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# RESEARCH ARTICLE

# EXPERIMENTAL ANALYSIS OF LOW SAFE LIMIT CHARGE OF LPG REFRIGERANT WITH TIO2 NANOLUBRICANT ON DOMESTIC REFRIGERATOR

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## ABSTRACT

Liquefied Petroleum Gas (LPG) refrigerant consist the mixture of propane and butane in the ratio 60/40% by mass and has the characteristics of low global warming potential, non - ozone depleting potential and high energetic efficiency has improved the performance of domestic refrigeration in the recent years. Effect of limit charge in vapour compression refrigeration system plays an important role in the power consumptions. On the other hand, the flammability of LPG refrigerant requires safe limit charging approach. This work experimentally analyzed the performance of 20 and 30 g charges of LPG refrigerant with a small portion 0.1g/litre 15nm TiO2 nanoparticle lubricant on a modified 100 g charge R134a domestic refrigerator working with a 110 watts with hydrofluorocarbon (HFC) compressor. Analyses were carried using RefProp 9.1 NIST software. The result reveals that cooling capacity improved with 131 and 122% while compressor work input reduces with 45.5 and 40% and these brought about reduction in pressure ratio of 42.7 and 30.2% and reduction in COP by 27.1 and 44.5% for 20 and 30 grams charge of 0.1 g/ litre LPG nanolubricant when compared with pure R134a refrigerant. Low safe limit charges of LPG refrigerant with nano lubricant found improved the efficiency of a domestic refrigerator. Therefore LPG-nanolubricant can serve as a replacement for R134a in vapour compression refrigeration system.



## INTRODUCTION

Energy conservation, efficient cooling system and safety of the environment have become a thing of global concern in refrigeration technology in recent years due to the increasing energy prices and adverse consequent environmental impact (Odunfa *et al*., 2014). The environmental concern brought about the establishment of the United Nations Montreal and Kyoto protocols (USA, 1987 and Kyoto Protocol to the United Nations Framework Convention on Climate Change, 1997) which are known as major global restrictions, monitoring nations to control the use of some refrigerants which include chlorofluorocarbons and hydrofluorocarbons that deplete the ozone layer, and some hydrofluorocarbons (HFCs) compounds which emit greenhouse gases (GHGs). Recently, Energetic efficiency, low global warming potential and non-ozone depleting characteristics of substitute hydrocarbon refrigerants investigation has increased in domestic refrigeration applications in the last decade but it has flammability problem which called for low safe limit charge method (David 2010).

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Fundamentals of refrigeration reveals that the rate of depletion of the ozone layer, which limits the harmful effect of sun's ultraviolet ray energy and thus protects all living things including human which are most affected is catastrophic. Also the chlorine particles in chlorofluorocarbons causing depletion of ozone require immediate elimination and this leads to the strict prohibition of CFCs. It is therefore becomes imperative to change from the use of ozone depleting refrigerant to eco friendly refrigerants in refrigeration system (Dalkilic, 2010) M. Fatouh (MacKenzie, 1991), varying butane and propane LPG (liquefied petroleum gas) refrigerant composition which was investigated as a replacement for R134a. The analysis favoured the selection 60/40% propane butane mixture of LPG as drop in substitute for R134a irrespective of the selected working environment. Bolaji, (2010) made an attempt to replace R134a with environmentally friendly, non-toxic and low GWP HFCs (R32 and R152a) in a domestic refrigerator system which was feasible. Mohamed (2015) investigate the energy and exergy analysis of LPG (Liquefied petroleum gas) as a drop in replacement of R134a in domestic refrigerator using MATLAB and REFPROP, result indicate that LPG has the lowest COP with exergetic efficiency while R600 has the highest When compared to R134a refrigerant, the COP for

