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Experimental study of refrigerant replacement from R-22 to R-290 hydrocarbon in domestic AC

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ABSTRACT

Most of the refrigerant used in split-type AC machines is HCFC type R-22, which can potentially damage the ozone layer and global warming. Musicool-22 is a trade name for the hydrocarbon refrigerant R-290, an alternative refrigerant that can replace R-22. Tests were carried out on the test equipment by comparing R-22 and Musicool-22 with the same variation of thermal load. Based on the test, the performance of the two working fluids can be determined by determining the coefficient of performance (COP) and comparing it with various cooling loads. In addition, it is proven that using Musicool-22 can save electrical energy and the power value of the compressor. The data measured are temperature, pressure, voltage, and electric current. Based on the results of calculations carried out by changing R-22 to Musicool-22, it shows that the COP value increases. The highest COP of R-22 is 2.45 at an 80-Watt load, and Musicool-22 is 4.21 at a 320-Watt load. The application of Musicool-22 can save electrical energy by 15.40%. Moreover, it saved electricity usage costs of IDR 44,450.53 per month.

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INTRODUCTION

The application of technology to cooling systems is increasing significantly. One application of this technology is cooling the room to create a comfortable atmosphere during activities. This cooling system is often used for cooling rooms in buildings, means of transportation, and preservation and processing of foodstuffs. Most new buildings are now equipped with AC (Air Conditioning) machines, such as residences, offices, schools, and public facilities, such as terminals, stations, and airports. Refrigeration machines use refrigerant to transfer heat from a room to the environment. In Indonesia, the HCFC group is the most widely used refrigerant in split type AC machines, namely type R-22 or Freon. This HCFC refrigerant has the potential to damage ozone and global warming. The Minister of

Industry Regulation No. 41 explains the prohibition of using HCFC in the industrial sector (Joni Santoso, 2018). Thus, in the future, HCFC will not exist. Hydrocarbons are alternative refrigerants that can replace HCFCs. In Indonesia, several companies have hydrocarbon refrigerant products. One is PT—Pertamina with the trade name Musicool-22 which contains R-290. However, hydrocarbons have the disadvantage of being flammable (Abas et al., 2018), but Musicool-22 is a better replacement for R-22 due to its excellent ambient, thermo-physical properties, and energy-saving performance (Pujianto, Tamtomo Kiono, &; Tony Suryo, 2019).

MC-22 refrigerant has lower GWP and ODP values than R-22 (Urip Prayogi &; Rohman Sugiono, 2022). This means that the MC-22 is more environmentally friendly. Previous research has proven that R290 or MC-22 is a better alternative to R-22 based on environmental impact (Joudi &; Al-Amir, 2014). Based on thermodynamic properties, Musicool-22 is estimated to save electrical energy consumption from AC machines. A comparison of the use of R22 and R290 (MC-22) in the Split AC experiment with variations in condenser fan rotation shows that R290 can save electrical energy consumption from 2.1 A to 2.0 A (Wabang, Hattu, &; Abanat, 2021). Research on improving energy efficiency was also carried out at the Faculty of Civil Engineering Planning, Sepuluh Nopember Institute of Technology Surabaya, namely by retrofitting the working fluid of several cooling machines from R-22 using Musicool-22 which saves electrical energy by 20% (Widyastuti, Putra, Hantoro, Novianarenti, &; Safitra, 2014).

The performance comparison between these two refrigerants can be determined by testing hydrocarbons in AC machines designed for HCFCs. This study aims to determine the performance coefficient (COP) of the two refrigerants, prove that Musicool-22 can save electrical energy consumption, and compare the power use of the two refrigerants.

The test was conducted using an AC machine with the same control variable, i.e., thermal cooling load in the test cabin, to obtain accurate comparison data from applying these two refrigerants.

METHOD

This research was conducted using experimental methods, namely direct observation, to obtain data through experiments. The experiment was conducted using test equipment designed by the objectives of this study.

