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## Article

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# Energy performance evaluation of R600a/MWCNT-nanolubricant as a drop-in replacement for R134a in household refrigerator system

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## Abstract

Vapour compression refrigerator systems working with R134a are associated with high energy demand and environmental problems and refrigerator consumers' prioritise energy consumption in choosing their choice of refrigerator systems. Therefore, this research work investigated R600a in MWCNT-nanolubricant (0.4 g/L and 0.6 g/L) as a drop in replacement for R134a refrigerant in a household refrigerator system with varied mass charge of R600a (50, 60 and 70 g). The refrigerator was instrumented at the inlet and outlet of the refrigerator compressor, condenser, expansion valve and evaporator. Two bourdon type pressure gauges were connected to the compressor inlet and outlet of the system. The results were taken and evaluated and compared with the result obtained through R134a refrigerant in the system. The result showed that R600a perform better in terms of COP, power consumption and cooling capacity compared to R134a in the system with lower evaporator temperature of  $-11^{\circ}\text{C}$  and power consumption of 0.0639 kW and highest COP in the system. Therefore, R600a/MWCNT- nanolubricant can serve as a drop in replacement for R134a in the household refrigerator.

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**Keywords:** GWP; R134a; R600a; MWCNT; COP; Power consumption

## 1. Introduction

Major energy demand in homes and commercial buildings is as a result of refrigeration, heating, ventilation and air-conditioning systems. Hence, energy researchers are looking into improving the energy consumed by comfort systems such as the household refrigerators and air-conditioning systems [1]. Introducing nanofluids into vapour compression systems is capable of giving that solution to the high energy consumption associated with refrigeration systems. Choi et al. [2] found out that the use of nanoparticles as additives in refrigerator in nanolubricant and nanorefrigerant has the potential to enhance its thermal properties. When nanoparticles are dispersed in the lubricant

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### Nomenclature

VCRS	Vapour compression refrigeration system
MWCNT	Multiwall carbon nanotube
POE	Polyester Oil
TEM	Transmission electron microscope
<i>COP</i>	Coefficient of performance
$Q_{evap}$	Cooling capacity (W)
$W_C$	Compressor power input (W)
$h$	Enthalp (kJ/kg)

### Subscripts

1	Evaporator outlet
2	Compressor outlet
3	Condenser outlet
4	Evaporator inlet

or refrigerant they are called Nanolubricants or Nanorefrigerants. Part of the advantages of nanoparticles in the compressor lubricant is that they enhance the thermal conductivity and reduce friction and wear which in turns cause an enhancement in the heat transfer rate and reduce the pumping power required by the compressor for the effective operation of a system [3]. However, the performance of nanoparticles in the base fluid largely depends on the size, shape, and concentration of the nanoparticles [4].

