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Comparison of coefficient of performance (COP) values in training kits for air conditioning systems in cars with condensation using air and water

N Hidayat[1*], Milana[1], M Y Setiawan[1], A Ikhlas[1], J Sardi[1], N Lusi[2], and W A Widodo[3]

[1] Universitas Negeri Padang, Padang, Indonesia
[2] Politeknik Banyuwangi, Banyuwangi, Indonesia
[3] Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
[*]Corresponding author email: nuzulhidayat@ft.unp.ac.id

Abstract

This research aims to compare the coefficient of performance (COP) of the air conditioning system in a car training kit that uses two different types of condensation, namely using air and water. The research was carried out by implementing these two condensation methods in a car AC system in a training kit designed to simulate real conditions. The data collection method involves measuring the energy consumption and cooling efficiency of both systems. Testing is carried out in various environmental conditions which include variations in temperature, humidity, and other operational conditions that can affect the performance of each system. The research results show a comparison of COP between air conditioning systems that use air and water condensation. The findings show that systems using air condensation have a lower COP, namely 2.24, compared to systems using water condensation with a value of 2.53 in a certain range of conditions. The efficiency of both systems is also influenced by certain environmental factors, but the efficiency value for condensation with air remains lower with a value of 56.92, while with water condensation with a value of 65.10, this gives an indication that condensation using water is better in the air conditioning system in cars. The conclusion of this research is that both condensation methods have their respective advantages and disadvantages in terms of efficiency and performance.

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Keywords

Air conditioning systems, Cars with condensation, COP value

Introduction

The research on the comparison of COP (Coefficient of Performance) in car air conditioning systems using air and water condensation aims to enhance the cooling system efficiency in vehicles. One of the conducted studies indicated that the use of water condensation can increase the COP value of the car AC system [1][2]. Additionally, research was carried out to compare the COP values between refrigerants R-134a and MC-134 in car air conditioning systems. This study aimed to determine which refrigerant is more efficient in increasing the COP value in car air conditioning systems [3][4]. Another study was conducted to compare the cooling effect and performance between a mobile air conditioner using an accumulator and one without using an accumulator [5]. Furthermore, research was conducted to understand the influence of water coolant media on the condenser's ability to work in the cooling machine[6]. This research involved modifying the condenser by using water coolant media to enhance the cooling equipment's COP performance.

The research evaluates the feasibility of using off-grid solar-powered air conditioning systems for residential buildings. The system aims to replace conventional refrigerants with natural ones to reduce CO_2 emissions and dependence on non-renewable energy sources. Researchers developed a mathematical model to assess the system's performance using different refrigerants. They also constructed a prototype AC unit powered by solar panels and battery storage. Results indicated that natural refrigerants R290 and R600a are suitable replacements for conventional refrigerants, exhibiting increased COP and exegetic efficiency. The study provides guidelines for designing environmentally friendly air conditioning systems using renewable energy sources. According to this research, the COP (Coefficient of Performance) of the system is influenced by different refrigerant temperatures and condensation. Experimental results showed that compared to R134a, the COP of R290 increased by 2.42% at various condensation temperatures. Furthermore, the COP decreased by 36.1% when the condensation temperature was raised from 37 to 52°C. The document also mentions that R600a exhibited the highest COP value among the refrigerant candidates at different condensation temperatures. Therefore, the COP of the system varies depending on the choice of refrigerant and condensation temperature [7][8].

The study focuses on enhancing performance and optimizing household air conditioning systems through the adoption of new nanolubricants. Researchers evaluated key performance parameters such as heat absorption, compressor work, cooling capacity, Coefficient of Performance (COP), and power consumption. They found that nanolubricants exhibited better heat absorption compared to pure lubricants and heat absorption decreased with increasing initial refrigerant load. However, cooling capacity performance increased with an increase in the initial refrigerant load. COP showed an increasing trend at all nanolubricant concentrations, and using nanolubricants with specific concentrations and refrigerant loads resulted in reduced electrical power consumption. This study also utilized a central composite design of surface response methodology to determine the optimal nanolubricant configuration. The researchers concluded that nanolubricants show potential in enhancing the overall performance of household air conditioning systems. The use of nanolubricants in household air conditioning systems impacts compressor operation. The introduction of nanolubricants led to a reduction in compressor work due to better lubrication effects and tribological impacts. This implies that the compressor requires less effort to compress the refrigerant and increase system pressure, resulting in reduced compressor work. The reduction in compressor work was observed up to a concentration of 0.15 vol% of nanolubricant.

