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Performance Analysis of Different Refrigerants in Automobile Air Conditioning Equipment Using Variable Capacity Compressor

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Abstract

In this study, the experimental performance of the use of R1234yf refrigerant alternative to R134a refrigerant in an automobile air conditioning system with variable capacity compressor was investigated. The automobile air conditioner consists of a variable capacity compressor, evaporator, condenser, liquid tank and expansion element. The experimental air conditioner is equipped with computer-aided control systems to obtain the desired experimental conditions and data collection systems for measuring and collecting experimental data. Tests were performed at different compressor speeds and different condenser and evaporator inlet air flow temperatures. Energy analysis was applied to the obtained experimental data and the results were presented in comparative graphs. In the results, it was seen that while the cooling effect coefficient and evaporator outlet air flow generally decreased in both refrigerants with the increase of the compressor speed, the mass flow rate of the refrigerants, the compressor outlet temperature, the heat discharged from the condenser, the cooling capacity and the compressor power increased. In cases where the evaporatör inlet airflow temperature is low, it has been observed that the change in the data is very small with the increase of the compressor speed with the effect of the capacity control system

Keywords: Variable capacity compressor, Automobile air conditioning, R1234yf, R134a, Refrigeration.

Research Article

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1. Introduction

The use of energy in air-conditioning systems and the costs spent are important. Developments in this area play an important role in the future planning of the food, beverage, chemical and automotive industries. This shows that a small improvement in the operating systems of these large, costly and high-demand industries can result in a large reduction in optimization cost, resulting in significant savings. For this reason, various optimizations can be studied in order to reduce the damage to the environment and to save energy consumption by adhering to the requirements of air conditioning systems. The f-gas rules put forward by the European Union have set an upper limit of 150 for the global warming value (GWP) of the refrigerants used in the automobile air conditioning systems of all vehicles that will enter the EU automobile market from 2017 to the present. Refrigerants with a GWP value above 150 are hydrofluorocarbons, which has restricted their use.[1] R134a refrigerant has been used frequently in automobile air conditioning systems since 1994. Considering the rules set by the European Union, carbon dioxide (CO2), R1234yf or R1234ze refrigerants with a much lower GWP value should be used as an alternative to R134a refrigerant.

Although carbon dioxide is a natural refrigerant gas, it is a nonflammable fluid. Since the working pressure value in air conditioning systems is very high, it works with high compressor power. This causes a decrease in the coefficient of performance (COP) together with leakage problems in the air conditioning system. Another alternative refrigerant is R1234yf hydrofluoroolefin (HFO). The newly developed R1234yf has a low burning rate and in addition, it has a GWP value of 4 in the literatüre [2]. Minor and Spatz [3] reported system performance measured on a bench scale device using components of a small car's air conditioning system. Yohan Lee and Dongsoo Jung [4] performed the performance of R1234yf and R134a in an experimental automobile air conditioner under summer and winter air conditioning seasonal conditions. Adrian Mota-Babiloni et al. [5] investigated the performance of R450 refrigerant instead of R134a in a vapor compression system under various operating conditions. Mahmoud Ghodbane [6] made a research on R152a and hydrocarbon refrigerants in mobile air conditioning system. prof. Jignesh K. Vaghela [7] conducted a study on the comparative evaluation of an automobile air conditioning system using R134a and alternative refrigerants. Zilio et al. [8] reported simulation results for R1234yf in a typical automotive system. A.mota-Babiloni et al. [9], in recent years, have studied on mixtures of hydroxide olefins and R32. Gaurava and Raj Kumarb [10] studied the thermoeconomic analysis of R1234yf as a substitute for R134a in automobile air conditioning application. Yuan et al. [11] in their study, used heat pump application in the air conditioning systems of electric cars, which are seen as new generation cars, and stated that the use of R152a and R1234yf refrigerants as refrigerants instead of R134a would reduce their emissions by 10-23% and 3-18%, respectively. Chen et al. [12] examined the performance values of R152a and R1234yf refrigerants, which they stated to have similar thermodynamic properties to R134a refrigerant. They stated in the study that the working pressure and temperature of R1234yf were similar to R134a, but R1234yf had a deterioration in cooling capacity and coefficient of performance (COP) of 11% and 16%, respectively. In addition, they wrote that R152a has higher volumetric efficiency (18%), adiabatic efficiency (13%) and cooling capacity (6%), higher cooling capacity and COP than R134a refrigerant. At an evaporator temperature of 0 °C, the COP of R152a, R1234yf and R134a were 2.8, 1.8 and 2.3, respectively.