In the past, some researchers have studied the use of nanolubricants in cooling systems such as vapour compression system (VCRS) in order to enhance its performance. Nabil et al. [5] evaluated water/ethylene glycol (EG) mixture in terms of heat transfer performance with TiO<sub>2</sub> nanoparticles within a range of 30 °C to 80 °C. The result obtained show a 15.4% improvement at 60 °C. Wang et al. [6] compared fullerene (C70) and NiFe<sub>2</sub>O<sub>4</sub> nanolubricant with the base lubricant in an automobile air-conditioning (A/C) system. The result showed that COP of the A/C system was increased by 23%. Also, a reduction in the coefficient of friction was achieved which means a reduction in wear. Melnyk [7] tested Al<sub>2</sub>O<sub>3</sub> and TiO<sub>2</sub> nanoparticles with R600a refrigerant using mineral oil in VCRS. The result indicated that R600a/Al<sub>2</sub>O<sub>3</sub> and R600a/TiO<sub>2</sub> performances improved in terms of thermal conductivity and viscosity in the system. Babarinde et al. [8] also carried out an experiment on the use of R600a as a direct replacement for R134a in a VCRS, the result showed that R600a/TiO<sub>2</sub> performed better compared to R134a in terms of COP and power consumption in the system. Sun et al. [9] evaluated the performance of the heat transfer of MWCNT-OH/R141b and MWCNTCOOH/R141B in a cooling system by varying the volume concentration (0.059, 0.117 and 0.17655%vol) at vapour quality range of 0.2–0.7. The result showed that heat transfer coefficient of MWCNT-COOH/R141B was higher compared to MWCNT-OH/R141b. Mahmoud [10] also investigated the performance of Single-Wall Carbon Nanotube (SWCNT) in refrigeration system using R134a as working fluid. The nano concentration was varied from 1% to 5 vol% within the temperature range of 300 K to 320 K. The result showed an increase in thermal conductivity and specific heat transfer of SWCNT/R134a in the system compared to pure R134a. Hung and Gu [11] also carried out research on MWCNT Nanofluid in a hybrid energy system. The MWCNT was added as an additive in water with a weight fraction of 0.125%, 0.25% and 0.5% to produce a Nanofluid. The 0.125% Nanofluid showed a 5% increase in the heat transfer behaviour compared to the water.

From the existing literature, MWCNT nanoparticles are capable of increasing the thermal conductivity, and heat transfer rate when used as additives in the base fluid. Currently, there is more literature on the use of MWCNT in halogenated refrigerant and water. Furthermore, MWCNT nanoparticles have not been investigated in hydrocarbon refrigerants of which R600a is one of such. Today, household refrigerator designed to work with R134/POE oil are still in use, especially in the developing countries. Therefore, there is a need to replace them with improved R600a/MWCNT-Mineral oil. This work presents the application of R600a/MWCNT using mineral oil as the lubricant to replace R134a in the household refrigerator system.

## 2. Experimental procedures

The household refrigerator used as test rig for this experiment was primarily designed to work with POE-Oil and 100 g R134a. Therefore, R134a is used as a baseline for this experiment. The refrigerator was evacuated with the aid of vacuum flasher before use and after each experiment. In this present study R600a/MWCNT-nanolubricant is used as a drop on a replacement for R134a in a household refrigerator. R600a is considered due to its Zero ODP and very low GWP compared to R134a [12].

The R600a refrigerant was varied within the range of 50 g–70 g. The lubricant used for R600a refrigerant was 1 L lubricant (mineral oil). MWCNT-nanolubricant was selected for this experiment because of its good, energy storage, thermal properties and very large surface area. The MWCNT nanolubricant used has a specification of  $10 \text{ nm} \pm 1 \text{ nm} \times 4.5 \text{ nm} \pm 0.5 \text{ nm} \times 3\text{--}6 \mu\text{m}$  as stated by the manufacturer in Table 2. The transmission electron microscope of the MWCNT nanoparticles is shown in Fig. 2.

The MWCNT nanolubricant was prepared with 1 L of lubricant (mineral oil). Different samples of 0.4 g/L and 0.6 g/L MWCNT-nanolubricant concentrations were prepared. Digital charging scale was employed to measure the nanoparticles before dispersed into the lubricant. The mixture of the MWCNT and the lubricant was stirred with the help of magnetic stirrer for 45 min. Also, ultrasonic homogeniser was used to homogenised the MWCNT-Lubricant mixture together for 3 h within a temperature range of  $15 \text{ }^\circ\text{C}$ – $20 \text{ }^\circ\text{C}$  [13]. Each MWCNT-nanolubricant was tested for 50 g, 60 g and 70 g of R600a. Fig. 3 shows the preparation flow chart of the MWCNT-nanolubricant while Table 4 shows the properties of the POE and the mineral oil used for the experimental study.