However, at a concentration of 0.2 vol%, there was an increase in compressor work. This increase can be associated with a higher concentration of nanoparticles, resulting in an increase in the pressure level within the refrigerant channel. Overall, the use of nanolubricants in household air conditioning systems can help reduce compressor work and improve system efficiency. Nanolubricant concentration impacts the Coefficient of Performance (COP) in residential air conditioning systems. Evaluation of the nanolubricant's effect on COP showed that COP increases with an increase in nanolubricant concentration up to a certain point. Specifically, COP shows an increasing trend at all nanolubricant concentrations when operating with R32 refrigerant. The highest COP increase was recorded at a concentration of 0.15 vol% and an initial refrigerant charge of 0.442 kg. At this concentration, COP increased between 3.12% and 32.26%. However, beyond the 0.15 vol% concentration, COP starts to decrease, especially at a concentration of 0.2 vol%. This decrease in COP could be due to a significant increase in the density of the refrigerant and nanolubricant mixture at higher concentrations. Overall, the utilization of nanolubricants in residential air conditioning systems has the potential to improve COP, but the optimal concentration needs to be determined based on specific conditions and requirements [9][10].

In the conducted study, the performance of the variable-circuit heat exchanger (VCHX) system was compared to the conventional heat exchanger (CHX) system in heating mode. The VCHX system is more suitable for high heating capacity conditions, while the CHX system performs better in low heating capacity conditions. As the heating capacity increases, the Coefficient of Performance (COP) of the VCHX system is initially lower and then higher than the CHX system. In the heating capacity range of 1400~5600 W, the VCHX system achieves a COP increase of 4.8~6.3% compared to the CHX system. The VCHX system also shows a significant increase in average heating capacity and COP at low-temperature heating conditions. In the cooling mode, the COP of the VCHX system consistently outperforms the CHX system. The VCHX system achieves a significant COP increase in the cooling capacity range of 1500~5000 W. The COP increase ranges from 12.8% to 4.8% compared to the CHX system. However, the COP increase decreases with an increase in cooling capacity. The VCHX system performs better in both intermediate and rated cooling conditions. Overall, the VCHX system excels in COP performance in both heating and cooling modes. Specific performance improvements vary depending on the heating or cooling capacity range [11][12].

From the aforementioned studies, an intriguing area for development and exploration lies in designing energy-efficient air conditioning systems with optimal performance. Therefore, there are ample opportunities for further advancements, including in the condensation process occurring within the condenser. This process involves transforming the refrigerant from a gaseous state to a liquid state, releasing heat, and increasing the pressure generated by the compressor. In study [6] research was conducted on a direct car engine, where controlling the released heat was still challenging due to the complex positioning and placement of the condenser, making it difficult to access during the water spraying process. Hence, in this study, testing was performed using a developed air conditioning system training kit tailored to resemble a typical car air conditioning system. Conducting tests with this training kit allows easier and more flexible access to air cooling components, particularly the condenser. Consequently, this research can effectively explore the Coefficient of Performance (COP) in mobile air conditioning systems utilizing air and water condensation.

Method

Specifications of the training kit

This research falls under experimental research using a post-test-only control design experimental model (Table 1). The study aims to determine the coefficient of performance comparison in a training kit driven by an electric motor using condensation processes with air and water. The testing is conducted using an air conditioning system training kit powered by a 3-phase electric motor and regulated by an inverter to control the speed [13]. For further clarification, please refer to Figure 1 for the design of the training kit and Figure 2 for the completed training kit.

