

COMPARATIVE PERFORMANCE BETWEEN R134a AND R152a IN AN AIR CONDITIONING SYSTEM OF A PASSENGER CAR

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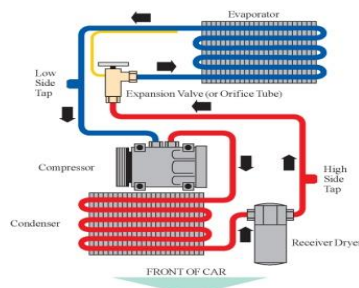
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Graphical abstract



Abstract

The present study investigates numerically the performances of an automotive air conditioning (A/C) system using R134a and R152a as working fluids for various engine running speeds. There are three engine rotation variations, i.e., 1000 rpm, 2000 rpm and 3000 rpm that represent idle, city and high speed conditions, respectively. The compressor volumetric efficiencies for 1000 rpm, 2000 rpm and 3000 rpm are 0.75, 0.65 and 0.55, respectively. The results show that the cooling capacities of R152a are slightly lower than that of R134a at the condensing temperatures of 40°C and 45°C. However, at the condensing temperature of 50°C, the cooling capacity of R152a is higher than that of R134a up to 5.0%. In addition, COPs of R152a are higher than that of R134a for all the condensing temperature. The increase of condensing temperature is more dominant to the COP improvement rather than the increase in engine rotation. The highest COP improvement is 13.5%.

Keywords: Automotive air conditioner, cooling capacity, global warming potential, R134a, R152a

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1.0 INTRODUCTION

It is well known fact that R134a is widely used as working fluid in automotive air conditioners (A/C). Although this refrigerant has zero ODP (ozone depletion potential), it still has high GWP (global warming potential), that is 1,430 (100-year) [1-4]. The use of R134a in all vehicles A/C will be banned in Europe from 2017 [5]. The European Union issued a regulation to utilize the refrigerant with GWP fewer than 150. This requirement forced the car manufacturers to begin changing the use of R134a with a more environmentally friendly refrigerant. One

of alternatives is R152a, which is used as a substitute refrigerant for R134a. The use of R134a as working fluid to replace R12 in automotive A/C was carried out in the 1990s, because the R12 has high ODP. Furthermore, because R134a still has high GWP, it also must be phase out in the near future. Table 1 depicts the properties of R134a and R152a [6]. The table shows that the normal boiling temperature (NBP) of R134a is slightly lower than that of R152a, but the GWP of R134a is much higher than that of R152a. As a result, R152a is recommended by several researchers as a substitute for refrigerant for R134a in the near future [7-9]. The comparison of pressure versus saturation temperature

of R134a and R152a is shown in Figure 1 [6]. It can be seen that the saturation temperature of R134a is slightly higher than that of R152a for the same pressure. It means that in normal operating condition, the compression ratio of R134a is slightly higher than that of R152a for the same evaporating and condensing temperatures.

Ghodbane [10] carried out numerical analysis on automotive A/C system using R152a as working fluid. He reported that the COP of R152a increased by 11% and 15% for idle and road condition, respectively. An experimental comparison was performed by Kim *et al.* [11] on an automotive A/C using a swash-plate open-type compressor with refrigerant R134a and R152a. Their results showed that the COP of R152a was 20% higher than that of R134a. Bryson *et al.* [12] carried out an experiment on the automotive A/C and reported that the COP and the cooling capacity of R152a were higher by 9% and 2%, respectively, than that of R134a. Furthermore, Cabello *et al.* [13] conducted an experiment using a hermetic compressor in a refrigeration system. Refrigerant replacement from R134a to R152a in the system was carried out by a conventional “drop-in”. The results revealed that the COP of R152a increased up to 13%, and the cooling capacity decreased by 10%, compared to R134a. Bolaji [14] performed an experimental study on a domestic refrigerator by replacing directly R134a with R152a. He reported that the COP of domestic refrigerator increased by 4.7% when the R134a was replaced by R152a.

