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# Performance of a Limited Charge of R600a and LPG Refrigerants in a Domestic Refrigerator Using R134a Refrigerant in Different Ambient Conditions

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## Abstract-

In this work, a slightly modified 100g R134a domestic refrigerator was retrofitted with limited mass charge (30g) of R600a and LPG refrigerants and tested in different ambient temperature conditions (19, 21, 23 and 25 °C). The test rig was fitted with appropriate instrumentation for experimentation. Performance characteristics investigated with the test rig at steady state include evaporator air temperature, discharge temperature and power consumption. Results showed that the retrofitted hydrocarbon refrigerants in the system at the ambient conditions gave power consumption, discharge temperature, condensing pressure lower by 15 – 45 %, 16 – 30 % and 25 – 62 % than R134a refrigerant. In addition, the cabinet temperature of the system with the hydrocarbon refrigerants were higher than R134a by 10 - 60 %. In conclusion, the investigated energetic characteristics of the system improved with reducing ambient temperature and all conditions with infused hydrocarbon refrigerants attained cabinet temperatures lower than -3 °C in accordance to ISO 8187 recommendation for domestic refrigerators.

Keywords: Ambient temperature, R600a, LPG, R134a

## 1. Introduction

Fulfilling the objectives of international environmental protection protocols (such as Montreal and Kyoto protocols) and reducing growing energy demands is justifying the need for alternative refrigerants that are capable of reducing energy consumptions of conventional refrigerators (Bozelin, 2013). Most household refrigerators currently use R134a refrigerant due to its excellent thermodynamic and thermo-physical properties [1]. However, its global warming potential and energy consumption is high. Thus, the adverse implications of R134a refrigerant on environmental, ecological and human health are justifying its imminent phase down and phase out.

Many researchers have proposed that hydrocarbon refrigerants have benign effects on the environment, thermodynamically efficient, chemically stable and suitable retrofits to conventional refrigerants (such as chlorofluorocarbons, hydro chlorofluorocarbons and hydro fluorocarbons). Studies by Adelekan et al., [2] Ohunakin et al., [3], Ahamed et al., [4] and Srinivas et al., [5], corroborates that LPG refrigerant performed better in comparison to R134a refrigerant within domestic refrigerators. Liquefied petroleum gas (LPG) and other hydrocarbons are still being used in refrigeration systems despite their flammability concerns. Zero Ozone depletion potential, low global warming, inexpensiveness and availability in bulk quantity and safety as long as they are within charge limit of 150g characteristics were highlighted reasons for this selection [6], [7], [8], [9]. Properties of some hydrocarbon refrigerants used in refrigeration systems in comparison to conventional refrigerant like R12, R134a are as shown in Table 1



Table 1. Properties of some refrigerants

Refrigerant	Chemical formula	Liquid density (kg/m <sup>3</sup> ) at 20 °C	Molecular weight	Explosive limits in air (% by volume)	Safety group	ODP	GWP
<b>R600a</b>	<i>i</i> C <sub>4</sub> H <sub>10</sub>	556.9	58.1	1.8–8.4	A3	0	4
<b>R290</b>	C <sub>3</sub> H <sub>8</sub>	500.1	44.0	2.3–7.3	A3	0	3
<b>R436A</b>	C <sub>3</sub> H <sub>8</sub> + <i>i</i> C <sub>4</sub> H <sub>10</sub>	525.0	49.33	3.7–9.5	A3	0	3
<b>R134a</b>	CH <sub>2</sub> FCF <sub>3</sub>	1225.3	102.0	Nonflammable	A1	0	1430
<b>R12</b>	CCl <sub>2</sub> F <sub>2</sub>	1328.9	120.9	Nonflammable	A1	1	10,900

In addition, hydrocarbon-based refrigerants are expected to work efficiently irrespective of the surrounding ambient temperature condition of their refrigeration system. In the study concluded by Geppert and Stamminger [10], it was concluded that domestic refrigerators are expected to function in all ambient conditions. Authors therefore experimentally investigate the effect of varying ambient temperature condition in an R134a refrigerator retrofitted with R600a and LPG refrigerants.