The 100 g of R134a refrigerants was first introduced into the system with the aid of digital charging scale. The system was evacuated and flushed after. Then R600a refrigerants were charged into the system. The temperature readings were taken at the inlet and outlet of each refrigerator components (compressor, condenser, expansion valve and evaporator) for each experiment with K type thermocouples connected to the inlet and outlet of each component. Also, two Bourdon type pressure gauges were connected to the inlet and out of the compressor to measure the inlet and outlet pressure of the compressor. A digital wattmeter was used to measure the power consumed by the refrigerator compressor. The experiment was carried at an average environmental temperature of  $27 \text{ }^\circ\text{C}$ . The experimental set-up, measuring instruments, uncertainties, experimental condition and range are shown in Fig. 1, Tables 3–4. The experiment outputs were evaluated and compared with the performance of R134a. Performances such COP, power consumption, cooling capacity of the system were evaluated using Eqs. (1)–(3) (see Table 1).

The refrigerator system performance was calculated using equations below

$$= \dot{m}(h_1 - h_4) \quad (\text{kW}) \quad (1)$$

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

$$COP = \frac{Q_{evap}}{W_c} \quad (3)$$

**Table 1.** Characteristics of the refrigerants.

S/N	Refrigerants	Normal boiling point ( $^\circ\text{C}$ )	ODP	GWP	Critical Temp. ( $^\circ\text{C}$ )	Safety group	Molar mass
1	R134a	−26.07	0	1300	101.06	A1	102.03
2	R600a	−12	0	20	135	A3	56.12

**Table 2.** Specification of the nanoparticles.

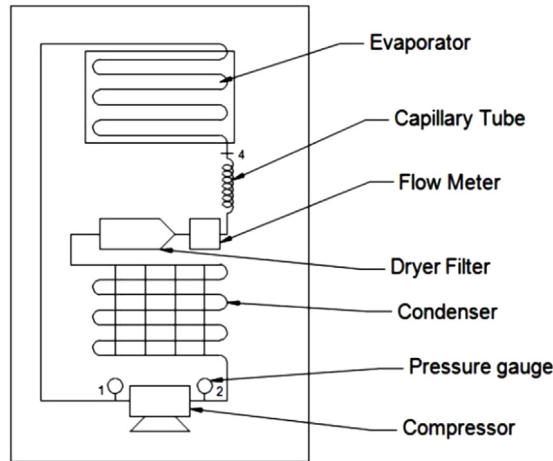
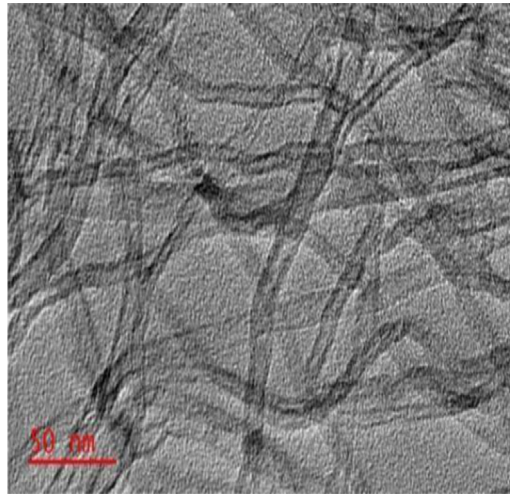
Table		Nanoparticles	Information	
S/N	Type		Specification	Manufacturer
1	Multi-Wall carbon nanotube		$10 \text{ nm} \pm 1 \text{ nm} \times 4.5 \text{ nm} \pm 0.5 \text{ nm} \times 3\text{--}6 \mu\text{m}$	Aldrich

## 3. Results and discussion

The comparison of the performance of R134a, R600a in the bsae lubricant (mineral oil) and MWCNT-nanolubricant concentrations is being discussed considering evaporator air temperature, COP, power consumption and cooling capacity.

