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Investigation of Household Refrigerator System with Varied Capillary Tube Length

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Abstract-
In this paper, the performance of R600a was investigated in a household refrigerator originally designed to work with R134a using varied capillary tube length (1.0, 1.15, 1.30 and 1.45 m). The refrigerator was instrumented with four thermocouples at the inlet and outlet of the major components. Also, two pressure gauges were connected to the compressor to measure the suction and discharge of the compressor. The experimental results were used to evaluate the performance of the system. The results showed that at optimal capillary tube length the COP and cooling capacity of R600a in the system increased with 45% and 4.2% respectively and the power consumption reduced with 25% using 1.30 m varied capillary tube length compared to R134a. Conclusively, R600a can serve as a retrofit in the household refrigerator systems originally designed to work with R134a refrigerant.

Keywords: COP, power consumption, R134a, R00a, capillary tube

1.0 Introduction

Hydrofluorocarbon (HFC) refrigerants have been listed as one of the chemicals used in a refrigeration system as working fluid that contribute to climate change due to the presence of fluorine in them according to the Kyoto protocol [1], [2]. As a result, a timeline has been set to phase out the use of HFC's refrigerant in refrigeration systems. However, up to date, HFCs refrigerant is still very much in use in major parts of the world as working fluid in vapour compression systems. The most commonly used HFC's today include R134a, R410A and R404A. Although, these refrigerants have zero Ozone Depleting Potentials (ODPs) the global warming is still high compared to natural refrigerants. Some countries in Europe have banned the use of HFC's refrigerant in household vapour compression systems and natural refrigerants have been adopted as an alternative to HFC's refrigerant in household refrigerators. Hydrocarbon refrigerants (HC's) is one of these refrigerants [3]. Hydrocarbon refrigerants are more attractive because of their good thermophysical properties, zero ozone-depleting potentials (ODPs) and very low global warming potentials (GWPs).

Some studies have been carried out on the use of hydrocarbon refrigerants in vapour compression systems. Oyedepo et al. [4] conducted an experiment on a refrigerator designed for R12 refrigerant. The R600a refrigerant was investigated in the system. It was discovered that R600a gave the highest cooling capacity of 9.18% and R600a with 1.5m capillary tube length gave the lowest power consumption. The power consumption was 24% lower and the COP was 6.3% higher compared to R12 in the system. Jung et al [5] investigated the performance of R290/R600a to replace R12 in a domestic refrigerator. Ansari et al. [6]

conducted an experiment on the use of R1234ze and R1234yf substitute for R134a in a vapour compression system. The result showed that R1234ze and R1234yf performed better in terms of efficiency defect with condenser exhibiting the highest exergy defect among the components of the system. Bolaji [7] also carried out a study on the use R152a and R32 to replace R134a a domestic refrigerator, the result showed that the COP of R152a was 4.7% higher than R134a with a lower energy consumption while the COP of R32a was 8.5 % lower than R134a in the system. The result showed that R290/R600a showed better replacement for R12 in the system. Jwo et al (Jwo, Ting, & Wang, 2009) researched a mixture of R600a and R290 as a drop-in replacement for R134a in a 440L size refrigeration system. The results showed a reduction of 4.4%, 17.4% and 40% in the energy consumption, running time and refrigerant charge respectively. However, there was no detail about the cooling capacity of the system.

Today, the use of existing domestic refrigerator working with R134a is still very prominent, especially in developing countries. This study focuses on how existing refrigerator primary designed to work with R134a can be replaced with R600a with improved performance in terms of COP, power consumption and cooling capacity.

2.0 Experimental method and procedure

The experiment was carried out in a domestic refrigerator primarily designed to work with a 100g mass charge of R134a. The R134a refrigerant was used as the base refrigerant for this experiment. The original capillary tube length of the refrigerator was 1.0 m. The refrigerants were charge into the system using 100 g of R134a with 1.0 m capillary tube length. The system was retrofitted using 60 g of R600a with varied capillary tube length (1.0, 1.15, 1.30, and 1.45 m). The 60 g of R600a was selected because hydrocarbon refrigerants possess lower density compared to HFCs. Therefore lower mass charge is required for effective operation [8], [9]. The refrigerants were charged into the system with the digital charging system. The inlet and outlet temperatures of each component (compressor, evaporator, condenser and capillary tube) of the system were taken. Four thermocouples were used to measure the temperature at each component inlet and outlet. Two pressure gauges were connected to measure the suction and discharge pressure of the compressor. The specification of the refrigerator used for the experiment is shown in Table1. The experimental setup and condition are shown in Figure 1 and Tables 3 - 4. The properties of R134a and R600a refrigerants are shown in Table 2. The pressure and temperature readings the pressure and temperature readings were recorded and repeated for five times at intervals of 30 minutes for a period of 300 minutes. The temperature and pressure readings recorded were used to determine the performance of the system using the Ref-prop, version 9.0. The experimental results were analysed and compared with performance R134a refrigerant in the system using equation 1-3.

