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An Experiment Study on the Air Conditioning System Performance of R-134a and MC-134 Refrigerant in D8R Caterpillar Units

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ABSTRACT

Refrigerant is a crucial cooling component for the refrigeration cycle. In heavy equipment, the cooling system still relies on the R-134a unit with many weaknesses, including global warming effects and other air conditioning system problems. An alternative substitute for R-134a has been found, i.e., a hydrocarbon refrigerant or MC-134. This product has several advantages compared to R-134a, especially its environmentally friendly aspect. It does not contribute to the damage of the ozone layer and is completed with good physical characteristics and thermodynamic properties. Overall, it has better performance than R-134a, proven on the Nissan Evalia unit. This study aims at testing heavy equipment, especially the D8R caterpillar unit because limited studies discuss heavy equipment regarding its MC-134 performance. This research was carried out at the Petrosea Ltd workshop. The research was done through experimental methods. The first stage was retrofitting R-134a with MC-134 on the D8R caterpillar unit. The data collection was conducted ten times with an interval of 3 minutes. The second step WAS using MC-134 and taking the same data as the first step. The compressor work on the MC-134 increased by 145.96% compared to R-134a. The result of the study showed that the heat energy released by the condenser using MC-134 increased by 157.833%. 161.625% for the refrigeration effect, and 5.21% for the COP value, respectively, compared to R-134a.

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1. Introduction

Comfort air conditioners are now widely utilized in homes, workplaces, commercial buildings, airports, hospitals, and mobile applications such as trains, vehicles, and aircraft. The growth of modern electronic, pharmaceutical, chemical, and other industries is largely due to industrial air conditioning [1]. The ozone depletion potential (ODP) of chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants has led to a rise in the usage of hydrofluorocarbon (HFC) refrigerants during the last 20 years or so [2]. Although HFC refrigerants have no ozone depletion potential, several of them have quite high global warming potential values. They are one of the six greenhouse gases, and according to the Kyoto Protocol (1997), their emissions must be reduced [3], [4].

Many factors influence the efficiency of a refrigeration system, including the efficiency of the compressor, the type of refrigerant used, the efficiency of the condenser and evaporator, and the

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performance of the expansion valve [5]. One of the main components in air conditioning is refrigerant [6], which until now, especially in heavy equipment, still relies on refrigerant R-134a [7]. Therefore, efforts to be independent of this type of refrigerant need to be intensified.

An alternative substitute for refrigerant R-134a, which is known as hydrocarbon refrigerant or Musicool MC-134 (MC-134), has been found, where this product has several advantages compared to R-134a refrigerant, including being environmentally friendly, avoiding damage to the ozone layer, relatively lower prices, and also having good physical and thermodynamic properties so that it has better performance than refrigerant R-134a [8], [9]. This study aimed to determine the results of the comparison test of performance and COP when using refrigerant R-134a and MC-134 in the air conditioning system of the caterpillar D8R unit.

2. Method

This research was carried out at the PT. Petrosea workshop. The research method used is a field experiment with the object of research on the experimental study of Air Conditioning performance using Refrigerant R-134a and MC-134 in the Caterpillar D8R Unit, by determining the comparison between the performance and COP values of the two different types of refrigerants [10]. Based on the data of each type of refrigerant test result, the calculation was conducted.

3. Results and Discussion

3.1 Results for Refrigerant R-134a

From the experiments, the data of R-134a consisting of the air temperature of cabin room, outside of cabin, pressures, temperatures in several points and engine speed were observed every three minutes and are presented in Table 1.