In the literature, researches have been made on many expansion elements and compressor types as well as different refrigerants, but in most of them, it has been tried to draw conclusions through numerical studies and models. In this study, the performance effects of the use of R134a and R1234yf refrigerants with a variable capacity compressor were experimentally investigated.

2. Experimental System

The automobile air conditioning system in which the experimental studies were carried out is shown in Figure 1. Test device components consisting of original automobile air conditioning system cycle elements; It consists of the conditioning equipment that creates the test conditions, the data collection to receive the test data and the control system that provides the control of the conditioning equipment. All system elements of the test device were placed in the condenser and evaporator air ducts with a test table. The vapor compression refrigeration cycle components of the experimental device consist of condenser, thermostatic expansion valve, evaporator, liquid tank/filter dryer, double condenser fan, evaporator fan, hand valves and variable capacity compressor element. The refrigeration cycle components of the experimental device are given in Table 1. The schematic view of the experimental device is given in Figure 2.

Fig. 1. Experimental automobile air conditioning system

Coriolis type mass flow sensor, which measures the mass flow rate of the refrigerant circulating in the system in the test device, is placed in the liquid line of the refrigeration cycle as in Figure 2. Again, as can be seen in Figure 2, temperature and pressure sensors are located in order to take the temperature (T) and pressure (P) values of the refrigerants from certain points.

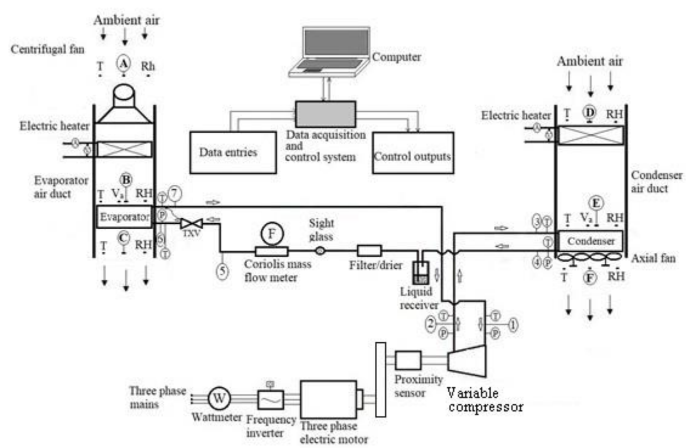

Fig. 2. Schematic view of the experimental system.

Table 1. Experimental automobile air conditioner refrigeration cycle elements.

Cycle Element	Cycle Element Model
Expansion valve	Thermostatic expansion valve
Internal heat exchanger)	Opposite coaxial internal heat
Condenser	Exchanger
Evaporator	Laminated type
Variable capacity compressor	Sanden SD7V16

Air flow and temperature and relative humidity sensors were placed at the points given in Figure 1 to measure the air flow rate (Vh) and temperature (T) and relative humidity (Rh) data of the air passing over the evaporator and condenser in the test device. The characteristics of the measuring devices used in the experimental device are presented in Table 2.

Table 2. Experimental automobile air conditioner measuring devices technical specifications.

Measured parameter	Trademark /Model	Accuracy precision	Measuring range
Pressure gauge	VICA / S-10 E+E	≤ 0,25	0-25
Air flow velocity meter	ELECTRONIC / EE65-VCK200	0,2	0,2 / 10
Refrigerant temperature gauge	T type thermocouple	± 0.4 °C	− 40/123 °C
Mass flow meter	Krohne Optimass 3300C H04 Coriolis flowmeter	± 0.1%	0–450 kg h^{-1}
Relative humidity meter	SHT71 humidity sensor	± 3%	0–100%
Air temperature meter	SHT71 temperature sensor	± 0.4 °C	− 40–123 °C

3. Thermodynamic Analysis

The inlet and outlet refrigerant temperatures of the vapor compression refrigeration cycle elements were measured in the air conditioning system where experiments were carried out with two different refrigerants (R134a, R1234yf). The pressure values of the evaporator and condenser were measured from the inlets of these elements and the pressure loss in the system was neglected. The pressure values of the variable capacity compressor were measured from the compressor inlet and outlet.