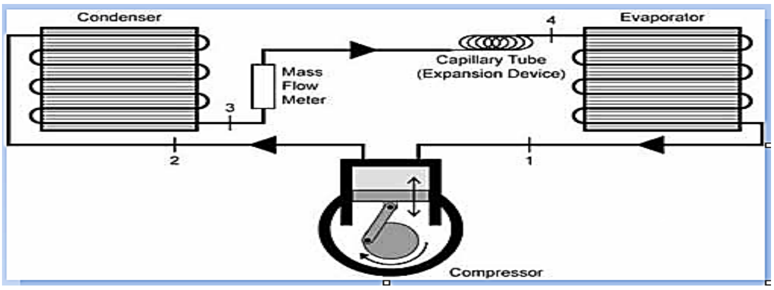

Figure 1. Schematic diagram of the experimental setup

Table 1: Specification the refrigerator system

S/N	Parameters	Unit
1	Refrigerant mass charge	100g
2	Refrigerant	R134a
3	Environment temperature	1±27ºC
4	Power rating	100W
5	Voltage rating	220-240V
6	Capillary tube length	1.m
7	Evaporator type	Air-cooled
8	Evaporator size	80itres

Table 2. Characteristics of the refrigerants

Refrigerant	Normal boiling point (º C)	ODP	Critical temp. (º C)	GWP	Safety group	Molar Mass
R134a	-26.07	0	101.06	1300	A1	102.03
R600a	-12	0	135	20	A3	56.12

Table 3. The uncertainty of the instrument used

Characteristic	Range	Uncertainty
Temperature	50 – (-40) ºC	± 0.10%
Power	0 – 3500 (W)	± 0.10%

Table 4. The experiment ranges and parameters

Parameter	R134a	R600a
Capillary tube length	1.0	1.0, 1.15, 1.30 and 1.45 m
Refrigerant	100 g	60 g
Lubricating oil	POE	Mineral
Ambient temperature	27 ºC	27 ºC

The system performance of the system was evaluated using the equation 1-3
Cooling capacity (Q_{evap}) is capacity given by

$$Q_{evap} = m(h_4 - h_1) \quad \text{(kW)} \qquad (1)$$

Q_{evap} (kW) represents the cooling capacity in the system, h_4 and h_1 represent the enthalpy at the evaporator and compressor inlet while m represent the mass flow rate of the system.

The compressor power input is given by

$$W_C = m(h_2 - h_1) \quad \text{(kW)} \qquad (2)$$

Wc (kW) represents thecompressor power in the system, h_2 represents the entaply at the compressor outlet.

Coefficient of performance

$$COP = \frac{Q_{\text{evap}}}{Wc} \qquad (3)$$

3.0 Results and discussion

The performance analysis of R134 and R600a with varied capillary tube length are discussed below.

Figure 2 shows the pulldown time of the system. The pull-down time decreases with an increase in capillary tube length until it reaches 1.45 m capillary tube length. The pulldown time for R134a and R600a with 1.0, 1.15, 1.30, and 1.45 m capillary tube length are 210. 210, 240, 210 and 210 minutes with temperature of -6, -4, -8, -12 and -10 ºC respectively.

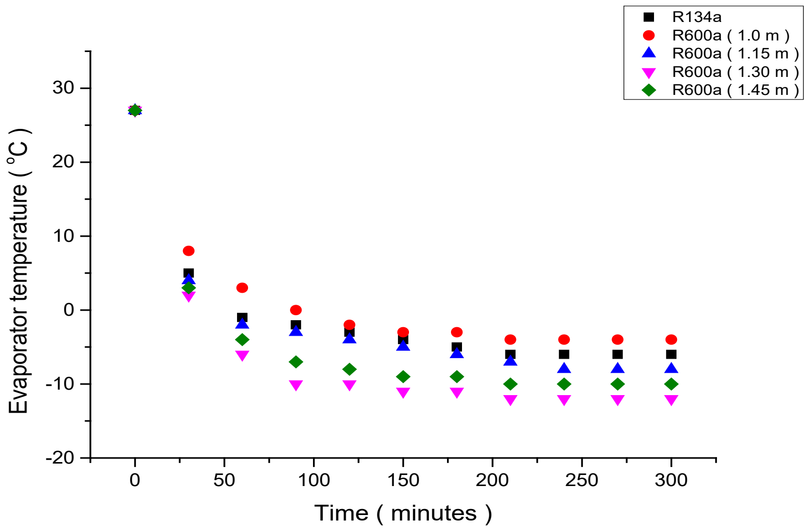

Figure 2 Effect of capillary tube length on the pulldown time of the system.

