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Effect of Ambient Temperatures on an R134a Domestic Refrigerator Retrofitted with R600a and LPG Refrigerants

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Abstract-

The effect of ambient temperatures (19, 21, 23 and 25 °C) on energetic performance of an R134a domestic refrigerator retrofitted with varied mass charges (40, 50, 60 and 70g) of R600a and LPG (60/40 Propane-butane mixture) refrigerants was studied. The R134a domestic refrigerator was slightly modified with valves and integrated with appropriate pressure gauges, digital thermocouples and a watt meter to monitor the pressures, temperatures and the energy consumptions of the refrigerants within the system in the ambient conditions. Performance test investigated at steady state were pressure ratio, energy consumption, discharge and cabinet temperatures respectively. In conclusion, results showed that the retrofitted hydrocarbon refrigerants could be suitable replacements in all regards, provided adequate optimization is done.

Key words: Ambient temperature, R600a, LPG, R134a

1. Introduction

Domestic refrigerators are considered one of the major energy consuming household appliance [1]. Due to the popularity of domestic refrigerator, they accounts for about 30% of the world's total energy consumption [2]. Manufacturers of domestic refrigerators expect them to function optimally irrespective of their climate condition and enclosed or ambient operation temperature. It was concluded in the work of Geppert & Stamminger [3] that ambient temperature of domestic refrigerators is the influential factor on their energy consumption. Besides, the need to reduce energy consumptions of domestic refrigerators is crucial because it crux to their direct emissions. In addition, total warming equivalent impacts (TEWI) of refrigerators varies directly with their energy consumptions (Rasti et al. [4]). Thus, development of environmentally efficient refrigerators is attainable with the production of energy efficient refrigerators regardless of their operating ambient temperature conditions. Presently, the economic advantage, availability, thermodynamic and thermophysical characteristics of halogenated refrigerants (especially hydrofluorocarbon refrigerants) are justifying their widespread adoptions in most vapour compression refrigeration systems [5].

The release of hydrofluorocarbon (HFC) must be reduced in accordance to Kyoto Protocol recommendations to the United Nations Framework Convention on Climate change (UNFCCC). HFCs contribute immensely to greenhouse gas emission, thus are to be phase down and out with efficient and environmentally friendly refrigerants. Most refrigerators widely adopt R134a (HFC) refrigerant on the basis of its excellent cooling capacity. However, it has high global warming potential (about 1430) which makes it environmentally lethal. In addition, it has strong chemical polarity, thus traditional mineral oil cannot be used with it as working fluid in



refrigerators. R134a is compatible with polyol-ester (POE) oil as lubricant. Nevertheless, POE oil is known to be hydroscopic and hydrolytic which give rise to problems like severe friction in the compressor and bulging equipment that chokes flow of refrigerant within refrigeration systems. The need for a long term retrofit refrigerant which meet the objectives of international environmental protection protocol is apparent [5]. Specification of some commonly utilized refrigerants within refrigeration systems are described in Table 1.

Table 1. Specification of some refrigerant classes

S/N	Class	Refrigerant	Critical Pressure (MPa)	Critical Temperature (K)	OD Potential (Yes/No)	GW Potential	ASHRAE Flammability Classification
1	CFCs	R32	5.78	351.26	Yes	675	A2
		R22	4.99	369.3	Yes	1810	A1
2	HFCs	R134a	4.06	374.21	No	1430	A1
		R152a	4.52	386.41	No	124	A2
3	HCFCs	R11	4.41	470.96	Yes	4750	A1
		R12	4.14	384.97	Yes	10900	A1
4	HCs	R290	4.25	369.89	No	3	A3
5	HC	R600a	3.63	407.81	No	4	A3
6	Blend	R436a	4.27	389.04	No	3	A3