• Cooling capacity of the system:

$$\dot{Q}_{evap} = \dot{m}_r(h_7 - h_6) \quad (1)$$

• The amount of heat released to the environment in the condenser:

$$\dot{Q}_{cond} = \dot{m}_r(h_3 - h_4) \quad (2)$$

• Compressor power:

$$\dot{W}_{comp} = \dot{m}_r(h_2 - h_1) \quad (3)$$

• Coefficient of Performance (COP):

$$COP = \frac{\dot{Q}_{evap}}{\dot{W}_{comp}} \quad (4)$$

calculations were made using the equations.

4. Results and Discussion

Comparative performance analysis of R134a and R1234yf refrigerants of experimental automobile air conditioner with variable capacity compressor is presented in Figure 3-9 depending on compressor speed. Compressor speed varies between 750-2750 rpm. Evaporative and condenser air inlet streams; It consists of 3 parts as $T_{evap} = T_{cond}$=40℃, T_{evap} = 25℃, T_{cond} = 32℃, $T_{evap} = T_{cond}$ = 25℃. In addition, air flow velocities were determined as $V_{av,cond}$ = 3.4 m/s, $V_{av,evap}$ = 2 m/s.

The variation of the evaporator air outlet temperature with the compressor speed in the use of different refrigerants of the Experimental Automobile Air Conditioner Containing a Variable Capacity Compressor is shown in Figure 3. As the compressor speed increases, the evaporator air outlet temperature decreases in both refrigerants. When working with R1234yf refrigerant for $T_{evap} = T_{cond}$ = 25℃ condition, 6.45% higher than R134a, T_{evap} = 25℃, 27.5% higher for T_{cond} = 32℃ condition, $T_{evap} = T_{cond}$ For the case of =40℃, it is about 5.5% lower.

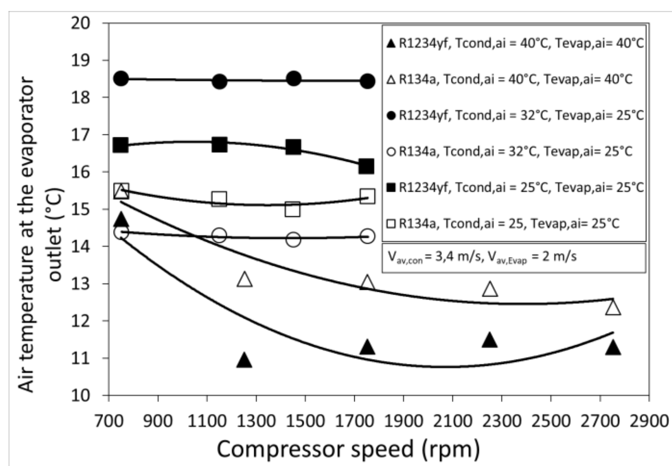

Fig 3. Variation of evaporator air outlet temperature with compressor speed.

The variation of refrigerant mass flow rate with compressor speed is shown in Figure 4. As the compressor speed increases, the mass flow rates of R134a and R1234yf refrigerants also increase. For low airflow inlet temperatures, it is seen that R1234yf refrigerant uses a mass flow rate of around 75% lower than R134a refrigerant. When we look at the case of $T_{evap} = T_{cond}$=40°C, the mass flow rate of R1234yf is 55% higher than R134a.