R134a is higher than that of LPG by 10%. While exergetic efficiency is higher by 5%. LPG is readily available in large amounts and relatively cheap. Liquefied Petroleum Gas (LPG) is a flammable hydrocarbon mixture of gases commonly used as a fuel in automobiles and heating systems. Other trending emerging replacement systems such as heating ventilation and air condition with aerosol propellant are replacing chlorofluorocarbons with LPG in an effort to reduce damage to the environment. Varieties of LPG available includes varying composition mixtures of primarily butane C4H10 and propane C3H8 which composition changes due season, rainy season contains more propane while dry season contains more butane. Traces of Propylene and butylenes are commonly present in negligible concentration [1; 2; 3]. Oyelami and Bolaji (2015), favoured the selection of LPG refrigerant through experimental analysis of its refrigeration capacity, power consumption by d compressor, and coefficient of performance (COP) and with those of R134a, they concluded LPG was better. Addition of nano-particles improved best performance in refrigeration systems. Radermacher (1996) in the recent domestic's development considered hydrocarbon as alternative fluids for refrigeration, air-conditioning and heat pump applications. While pure butane, propane or their mixtures can be adopted, but the flammability properties has led to minimal charge of LPG. In the work of Bi *et al*., (2011), nano-particles were used to improve the performance between lubricant and HFC refrigerants. Heat transfer characteristics were also found to be improved by up to 20% when R11 refrigerant was mixed with TiO2 in Wu *et al*., (2008). It was also found out in the work of Peng *et al*., (2009), that heat transfer coefficient of CuO in R113 refrigerant was enhanced than in pure R113 refrigerant. Dr. S. Periyasamy and M. Saravanan, (2014) carried out studies on vapour compression refrigeration system experimentally using hydrocarbon mixtures and R-12 refrigerant. The result shows that higher refrigerating effect and better heat transfer obtained. P.shanmugasundaram *et al*. (2013) experimental analyse the effect of charge level on the performance of domestic Refrigerator. The result reveals that better cooling effect and higher COP was achieved. According to the present study experimental analysis of low safe limit charge of LPG refrigerant with Tio2 nanolubricant on domestic refrigerator, the potential effect of low limit safe charge was explored. The prime objective of the this studies are; (i) The effect of low safe limit charge on vapour compression refrigeration. (ii) To determine the performance of the system using low limit charge of LPG nano-lubricant. (iii) To know whether low safe charge limit of LPG nano-lubricant could replaced R134a refrigerant.

## MATERIALS AND METHODS

The experiment employed an existing R134a refrigerant fluid small domestic refrigerator with evaporator capacity of 42 litres, compressor rating of 50Hz -110watts and refrigerant charge 100 grams Table 1. The domestic refrigerator also had 1m capillary tube length and 2mm diameter array of condenser fins design to operate at above -3°C evaporator air temperature based on ISO requirement for standard evaporator air temperature for small refrigerator size (ISO, 1991). The refrigerator was slightly modified with attachment of thermocouple K for measuring the inlet and outlet of the evaporator and the compressor, refrigerant suction temperature T1, refrigerant discharge temperature T2, condensing temperature T3, and evaporator inlet temperature T4, TAIR was recorded within the evaporator space, pressure gauge device was also incorporated to measure the suction and discharge pressure at of the compressor Fig 2 for the setup. A digital weighing scale that can measure between 5-5000 grams was employed for charging the required gram charge of refrigerant while ultrasonic vibrator (Branson M2800H) was used to prepare homogenized mixture of nano-particle and compressor mineral oil. The power consumption was measured using a digital Watt meter [RoHS] while vacuum pump was used for evacuation of charged refrigerant. See Table 2 for measuring instruments characteristics. The LPG and mineral oil used was purchased locally from Ogun gas limited, Nigeria Table 3. The 15nm size TiO2 nano-particle was introduced into the refrigerator characteristic can be found in Table 4. The experimental refrigeration characteristics of the domestic refrigerator were based on evaporator temperature performance. The LPG refrigerant was analyzed using 60/40% propane butane mixture under REFPROP 9.0 NIST software define new mixture of liquid/vapour saturation and superheated enthalpies and entropies respectively. Pure mineral oil HFC compressor charged with 100 grams of R134a refrigerant performance was recorded compared with low charge of LPG refrigerant [20 and 30 grams] enhanced with 0.1g/ temperature and pressure characteristics at monitored location of the refrigerator for the determination litre 15nm TiO2 nano-particle. The experiment was repeated five times for repeatability. A vacuum pump was adopted for extracting spent working fluid to the ambient after each trial, in preparation for another experiment.

The following assumptions and equations were utilized;

- Steady state condition
- No pressure drop through the pipe line of the refrigerator.
- Sub cooling and super heating do not takes place
- h3 is equal to h4
- The Inlet and outlet of evaporator pressure are equal.
- The Inlet and outlet of the condenser pressure are equal

**Table 1. Description of the Refrigerator System**

| S/N | Refrigerator | Description | Units |
|---|---|---|---|
| 1 | Evaporator | size 42 | litres |
| 2 | Power rating | 50Hz - 110 | Watts |
| 3 | Voltage rating | 220-240 | Volts |
| 4 | Refrigerant charge | Size 100 | grams |

Qevap = $m$(h1–h4) (W)……................................(1)

Qevap = Refrigerator capacity
Where $m$ = mass flow rate (kg/s)
$h_1$ = Saturated vapour state
$h_2$ = Superheated vapour state

The compressor power consumption

(Wc ) = $m$ ($h_2$-$h_1$) (W) ................ (2)

Compressor pressure ratio, (PR) is given as: PR $PdisPsuc$
$Pressure\ disc\ \ arge\ Pressure\ suction$ …. (3)

Where: Pdis = compressor discharge pressure (KN/m2)