## 2.0 Methodology

### 2.1 Experimental rig and environment

A slightly modified 50 litres domestic refrigerator using 100 g R134a was retrofitted with 30g mass charges of LPG and R600a refrigerants, and tested in different ambient temperature conditions (19, 21, 23 and 25 °C), under a no-load operation condition. The experimental rig was a single door, manual defrost and tropical class refrigerator consisting of an evaporator cabinet, a compressor, a condenser, an expansion valve and a capillary tube (See Table 2 and 3 for the specification of the test unit, the uncertainty and the measurement range of instrument).

Table 2: Specification of the test unit

Item	Specification
Unit type	Fridge
Evaporator Volume	69 L
Refrigerants/Lubricant	R600a, LPG, R134a/Mineral oil
Compressor	100 Watts
Evaporator	Cross flow fin and heat exchanger
Condenser	Air cooled
Expansion Device	Capillary tube

Table 3. Uncertainty and measurement range of instrument

S/N	Range	Characteristics	Uncertainty
1	0 -5000 w	Power	$\pm 0.1\%$
2	0 – 2500 Kpa	Pressure	$\pm 0.1\%$
3	-50 – 750°C	Temperature	$\pm 0.1\%$

## 2.2. Experimental procedure

The test rig was fitted with appropriate pressure gauges, digital thermocouples and a watt meter. The investigated steady state energetic characteristics include; evaporator air temperature, discharge temperature, pressure ratio, condensing pressure and power consumption. The thermocouples were used to measure the evaporator temperature ( $T_{air}$ ), suction temperature ( $T_1$ ), discharge temperature ( $T_2$ ), condensing temperature ( $T_3$ ), while the pressure gauges measured the suction pressure ( $P_1$ ), discharge pressure ( $P_2$ ) and condensing pressure ( $P_3$ ) of the refrigerant and the watt meter to measure the instantaneous compressor power consumption (see Figure 1 for the experimental setup of the rig). The rig was carefully checked and cleaned before the commencement of every trial conditions. The refrigerant was charged into the refrigerator through the compressor inlet with the help of a charging system. Firstly, LPG (30g charge), from 19 – 25 ° C followed by R600a (30g) from 19 – 25 ° C and lastly R134a (100g) from 19 – 25 ° C were separately tested within the system. The pressure readings were used to determine the pressure ratio.