Table 1 The properties of R134a and R152a [2, 6]

Refrigerant	Chemical formula	NBP (°C)	GWP (20-yr)	GWP (100-yr)
R134a	C ₂ H ₂ F ₄	-26.07	3,830	1,430
R152a	C ₂ H ₄ F ₂	-24.02	437	124

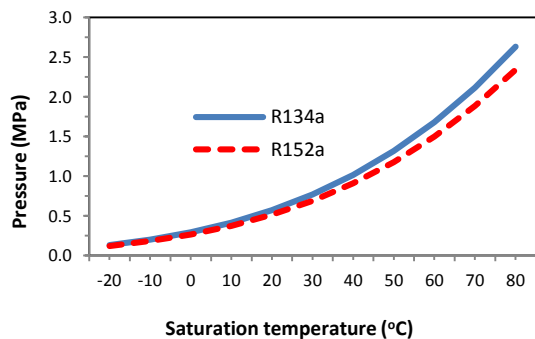


Figure 1 Pressure vs. saturation temperature

The aim of this paper is to investigate the performances of an automotive A/C using R134a and R152a at various engine rotations. Three engine rotations will be discussed in this paper, where they represent the three conditions of a typical car, namely idle, in the city and high speed in the high

way, with engine rotations of 1000, 2000 and 3000 rpm, respectively.

2.0 METHODOLOGY

The thermodynamic cycle of an automotive A/C in pressure vs. enthalpy (P-h) diagram using R134a and R152a as working fluids is presented in Figure 2. The working principles of automotive A/C is vapor compression refrigeration cycle that is driven by car engine. As a result, the cooling capacity and input power of the automotive A/C depends on the engine rotation. The higher the car engine speed, the higher the cooling capacity and the input power required from the compressor.

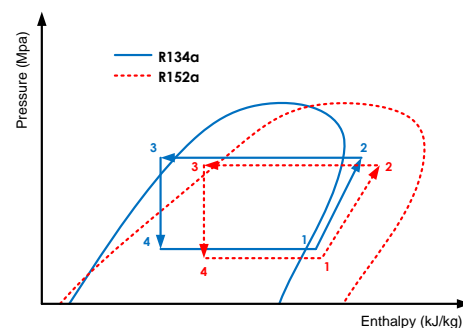


Figure 2 Thermodynamic cycle of automotive A/C system using R134a and R152a

2.1 Modeling Procedure

During operation, car engine may rotate from low to high rotation depending on the driving condition. In the modeling, three engine rotations, i.e., 1000, 2000 and 3000 rpm are selected. The engine rotation of 1000, 2000 and 3000 rpm represent idle, in the city and in high speed conditions, respectively. Five performance results of automotive A/C, namely the cooling capacity, the input power, the COP, the compression ratio and the discharge temperature will be presented. There are some assumptions applied in the modeling:

- The superheat at the evaporator is the same with subcooling in the condenser.
- The superheat is 1, 2, 3K for 1000, 2000 and 3000 rpm, respectively.
- The superheat in the evaporator is not calculated as the cooling capacity.
- The compressor volumetric and isentropic efficiencies are the same, namely 0.75, 0.65 and 0.55 for 1000, 2000 and 3000 rpm, respectively.
- The compressor has a constant displacement, that is $120 \times 10^{-6} \text{ m}^3 \cdot \text{rev}^{-1}$.
- The expansion process is isenthalpic and enthalpy of entering refrigerant to evaporator is saturated condition.

- The pressure drops in all components are ignored.

2.2 Calculation Method

The cooling capacity (Q_{evap}), input power of the compressor (P_{comp}), COP, mass flow rate and compression ratio (CR) are calculated using Eqs. (1) - (5), respectively.

$$Q_{evap} = \dot{m} \cdot (h_1 - h_3) \tag{1}$$

$$P_{comp} = \dot{m} \cdot (h_2 - h_1) \tag{2}$$

$$COP = \frac{Q_{evap}}{P_{comp}} \tag{3}$$

$$\dot{m} = \frac{rpm}{60} \cdot Disp_{comp} \cdot \rho_{suct} \cdot \eta_{vol} \tag{4}$$

$$CR = \frac{P_{disc}}{P_{suct}} \tag{5}$$

where $Disp$ is the compressor displacement ($m^3 \cdot rev^{-1}$), ρ_{suct} (kg/m^3) is refrigerant density at suction, η_{vol} is the compressor volumetric efficiency and P_{disc} (MPa) is discharge pressure.