Psuc = compressor suction pressure (KN/m2)

Coefficient of performance

COP = $Qeva/Wc$ = 1 4/ 2 1 ……………………..……(4)

## RESULTS AND DISCUSSION

The result analysis is shown in the figures below Fig. 3. shows the variation of pressure ratio with evaporator temperature of the tested refrigerants. All tested refrigerants recorded a decreasing pressure ratio with increasing evaporator temperature. Both tested nano-lubricants had reduced mean pressure ratio of 42.7% and 30.2% for 20 and 30 grams charge LPG nano-lubricants when compared to R134a

Fig. 4. Indicates the variation of compressor work input with evaporator temperature. It was observed that compressor work input increases with increase in evaporator temperature. Furthermore, the LPG nano-lubricant utilized lower compressor work input than that obtained for R134a for all evaporator temperatures. Overall mean compressor work input obtained for the tested LPG nano-lubricants reduced by 45.5% and 40%.

Fig. 5. Reveals the variation of cooling capacity with evaporator temperature of the mixture of LPG with nanoparticle and R134a. Cooling capacity increased with increasing evaporator temperature. The mean cooling capacity obtained from LPG nano-lubricants was higher than that of R134a by 131 and 122% when compared.

**Table 2. Characteristics of measuring instruments**

| S/N | Measured Data | Manufacturer 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 Consumption | Digital Watt/Watt-h-meter | 1-3000W(0.0001-1-999.9 kWh) | ±1% |

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

| Particle type/Refrigerant | Particle Size (nm) | Purity (%) | Manufacturer | P code |
|---|---|---|---|---|
| LPG | | 40/60%propane butane | Ogun gas LImited | |
| Titanium dioxide (TiO2 | 15nm | 99.7 | Alfa Aesar | |

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

| S/N | The characteristics of lubricating oil | Units |
|---|---|---|
| | Oil type capella | Mineral oil |
| 1 | ISO viscosity grade | 68 |
| 2 | Flash point | -36°C |
| 3 | Density at 15°C kg/L | 0.91 |
| 4 | Kinematic viscosity (mm2/s) at 40°C | 68 |
| 5 | Kinematic viscosity (mm2/s) at 100°C | 6.8 |
| 6 | Viscosity index | 22 |