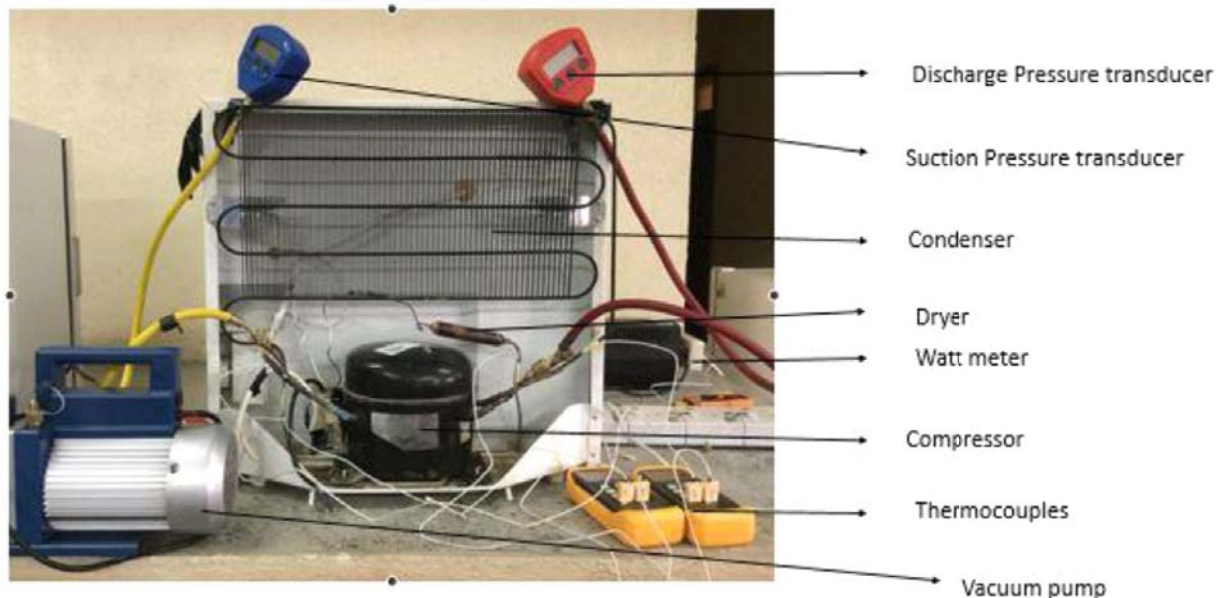


Figure 1: Experimental Setup

## 3. Results and discussion

The experimental investigation results of LPG and R600a as retrofit for R134a in different ambient temperature in the domestic refrigerator that was utilized for the experiment are as discussed.

### 3.1 Power Consumption Variation

Power consumption is the summation of energy input to the compressor during its operation. Figure 2 shows the power consumption of the selected hydrocarbons in comparison to R134a refrigerant

at the selected ambient temperature (19, 21, 23 and 25 °C). The power consumptions of the system with the infusion of the selected hydrocarbon refrigerants were lower in comparison to R134a refrigerant by 15-45 %. Overall, the range of power consumptions recorded within the rig for the LPG refrigerant was higher than R600a refrigerant. The maximum and minimum power consumptions recorded at the various ambient temperature for LPG refrigerant within the system were 91 W for 25 °C and 83 W at 19 °C ambient temperature respectively. While the infusion of 30g R600a refrigerant gave the highest power consumption value of 75 W at 25 °C and least power consumption value of 70 W at 21 °C ambient temperature.

Table 4: Steady State Cabinet Air Temperature Variation

Refrigerant type	Ambient temperature (°C)			
	19	21	23	25
30g R600a	-6	-5	-6	-5
30g LPG	-11	-8	-9	-7
R134a	-16	-11	-10	-15

Source: Researcher's findings

### 3.2 Cabinet Air Temperature Variation

Table 4 depicts the cabinet air temperature variation of the hydrocarbons and R134a refrigerants across all selected ambient temperatures. The application of LPG and R600a refrigerants within the R134a refrigeration system gave higher evaporator temperatures in comparison to the baseline (100g R134a). It was observed that the highest cabinet air temperatures within the rig was seen with R600a refrigerant. In addition, all infused refrigerant at the different ambient conditions attained temperatures lower than ISO 8187 recommended temperature (i.e. -3 °C) for domestic refrigerators.