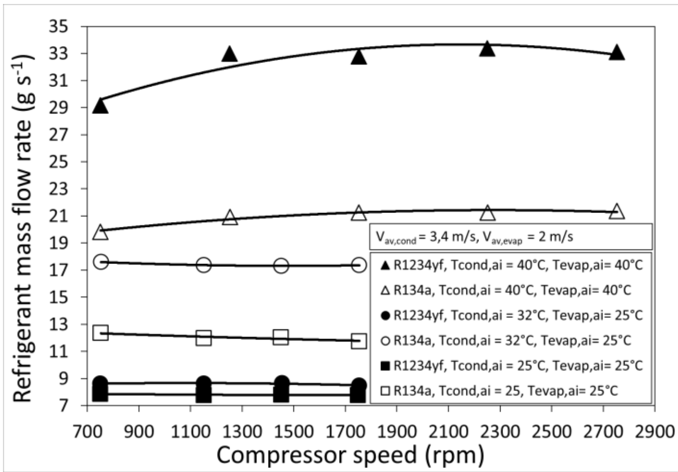

Fig 4. Variation of refrigerant mass flow rate with compressor speed.

The variation of the compressor outlet temperature with the compressor speed is presented in Figure 5. As the compressor speed increases, it is seen that the compressor outlet temperature tends to increase in both refrigerants. R134a refrigerant gives 6-7°C higher compressor outlet temperature than R1234yf for $T_{evap} = T_{cond}$=40°C. In other cases, it is seen that the compressor outlet temperature is 5-6°C higher than the R134a refrigerant R1234yf.

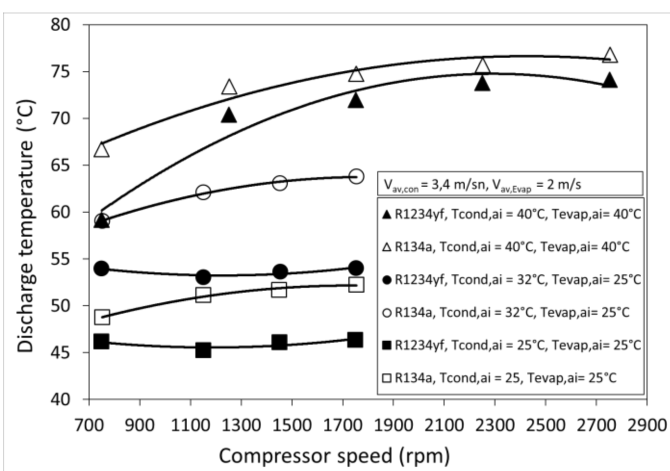

Fig 5. Variation of compressor outlet temperature with compressor speed.

The variation of the heat dissipated in the condenser with the compressor speed is shown in Figure 6. When we examine this graph, it is seen that the amount of heat dissipated in the condenser increases when the evaporator air flow inlet temperature remains constant and the condenser airflow inlet temperature increases. Although the compressor speed increases at low airflow inlet temperatures, the change in the amount of heat dissipated in the condenser is very limited. However, at high airflow inlet temperatures, as the compressor speed increases, the amount of heat removed from the condenser increases. In the case of R1234yf refrigerant $T_{evap}=T_{cond}$=40°C, the amount of heat dissipated in the condenser is 0.5 kW more than R134a. Considering the $T_{evap}=T_{cond}$=25°C condition as the low airflow inlet temperature, approximately 2.5 kW of heat is lost in the condenser for R134a, while it remains at 1.4 kW in R1234yf. This shows that the amount of heat dissipated in the condenser in R134 is 78.5% more than in R1234yf.

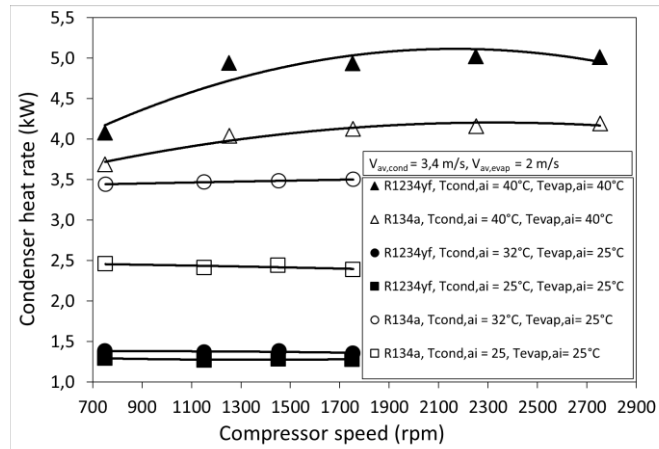

Fig 6. Variation of the heat dissipated in the condenser with the compressor speed.