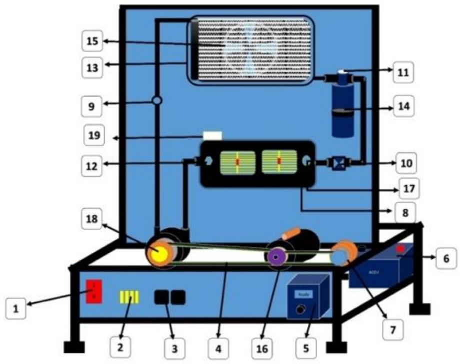

Figure 1. Design of the training kit for the air conditioning system found in automobiles

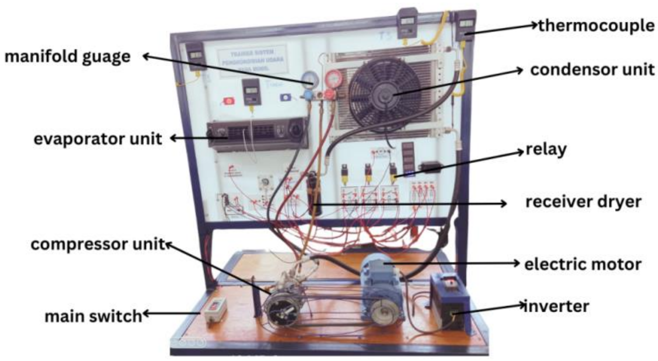

Figure 2. Training kit for the air conditioning system found in automobiles

Table 1. Specification

No	Component name	Specification	Amount
1	Main switch	5 terminals	1
2	Fuse	20 Amperes	4
3	Relays	4 feet	4
4	V-belts	Type B	2
5	Inverters	ATV312HU22N4	1
6	Step down transformers	12V 45 Amperes	1
7	Evaporators	Pipe and fin type	1
8	Dual pressure switches	Minimum 1.5 kg/cm^2 - Max 15 kg/cm^2	1
9	Expansion valve	thermostatic expansion valve	1
10	Lookout glass	Transparent glass	1
11	Blower switch	5 terminals	1
12	Condenser	straight fin flat tube	1
13	Receiver drier	Dryer type	1
14	Cooling fan	Electric dynamo	1
15	Electric motors	Three-phase induction motor 3 HP/2.2Kw	1
16	Thermostats	Mechanical models	1
17	AC compressor	Wobble plates	1
18	Blower resistance	prisoner	1

Data analysis technique

The data obtained from measurements is entered into the prepared table. Using the P-h diagram, the pressure data for the refrigerant P^{evap} and P_{cond} have been obtained; it is advisable to convert the units from P_{sia} to B_{ar}.

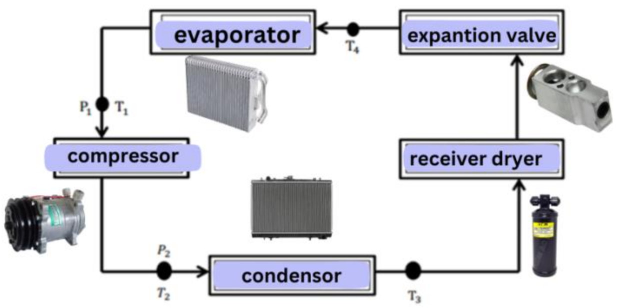

Figure 3. Test points on the air conditioning training kit

Calculate the work per unit mass on the refrigerant performed by the compressor using the equation:

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

Calculate the heat released by the condenser per unit mass of refrigerant (Qout) using the following equation:

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

Calculate the heat absorbed by the evaporator per unit mass of refrigerant (Qin) using the following equation:

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

Calculating values 〖COP〗 _actual on the car AC trainer using the following equation:

$$COP_{actual} = (h_1 - h_4) / (h_2 - h_1) \quad (4)$$

Result and Discussion

After taking data from the air conditioning training kit, the information that will be obtained includes the pressure values on the refrigerant (P_1 and P_2) and the temperature on the refrigerant (T_1, T_2, T_3, dan T_{evap}). This data was obtained from measurements on the Manifold Gauge and Thermocouple installed in the air conditioning training kit.

Data calculation and data processing

From the data that has been obtained and by depicting it on the P-h diagram, the enthalpy value (h) can be determined. In the research that has been carried out, the refrigerant used is the R134a type refrigerant, so the P-h diagram used is the R134a P-h diagram. Calculation of pressures P_1 and P_2 plus 1 atm and converted to bar. (1 psia = 0.0689 bar). The following is an example with a P_1 pressure of 29 psig and a P_2 pressure of 300 psig. Example of data calculated using data in the 2nd minute.