Table 1. Data of R-134a test results

Time (Minutes)	Cabin Room Temp-erature (°C)	Outside-of-cabin Air Tempe-rature (°C)	***Pressure* (psi)**		***Temperature* (°C)**				Engine Speed (RPM) [5]
			P1	**P2**	**T1**	**T2**	**T3**	**T4**	
3	18.1	38	25	187	38.1	65	52.9	12	1200
6	17.8	38.2	26	190	38.6	66.7	53.2	11.7	1200
9	16.7	38.4	26	190	38.9	67.3	54.5	11.5	1200
12	15.8	38.5	26	190	39.5	67.9	55.3	11.1	1200
15	15.5	38.8	26.5	190	40.1	68.4	55.6	10.6	1200
18	15.1	39	26.5	195	40.7	68.8	56.9	10.2	1200
21	14.6	39.4	27.8	195	41.6	69.1	57.8	9.1	1200
24	14.3	39.5	28	195	42.1	69.5	58.6	8.7	1200
27	13.5	39.7	28	197	42.9	69.7	59.8	8.3	1200
30	12.8	39.8	28	200	43.8	70.6	60.9	7.4	1200
Average	15.42	38.93	26.78	192.9	40.63	68.3	56.55	10.06	1200

Then, the data of R-134a comprising enthalpy, compressor performance, the heat energy released by the condenser, the heat energy absorbed by the evaporator, and the coefficient of performance (COP) every three minutes, are presented in Table 2.

Table 2. Calculation Results of Refrigerant R-134a

Time	Enthalpy			Com-pressor work h2 - h1 (Win)	The heat energy released by the condenser h2 - h3 (Qout)	The heat energy absorbed by the evaporator h1 - h4 (Qin)	COP
	h1	h2	h3=h4	Win	Qout	Qin	
Minutes	(kJ/kg)	(kJ/kg)	(kJ/kg)	(kJ/kg)	(kJ/kg)	(kJ/kg)	
3	403.99	433.06	295.70	29.07	137.36	108.29	3.66
6	403.83	434.40	298.59	30.57	135.80	105.23	3.44
9	403.72	434.69	299.62	30.97	135.07	104.09	3.36
12	403.49	435.02	300.66	31.52	134.36	102.83	3.26
15	403.22	435.31	301.52	32.09	133.79	101.69	3.17
18	402.99	435.55	302.21	32.55	133.33	100.78	3.10
21	402.38	435.85	302.74	33.46	133.10	99.64	2.98
24	402.16	436.08	303.43	33.93	132.64	98.72	2.91
27	401.93	436.23	303.78	34.30	132.44	98.14	2.86
30	401.43	436.77	305.36	35.34	131.40	96.06	2.72
Average	402.92	435.35	301.37	32.44	133.99	101.55	3.15

3.2 The Calculation for Refrigerant R-134a

Data obtained from the experiments were then calculated as the following [11]–[13], below is one example for time interval of 3:

a. Compressor work

$$W_{in} = h_2 - h_1 \quad (1)$$

$$W_{in} = 433.06 - 403.99$$

$$= 29.07 \text{ kJ/kg}$$

b. The heat energy released by the condenser

$$Q_{out} = h_2 - h_3 \quad (2)$$

$$Q_{out} = 433.06 - 295.70$$

$$= 137.36 \text{ kJ/kg}$$

c. The heat energy absorbed by the evaporator

$$Q_{in} = h_1 - h_4 \quad (3)$$

$$Q_{in} = 403.99 - 295.70$$

$$= 108.29 \text{ kJ/kg}$$

d. Coefficient Of Perfomance (COP)

$$COP = \frac{Qin}{Win} = \frac{108{,}289}{29.601} = 3.66 \quad (4)$$

e. Maximum coefficient of performance (COPmax)

$$COP_{max} = T_{room} / (T_{outside} - T_{room}) \quad (5)$$

$$= (18.1+273.15)/((38.0+273.15)-(18.1+273.15))$$

$$= 14.64$$

3.3 Results for Refrigerant MC-134

Meanwhile, the data of MC-134 consisting of the air temperature of cabin room, outside of cabin, pressures, temperatures in several points and engine speed were observed every three minutes and are presented in Table 3.