In a study, a variable is needed to determine the effect of changes in one object, which can cause changes in other objects. There are several variables involved in this study, which are as follows.

- The independent variables are the working fluid, two refrigerants, and the heat load from no load to 80, 160, and 320 Watts.
- Variable bound refrigeration machine designed for R-22 fluid with temperature and pressure gauges at 4 test points for testing both fluids in this study.
- Control variable: suction pressure of the test cycle and room temperature.

Cooling System

A refrigeration system is a unit of several components that transfer heat through refrigerant as a heat transfer medium. This refrigeration system aims to regulate the temperature in Indoor to be lower than in the outdoor environment. The refrigeration machine consists of four main components: the compressor, condenser, expansion valve, and evaporator.

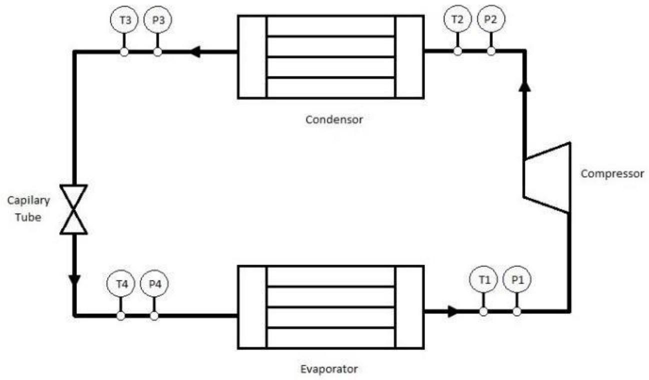

Figure 1. Scheme of the cooling machine on the test equipment

The process details on the refrigeration cycle shown in Figure 1 are described as follows:

- Process 1-2: Compression is compressing refrigerant on a compressor. In the ideal case, it can be called isentropic compression, with the entropy value in phase 1 equal to phase 2.
- Process 2-3: Condensation, which means the process of heat transfer from the refrigerant to the environment at the same pressure. The refrigerant leaves the condenser in a liquid state.
- Process 3-4: Expansion, which means a decrease in pressure so that the temperature drops below about temperature.
- Process 4-1: Evaporation, which means the process of heat transfer from a high-temperature room to a low-temperature refrigerant at constant pressure.

Table 1. Refrigeration System Calculation Symbol

Symbol	Information
H1	Compressor enthalpy inlet (kJ/kg)
h2	Condenser entry enthalpy (kJ/kg)
H3	Expansion valve inlet enthalpy (kJ/kg)
H4	Evaporator entry enthalpy (kJ/kg)
$\dot{m}$	Working fluid flow rate (kg/s)
p1	Compressor inlet pressure (bar)
p2	Condenser inlet pressure (bar)
p3	Expansion valve inlet pressure (bar)
p4	Evaporator inlet pressure (bar)
T1	Compressor inlet temperature (bar)
T2	Condenser inlet temperature (bar)
T3	Expansion valve inlet temperature (bar)
T4	Evaporator inlet temperature (bar)
Qin	Heat absorbed (kW)
Qout	Heat received (kW)
B	Performance coefficient

The incoming heat can be calculated from this process, that is, the heat received during the evaporation process. The calculation of heat input uses the following equation:

$$\frac{Q_{in}}{\dot{m}} = h_1 - h_4 \qquad (1)$$

Then the following equation can determine the power of the compressor to increase the refrigerant pressure after leaving the evaporator.

$$\frac{\dot{W}_C}{\dot{m}} = h_2 - h_1 \qquad (2)$$

This process generates heat due to increased pressure, which will be discharged. The following equation calculates the heat output

$$\frac{Q_{Out}}{\dot{m}} = h_2 - h_3 \qquad (3)$$

The following process is the throttling or expansion process. There is a pressure drop with the same enthalpy in this process to obtain it.

$$h_4 = h_3 \qquad (4)$$

From the equation above, the performance coefficient of the refrigeration system is calculated using the following equation.

$$\beta = \frac{\frac{Q_{in}}{\dot{m}}}{\frac{\dot{W}_C}{\dot{m}}} = \frac{h_1 - h_4}{h_2 - h_1} \qquad (5)$$

The achievement coefficient is a measure of the efficiency of a refrigeration system. They are usually called the coefficient of performance (COP) (Moran, 2018). The enthalpy value (h) is obtained in two ways. First, property table data for each refrigerant is searched based on the temperature and pressure measured. Second, interpolate if temperature and pressure data are unavailable in the refrigerant properties table.