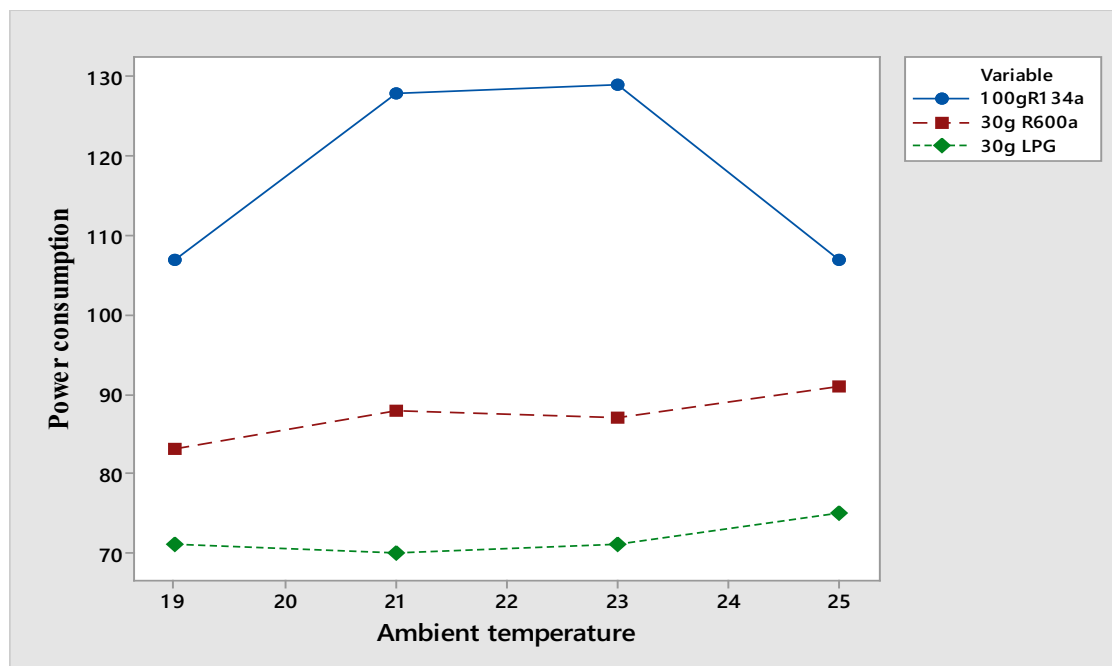


Fig. 2: Power Consumption Variation of the system

### 3.3. Discharge Temperature Variation

One of major factor influencing durability of refrigerators in application is compressor discharge temperature. The properties of lubricants and the life of compressor are adversely affected by very high compressor discharge temperature [8]. The discharge temperature variation within the rig is as shown in figure 3. The use of LPG and R600a refrigerants brought about reduced discharge temperature in the range of 16- 30 % in comparison to the baseline setup. The maximum discharge temperature for LPG was 68 °C at both 21°C and 25 °C, while the minimum discharge temperature was 63 °C at 19 °C. Similarly, the highest discharge temperature seen with R600a refrigerant was 63 °C at 23°C, while the least discharge temperature was 59 °C at 21 °C.

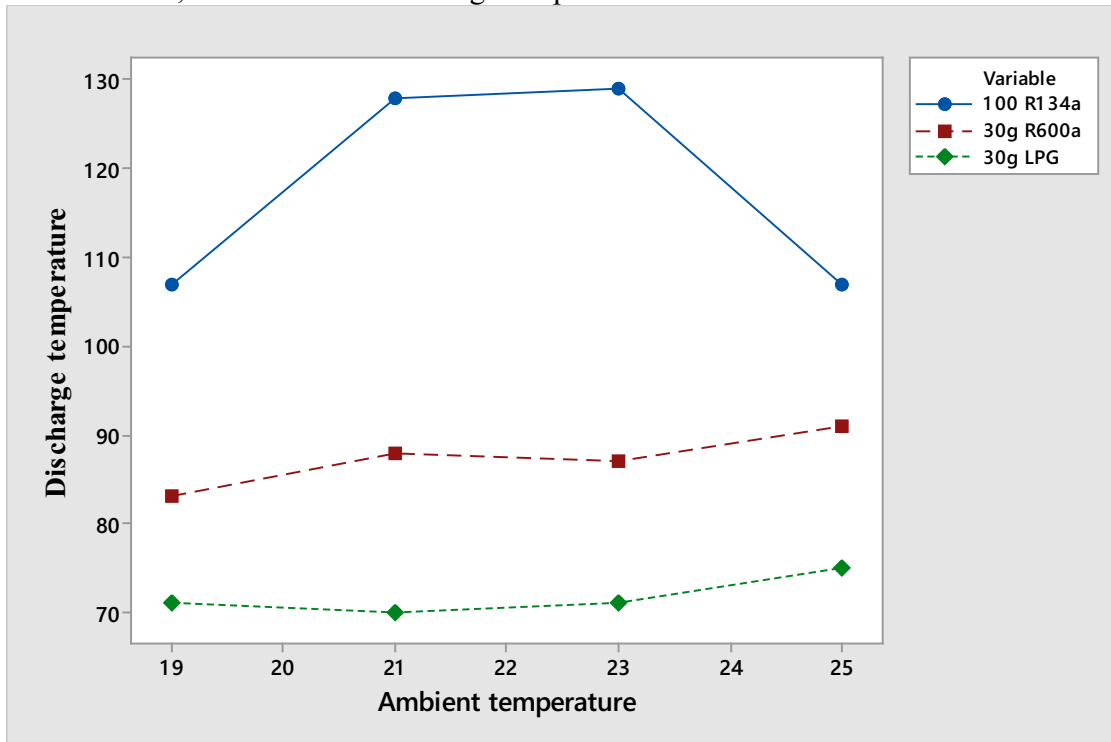


Fig 3: Discharge temperature Variation of the system

### 3.4. Condensing Pressure Variation

The condensing pressure variations of LPG, R600a and R134a working fluids at different ambient temperatures is as illustrated in figure 4. A lower condensing pressure seen within the rig when LPG and R600a in comparison to R134a refrigerant. For both LPG and R600a, the percentages in comparison with R134a reduced by 25– 62 %. The maximum condensing pressure for LPG was 170 psi and the minimum condensing pressure was 154 psi. While, the maximum condensing pressure for R600a was 100 psi and the minimum was 90 psi.