Hydrocarbon based refrigerants (especially Liquefied petroleum gas (LPG) and R600a refrigerants) have been widely reported by researchers to be energy efficient and environmentally friendly substitutes to halogenated refrigerants in vapour compression refrigeration systems. According to researchers [7], [8], [9], [10], LPG refrigerant performed better in comparison to R134a refrigerant in domestic refrigerators. Liquefied petroleum gas (LPG) and other hydrocarbons are being increasingly adopted in refrigeration systems despite their flammability concerns. This is due to their zero Ozone depletion potential, low global warming potential, inexpensiveness, availability in bulk quantity characteristics and safety as long as their charge limits does not exceed 150g [11]. Besides, high energy efficiency and workability of hydrocarbons (especially liquefied petroleum gas) in existing refrigeration systems with or without modifications is the principal justification for their use in vapour compression refrigeration systems [6], [7]. Generally, hydrocarbons have good miscibility with mineral oils, excellent environmental characteristics and suitable compatibility with common materials employed in refrigeration equipment [12], [13], [14], [15]. The need to investigate influences of ambient temperature variations on energetic performance of an R134a domestic refrigerator retrofitted with selected mass charges of R600a and LPG refrigerants justified this investigation.

2. Methodology

2.1 Experimental rig and environment

A slightly modified 50 litres domestic refrigerator using 100 g R134a was retrofitted with 40, 50, 60 and 70 g 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 2-4 for the uncertainty, measurement range of instrument and the details of the subcomponent).

Table 2 Uncertainty and Measurement Range of Instruments

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	$\pm 0.1\%$

Table 3: 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

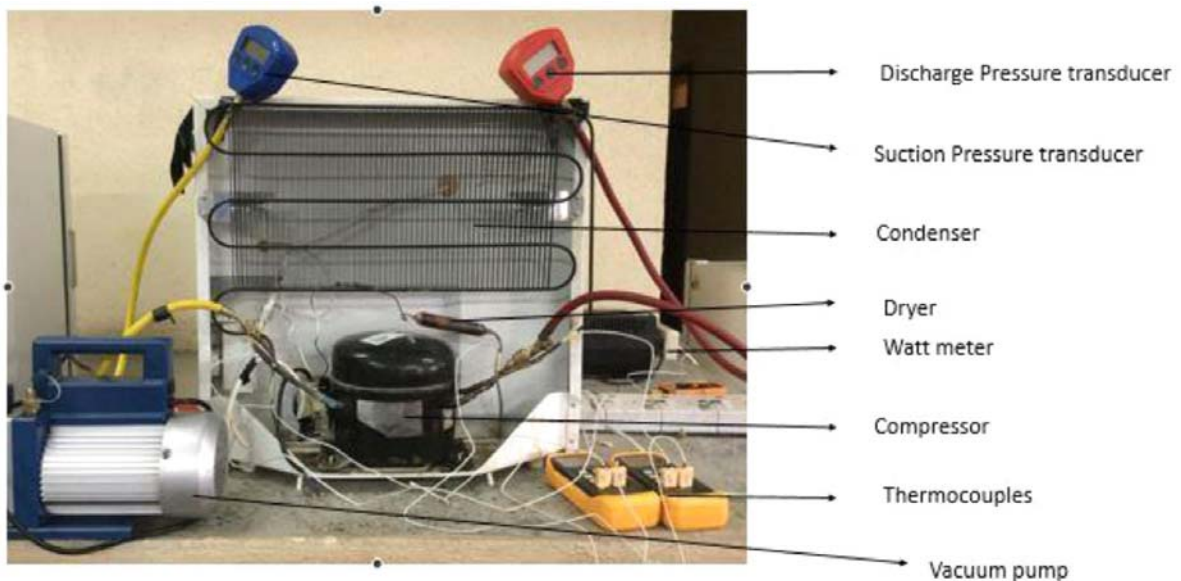


Figure 1: instrumentation of the test rig

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 instrumentation of the rig). The rig was carefully evacuated 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 (from 40grams to 70grams charge), followed by R600a (from 40grams to 70grams) and lastly R134a (100g) were separately tested within the system. The pressure readings were used to determine the pressure ratio.

3. Result and discussions

3.1 Power Consumption Variation

Power consumption is the summation of the energy consumed by the compressor of a refrigerator in operation. Figure 2 depicts the variations in the power consumption of the test rig with the hydrocarbon based refrigerants and selected ambient conditions. It can be seen that the least power consumption value of 66 W was obtained at the least ambient temperature ($-19\text{ }^\circ\text{C}$) with 60g R600a refrigerant. While, the 100g R134a refrigerant gave the highest power consumption with the test rig at $23\text{ }^\circ\text{C}$. In addition, it was observed that irrespective of the ambient temperature condition of the test rig, the hydrocarbon based refrigerants' power consumptions decreased and increased with increasing mass charges (40-70 g).