Research Procedure

The refrigeration system comprises a compressor, condenser, expansion valve, evaporator, and a small room for temperature testing.

All equipment is assembled into one unit, making it easier to move. The cooling equipment has a panel meter for temperature, a heating load regulator, an ampere meter, a volt meter, and a heating load in the cabin. The image of the testing tool is shown in Figure 2.

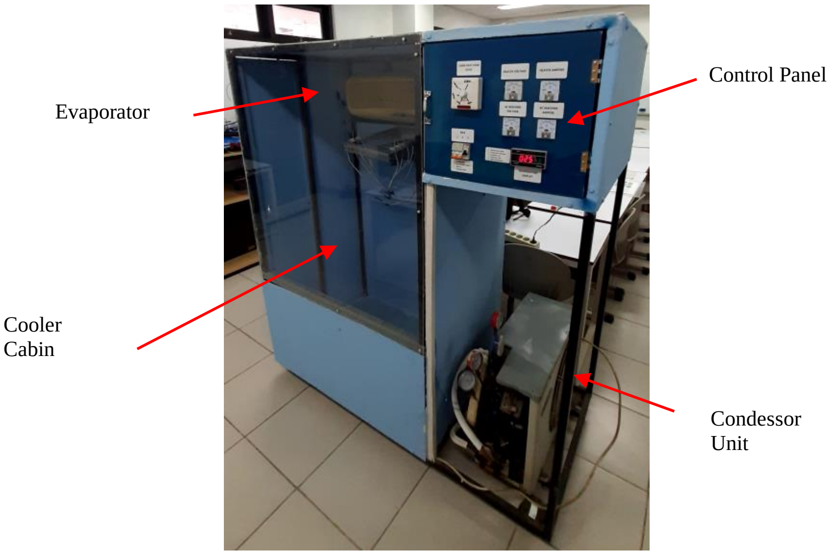

Figure 2. Experimental Equipment

Tests are performed to take data on temperature, pressure, electric current flowing to the compressor, and voltage used for both working fluids R-22 and R-290. Tests on both types of working fluids use load variations of 0, 80, 160, and 320 Watts to determine the COP value of the system.

RESULTS AND DISCUSSION

Temperature and pressure values are obtained at 4 test points based on tests from the thermodynamic side as follows:

Table 2. R-22 Temperature and Pressure Data

Load (Watt)	Temperature (^{oC})				Pressure (psi)			
	T1	T2	T3	T4	P1	P2	P3	P4
0	13	57	30	11	61	231	225	68
80	14	58	30	11	62	233	226	69
160	15	58	31	12	62	233	226	69
320	15	59	33	12	66	238	230	70

In addition to taking temperature and pressure data, test equipment is also designed to measure voltage and current from AC machines. The power of the system being tested can then be calculated from the voltage and current data. The power is the power of the AC machine with all its components.

Table 3. MC-22 Temperature and Pressure Data

Load (Watt)	Temperature (^{oC})				Pressure (psi)			
	T1	T2	T3	T4	P1	P2	P3	P4
0	14	52	32	11	60	214	208	62
80	15	53	32	11	62	217	212	66
160	15	53	33	12	62	218	214	66
320	16	54	33	12	65	221	215	67

Table 4. AC power on R-22

Load (Watt)	R-22		
	Voltage (V)	Current (A)	Power (Watts)
0	219	3.1	678.9
80	219	3.3	722.7
160	219	3.6	788.4
320	219	3.8	832.2

Table 5. AC power on MC-22

Load (Watt)	MC-22		
	Voltage (V)	Current (A)	Power (Watts)
0	220	2.7	594
80	220	2.8	616
160	220	2.9	638
320	220	3.2	704

The calculation results in tables 4 and 5 show that the R-22 power starts from 678.9 Watts without load and 832.2 Watts at the most significant load. Then, the MC-22 has a power of 594 Watts as the lowest power and 704 Watts as the highest power. The second increase in the heat load of refrigerants increases power due to immense heat transfer systems at large loads.

