The Effect of Retrofitted Refrigerant and Environmental Temperature on the Performance of Air Conditioner: An Experimental Study

A. Nugroho¹², A. Nurkholis¹, R. A. Maulana¹ and T. Priangkoso¹

1Jl. Menoreh Tengah X/22. Sampangan, Semarang 50236
2Corresponding author’s e-mail: agungnugroho3006@gmail.com

Abstract. There are several factors that influence the efforts to increase the performance of an air conditioner (AC), one of which is the selection of working fluid, environmental condition, and device components. Refrigerant is the most vital substance which determines the efficiency of the cooling machine. In addition, ambient air temperature and humidity are other important factors that affect the performance of the cooling machine. Therefore, it is extremely crucial to calculate the environmental condition, which is the air temperature, so that the cooling machine can work optimally. Currently, the refrigeration system uses R-22 refrigerant. However, the use of R-22 has a high ODP (ozone depletion potential) value, thus having a risk of damaging the ozone layer. As a safer alternative, the use of hydrocarbon refrigerants, such as R134a and R290, can solve this problem as they do not have any ODP. This study was conducted by retrofitting the synthetic refrigerant in Air Conditioner (AC) 1 HP with various types of hydrocarbon refrigerant. The outside air temperatures used were 30°C, 50°C, 60°C, and 70°C, while the airflow velocity across the condenser also varied, namely 4.8 m/s, 5.8 m/s, 6 m/s, and 6.6 m/s. From the results of this study, it is known that retrofitting synthetic refrigerants into hydrocarbon refrigerants can increase the coefficient of performance (COP) of the air conditioner. The uses of R134a and R290 hydrocarbon refrigerants increase the COP by 19% and 24.5%, respectively. In addition, lower ambient temperature will reduce the required electrical power. R290 Refrigerant has the best COP value compared to R22 and R134a.

Keyword: Retrofitted, Refrigerant, hydrocarbon, COP.

1. Introduction
Global warming and equitable climate actions are an issue of interest all over the world. Turning on the air conditioner (AC) which still uses synthetic refrigerants contributes greatly to global warming. The use of synthetic refrigerants is now limited due to their negative impact on the environment. Unfortunately, the working fluids or refrigerant from the synthetic compound group are still more dominantly used in refrigeration machines. The terrible impact of synthetic refrigerant that underlies the limitation of its application is that it can harm the ozone layer and cause global warming. The widely-used R22 Refrigerant in refrigeration and air conditioning devices, for example, will escape into the atmosphere when a malfunction occurs, leading to the depletion of the ozone layer. Sales of new devices that use R22 are decreasing gradually at present, and the production of R22 Refrigerant will be discontinued. However, there are still many devices available on the market containing dangerous
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Refrigerants that must be replaced with ones that do not deplete the ozone layer [1]. The good news is that, in the development, synthetic refrigerants used today are ozone friendly, in the sense that they will not damage the ozone layer if they are not released to the open air. However, refrigerants such as R410A and R407C still have a major contribution to global warming since they still have high global warming potential values [2].

Based on the explanation above, efforts on finding other refrigerants that are environmentally friendly continue to this day. One refrigerant that is incredibly friendly to the environment is the natural one. This type of refrigerant does not destroy the ozone layer and its effect on global warming is negligible. In addition, this refrigerant has cooling characteristics similar to existing synthetic refrigerants. For example, propane (R290) has similar cooling properties to R22 [3]. R290 has a lighter density than R22 so its use only requires about half of the existing refrigerant. Furthermore, R290 has a higher COP than R22 in the same system, with the cooling capacity being slightly lower than R22 [4]. With the similar characteristics of R290 to R22, there is a high possibility that R290 will be used as a refrigerant in the future. In the current transition period where the use of synthetic refrigerants that are not environmentally friendly is starting to be reduced, R290 is a greener alternative as it can be used directly on systems that previously use R22 without making any modifications. In addition to the refrigerant, erratic weather changes are another factor that affects the performance of a cooling machine. During a scorching hot day, the condenser will not exchange heat maximally and it will have to work harder, resulting in the temperature of the refrigerant in the machine’s working system to also be fluctuating. Condenser temperatures get lower to the resulting environment.

Table 1. ODP and GWP Refrigerant [5]

| Refrigerant | ODP | GWP | NBP (°C) |
|-------------|-----|-----|---------|
| CFC 11      | 1.00| 4600| 23.8    |
| CFC 12      | 0.86| 4000| -29.8   |
| R134a       | 0.00| 1300| -26.2   |
| HCFC 22     | 0.06| 1700| -40.7   |
| HC 600      | 0.00| 2.7 | -0.5    |
| HC 290      | 0.00| 1.1 | -42.1   |

Apart from its extremely favorable thermal properties, R290 has the disadvantage of being flammable. Thus, the safety of the cooling machine that uses R290 needs to be considered, especially at the risk of leakage [6]. The condenser pressure is exceptionally vital for the cooling system as it determines the performance of the cooling system. If the pressure is low, the condenser temperature will not be high enough to dissipate the heat absorbed by the evaporator. High condenser pressure is great for the transfer process from the condenser to the surrounding environment since the condenser temperature will also be high. However, it will also cause the compressor to work harder to provide higher pressure. A previous study finds that an increase in the condenser temperature, which also improves the condenser pressure, will enhance the cooling of a cooling machine [7]. However, another prior study argues that if the condenser pressure increases, the COP of the cooling machine will decrease [8]. Therefore, the present study will pay attention to the effect of ambient air temperature and air condenser speed on the performance of the cooling machine.