To determine the cooling capacity, input power and COP improvements due to drop-in from R134a to R152a (for the same condensing temperature), Eqs. (6) - (8) will be applied.

$$Q_{evap_imp} = \frac{Q_{evap_R152a} - Q_{evap_R134a}}{Q_{evap_R134a}} \tag{6}$$

$$P_{comp_imp} = \frac{P_{comp_R152a} - P_{comp_R134a}}{P_{comp_R134a}} \tag{7}$$

$$COP_{imp} = \frac{COP_{R152a} - COP_{R134a}}{COP_{R134a}} \tag{8}$$

The refrigerant properties of R134a and R152a are provided by CoolPack software. Using Eqs. (1)-(5), the performances of automotive A/C can be calculated.

3.0 RESULTS AND DISCUSSION

The numerical results of R134a are compared with that of R152a system. In the comparison, the evaporating temperature of system is 5°C, with three condensing temperatures, viz. 40°C, 45°C and 50°C, respectively

3.1 Cooling Capacity

Figure 3 shows the cooling capacity for R134a and R152a for various condensing temperatures. The cooling capacities of R134a and R15a are represented by continuous and dash lines, respectively. It can be seen that the cooling capacity of R152a is lower than that of R134a for the condensing temperature of 40°C and 45°C. However, for the condensing temperature of 50°C, the cooling capacity of R152a is higher than that of R134a. The cooling capacity improvement is shown in Figure 4.

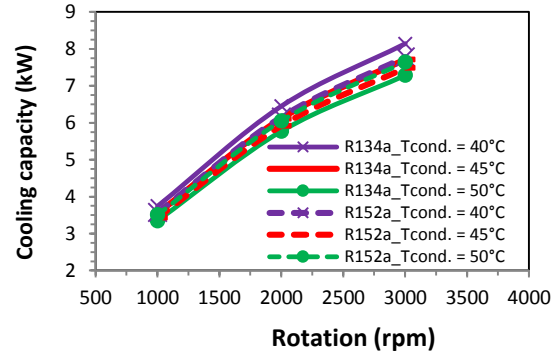


Figure 3 The cooling capacity vs. rpm for R134a and R152a

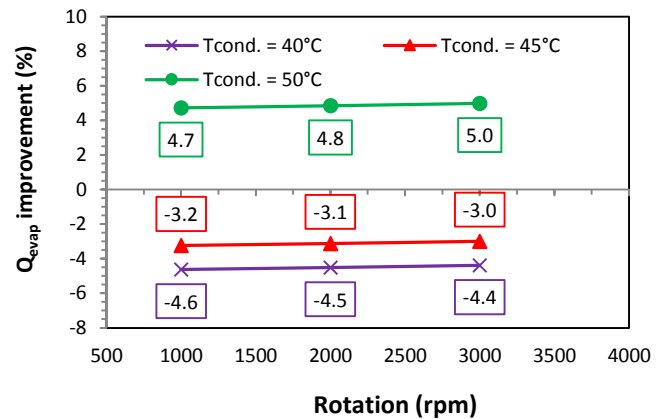


Figure 4 The cooling capacity improvement vs. rpm

Figure 4 shows that at the condensing temperature of 40°C and 45°C the cooling improvement is negative. It means that at those condensing temperatures, the cooling capacity of R152a is lower than that of R134a. Also, at those condensing temperatures, the cooling capacity improvement slightly decreases with the increase in engine rotation. The cooling capacity improvement of R152a occurs at the condensing temperature of 50°C. At this condensing temperature, the cooling capacity slightly increases as the engine rotation increases. For example, at 1000 rpm, the cooling capacity improvement is 4.7% and increases by 5.0% at 3000 rpm. Compared to the experiment carried out by

Bryson *et al.* [12], the numerical results was not too far with their experimental results. As mentioned in the previous section, an experimental investigation on the automotive A/C carried out by Bryson *et al* [12] reported that the cooling capacity improvement on the replacement of R134a with R152a was 2%.