**Table 3.** Specifications of the measuring instrument and uncertainty.

S/N	Parameter	Specification	Range	Uncertainty
1	Temperature	Digital thermocouple K	−50 °C–700 °C	±3 °C
2	Pressure	Bourdon gauge	0–2000 kPa	±1%
3	Power consumption	Digital Watt/Watt-h-metre	1–2000 W (0.0001–999.9 kWh)	±1%

**Fig. 1.** Experimental setup.**Fig. 2.** Transmission electron microscope image of MWCNT nanoparticles.

Figs. 4–6 illustrate the pull-down time of R134a and R600a in 0.4 g/L and 0.6 g/L MWCNT-lubricant. It can be observed that R134a has an evaporator temperature of  $-8$  at a pull-down time of 210 min while R600a in 0.4 g/L of MWCNT-nanolubricant concentration has the shortest pull-down time and lowest evaporator air temperature. The evaporator air temperature of  $-6$  °C,  $-11$  °C and  $-3$  °C at a pull-down time of 180, 150 and 90 min was recorded for 50, 60 and 70 g of R600a in 0.4 g/L MWCNT-nanolubricant concentration. Also, evaporator air temperature of  $-8$  °C,  $-11$  °C and  $-5$  °C at a pull-down time of 210, 240 and 210 min was recorded for 50, 60 and 70 g of R600a in 0.6 g/L MWCNT-nanolubricant respectively. The improvement is as a result of enhancement in heat transfer due to the increase thermal conductivity of the system.

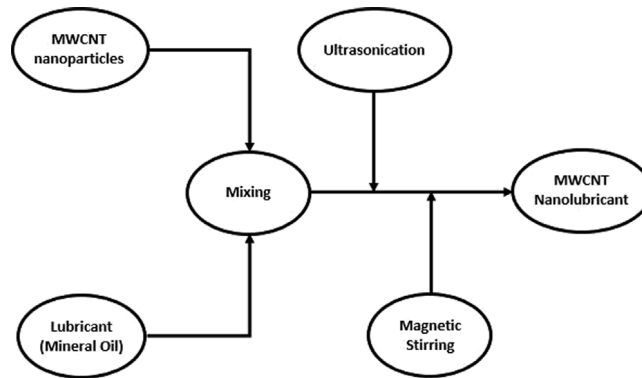


Fig. 3. MWCNT nanolubricant flow chart.

Table 4. Experimental conditions.

S/N	Parameter	Range
1	Refrigerant mass charge	50, 60 and 70 g
2	Refrigerant	R600a
3	Compressor lubricant	Pure-lubricant, MWCNT nanolubricant
4	MWCNT	$10 \text{ nm} \pm 1 \text{ nm} \times 4.5 \text{ nm} \pm 0.5 \text{ nm} \times 3\text{--}6 \mu\text{m}$
5	Nano-lubricant concentration	0.4, 0.6 g/L
6	Ambient Temp.	27 °C
7	Capillary length	1.5 m
8	Condenser	Air-cooled
9	Evaporator capacity	70 L
10	Density at 15 °C (POE)	0.980
11	Density at 15 °C mineral oil	0.914
12	Kinematic viscosity at 40 °C/100 °C (POE)	32 cSt/5.8 cSt
13	Kinematic viscosity at 40 °C/100 °C mineral oil	30 cSt/4.4 cSt

Fig. 7 shows the cooling capacity of R134a and R600a in MWCNT-nanolubricant in the refrigerator system. The cooling capacity first slightly decrease with 0.4 g/L of MWCNT-nanolubricant for 50 g of R600a then continue to improve with the introduction of the MWCNT-nanolubricant into R600a. The cooling capacity of R600a increases with increase in the concentration of MWCNT-nanolubricant from 0.4 g/L to 0.6 g/L in the system until it attained its optimal mass charge. The cooling capacity of R600a in MWCNT-nanolubricant increases within the range of 3.5%–12.9%, 11.90%–14.30% and 3.20%–14.90% for 50 g, 60 g and 70 g of R600a in MWCNT-nanolubricant respectively

The 60 g of R600a in 0.4 g/L MWCNT-nanolubricant has the highest cooling capacity of 0.1893 kW with an evaporator air temperature of  $-11$  °C. This general increase in the cooling capacity of MWCNT-lubricant is due to the increase in thermal conductivity of the R600a in MWCNT-nanolubricant compared to the R134a.