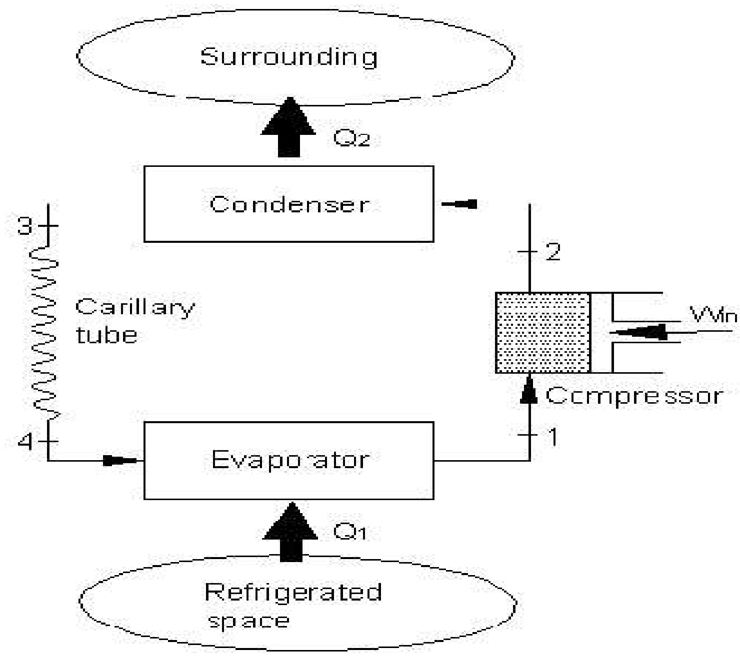


**Fig. 1. Schematic diagram of Refrigerator**

**Fig. 2. Experimental Setup**

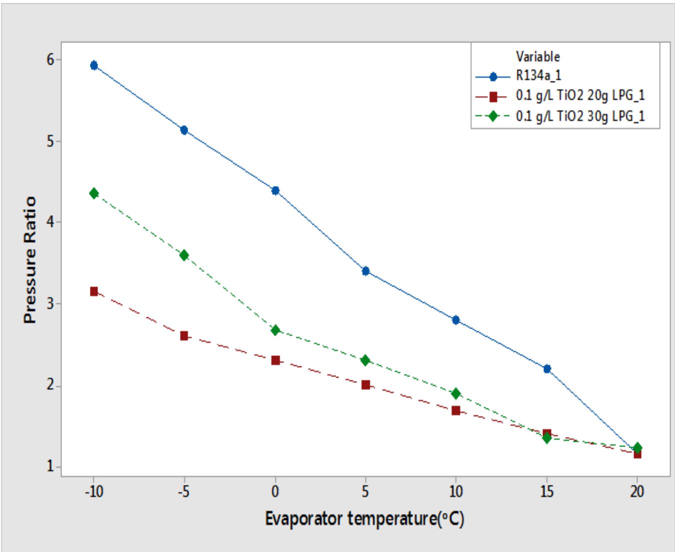


**Fig. 3. Variation of Pressure ratio with evaporator temperature**

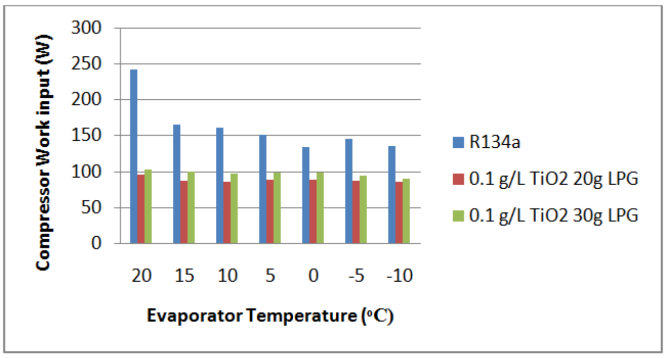


**Fig. 4. Variation of Compressor work input with Evaporator Temperature**

Fig. 6. shows the variation of the coefficient of performance with evaporator temperature. The coefficient of performance decreased with decrease in evaporator temperature. Observed increase of mean COP by 361% and 263% for 20 and 30 grams 0.1 grams/litre LPG nano particle lubricant was obtained when compared with R134a.

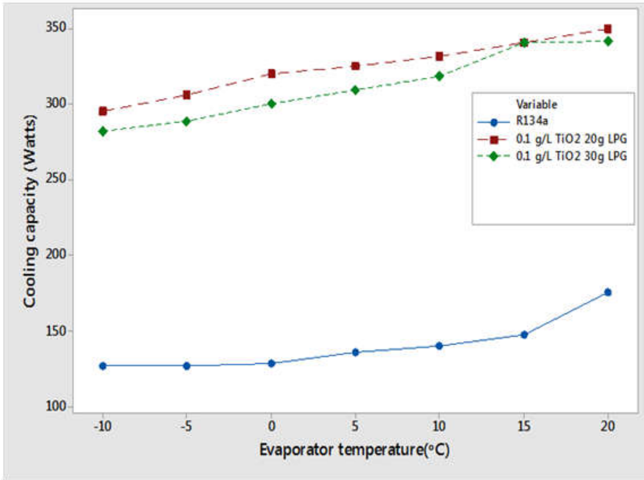


**Fig. 5. Variation of cooling capacity with evaporating temperature**

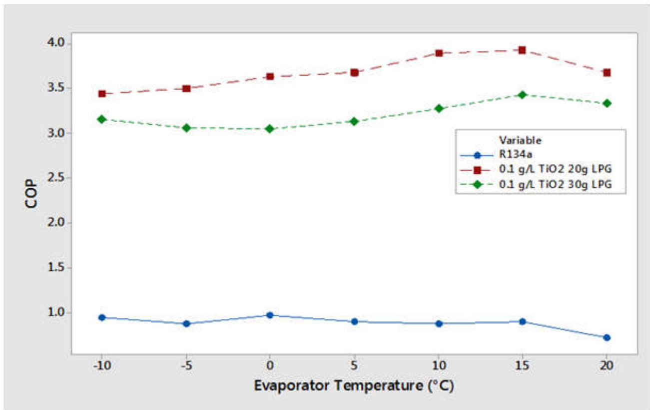


**Fig. 6. Variation of Coefficient of performance with evaporator temperature**

## Conclusion

The experimental investigation of 20 and 30 grams charges utilizing 0.1 g/ litre nano-lubricant compared to R134a pure lubricant performances in respect of compressor work input, pressure ratio, cooling capacity and coefficient of performance (COP) revealed the following observations;

- Refrigerator using LPG nano lubricant sustained with low pressure ratio of 42.7% & 30% than R134a, which indicates that system using low limit charge of LPG nano-lubricant performed better and reliably.
- The compressor work input of the refrigerator using LPG nano-lubricant reduced by 45% and 40% when compared to R134a. This invariably relate to better energy efficiency. The cooling capacity of the refrigerator using low limit charge of LPG nano-lubricant improved by 131% and 122% when compared to R134a.
- The coefficient of performance of low limit charge of LPG nano-lubricant increased by 361% & 263% when compared to R134a.

From the above conclusion, nano-lubricant improved the performance of low safe limit of LPG refrigerant in domestic refrigeration and it can be used as replacement for R134a.

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