Looking at the cooling graph in Figure 6, as the compressor speed increases, there is an increase in the cooling capacity for both refrigerants at high airflow inlet temperatures, while it follows a constant line at low airflow inlet temperatures. The highest cooling capacity is at the high airflow inlet temperature of the R1234yf refrigerant with an average of 3.5 kW. Another reason for this situation is that the highest flow rate is in the R1234yf refrigerant for $T_{evap}=T_{cond}$=40°C as seen in the mass flow graph in Figure 4. At low airflow inlet temperatures, R134a refrigerant shows a 1-2 kW higher cooling capacity than R1234yf.

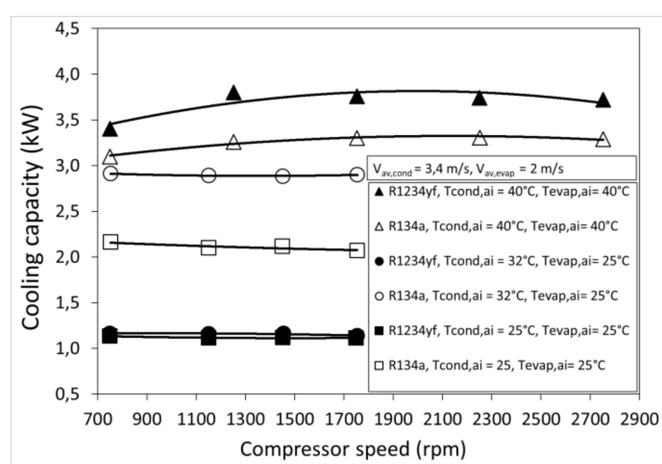

Fig 7. Variation of cooling capacity with compressor speed.

The variation of compressor power with compressor speed is given in Figure 8. Increasing the compressor speed causes an increase in compressor power regardless of the refrigerant type. If the refrigerants are compared for the T_{evap}=T_{cond}=40°C condition, the R1234yf refrigerant uses 50% higher compressor power with an increase of 0.35 kW compared to R134a.

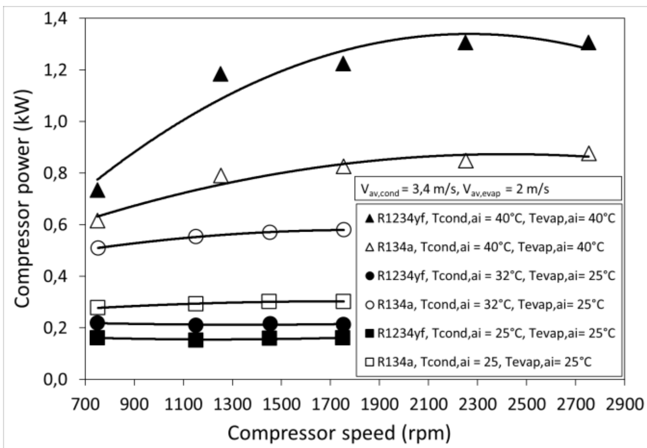

Fig 8. Variation of compressor power with compressor speed.

The variation of the Coefficient of Performance with the compressor speed is given in Figure 9. It is seen that the COP decreases with the increase of the compressor speed, except for the low air inlet temperatures of the R1234yf refrigerant. Since the increase in compressor speed will increase the compressor power, COP shows a corresponding decrease. It is seen that the COP value of R134a is 20% higher than R1234yf at high airflow inlet temperatures and 2% higher at low airflow inlet temperatures.