Fig. 8 depicts the power consumption of the system and the effect of MWCNT-nanolubricant on the power consumption of the system. The power consumption of R600a in MWCNT-nanolubricant concentration decreases with the introduction of MWCNT nanoparticles into the lubricant until it reaches its optimal concentration and mass charge for R600a in the MWCNT-nanolubricant. The power consumption of 0.4 g/L and 0.6 g/L MWCNT -nanolubricant is lower within the range of 0.0612 kW–0.0719 kW, 0.0639 kW– 0.0728 kW and 0.0761 kW–0.0814 kW for 50 g, 60 g and 70 g of R600a in 0.4 g/L and 0.6 g/L of MWCNT-lubricant respectively with 60 g of R600a in 0.6 g/L of MWCNT-nanolubricant having the lowest evaporator and lower power consumption of 0.0639 kW at  $-11$  °C compared to R134a. This is as a result of a reduction in the pumping power of the compressor due to the tribological behaviour of MWCNT to reach a lower evaporator temperature.

Fig. 9 shows the effect of MWCNT-nanolubricant on the COP of the refrigerator system. The COP of R600a in MWCNT-nanolubricant is higher than R134a. The COP of R600a in the 0.4 g/L and 0.6 g/L of MWNT-Lubricant ranges from 2.6–2.8, 2.6–2.9 and 1.84–2.5 for 50 g, 60 g and 70 g of R600a respectively. The 60 g of R600a in 0.6

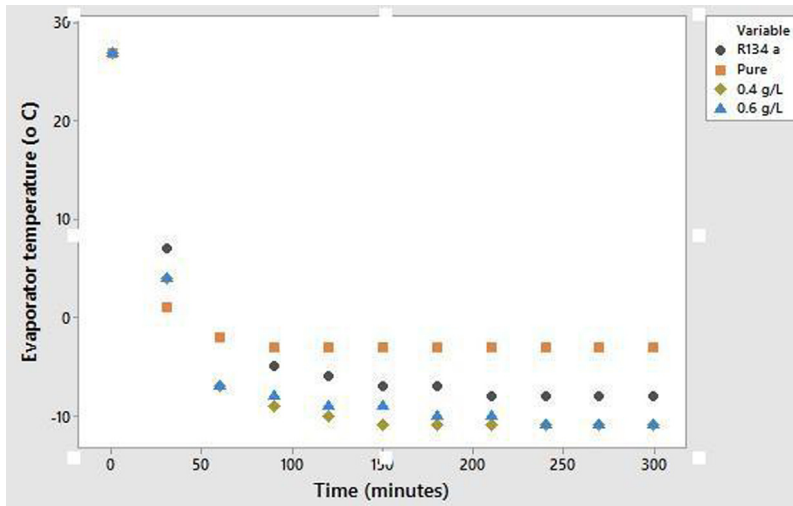


Fig. 4. Effect of MWCNT nanolubricant on the pull-down time of 50 g of R600a.