Table 3. Data of Refrigerant MC-134 test result

Time (Minutes)	Cabin Room Tempe-rature (°C)	Outside-of-Cabin Air Tempe-rature (°C)	*Pressure* (psi)		*Temperature* (°C)				Engine Speed (RPM) [5]
			P_1	P_2	T_1	T_2	T_3	T_4	
3	12.3	38.1	24	180	35.5	62.4	48.1	9.3	1200
6	11.4	38.5	24	180	34.9	62.6	48.8	9	1200
9	11.1	38.9	25	185	34.5	62.8	49.1	8.8	1200
12	10.5	39.1	25	185.7	34	63.2	49.6	8.2	1200
15	9.9	39.4	25	185.7	33.7	63.6	49.9	8	1200
18	9.6	39.7	26.6	190	33.2	63.9	50.4	7.8	1200
21	9.3	39.8	26.6	190	32.8	64.1	50.8	7.5	1200
24	8.9	39.9	27.1	192	32.6	64.5	51.1	7.2	1200
27	8.6	40	27.1	192	31.5	65.6	52.7	6.5	1200
30	8.4	40.2	27.5	195	30.2	66.1	53.2	6	1200
Average	10	39.3	25.8	187.5	33.3	63.9	50.3	7.8	1200

Likewise, the data of MC-134 comprising enthalpy, compressor performance, the heat energy released by the condenser, the heat energy absorbed by the evaporator, and the coefficient of performance (COP) every three minutes, are presented in Table 4.

Table 4. Calculation of Refrigerant MC-134

Time	Enthalphi			Com-pressor work $h_2 - h_1$ (Win)	The heat energy released by the condenser $h_2 - h_3$ (Qout)	The heat energy absorbed by the evaporator $h_1 - h_4$ (Qin)	COP
	h1	h2	h3=h4	Win	Qout	Qin	
Minutes	(kJ/kg)	(kJ/kg)	(kJ/kg)	(kJ/kg)	(kJ/kg)	(kJ/kg)	
3	498.3	570.52	217.76	72.22	352.75	280.53	3.8
6	497.1	571.42	219.86	74.32	351.55	277.23	3.7
9	496.4	572.02	221.56	75.62	350.45	274.83	3.6
12	495.9	573.32	224.56	77.42	348.75	271.33	3.5
15	495.6	574.12	227.16	78.52	346.95	268.43	3.4
18	495.2	575.02	229.66	79.82	345.35	265.53	3.3
21	494.5	575.72	231.46	81.22	344.25	263.03	3.2
24	494.1	576.42	233.96	82.32	342.45	260.13	3.1
27	492.5	579.52	241.76	87.02	337.75	250.73	2.8
30	491.9	581.22	246.86	89.32	334.35	245.03	2.7
Average	495.15	574.93	229.47	79.78	345.46	265.68	3.31

3.4 The calculation for Refrigerant MC-134

Data obtained from the experiments were then calculated as the following [11]–[13], below is one example for time interval of 3:

a. Compressor work

$W_{in} = h_2 - h_1$ (6)

$W_{in} = 570.52 – 498.30$

$= 72.22$ kJ/kg

b. The heat energy released by the condenser

$Q_{out} = h_2 - h_3$ (7)

$Q_{out} = 570.52 – 217.77$

$= 352.75$ kJ/kg

c. The heat energy absorbed by the evaporator

$Q_{in} = h_1 - h_4$ (8)

$Q_{in} = 498.30 – 217.77$

$= 280.53$ kJ/kg

d. Coefficient of Perfomance (COP)

$COP = \frac{Q_{in}}{W_{in}} = \frac{280.53}{72.22} = 3.88$ (9)

e. Maximum coefficient of performance (COP_{max})

$COP_{max} = T_{room} / (T_{outside} - T_{room})$ (10)

$= (12.3+273.15)/((38.1+273.15)-(12.3+273.15))$

$= 11.06$

3.5 Discussion

3.5.1 Compressor Work

For each type of refrigerant, it can be seen from Fig 1, that the longer the time interval, the higher the compression work. This is caused by the lower evaporator temperature [14].