Figure 3 shows the power consumption of the system. The power consumption of R134a and R600a with 1.0, 1.15, 1.30, and 1.45 m capillary tube length are 94, 85, 78, 70 and 79 W respectively. The power consumption decreases with an increase in capillary tube length until it reaches 1.30 m capillary tube length. This means the optimal capillary tube extension for R600a in the system is 1.45 m. The power consumption decreases with 9.5, 17.0, 25.5 and 16 % for the varied capillary tube length compared to R134a in the system respectively. This result can be linked to a decrease in evaporator temperature discharge pressure of the compressor in the system.

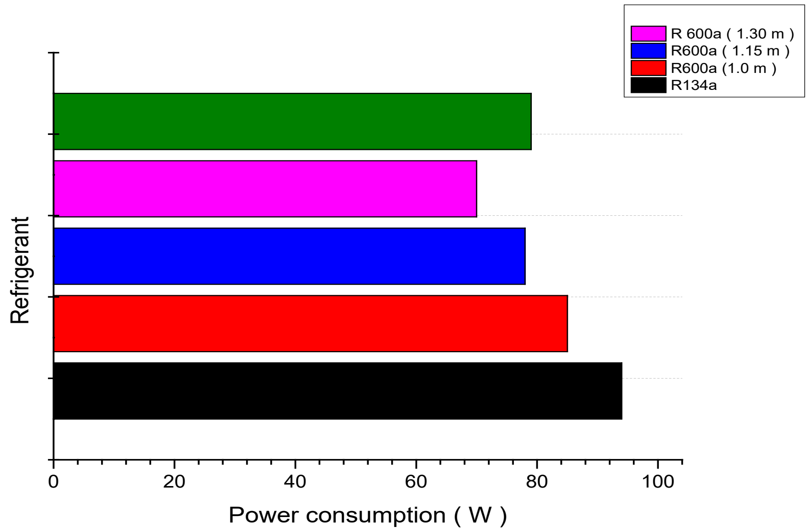

Figure 3 Effect of capillary tube length on the power consumption of the system.

Figure 4 illustrates the cooling capacity of the refrigerator system improves with an increase in capillary tube length. The cooling capacity of R134a and R600a with 1.0, 1.15, 1.30 and 1.45 m capillary tube length are 160.1, 148.7, 157.2, 166.8 and 164.8 W. The cooling capacity of R134a is 7.1 % and 1.8 % higher than R600a with 1.0 m and 1.15 m, but with 1.30 m and 1.45 m capillary tube length the cooling capacity of R600a increases with 4.2 % and 2.9 % respectively.

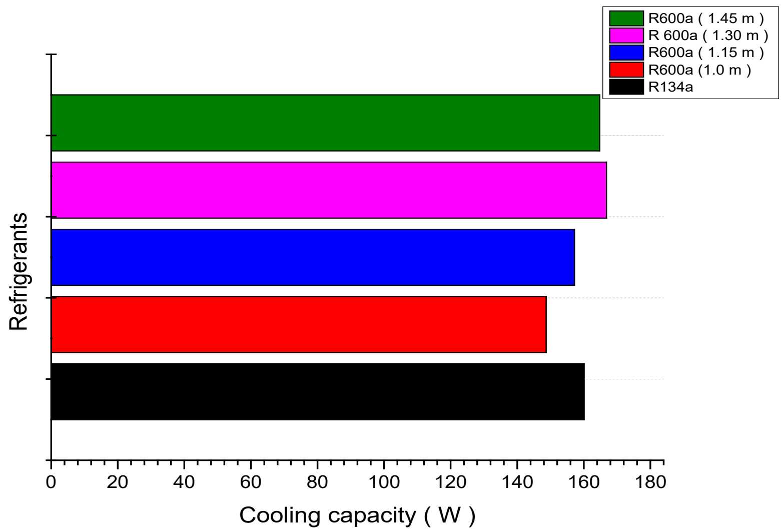

Figure 4 Effect of capillary tube length on the cooling of the system.

Figure 5 the coefficient of performance of the system is higher than the based refrigerant throughout the experiment. The COP of R134a and R600a with 1.0, 1.15, 1.30 and 1.45 m capillary tube length are 1.70, 1.75, 2.02, 2.48 and 2.09 respectively. The COP of R600a with increase with 2.9, 18.8, 45.8 and 22.9 % respectively. This is due to a decrease in the power consumption of the system with varied capillary tube length.