Split AC is a tool used to condition the room temperature so that it is lower than the ambient temperature. The working principle of an air conditioner is to absorb the heat of the cooled air in the room, then release it to the outside environment. The performance of split AC is influenced by several factors, namely the refrigerant, the environment, and the components of the AC itself [9]. Cooling systems generally use R22 Refrigerant which has an ODP (ozone depletion potential) value, thus damaging the ozone layer. There are numerous refrigerants that are environmentally friendly, one of which is HC (hydrocarbon). Hydrocarbon refrigerants have several advantages such as being
environmentally friendly as they do not have any ODP (ozone depletion potential) as well as having a difference in heat transfer which has good air phase density and solubility and is good with mineral lubricants [10]. As mentioned previously above, a previous study finds that an increase in the condenser temperature, which also improves the condenser pressure, will enhance the cooling of a cooling machine [7], but while another prior study argues that if the condenser pressure increases, the COP of the cooling machine will decrease [8]. American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) defines refrigerant as the working fluid in refrigeration, air conditioning, and heat pump systems [11]. In addition to the type of refrigerant, the air temperature also affects the performance of the split AC. Therefore, paying attention to the environmental conditions is extremely needed for the cooling machine to work optimally. This study aims to determine the effect of air temperature on the performance of a split AC with 1 HP power using three types of refrigerator, namely R22, R134a, and R290. Various ambient temperatures were examined in this study, i.e. 30°C, 50°C, 60°C, and 70°C. The experimental study was carried out in the Energy Conservation Laboratory of Wahid Hasyim University.

2. Method

The test was carried out on a split type air conditioner with a power capacity of 1 HP, whose synthetic refrigerant (R22) was retrofitted with hydrocarbon refrigerants R134a and R290. The applied ambient air temperatures were 30°C, 50°C, 60°C, and 70°C. In the experiment, the effect of air velocity across the condenser, which was maintained at 4.8 m/s, 5.8 m/s, 6 m/s, and 6.6 m/s, was also studied. The setup of the experimental equipment used in this study is as shown in Figure 1, with the notations P1, P2, P3, and P4 representing a refrigerant pressure gauge [12]. Meanwhile, T1, T2, T3, and T4 are refrigerant temperature gauges utilizing Arduino-based instrumentation [13]. To determine the ambient temperature, a heater was installed on the outside of the condenser.

The performance of the AC is measured based on the COP (coefficient of performance) value using the following equation:

\[
\text{COP} = \frac{\dot{q}_e}{\dot{W}_c} = \frac{h_1 - h_4}{h_2 - h_1}
\]  

Heat absorbed by the evaporator \((\dot{q}_e)\) can be calculated based on the equation:

\[
\dot{Q}_e = h_1 - h_4
\]

Meanwhile, the compressor work \((\dot{W}_c)\) and the heat transfer can be calculated using the equations:

\[
\dot{W}_c = h_2 - jam_1
\]

\[
Q = mc\Delta T
\]
The amount is obtained from the calculation by using the CoolPack application to inspect the temperature and pressure measurements during the experiment. The results of the pressure and temperature measurements of the refrigerant were then analyzed to determine the performance of the split AC.

3. Results and Discussion

![Figure 2. Power consumption based on ambient temperature variation](image)

The results of the experiment show that a higher ambient temperature causes the compressor to work harder. In general, an increase in the air temperature will increase the power consumed by the air conditioning system. Replacing the existing refrigerant into R134a affects the power consumption, while R290 has better power usage efficiency compared to the other refrigerants. This is due to the density of R290 which lessens the work of the compressor, thus ultimately reducing electricity consumption. For the airflow velocity of 4.8 m/s, 5.8 m/s, 6 m/s, and 6.6 m/s, the compressor work decreases from 0.1222 kW to 0.1182 kW at the ambient temperature of 33°C. The compressor work decreases from 0.1274 kW to 0.1240 kW at an ambient temperature of 35°C if the air velocity across the condenser increases from 4.8 m/s to 6.6 m/s (See Figure 2).

![Figure 3. COP based on ambient temperature variation](image)

As seen in Figure 3, the obtained results are similar to those of a previous study which prove that the compressor pressure will increase if the ambient air temperature rises [14]. This will increase the compressor work value calculated from the enthalpy. The COP of R290 Refrigerant has the highest value compared to the other refrigerants. Generally, the higher the temperature, the lower the COP value of the cooling machine. For R22 Refrigerant, a decrease in COP value by 5% occurs at a temperature is 70°C. The use of R290 can reduce the COP value by 3% at the changing temperatures from the initial temperature of 30°C to 70°C. The best performance is seen at the retrofitting with R134a, with reduction in COP value of only 1% when compared to the temperature of 30°C. In general, as presented in Figure 3, the replacement of synthetic refrigerants into hydrocarbon refrigerants increases the COP value.
Figure 4 displays changes in air velocity across the condenser according to the theory of heat transfer (Equation 5). If the power absorbed from the evaporator remains, the power absorbed by the refrigerant in the condenser will also be constant. If the velocity of airflow across the condenser increases, the condenser pressure will be decreased to match the amount of heat absorbed by the condenser. The decrease in condenser pressure is to minimize the temperature difference between the condenser and the surrounding air so that with increasing wind speed, the heat lost by the condenser does not change. Figure 4 shows that fast heat exchange process affects COP. Airflow that passes through the condenser too quickly lowers the COP of the AC. This happens because there is a bypass when the airflow passes through the condenser, causing it to be unable to carry the heat in the condenser and release it to the outside environment.

4. Conclusion and Outlook
The higher the air temperature, the lower the coefficient of performance (COP) value of the air conditioner. The uses of R134a and R290 refrigerants increase the COP by 19% and 24.5%, respectively. Lower the ambient temperature will reduce the required electrical power. R290 Refrigerant has the best COP value compared to R22 and R134a and can be used without changing the original components of the air conditioner.

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