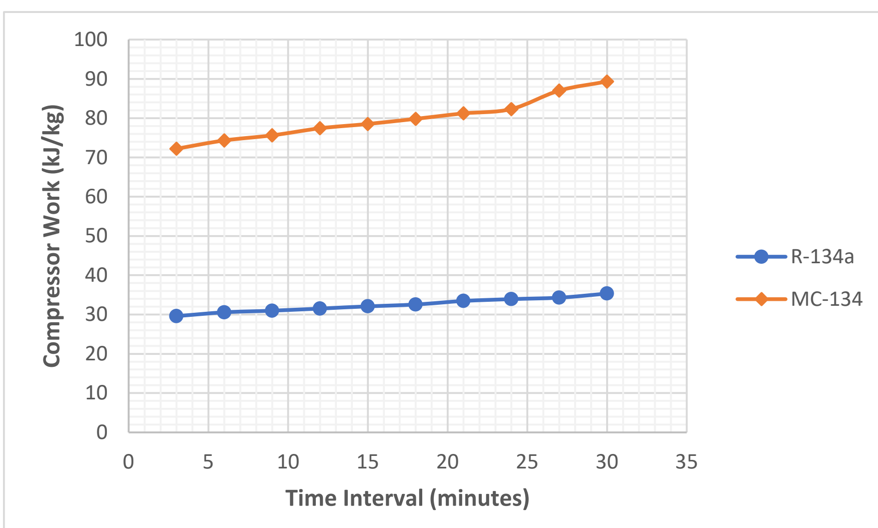

Fig 1. Comparison of compressor work versus time interval between R-134a and MC-134

After measuring the temperature at T_1, T_2, T_3, and T_4 on the caterpillar D8R air conditioning unit system, it was found that the average compressor work using MC-134 refrigerant is 145.96% greater than that of R-134a, as shown by Fig.2. It was influenced by the pressure and temperature in the inlet and outlet. This result is consistent in principle with the previous study [15].

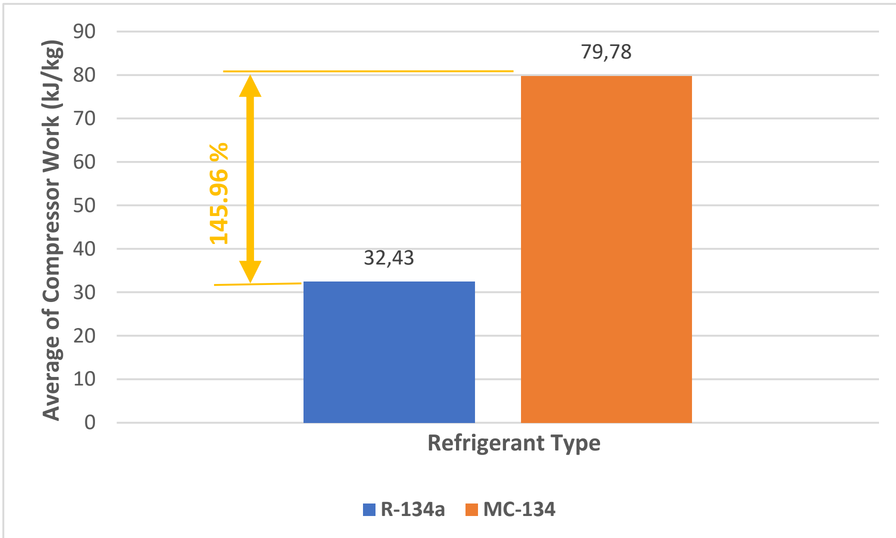

Fig 2. Comparison of the average of compressor work between R-134a and MC-134

3.5.2 The heat energy released by the condenser

Fig 3 shows the longer the time interval, the less heat energy released by the condenser. It is because the heat released by the refrigerant is getting smaller.