P_1 = 29 psig + 1 atm = 43,7 psia × 0,0689 bar/psia = 3,01 bar

P_2 = 300 psig + 1 atm = 314,7 psia × 0,0689 bar/psia = 21,6 bar

After converting the pressure, a P_1 and P_2 then by using the pressure values from P_1 and P_2, T_1, T_2 and temperature T_3, the vapor compression cycle can be depicted on the p-h diagram. From the test data that has been entered into the pH diagram, the amount of enthalpy at the specified test point will be obtained which has been entered in Table 1.

Table 1. Results with normal testing (constant electric motor rotation 2970 rpm)

No	Time (minute)	P_1 (psig)	P_2 (psig)	T_1 (°C)	T_2 (°C)	T_3 (°C)	Tevap (°C)	h_1 (Kj/kg)	h_2 (Kj/kg)	h_3 (Kj/kg)	h_4 (Kj/kg)
1	2	29	300	16.4	86.9	67.6	14.8	411	460	300	300
2	4	30	300	16.6	90.7	68.3	15.1	412	460	300	300
3	6	30	300	16.8	91.7	68.3	15.3	412	460	300	300
4	8	30	300	17.0	92.3	68.3	15.5	412	462	300	300
5	10	30	300	17.1	92.7	67.9	15.9	412	462	300	300

In Table 1, you can see the value of the working pressure of the constant air conditioning system, indicating that the air conditioning system is working well and normally. However, if we look at the temperature changes that occur at T_1, T_2 T_3 dan T_{evap}, it increases with the passage of operating time. This is a normal thing that when the air conditioning system is at rest, there is a tendency for the capability or performance of the air conditioning system to decrease due to the limited condensation process. on the condenser because it only relies on cooling from the wind produced by the cooling fan, where cooling using wind has a low condensation capacity. The condensation process using air is best at the beginning of condensation or within 2 minutes of operation. This is proven by the values obtained from the resulting pressure and temperature coming out of the condenser (T_2 hen there was a significant increase in the next minute with a magnitude of 5.8°C. The maximum temperature of T_2 found at 10 minutes with a value of 92.7°C.

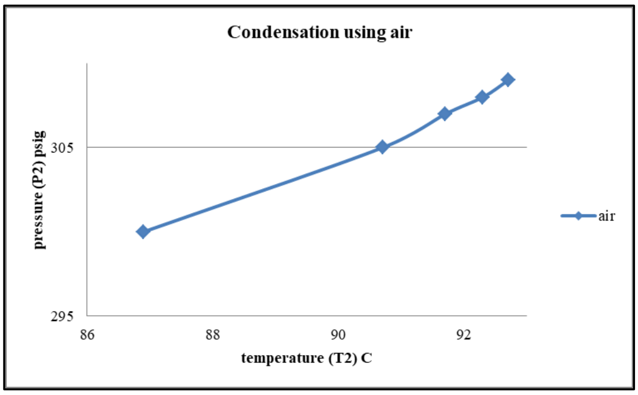

Figure 4. Comparison of changes in pressure and temperature with condensation using air

In Figure 4, it can be seen that with increasing pressure the temperature will also increase continuously, this is influenced by the ability of the condenser to condensate which is assisted by using air coming from the cooling fan. Table 2 are the test values obtained in testing by dousing the condenser components with water to obtain the following data. It can be seen that providing treatment by pouring water on the condenser provides significant changes in pressure changes which tend to decrease because in this condition the condensation process is better because the presence of water in the cooling condenser makes the change in form of the refrigerant better and faster. If we look at the increase in pressure and temperature which occurs with increasing time, it is quite stable and not extreme when compared in the first minute with up to 10 minutes where there is an increase of 0.7°C. he highest temperature that occurred after 10 minutes of operating T2 was 81.8°C. For a clearer comparison, see Figure 5.