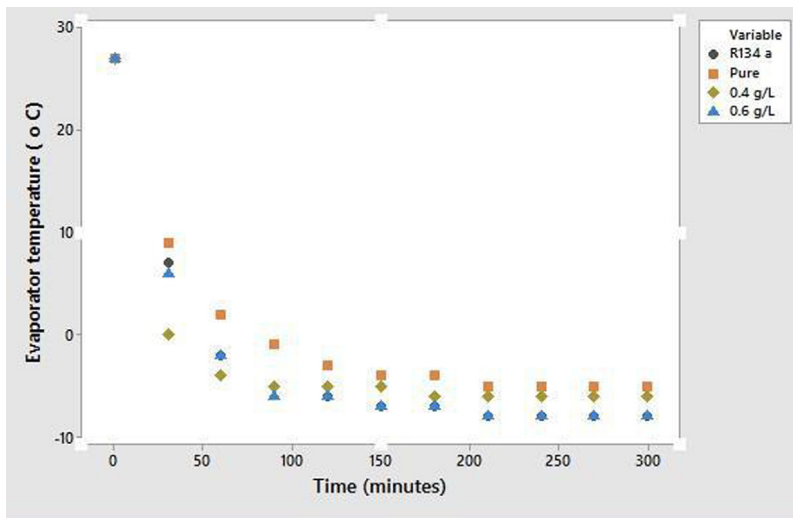


Fig. 5. Effect of MWCNT nanolubricant on pull downtime of 60 g of R600a.

g/L of MWCNT-nanolubricant has the highest COP. The improvement in the COP can be linked to the influence of the MWCNT nanoparticles on the system which led to a decrease in the friction and wears in the compressor which - caused a decrease in power consumption. Also, it can be attributed to enhancement in the heat transfer which led to higher cooling capacity compared to the R134a

Fig. 10 depicts the discharge pressure of the system. The compressor discharge pressure of R600a in MWCNT-nanolubricant is lower than R134a. The reduction in discharge pressure is also responsible for the reduction in the power consumption of the system. This can be credited to a reduction in friction and wear as a result of the introduction of MWCNT-nanolubricant into the system. One of the benefits of reduction in the discharge pressure of the refrigerator compressor is that it prolongs the life span of the compressor.

In this research it was noticed that for every mass charge of R600a refrigerant [see Table 5] MWCNTLubricant performed better in terms of pull-down time which established the enhancement in heat transfer rate, increase in thermal conductivity and most importantly the improvement in the energy efficiency of the system

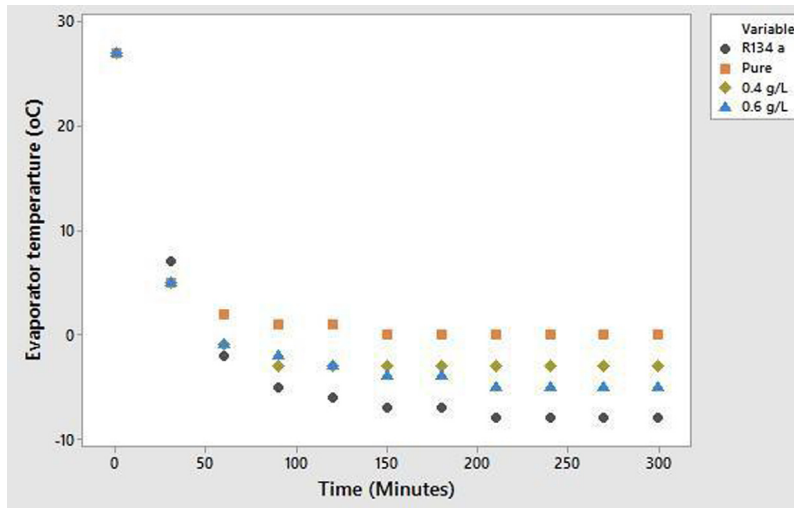


Fig. 6. Effect of MWCNT nanolubricant on the pull-down time of 70 g of R600a the system.