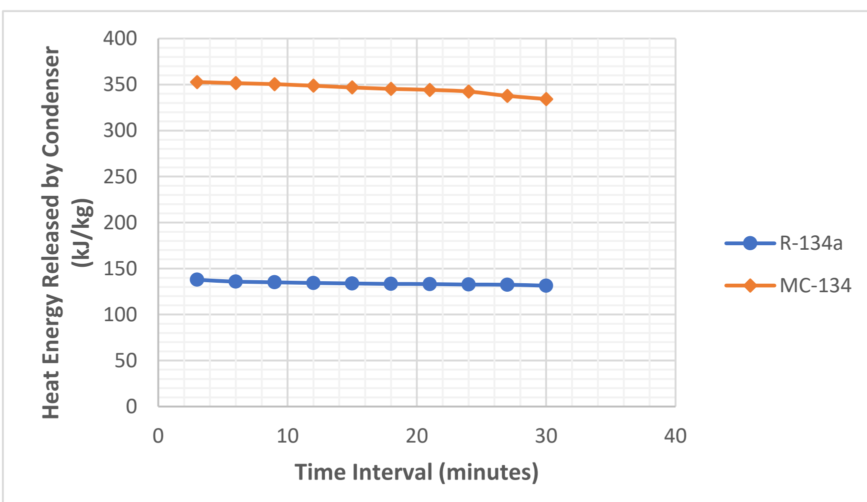

Fig 3. Comparison of heat energy released by condenser versus time interval between R-134a and MC-134

The heat energy released by the condenser using refrigerant MC-134 is 157.83% greater than that of R-134a, as depicted by Fig. 4. The greater heat energy released by the condenser can lower the refrigerant temperature in which the refrigerant goes to the expansion valve and then to the evaporator, which can increase the refrigeration effect.

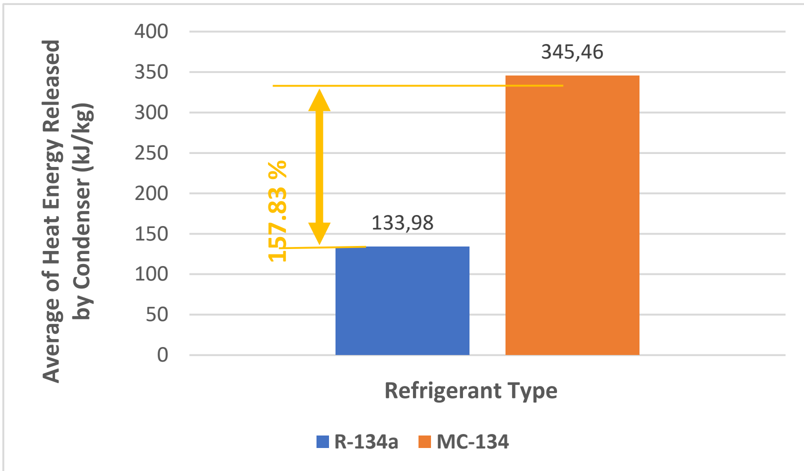

Fig 4. Comparison of the average of heat energy released by condenser between R-134a and MC-134

3.5.3 Refrigeration Effect

As shown by Fig 5, the longer the time interval, the less heat absorbed by the evaporator. This is because the temperature in the cabin has begun to cool down so that the heat absorbed by the evaporator decreases. The increase in refrigeration effect is affected by the ability of the evaporator to absorb heat from the outside to make it evaporate [16].

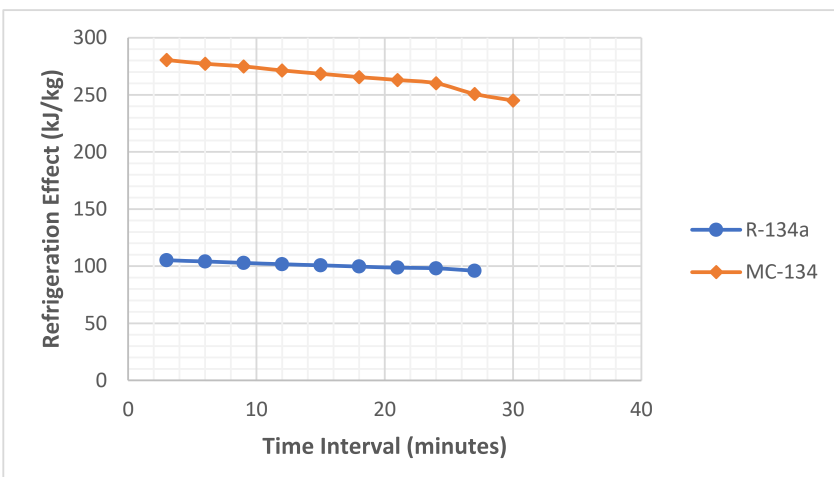

Fig 5. Comparison of refrigeration effect versus time interval between R-134a and MC-134

It can be seen from Fig 6., that the refrigeration effect of MC-134 is 161.62% greater than that of R-134a.