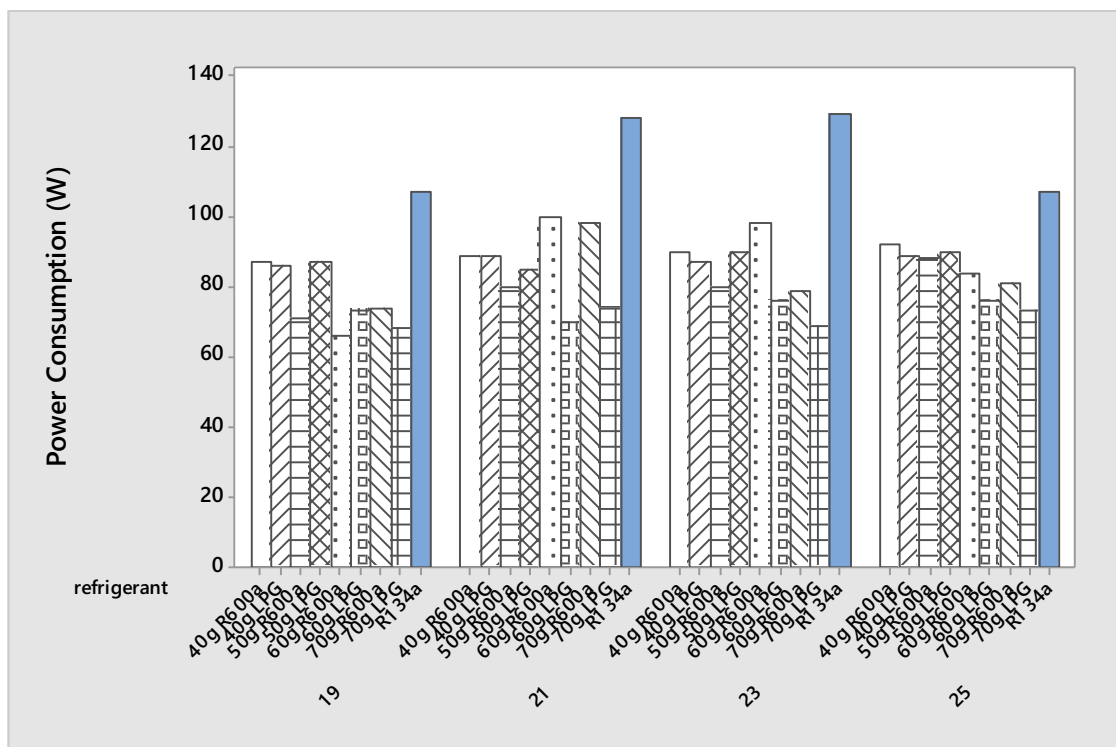


Fig. 2: Power consumption variation of the test rig

3.1 Evaporator Cabinet Temperature Variation

The influence of varying the refrigerant type, mass charges and ambient condition within the test rig on the evaporator cabinet temperature is as illustrated in Table 4. It can be seen that reducing the ambient temperature of the rig significantly brought about reduction in the evaporator cabinet temperature.

Also, the infusion R134a refrigerant at 19 °C, the least evaporator temperature was -3 °C with 70g of LPG while the highest was -12°C with 40g of LPG. At 21°C, the least was -1 °C with 70g charge of LPG while the highest was -11°C with 40g charge of LPG. At 23°C, the least evaporator temperature was -1 °C with 70g of LPG while the highest was -10 °C with 40g of LPG. At 25°C, the least was 1°C with 70g charge of LPG while the highest was -10°C with 40g charge of LPG. The overall least of LPG was -1°C with 70g charge at both 21°C and 23°C ambient temperature.