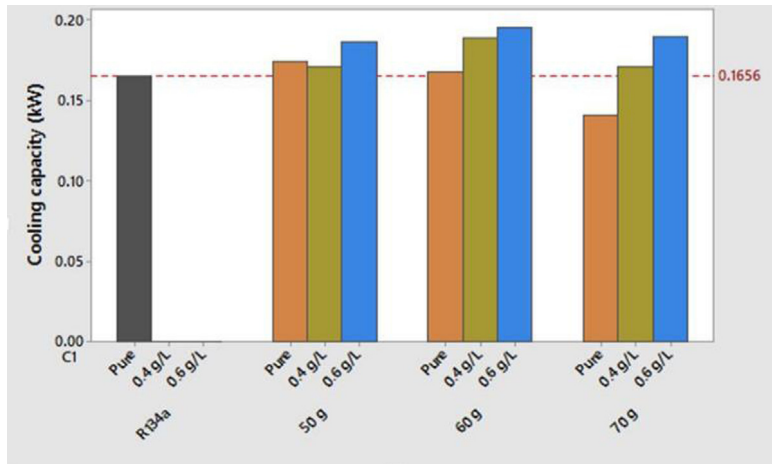


Fig. 7. Effect of MWCNT nanolubricant on the cooling capacity of the system.

Table 5. Summary of the experimental result of MWCNT-nanolubricant in the system.

S/N	Refrigerant mass charge (g)	Nanolubricant concentration (g/L)	Pull downtime (min)	Evaporator temp. (°C)	COP	Power consumption (kW)	Cooling capacity (kW)	Discharge pressure (MPa)
1	100 (R134a)	–	210	–8	1.84	0.0900	0.1656	0.81
2		Pure	210	–5	2.1	0.0821	0.1736	0.75
4	50	0.4	180	–7	2.8	0.0612	0.1714	0.59
5		0.6	210	–8	2.6	0.0719	0.1870	0.72
6		Pure	90	–3	2.1	0.0822	0.1679	0.68
7	60	0.4	150	–11	2.6	0.0728	0.1893	0.60
8		0.6	240	–11	2.9	0.0639	0.1853	0.60
9		Pure	150	0	1.6	0.0861	0.1410	0.75
10	70	0.4	90	–3	2.1	0.0814	0.1709	0.74
11		0.6	210	–8	2.5	0.0761	0.1902	0.66



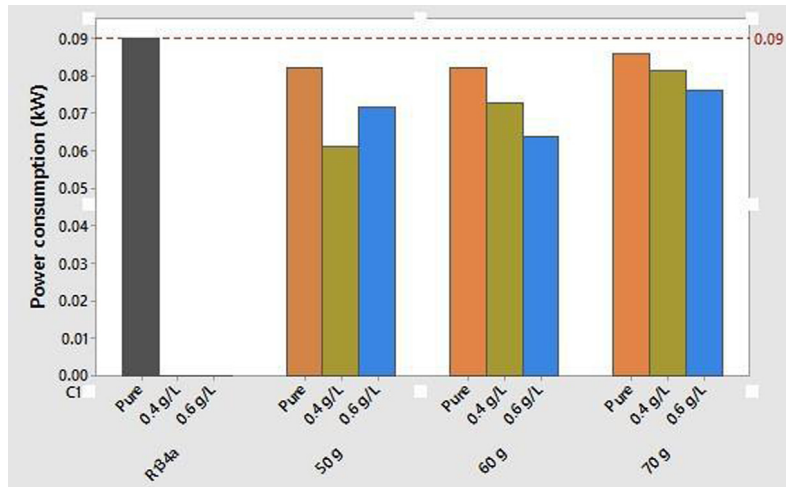


Fig. 8. Effect of MWCNT nanolubricant on the power consumption of the system.