3.2 Input Power

The compressor of automotive A/C is coupled by a belt to the engine. As such, the input power of the compressor is derived from the car engine. Higher input power results in an increase in fuel consumption of the car. Figure 5 illustrates the input power vs. engine rotation of the system A/C when using R134a and R152a as working fluids. The figure shows that for the same condensing temperature, the input power of R152a is lower than that of R134a. It can also be seen that the input power increase with the increase in the condensing temperature. Using Eq. (7), the input power improvement for each engine rotation and condensing temperature can be determined, and the results are shown in Figure 6.

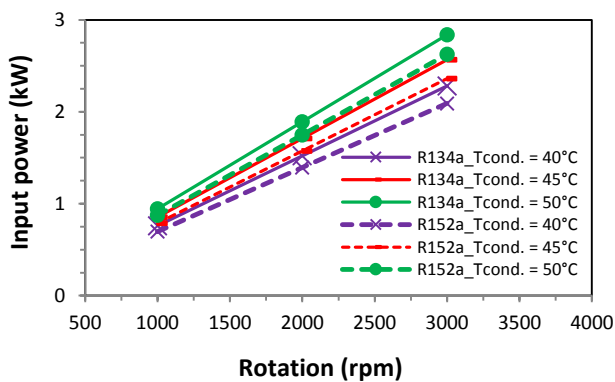


Figure 5 The input power vs. rpm for R134a and R152a

The results from Figure 6 show that for the same condensing temperature, the input power reduction is relatively constant. The input power improvement decreases with increase in the condensing temperature. The increase of 5°C on the condensing temperature decreases input power improvement by approximately 0.5%. The results indicate that the increase in condensing temperature will result in a decrease in the input power improvement. On the other hand, the increase in condensing temperature leads to increase in the input power, as shown in Figure 5

Figure 6 shows that the highest input power reduction is 8.5%, at 1000 rpm when the condensing temperature is 40°C. At this condensing temperature (40°C), the input power reduction only decreases by 0.1%. It means that the increase in engine rotation do not affect the input power reduction. It can be concluded that the use of R152a as a substitute refrigerant of R134a in the automotive A/C results in the input power reduction for all condensing

temperatures and engine rotations. In the other words, this conditions lead to reduction of fuel consumption on the car

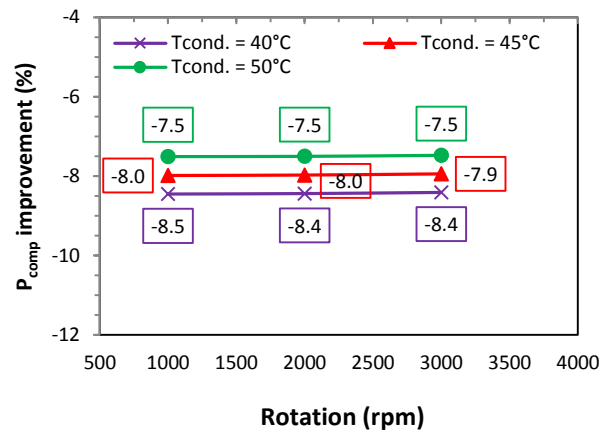


Figure 6 The input power improvement vs. rpm

3.3 Coefficient of Performance

The coefficient of performance (COP) is determined using Eq. (3). COP is the ratio between the cooling capacity and input power. This parameter is the most importance indicator of the performance of the air conditioner and refrigerator.