The application of R600a refrigerant within the system at an ambient temperature condition of 19 °C showed the least evaporator temperature was -3°C with 70g while the highest was -7°C with 40g of R600a. At 21°C, the least was -6°C with 70g charge while the highest was -6°C with 40g charge of R600a. At 23°C, the least evaporator temperature was -4°C with 70g while the highest was -8°C with 40g of R600a. At 25°C, the least was -2°C with 70g charge while the highest was -7°C with 40g charge of R600a. The overall least of R600a was -2°C with 70g charge at 25°C ambient temperature. The steady state evaporator temperatures of LPG, R600a and R134a at different ambient temperatures all met the standard in accordance to the ISO 8187 recommendation for domestic refrigerators except for 70g of LPG at 25°C with value of 1°C.

3.2 Steady State Compressor Discharge Temperature

The major factor influencing the durability of refrigerators is the compressor discharge temperature. The properties of lubricants and the life of compressor are adversely affected by very high compressor discharge temperature [4].

The discharge temperature seen within the rig with the infusion of LPG and R600a refrigerants in the selected ambient conditions were lower than R134a refrigerant (See figure 3). For LPG, the percentage reduction range in comparison to R134a refrigerant was 11– 39 %, while the utilization of R600a refrigerant gave percentages range of 15 – 41 % in comparison to R134a refrigerant. The maximum discharge temperature for LPG was 77 °C for 40g LPG at 25 °C, while the minimum discharge temperature was 47 °C for 70g LPG at 19 °C respectively. The range of discharge temperature for R600a was 70 °C for 60g R600a refrigerant in an ambient temperature condition of 23 °C and 46 °C for 70g of R600a refrigerant in an ambient condition of 19 °C respectively. Figure 4.3 describes the steady state discharge temperatures of LPG, R600a and R134a at selected ambient temperature conditions. The discharge temperature at steady state condition of the different charges of LPG refrigerant in the selected ambient temperatures showed that 25 °C and 40g LPG gave 77 °C which reduced with increasing mass charge to 72, 53 and 54°C respectively. Similarly, at 23 °C, 40g gave 73 °C and a decreasing discharge temperature was seen with mass charges discharge temperature values of 68, 51 and 50 °C respectively. At 21°C, 40g LPG refrigerant gave 71°C discharge temperature and decreased with increasing mass charge to 63, 50 and 51°C discharge temperature values respectively. The discharge temperature at 19°C

ambient condition and infusion of 40g LPG refrigerant gave 67 °C discharge temperature and reduced with increasing mass charge of LPG to 66, 50 and 47 °C respectively.

Also, for R600a, the discharge temperature at steady state of different charges of R600a at different ambient temperature showed that at 25°C, 40g showed 65°C, there was a reduction to 64°C with 50g, an increase with 60g charge with a value of 69°C, and then a decrease with 70g with a value of 54°C. At 23°C, 40g showed 64°C, there was an increase to 65 and 70°C with 50 and 60g respectively, then a decrease to 53°C with 70g charge. At 21°C, 40g showed 62°C, there was a reduction to 59°C with 50g, an increase with 60g charge with a value of 68°C, and then a decrease with 70g with a value of 60°C. At 19°C, 40g showed 61°C, there was a reduction to 54, 53 and 46°C with 50, 60 and 70g respectively. Therefore, the compressor discharge temperature decreases with increased mass charge (40-70g) for both LPG and R600a. The least of LPG and R600a showed a lower discharge temperature than R134a.

3.3 Steady State Condensing Pressure

Figure 4 shows the steady state condensing pressure of LPG, R600a and R134a at different ambient temperature. The condensing pressure seen within the rig when LPG and R600a were used in comparison to R134a were lower. For LPG, the percentages in comparison with R134a fall between 19– 66 % while for R600a, the percentages in comparison to R134a were lower by 15 – 61 %. The maximum condensing pressure for LPG was 183 psi and the minimum condensing pressure

was 75 psi while the maximum condensing pressure for R600a was 207 psi and the minimum were 82 psi. The condensing pressure at steady state of different charges of LPG at different ambient temperature showed that at 25°C, 40g showed 183psi and decreased to 175, 90 and 90 psi with 50, 60 and 70g charges respectively. At 23°C, 40g gave 180 psi, decreased to 170, 85 and 84 psi respectively. At 21°C, 40g gave 175 psi, decreased to 156 and 84 psi with 50 and 60g respectively and increased to 85 psi with 70g charge. At 19°C, both 40 and 50g gave 165 psi, then decreased to 83 and 75 psi with 60 and 70g charges respectively.