Then diagrams can be made to make it easier to analyze. In refrigeration systems, P-h diagrams are used to analyze the system's work.

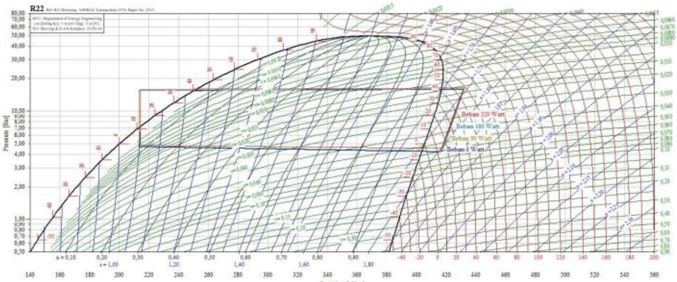

Figure 3. Diagram P-h R-22 with load variations

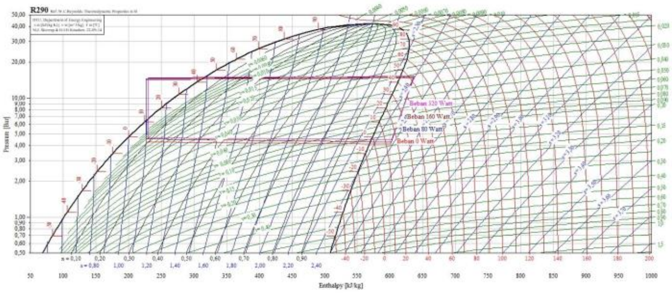

Figure 4. Diagram P-h R-290 with load variations

Figure 3 shows the actual P-h diagram for the R-22 refrigerant with thermal load variations in the test cabin. The diagram between R-22 and MC-22 cannot be combined because they differ in the value of the saturation curve. The lines in P-h diagrams R-22 and M-22 as a whole have a sharp slope. The sharper the slope, the greater the enthalpy value. The greater the load, the more tilted. This is appropriate because the more significant the load, the compressor must work heavier so that the power needed by the compressor is also greater.

In comparison, there are several differences between the P-h diagrams of R-22 and MC-22. Figure 4 is a P-h diagram of Musicool-22 that can be created using P-h diagram R-290. On the MC-22 line, the inclination angle is greater than that of R-22. That this line from point 1 to 2 corresponds to $\dot{W}_c$. In addition to the difference in slope is also in the length of the line. The lines on the MC-22 are shorter. However, we cannot determine that with a shorter, more upright line, the enthalpy difference in the compression process of MC-22 will be more minor. The large enthalpy and dome of the MC-22 are different from the R-22. For the effect of a large load such as on R-22, the greater the load, the greater the enthalpy value at point 2. So the line will be farther away from the dome.

Then it can be calculated the values of $Qin/\dot{m}$ and $\dot{W}c/\dot{m}$. From these calculations, you can calculate the coefficient of performance (COP) to determine each refrigerant's performance.