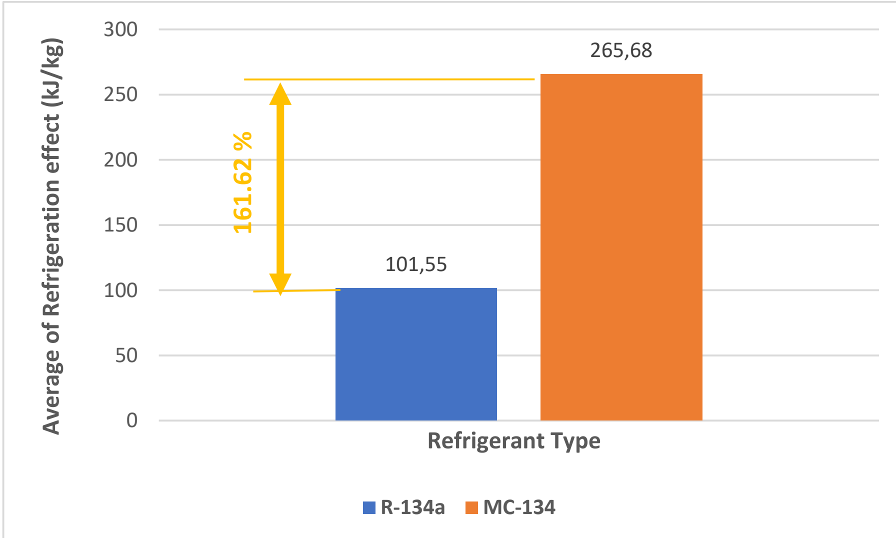

Fig 6. Comparison of the average refrigeration effect between R-134a and MC-134

3.5.4 Coefficient of Performance (COP)

Fig 7 shows that the longer the time interval, the lower the coefficient of performance. Coefficient of performance is a form of assessment of the performance of a refrigeration machine. The greater COP indicates that the refrigeration machine works better [13]. Higher values of COP represent higher efficiency.