Also, for R600a, the condensing pressure at steady state of different charges of R600a at different ambient temperature showed that at 25°C, 40g showed 168psi and decreased to 160, 119 and 113 psi with 50, 60 and 70g charges respectively. At 23°C, 40g gave 160psi, decreased to 138 psi with 50g, increased to 207 psi with 60g and decreased to 110 psi with 70g charge. At 21°C, 40g gave 150 psi, decreased to 144psi with 50g, increased to 205 psi with 60g and decreased to 155 psi with 70g charge. At 19°C, 40g gave 150 psi, decreased to 109 and 82 psi with 50 and 60g respectively and increased to 94 psi with 70g charge.

3.4 Steady State Pressure Ratio

The pressure ratio of the refrigerant influences influences the volumetric efficiency of the compressor (Mohanraj, 2013) Figure 5 shows the steady state pressure ratio of LPG, R600a and R134a at different ambient temperature. The pressure ratio seen within the rig when LPG and R600a were used in comparison to R134a were lower. For LPG, the percentages in comparison with R134a falls between 6 – 109 % while for R600a, the percentages in comparison to R134a were lower by 0 – 358 %. The pressure ratio for LPG was while the minimum pressure ratio was while the maximum pressure ratio was 100 W and the minimum pressure ratio was. The pressure ratio at steady state at different charges of LPG at different ambient temperature showed that at 25°C, 40g gave 21 and decreased to 18, 16 and 12 with 50, 60 and 70g charges respectively. At 23°C, 40g gave 23 and decreased to 19, 18 and 12 with 50, 60 and 70g charges

respectively. At 21°C, 40g gave 23, decreased to 20 with 50g, increased to 21 with 60g and decreased to 12 with 70g charges. At 19°C, 40g gave 24 and decreased to 19, 17 and 13 with 50, 60 and 70g charges respectively.

Also, for R600a, the pressure ratio at steady state of different charges of R600a at different ambient temperature showed that at 25°C, 40g gave 13 and increased to 14 for both 50 and 60g and decreased to 12 for 70g charge. At 23°C, 40g gave 14, increased to 20 with 50g and decreased to 13 for both 60g and 70g charges. At 21°C, 40g gave 14, increased to 16 with 50g and decreased to 13 and 11 for 60 and 70g charges respectively. At 19°C, 40g gave 14 increased to 55 with 50g and decreased to 43 and 16g with 60 and 70g charges respectively.

Therefore, the pressure ratio decreases with increased mass charge (40-70g) for LPG while the pressure ratio increased up to 50g and decreased up to 70g for R600a. The highest of LPG and R600a gave a higher pressure ratio than R134a.

Table 4: Steady state evaporator temperature of the selected refrigerant at different ambient temperature

Refrigerant type	Ambient temperature (°C)			
	19	21	23	25
40g R600a	-7	-6	-8	-7
40g LPG	-12	-11	-10	-10
50g R600a	-14	-9	-9	-6
50g LPG	-9	-9	-8	-7
60g R600a	-12	-9	-8	-11
60g LPG	-5	-6	-4	-3
70g R600a	-7	-6	-4	-2
70g LPG	-3	-1	-1	1
R134a	-16	-11	-10	-15