Table 6. Calculation result R-22

Burden (Watt)	R-22		
	$Qin/\dot{m}$ (kJ/kg)	$\dot{W}c/\dot{m}$ (kJ/kg)	BL OW
0	4.32	1.96	2.20
80	5.17	2.11	2.45
160	4.97	2.45	2.02
320	6.16	3.03	2.03

Table 7. MC-22 calculation result

Burden (watts)	MC-22		
	$Qin/\dot{m}$ (kJ/kg)	$\dot{W}c/\dot{m}$ (kJ/kg)	BL OW
0	9.32	2.98	3.12
80	10.62	3.28	3.23
160	11.44	3.17	3.6
320	15.04	3.57	4.21

Figure 5 is a COP graph of each test load for both refrigerants. Overall, the COP value of the test load with MC-22 is higher than R-22 because MC-22 has better refrigerant properties than R-22. The thermal conductivity of MC-22 is higher than that of R-22. With a higher conductivity value, heat absorption in the evaporator and heat release in the condenser become greater. This means that heat in the room is absorbed faster when using the MC-22. As a result, the working time of the compressor with MC-22 refrigerant is smaller than R-22, so it will save electrical energy consumed.

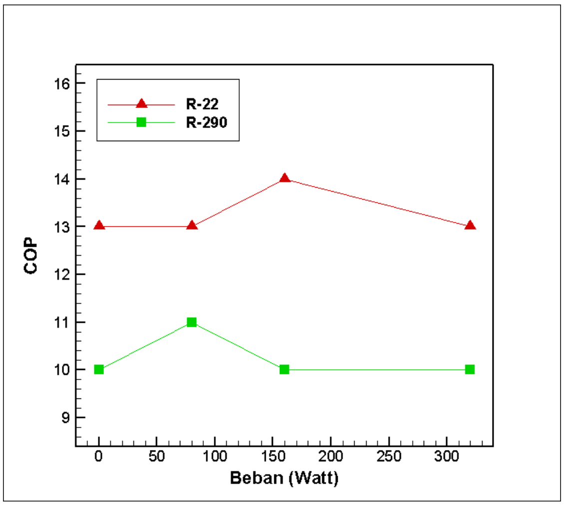

Figure 5. Performance Coefficient for Each Test Load

MC-22 refrigerant has better properties, such as lower viscosity, than R-22. The lower viscosity will ease the compressor workload and reduce the power required to operate the compressor when using the MC-22. COP is the ratio of heat absorbed Q_{in} divided by compressor power rating $\dot{W}_c$. Therefore, the COP value of MC-22 is higher because the value of MC-22 is higher, and the value of MC-22 is higher Q_{in} than MC-22 lower $\dot{W}_c$. However, the increase in heat load does not affect the increase and decrease in COP values. At R-22, the highest COP value of 2.45 was obtained at an 80 Watt workload; for MC-22, the highest COP value of 4.21 was obtained at 320 Watts. This means R-22 has the best cooling performance when loaded with 80 Watts and 320 Watts for MC-22.

In addition to thermodynamic calculations, AC engine power is calculated from the measured voltage and current values to determine which refrigerant uses less electrical energy.

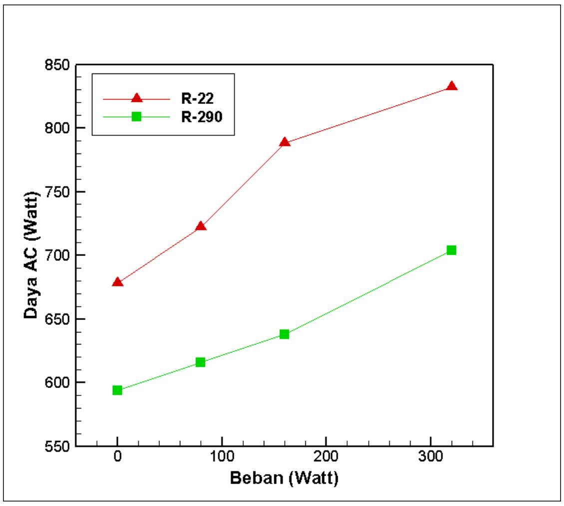

Figure 6. AC Machine Power at Each Test Load

Figure 6 compares AC engine power when using R-22 and MC-22. Overall, AC engine power using MC-22 is lower than R-22. This character proves that the characteristics of MC 22 refrigerant have a higher thermal conductivity value and lower viscosity than R-22, so the electrical energy consumption is smaller.