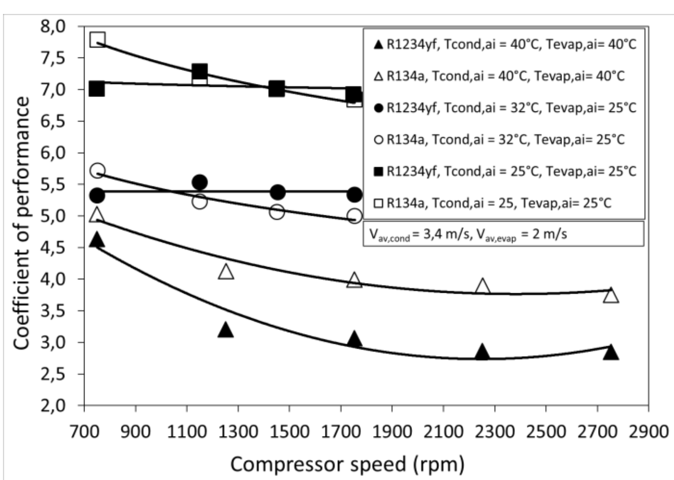

Fig 9. The variation of the Coefficient of Performance with the compressor speed.

5. Conclusions

In this study, the comparative results of the performance results of operating the variable capacity compressor with R1234yf, R134a refrigerants in automobile air conditioners are presented. The main results obtained in the study are presented below;

• It has been observed that the mass flow rates of R134a and R1234yf refrigerants increase as the compressor speed increases. For low airflow inlet temperatures, it has been observed that R1234yf refrigerant uses a mass flow rate of around 75% lower than R134a refrigerant. When we look at the high air flow inlet temperatures, it is understood that the mass flow rate of R1234yf is 55% higher than R134a.

• It has been observed that even though the compressor speed increases at low airflow inlet temperatures, the heat dissipated in the condenser follows a constant line, but at high airflow inlet temperatures, the amount of heat released from the condenser increases as the compressor speed increases. In the case of R1234yf refrigerant T_{evap}=T_{cond}=40°C, it was observed that the amount of heat dissipated in the condenser was 0.5 kW more than R134a. When looking at T_{evap}=T_{cond}=25°C as low airflow inlet temperature, it is observed that while R134a heats up about 2.5 kW in the condenser, it remains at 1.4 kW in R1234yf. This shows that the amount of heat dissipated in the condenser in R134a is 78.5% more than in R1234yf.

• It has been observed that while the cooling capacity increases with the increase of compressor speed at high airflow inlet temperature, it follows a constant line at low airflow inlet temperatures. It was observed that the highest cooling capacity was 3.5 kW on average, and the high airflow inlet temperature of the R1234yf refrigerant. It has been observed that at low airflow inlet temperatures, the R134a refrigerant shows a 1-2 kW higher cooling capacity than R1234yf.

• Compressor power usage has been observed to increase for both types of refrigerants with the increase in compressor speed. However, this increase is less observed at low airflow inlet temperatures. If the refrigerants are compared for the T_{evap}=T_{cond}=40°C condition, it is seen that the R1234yf refrigerant uses 50% higher compressor power by increasing 0.35 kW compared to R134a.

• It has been observed that the coefficient of refrigeration efficiency of the R1234yf refrigerant decreases with the increase of the compressor speed, except at low air inlet temperatures. It was observed that the COP value of R134a was 20% higher than R1234yf at high airflow inlet temperatures and 2% higher at low airflow inlet temperatures.

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Nomenclature

AAC	: Automotive air-conditioning
COP	: Coefficient of performance
$\dot{Q}$	: Heat transfer rate/kW
GWP	: Global warming potential
EU	: European Union
ODP	: Ozone depleting potential
HFO	: Hydrofluoroolefin
HFC	: Hydrofluorocarbon
P	: Pressure/kPa
T_{evap}	: Evaporator temperature
T_{cond}	: Condenser temperature
h	: Enthalpy
Q_{evap}	: Cooling capacity
Q_{cond}	: Condenser heat rate
W_{comp}	: Compressor power
m_T	: Refrigerant mass flow rate

Subscripts

av.cond	: Average condenser
av.comp	: Average compressor
comp	: Compressor
cond	: Condenser
evap	: Evaporator
r	: Refrigerant

Conflict of Interest Statement

The authors declare that there is no conflict of interest in the study.

CRediT Author Statement

Alpaslan Alkan: Conceptualization, Supervision, Validation
M. Sait İnan: Writing-original draft, Data curation, Formal analysis

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