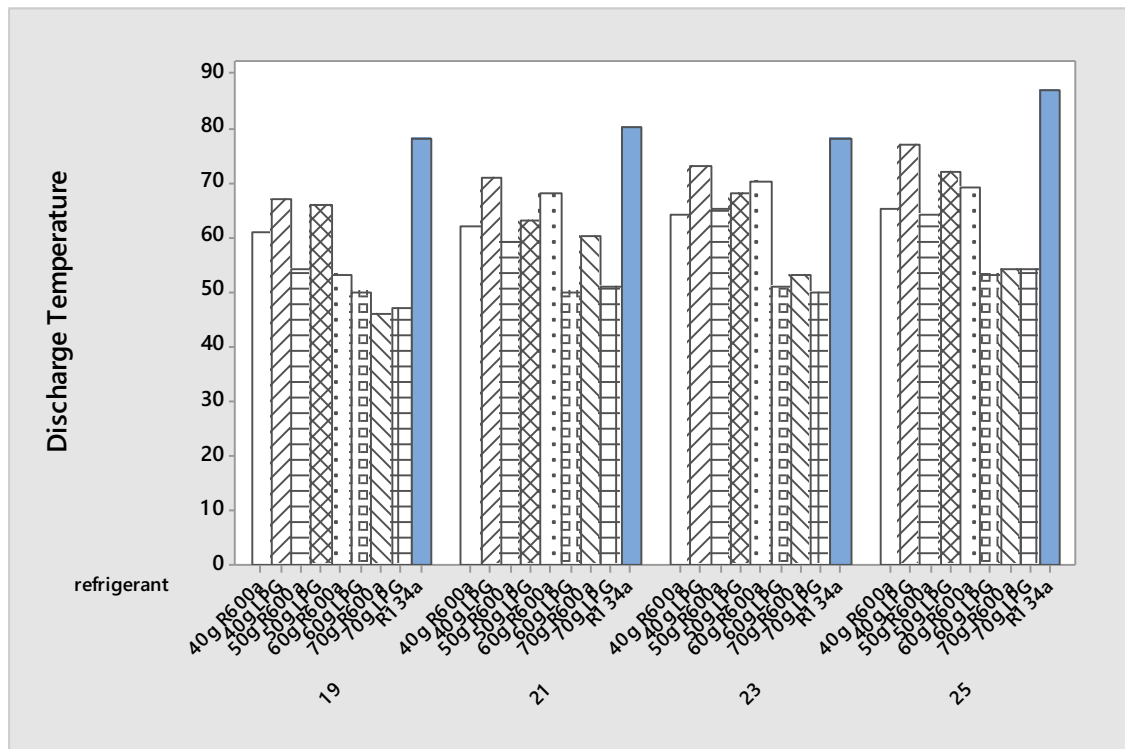


Fig 3: Variation of discharge temperature of the selected refrigerants at the different ambient temperatures

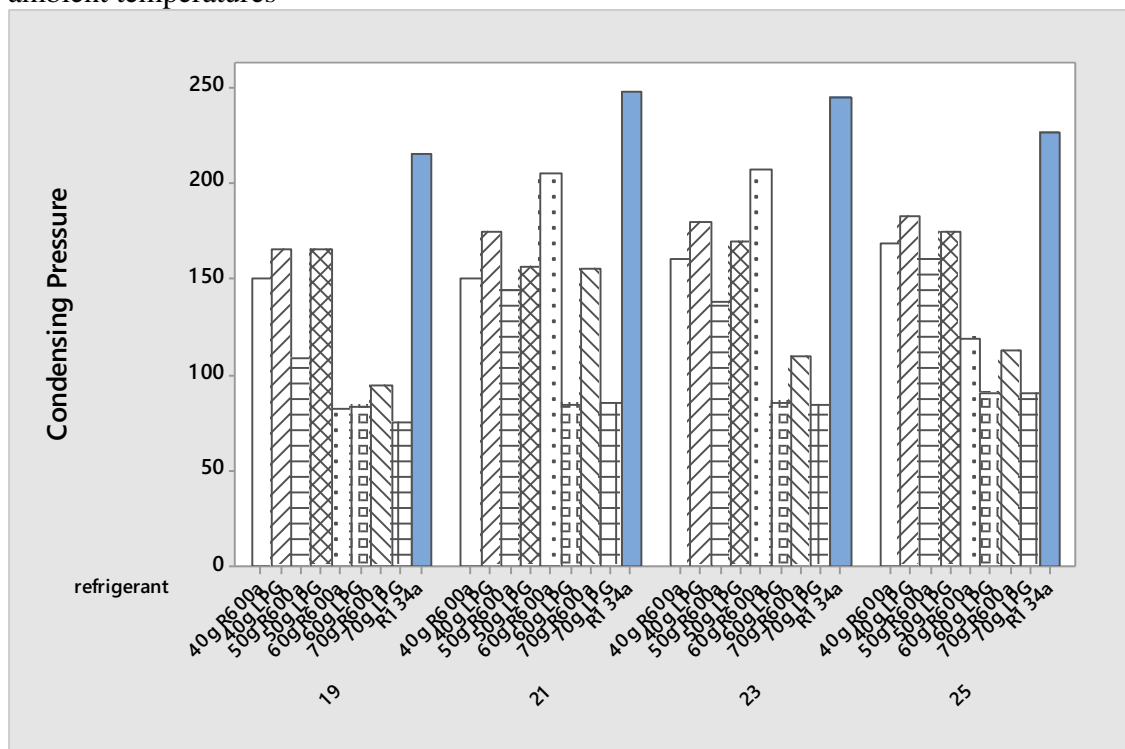


Fig 4: Steady state condensing pressure of the selected refrigerant, charges and different ambient temperatures