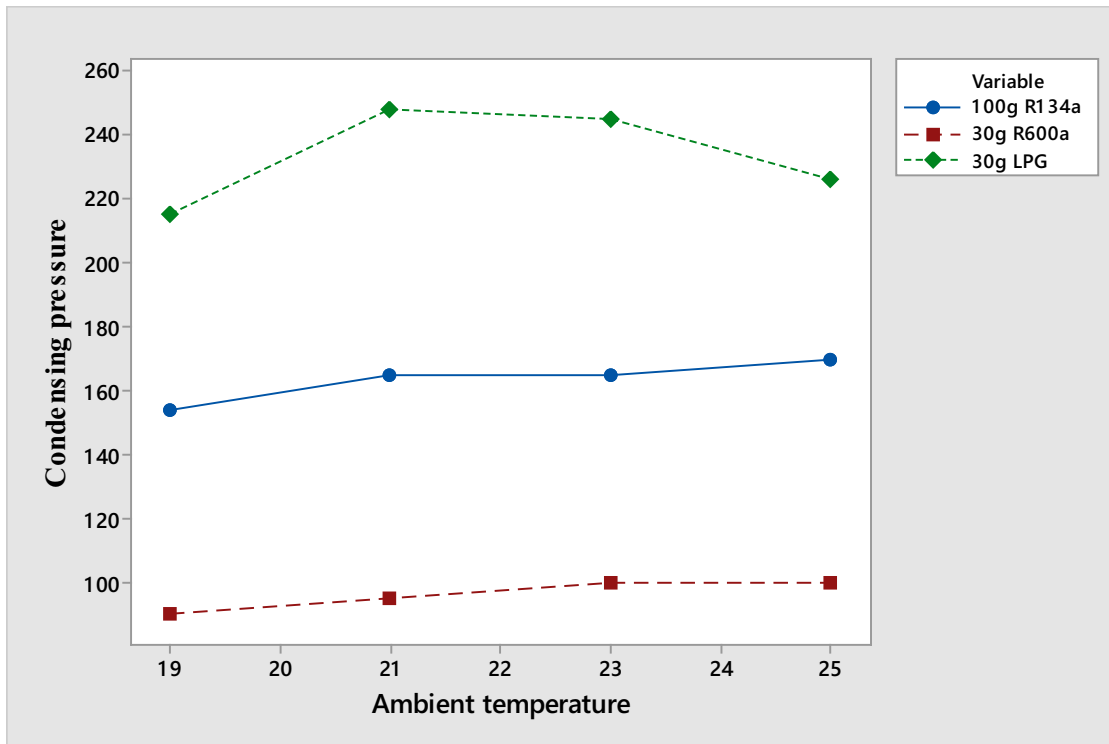


Fig 4: Steady state condensing pressure of the selected refrigerant, charges and different ambient temperatures.

In addition, the condensing pressures of the hydrocarbons increased with increasing ambient temperature. It was also observed that the least condensing pressure of the system was obtained with the use R600a refrigerant.

#### 4.0 Conclusion

The experimental investigation of 30g charge of LPG and R600a refrigerants in the modified R134a domestic refrigerator at the different ambient temperatures showed promising advantages as alternative refrigerants. The following were deduced:

1. The deliberately limited hydrocarbon-based refrigerant was safe and economically efficient in comparison to the R134a refrigerant.
2. Improved energy saving characteristics were observed with the hydrocarbon-based refrigerants.
3. The hydrocarbons-based refrigerants utilized lower discharge temperatures and condensing pressures which implies improved durability of the compressor.

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