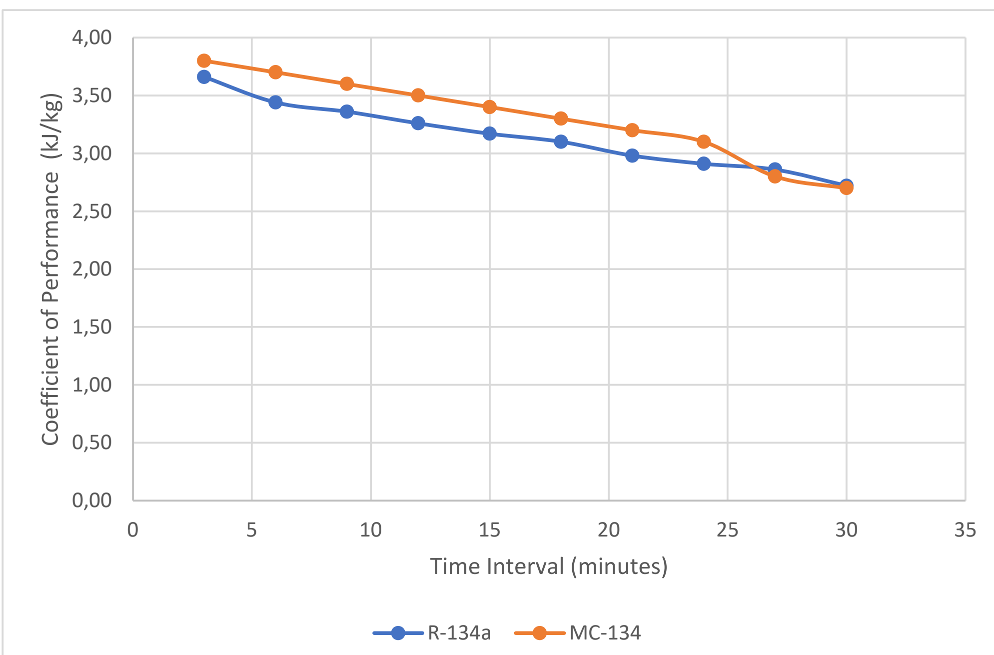

Fig 7. Comparison of COP versus time interval between R-134a and MC-134

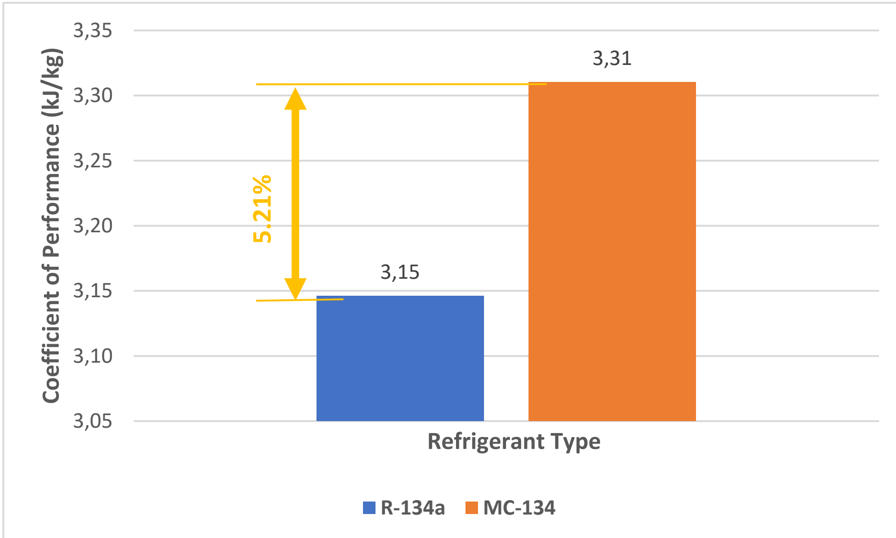

Fig 8. Comparison of the average of COP between R-134a and MC-134

The refrigerant that uses R-134a has an average COP of 3.15, while the hydrocarbon refrigerant MC-134 has an average COP of 3.31, which is 5.21% greater than that of refrigerant R-134a (Fig.8). Due to the greater the value of the refrigeration effect, the greater the COP obtained [16].

3.5.5 The maximum coefficient of performance (COP_{max})

As expected, the experimental data from both refrigerants showed a lower coefficient of performance than their maximum values operating between the same room and cabin temperatures. The smaller value can be attributed to the effects of an irreversibility process associated with realistic vapor compression cycles [17], [18].

4. Conclusion

Based on the research results, calculations, and data analysis, it can be concluded that compressor performance results on refrigerants using MC-134 increased by 145.96% compared to refrigerant R-134a. The heat energy released by the condenser using MC-134 increased by 157.83% compared to using refrigerant R-134a. The refrigeration effect using refrigerant MC-134 increased by 161.63% compared to using refrigerant R-134a. The Coefficient of Performance (COP) value using refrigerant MC-134 increased by 5.21% compared to using refrigerant R-134a.

After conducting research, testing, data collection and analysis, the suggestions that can be given are listed below: (a) Before arranging the test, make sure the function of the Air Conditioning system on the unit is in excellent condition, (b) Prior to changing the refrigerant using MC-134, flashing should be carried out first using a liquid solvent so that there is no remnant of the previous refrigerant (R-134a) which can affect the performance of the refrigerant MC-134, (c) Change the compressor oil by using synthetic oil or a higher grade or, if available, compressor oil, especially refrigerant MC-134, would be better, so it does not affect the life of the compressor or even damage the compressor, (d)

Further research is needed on use at intervals of days or months so that it can be ascertained that the performance of the refrigerant is excellent, (e) It is recommended that the refrigerant charge MC-134 be conditioned about 30% - 40% of the proper refrigerant mass amount, (f) Further research is needed on variations in blower rotation and engine speed, and (g) The uncertainty of test measurements would be declared.

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