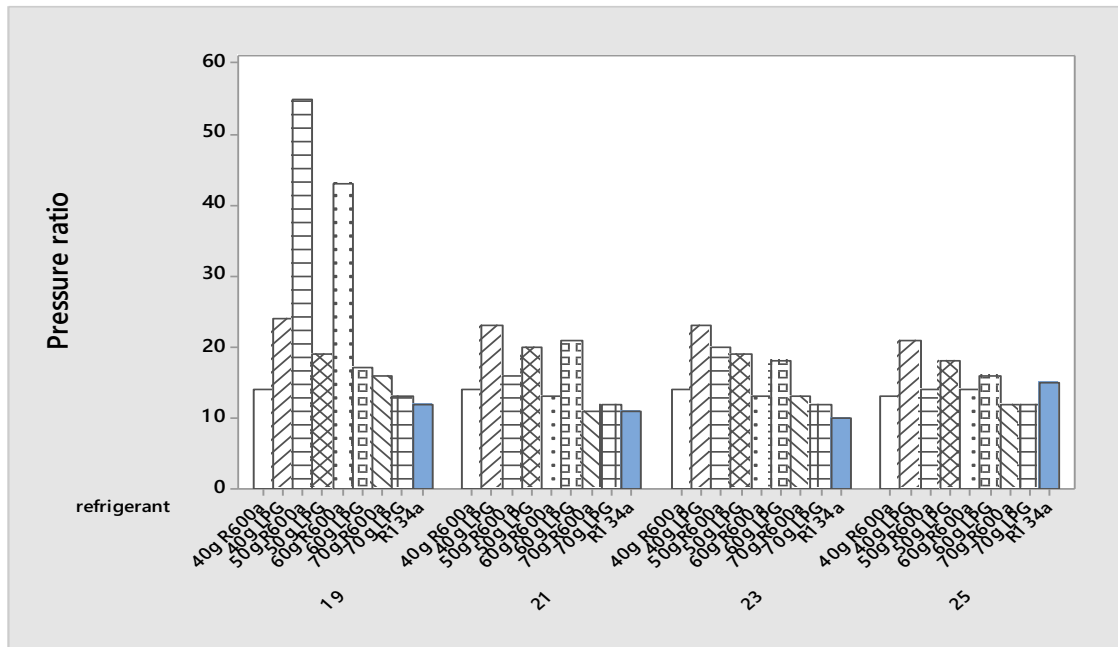


Fig 5: Steady state pressure ratio of LPG, R600a and R134a at selected charges at different ambient temperature

4. Conclusion

The experimental investigation of the various mass charges of LPG and R600a refrigerants in the modified R134a domestic refrigerator at the different ambient temperatures showed promising advantages as alternative refrigerants. Table 6.1 summarizes the major characteristic improvements the hydrocarbons refrigerant have over R134a refrigerant in the test system. LPG and R600a refrigerants utilized lower charges than R134a (100g charge) in the domestic refrigerator which implies better economic advantage. LPG and R600a offer improved environmental advantages in terms of zero ozone depletion potential and negligible global warming potential. Furthermore, they have high energy efficiency and workability in existing refrigeration systems with or without modifications and compatibility with existing subcomponent materials employed in conventional refrigeration equipment. The hydrocarbons based refrigerants gave lower power consumption, pressure ratio, discharge temperature, condensing pressure and very close cabinet air temperature in comparison to R134a refrigerant.

5. Recommendation

The influence of nanofluids on hydrocarbon based refrigerants have been identified as a promising prospect for improvement of domestic refrigeration. Thus, the application of nanofluid should be adopted for improved performance.

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