Therefore, the MC-22 has a lower-rated AC engine power for each load. The application of MC-22 can save electricity consumption because it can ease the compressor workload and directly impact the overall AC engine power.

Table 8. Duration of Compressor Operation

Burden	R-22 (Second)			MC-22 (Second)		
(Watt)	*tstart*	*toff*	*tone*	*tstart*	*toff*	*tone*
0	277	180	205	205	180	201
80	261	180	205	239	180	203
160	305	180	211	299	180	203
320	382	180	221	334	180	214

A comparison of the compressor running times between R-22 and MC-22 shows that the compressor starts up faster and reaches the set temperature for all variations in heat loads on the MC-22. This means the MC-22 transfers heat from the room to the environment faster. Based on the thermodynamic properties of MC-22 and R-22 described earlier, MC-22 has a higher thermal conductivity than R-22. Thus, the MC-22 can conduct heat more efficiently, saving compressor power and uptime.

Table 9. Calculation of R-22 and MC-22 Usage Costs

Power Limit (Watts)	Price (kWh)	Refrigerant Type	Cost per Month
900	Rp1,352.00	R-22	Rp270,032.26
		MC-22	Rp228,433.92
1300	Rp1,444.70	R-22	Rp288,547.04
		MC-22	Rp244,096.51
2200	Rp1,444.70	R-22	Rp288,547.04
		MC-22	Rp244,096.51
3500 s/d 5500	Rp1,699.53	R-22	Rp339,443.73
		MC-22	Rp287,152.59

At the highest load of 320 Watts, you are saving 15.40%. If the calculation of electricity cost savings per month is calculated assuming one month or thirty days, the usage per day is 8 hours, and the compressor is based on the power when the load is most excellent in the test, then the calculation of the cost of using R-22 and MC-22 is based on the basic electricity tariff of PLN July 2022 for household groups. From the cost calculation results in Table 9, MC-22 shows a savings of Rp41,598.34 at the 900 Watt power limit, Rp44,450.53 at the 1300 and 2200 power limits, and for the MC-22 3500 Watt power limit showing a savings of Rp52,291.14.

Until now, retrofit services from R-22 to MC-22 have been found in several major cities in Indonesia. The cost of retrofit ranges from Rp200,000 to Rp300,000.00 depending on the service provider and the air conditioner's capacity to be installed. The cost savings table shows that the savings were around Rp300,000.00 in approximately three months. In the first 3 to 4 months, the cost of use will be the same as if we continue to use R-22. Moreover, by the fifth month, it will be more cost-effective. However, not much is known about using hydrocarbons as a substitute for halocarbon refrigerants. There is not much socialization about hydrocarbon applications.

In addition to PT. Pertamina also has other companies that provide hydrocarbons for use as refrigerants. Technicians who usually provide air conditioning service and maintenance rarely offer hydrocarbon products because refrigerants are more expensive than hydrocarbon refrigerants. The price of MC-22 per kg is Rp180,000.00. Furthermore, the price of R-22 per kg is Rp42,000.00. Given these prices, AC technicians are reluctant to offer it to consumers who generally want minimal AC maintenance costs. Commercial air conditioner users do not want to replace refrigerant if the replacement price is high. This change can save electricity costs and be more profitable for air conditioning users.

CONCLUSION

Based on the results of this study, it can be concluded that:

- Switching from R-22 to MC-22 can increase the value of the Coefficient of Performance. The highest COP value at R-22 was 2.45 at a load of 80 Watts, and the highest COP of Musicool-22 was 4.21 at 320 Watts.
- The increase in Performance Coefficient is not linear with an increase in cooling load.
- The application of MC-22 can save electrical energy needed by AC machines because MC-22 can facilitate compressor workload, reducing AC engine power. At the highest load, R-22 applications on AC engine power of 832.2 Watts and Musicool-22 of 704 Watts.
- Replacing R-22 with Musicool-22 can save electrical power up to 15.40%.

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