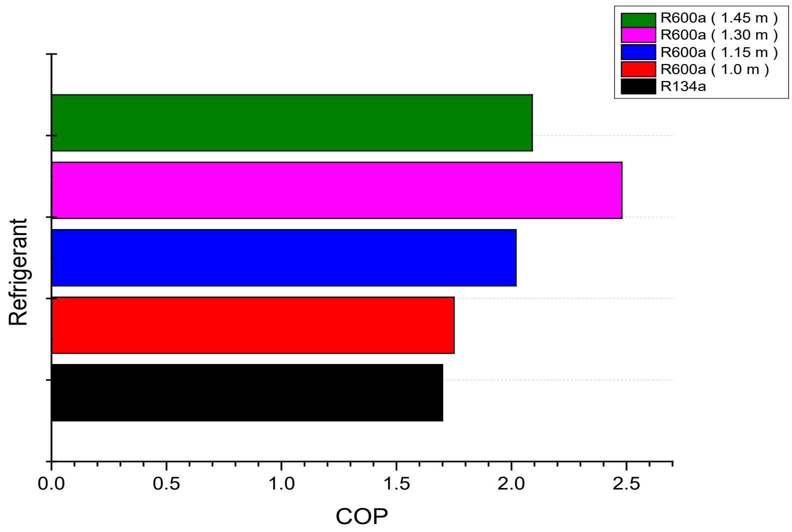

Figure 5 Effect of capillary tube length on the COP of the system.

Figure 6 shows the discharge pressure of R134a is higher than R600a throughout the experiment. However, the discharge pressure of R600a reduces with a decrease in power consumption and later increase as R600a power consumption increase in the system.

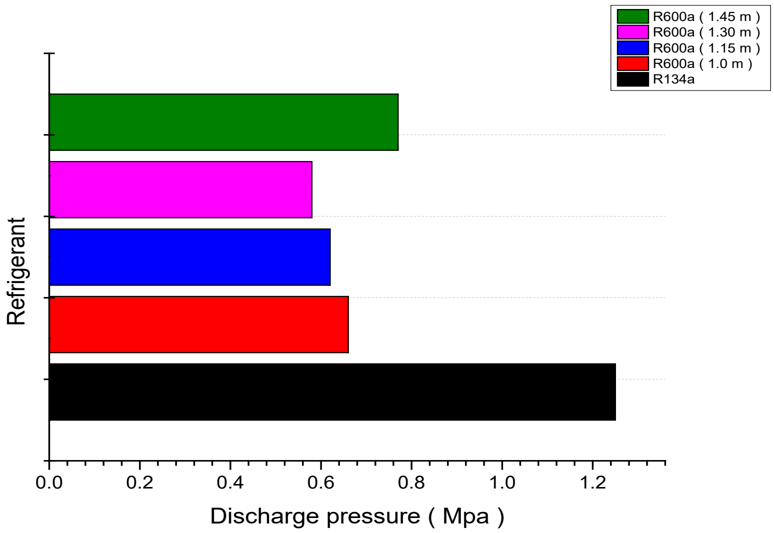

Figure 6 Effect of capillary tube length on the discharge pressure of the system.

Table 5 below shows a summary of the experimental test.

Tabel. 5 The summary of the experimental results

Parameter	R134a	R600a (1.0 m)	R600a (1.15 m)	R600a (1.3 m)	R600a (1.45 m)
Pull down temperature (°C)	-6	-4	-8	-12	-10
Coolin capacity (W)	160.1	148.7	157.2	166.8	164.8
Power consumption (W)	94.0	85.0	78.0	70.0	79.0
COP	1.70	1.75	2.02	2.48	2.09
Discharge pressure (MPa)	1.25	0.66	0.62	0.58	0.77

4.0 Conclusion

The use of R134a will soon be banned completely globally in the near future. R134a identified as a drop-in replacement for R12 in the domestic refrigerator due to its zero ODP. However, its global warming potentials are still very high compared to R600a. After careful experimental investigation, the following conclusion was made.

- The R600a presents higher COP in the system.
- lower power consumption was achieved for R600a with varied capillary tube length with R600a with 1.30 m offering the lowest power consumption compared to R134a.
- The cooling capacity of R600a was improved with an increase in capillary tube length in the system.
- Generally, the use of R600a as a retrofit in refrigerator originally designed to work with R134a is feasible, and the performance can be improved with the extension of capillary tube length. Therefore, R600a recommends as a substitute for refrigerator originally designed to work R134a

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