lower COP values.

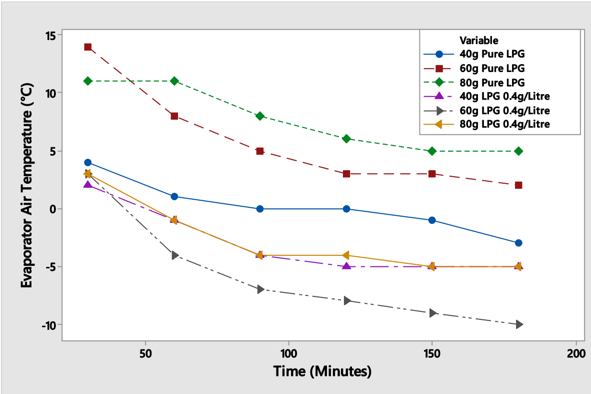


**Figure 2.** Pull down time characteristics.

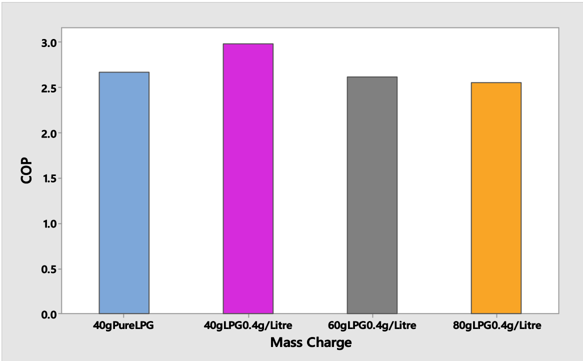


**Figure 3.** Coefficient of performance (COP).

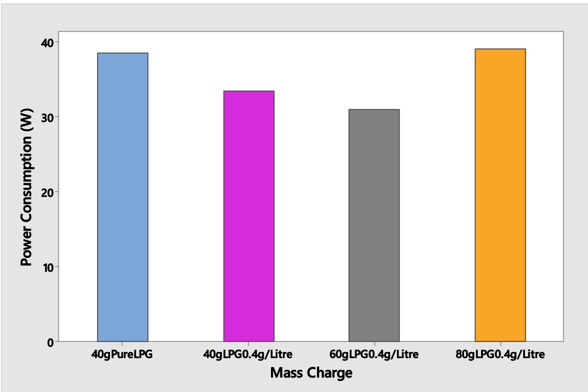


**Figure 4**. Power consumption.

The steady state power consumptions for pure 40 g LPG and all tested LPG varied gram charges using nano-lubricant is shown in **Figure 4**. The steady power consumption values within the rig were 38.58, 33.41, 31.05 and 39.08 W for optimum 40g LPG and all tested LPG varied gram charges

(40, 60, 80 g) using 0.4g/ L $Al_2O_3$ based nano-lubricant. It can be observed that both 40 and 60 g LPG 0.4 g/litre nano-lubricants had 13.4 and 19.53% lower power consumption than pure 40g LPG, while 1.28% increased power consumption was observed for 80 g LPG 0.4 g/litre.

## 4. Conclusion

The experimental investigation of pull down time, coefficient of performance and power consumption of various gram charges (40, 60 and 80 g) of LPG refrigerant using pure mineral compressor oil and 0.4 g/litre 13 nm $Al_2O_3$ nanoparticle homogenized in same compressor oil for a slightly modified domestic refrigerator was carried out. The result revealed $Al_2O_3$ nanoparticle worked efficient and safely in the domestic refrigerator. The following results were further deduced:

- All varied gram charges of LPG refrigerant using homogenized $Al_2O_3$ nanoparticle and compressor oil achieved ISO required evaporator air temperature of -3 °C at a faster rate (80, 56, 80 minutes for 40, 60 and 80g LPG 0.4 g/litre) than with pure compressor oil which only 40 g LPG achieved feat at 180 minutes.
- All varied gram charges of LPG nano-lubricant mixtures had lower evaporator air temperatures at steady state (180 minutes) than LPG-pure compressor oil mixture.
- The highest coefficient of performance was observed with 40 g LPG 0.4 g/litre nano-lubricant while the lowest was 80 g LPG 0.4 g/litre nano-lubricant.
- 60 g LPG 0.4 g/litre nano-lubricant had least power consumption whereas 80 g LPG 0.4 g/litre nano-lubricant consumed the kmost power.

In conclusion, energy and system efficiency advantage of homogenized 13 nm $Al_2O_3$ nanoparticle and mineral compressor oil justifies the cost implication of nanoparticle and worked safely in the domestic refrigerator.

## Conflict of interest

The authors declared no conflict of interest.

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