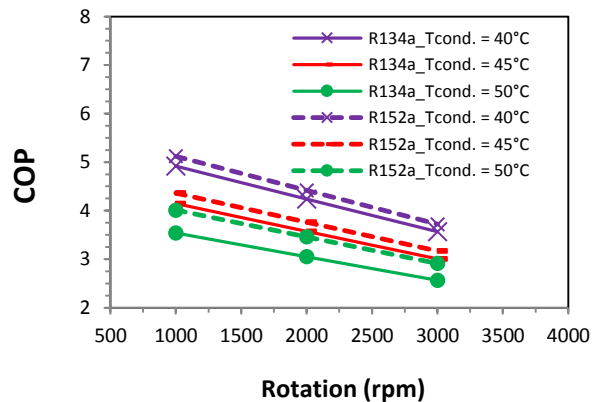


Figure 7 The COP vs. rpm for R134a and R152a

Figure 7 shows the correlation between COP and engine rotation. It shows that when the engine rotation is increased, the COP will decrease. It indicates that at high engine rotation, the efficiency of the automotive A/C decreases. It means that although at high engine rotation the A/C will generate higher cooling capacity, but the compressor also needs more input power from the engine. At high engine speed, the ratio of the cooling capacity to input power is lower than that of the lower engine rotation.

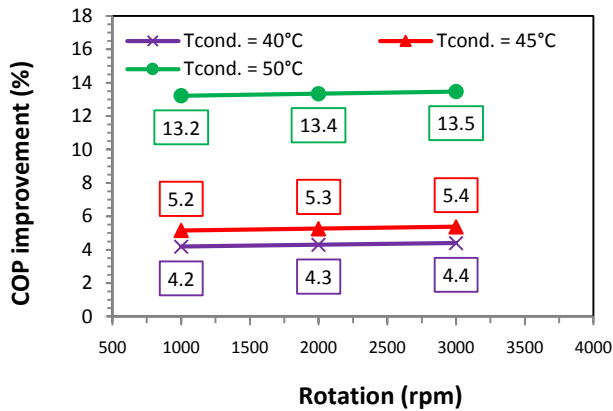


Figure 8 The COP improvement vs. rpm

Figure 8 depicts the COP improvement vs. engine rotation when the R134a is replaced by R152a in the automotive A/C system. The figure shows that for the same condensing temperature, the COP improves by about 0.1% when the engine rotation is increased from 1000 rpm to 2000 rpm and from 2000 rpm to 3000 rpm, respectively. The COP improvement rises significantly when the condensing temperature is increases, especially from the condensing temperature of 45°C to 50°C. With the increase in condensing temperatures, from 40°C to 45°C, for the same engine rotation, the COP improvement is raised by 1.0%. Meanwhile, the increase in COP improvement up to 8.0% is possible when the condensing temperature is increased from 45°C to 50°C for the same engine rotation.

Compared to the obtained experimental results by Kim *et al.* [11], the COP improvements of this study were lower for all the condensing temperatures. Because, as mentioned in the previous section, that the COP improvement in their experimental results was 20%. However, if compared to the experimental result obtained by Bryson *et al.* [12], the COP improvement in this study is lower for the condensing temperature of 40°C and 45°C, but higher for condensing temperature of 50°C. According to experimental result by Bryson, the COP improvement in his experiment was 9%. This indicates that the results based on the numerical approach in this study are similar to the experimental results. The slightly difference might be caused by the selection of compressor isentropic and compressor volumetric efficiencies in the study.

3.4 Compression Ratio

As defined in the Eq. (5), compression ratio is the ratio between discharge and suction pressure. This parameter is to indicate the effectiveness of compressor work. Higher compression ratio indicates that the compressor work is higher. In this study, the condensing temperature is assumed constant for all engine rotations. Figure 9 depicts the compression ratio vs. condensing temperature for R134a and

R152a. The figure also shows that the compression ratio of R152a is slightly lower than that of R134a for all condensing temperatures. These results confirmed the results obtained in Figure 6, that the input power of R152a is always lower than that of R134a for all condensing temperatures.