Table 2. Results when training kit conditions are flushed on the condenser and the electric motor rotates 2970 rpm

No	Time (minute)	P_1 (psig)	P_2 (psig)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_{evap}(°C)	h_1 (Kj/kg)	h_2 (Kj/kg)	h_3 (Kj/kg)	h_4 (Kj/kg)
1	2	18	220	10.0	81.1	57.6	12.1	410	456	282	282
2	4	18	210	9.0	81.1	56.7	11.9	410	460	280	280
3	6	18	200	8.7	81.5	53.1	10.8	410	460	278	278
4	8	14	200	8.2	81.5	57.6	11.8	408	460	276	276
5	10	14	180	8.0	81.8	53.6	10.7	408	460	276	276

In Figure 5, changes between pressure and temperature tend to decrease as the cooling system progresses. This condition is caused by the condensation process which is assisted by using water. By using water, the process of releasing heat from the condenser is better, although there is still an increase in temperature with operating time, but it is not significant and on the other hand otherwise the pressure tends to fall [14].

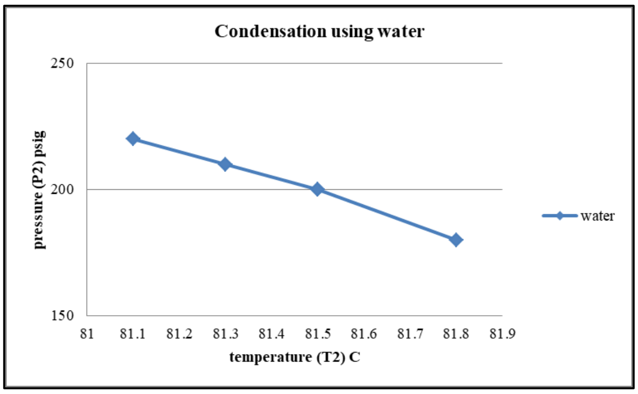

Figure 5. Comparison of changes in pressure and temperature with condensation using water

After getting the enthalpy value from h_1 to the enthalpy value at h_4 the next step is to find the value of the compressor work per unit mass of refrigerant or Win, the heat per unit mass released by the condenser or Win, he heats absorbed by the evaporator or Q_{out} , the actual COP value, the ideal Q_{in}, COP_{actual} ^{value}, COP_{ideal} value, the value of the efficiency of the AC or η.

Compressor work per mass of refrigerant (W_{in}) and the mass of refrigerant released by the condense (Q_{out}) from Table 3 can be seen in the comparison of the mass of refrigerant released with the condenser being flushed more. This proves that the condensation process is better and more optimal by pouring water into the condenser. For more details, you can see the comparison in Figure 6.

Table 3. Compressor work per mass of refrigerant (W_{in}), mass of refrigerant released by the condense (Q_{out}) and (Q_{in})

No	Time (minute)	Test Conditions					
		normal condenser			The condenser is flushed		
		(Win) kJ/kg	(Q_{out}) kJ/kg	(Qin) kJ/kg	(Win) kJ/kg	(Q_{out}) kJ/kg	(Qin) kJ/kg
1	2	49	160	111	46	174	128
2	4	48	160	112	50	180	130
3	6	48	160	112	50	182	130
4	8	50	162	112	52	184	132
5	10	50	162	112	52	184	132

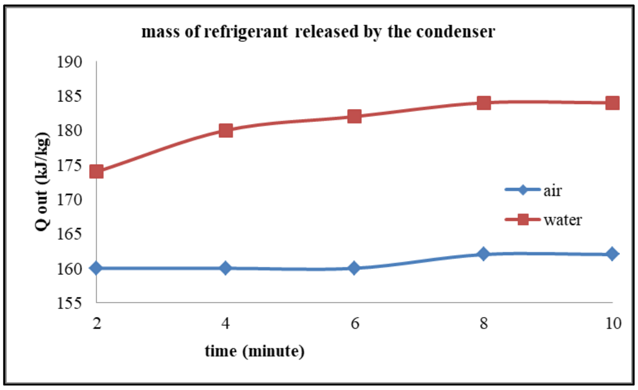

Figure 6. Comparison of the mass of refrigerant released by the condenser

From Figure 7, overall, the amount of refrigerant mass released is greater when the condenser is doused with water and this is proven by the condensation process which occurs within a duration of 10 minutes with a time interval of 2 minutes. Conditions like this prove that pouring water into the condenser will provide better heat release in the air conditioning system condenser [15]. COP_{actual} is used to express the performance of a car AC engine that works with a vapor compression cycle. After getting the actual COP value in the normal test and in the test of flushing the condenser with water, it will be entered into Table 4.