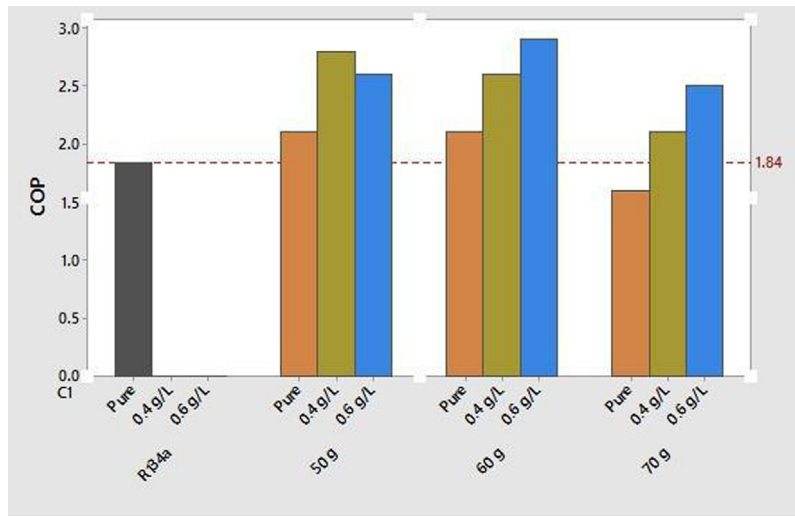


Fig. 9. Effect of MWCNT nanolubricant on the COP of the system.

#### 4. Conclusion

In this present study, the experimental analysis of R600a in MWCNT-nanolubricant concentrations was compared with the performance of R134a in a household refrigerator. The different mass charge of R600a refrigerant (50 g, 60 g and 70 g) was tested in different MWCNT-nanolubricants of 0.4 g/L and 0.6 g/L. Based on the experimental findings, and considering the performance of the refrigerator, these following conclusions were made for R600a in MWCNT-nanolubricant concentration.

- The 60 g mass charge of R600a in 0.6 g/L MWCNT Nano lubricant obtained the best result in terms of COP, with evaporator temperature  $-11\text{ }^{\circ}\text{C}$  at 150 min which meets the ISO 8187 standard temperature of  $-3\text{ }^{\circ}\text{C}$  at 180 min. Also, power consumption is lower compared to R600a in the pure lubricant. Therefore, it is considered as a drop-in replacement for the R134a refrigerant in a household refrigerator.
- The MWCNT-nanolubricant concentrations of 0.4 g/L and 0.6 g/L offer reduced power consumption throughout the experiment with the 50 g charge of R600a in 0.4 g/L MWCNT-nanolubricant with the lowest power

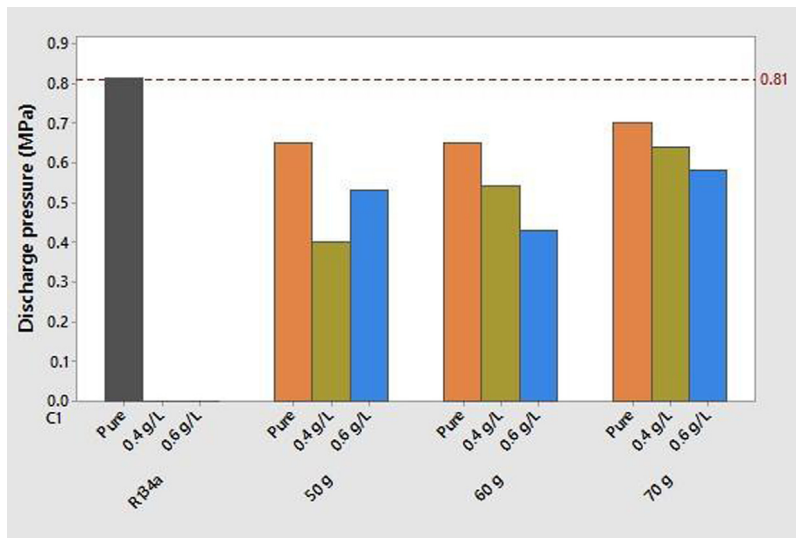


Fig. 10. Effect of MWCNT nanolubricant on the discharge pressure of the system.

consumption at an evaporator air temperature of  $-7^{\circ}\text{C}$ . Also, this can serve as a drop-in replacement for the R134a and pure lubricant in a household refrigerator.

- Since MWCNT-nanolubricant performs better in terms of COP, power consumption, cooling capacity and pull-down time in the refrigerator system, it is recommended as a drop-in replacement for R134a in a household refrigerator designed to work with R134a.

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