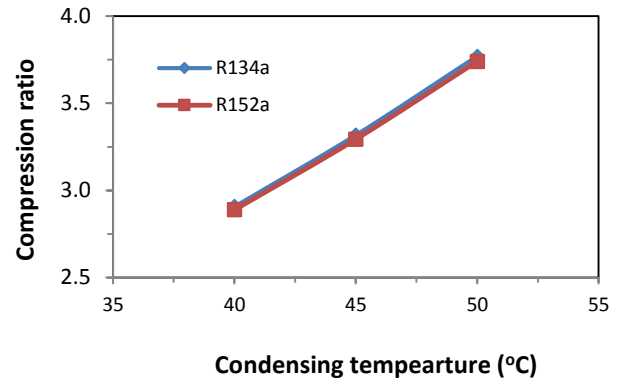


Figure 9 The compression ratio vs. rpm for R134a and R152a

3.5 Discharge Temperature

The discharge temperature is not directly related to the performance of the A/C system. However, this indicator can be utilized to indicate the performance of A/C system when certain refrigerant is used. The A/C system using a working fluid has a certain discharge temperature. When the system is having trouble, the discharge temperatures will rise. High discharge temperature affects the compressor reliability. In this study, the discussion is not on the troubled system but in the normal system. Figure 10 illustrates the discharge temperature vs. engine rotation of the automotive A/C using R134a and R152a as working fluids. The figure shows that the discharge temperature of R152a is higher than that of R134a with the difference being more than 10°C at the same engine rotation. The highest discharge temperature occurs at the condensing temperature of 50°C, which precisely is 94.8°C.

The differences of discharge temperature of R134a and R152a are shown in Figure 11. The figure shows that the discharge temperature different increases with increasing condensing temperature and engine rotation. The lowest and the highest discharge temperature difference are 10.8°C and 19.1°C, respectively.

During operation, high discharge temperature is undesirable because it can cause overheating of the compressor. The overheating of the compressor leads to premature wear of the compressor's cylinder and piston rings. The overheating also may cause lubricant to break down, causing accelerated wear in the compressor [15]. If the overheating occurs, the reliability of the compressor will decrease and failure will soon follow.

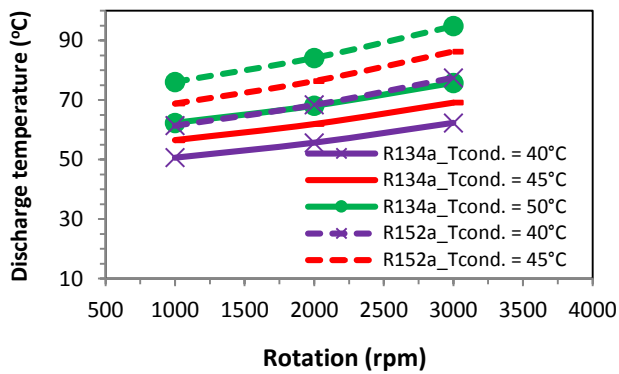


Figure 10 The discharge temperature vs. rpm for R134a and R152a

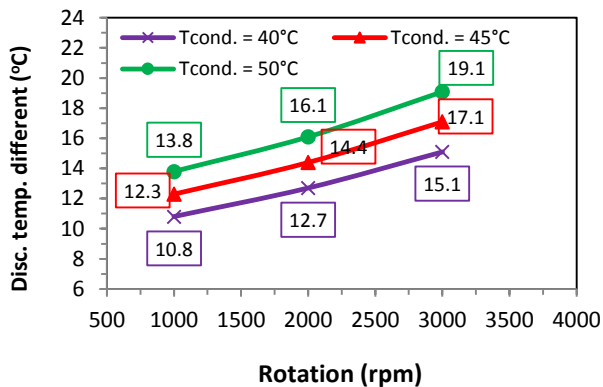


Figure 11 The discharge temperature difference of R134a and R152a

4.0 CONCLUSION

Based on the numerical approach on the working fluid replacement of R134a with R152a in the automotive A/C system, the following conclusions are noted:

- The cooling capacity improvements only occur at the condensing temperature of 50°C. The highest cooling capacity improvement attained was 5.0%.
- The input power reductions occur in all the condensing temperatures, and the highest input power occurs at the condensing temperature of 40°C, that is up to 8.5%. The input power reduction indicates that the use of R152a leads to decrease in the fuel consumption for automotive A/C application.
- The increment of COP improvement is caused by the increase in condensing temperature rather than the increase in engine rotation. The highest COP improvement attained was 13.5%.
- The use of R152a as refrigerant leads to significant increase in the discharge temperature. This

condition may shorten the life span of compressor.

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