Table 4. The actual COP values in tests under normal conditions

No	Time (minute)	Test Conditions					
		normal condenser			normal condenser		
		COP_{actual}	COP_{ideal}	η (%)	COP_{actual}	COP_{ideal}	η (%)
1	2	2.26	3.97	56.92	2.78	4.27	65.10
2	4	2.33	4.04	57.67	2.60	4.41	58.04
3	6	2.33	4.04	57.67	2.60	4.41	58.95
4	8	2.24	4.04	55.44	2.53	4.53	55.84
5	10	2.24	4.04	55.44	2.53	4.53	55.84

The COP value is greatly influenced by the pressure and temperature in the condenser, so this is a condition in line with the conditions of the condensation process in the condenser. From Table 4 it can be seen that the COP_{actual} value for cooling the condenser using air is highest at 2.26 at 2 minutes and then tends to decreased because the condensation ability of the condenser also decreased, whereas when the condenser was flushed it gave a better COP_{actual} value with a value of 2.78 and had the same trend as the previous one, a tendency to decrease because the condensation ability decreased due to operating time. The efficiency value of the air conditioning system has the same trend as the efficiency value of the air conditioning system, the best being the condenser that is flushed in 2 minutes of operation with an efficiency value of 65.10 while for the air-cooled condenser the highest efficiency value is 56.92 at 2-minute operation [1].

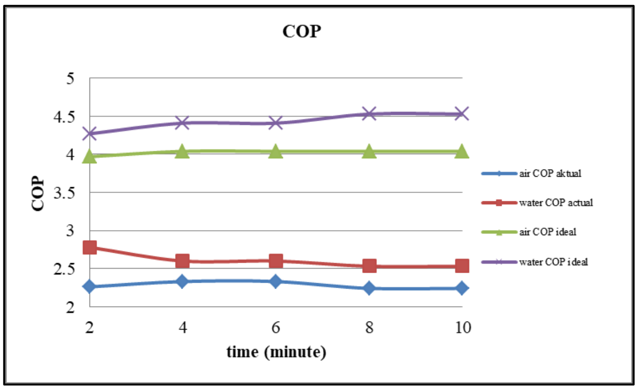

Figure 7. Amount of refrigerant mass

Conclusion

Under normal conditions (only air), the pressure at P_2 ranges from 29 psig to 30 psig, with a temperature at T_2 from 86.9°C to 92.7°C. When the condenser is flushed with water, the pressure at P_2 ranges from 14 psig to 18 psig, with a temperature T_2 from 81.1°C to 81.8°C. Under normal conditions, there is a significant increase in temperature from T_2 (T_3) of 5.8°C in a 10-minute time interval. With the condenser flushed, there is a relatively stable temperature increase, only about 0.7°C from T_2 (T_3) in the same time interval. The actual COP value in normal testing (only air) ranges from 2.24 to 2.33, with a system efficiency value (η) of around 55.44% to 57.67%. When the condenser is flushed with water, the actual COP value increases to around 2.53 to 2.78, with system efficiency reaching 58.04% to 65.10%. Under normal conditions, system efficiency in initial operation ranges from 55.44% to 57.67%, while in the best conditions with the condenser flushed the system efficiency ranges from 58.04% to 65.10%. The use of water as a condensation medium increases the system efficiency significantly, showing a large difference in COP values and system efficiency compared to just use air as a cooling medium. The use of water in the condenser provides a significant increase in the efficiency of the car's air conditioning system. Under normal conditions, the performance of a condenser that relies solely on air tends to be less efficient than when the condenser is doused with water. From these data, it is clear that the use of water as a condensation medium provides better results in improving the performance and efficiency of car air conditioning systems. Adding water to the condenser helps increase condensing capabilities, which in turn results in more efficient heat removal and better overall system performance.

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