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The Performance of Alternative Refrigerant Gas R152a as Mobile Air Conditioning Refrigerant

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In this study, the possible alternative replacement of R134a with R152 in the air conditioning (AC) system of an automobile has been investigated theoretically. The properties of the R152a is presented and compared with three different refrigerants (R134a, R22 and R12). At a constant condenser temperature, the effect of evaporator temperature (T_e=-20 ^{0}C – 0 ^{0}C) and compressor speed (n = 600 - 2,000 rpm) on the cooling load, the condenser heat load, compressor work, the mass flow rate of refrigerant and performance coefficient of the AC system have been examined with the help of a commercial computer program for refrigerants investigated. It was found that R152a and R134a do not lead to any significant difference on the performance of the refrigeration system. This result shows that with small modifications on the AC systems of current automobiles commonly using R134a, R-152a can be used as an alternative refrigerant since their compression ratios are almost the same.

1. Introduction

One of the steps on the global warming and ozone depletion is that the production of CFCs and HCFCs refrigerants needs to be stopped by the end of 1995 and 2030, respectively in the frame of Montreal Protocol 1987 (Riffat and Afonso, 1997). As these chemicals escapes into the atmosphere, they drift up to the stratosphere and their chemical bonds are broken by the intense UV-C radiation. As a result of this, chlorine reducing the ozone molecule to oxygen molecule is released (Bolaji and Huan, 2013). Although, majority of HFCs refrigerants have zero ozone depletion potential (ODP), their global warming potential (GWP) are extensively high. Medium/high-GWP HFCs need to be gradually replaced by Low-GWP HFCs until 2015 according to the EU regulations 2037/2000 (Benhadid and Benzaoui, 2012). For that reason, many of the researchers and RD departments of the companies producing refrigerants have diverted their efforts on the development of the more environmentally friendly refrigerants having zero or nearly zero GWP and ODP values.

Over the last decade, numerous attempts have been made by researchers to eliminate many of refrigerant-based problems in the present vapor-compression refrigeration systems. The following is the brief summary of the previously published studies. Dalkılıç and Wongwises (2010) proposed new refrigerants such as the binary non-azeotropic mixtures R290/R600, R290/R600a, R290/R1270, R290/R152a, and R32/R134a in various concentrations for the possible alternative replacement of CFC12, CFC22, and HFC134a. It was reported that refrigerant blends of R290/R600a (40/60 by wt. %) and R290/R1270 (20/80 by wt. %) can be used as an alternative of CFC12 and CFC22 refrigerants, respectively.(Park and Jung/2009) numerically and experimentally examined the possible replacement of R134a with R430A in the refrigeration systems of domestic water purifies. They pointed out that R430A is a good alternative for HFC134a in domestic water purifiers requiring no major change in the system. Mani and Selladurai (2008) conducted an experimental study on a vapor compression refrigeration system with the new R290/R600a refrigerant mixture as drop-in replacement for CFC12 and HFC134a. It was found that the R290/R600a (68/32 by wt%) mixture is higher refrigeration capacity and energy consumption level than CFC12 and HFC134a. (Bolaji, 2011) experimentally investigated the influence of ozone-friendly alternative refrigerants (R404A and R507) on the performance of a R22 window air-conditioner. The

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results revealed that R507 can be used successfully as a replacement refrigerant in existing window air-conditioners originally designed to use R22 refrigerant. Mohanraj (2013) carried out a theoretical study on the performance of a domestic refrigerator to exhibit possible replacement of R134a with R430A. The author expressed that R430A is an energy efficient and environmentally friendly alternative of R134a in domestic refrigerators. There are some studies in the literature about adsorb bed using using silica gel/water pair. Solmus at al., (2012) studied adsorbent bed dimensions, convective heat transfer coefficient between the cooling fluid and adsorbent bed and the thermal conductivity.

R134a refrigerant (HFC) has been commonly used in domestic refrigerators, freezers and the room sized and automobile AC systems for many years. However, HFC134a makes significant contribution to the greenhouse effect due to its high GWP value although it has zero ODP and hence, R134a needs to be replaced by more environmentally safe long term refrigerant in the near future. On the other hand, the use of HFC134a in the air conditioners of the automobiles produced after 2011 was restricted by EU F-Gases regulation and automobile air-conditioner directive. (Park and Jung/2009) Therefore, automotive industry has especially begun searching an alternative of R134a without making any modifications on the components of the current AC systems. In this context, R152a can be considered as an alternative refrigerant since it has zero ODP and little GWP as it is compared with that of R134a and compatible with the present refrigeration systems in terms of thermodynamic point of view. The main objective of this study is to theoretically investigate the possible alternative replacement of R134a used in the AC systems of present automobiles with R154a without making any considerable modifications on those systems.

2. General Properties of the Refrigerants and Theoretical Analysis

2.1 Thermodynamic Properties

The thermodynamic properties of the refrigerant R152a and the refrigerants widely used in cooling systems such as R134a, R12 and R22 are given in the literature (Bilen, 2012). The thermodynamic and physical properties of the refrigerant R152a are quite similar to that of R12 and R134a and thus, it can be considered as a possible replacement of R12 and R134a refrigerants. Other desirable parameters for the substitute refrigerants include high oil solubility, the ability to blend with other refrigerants, high vapor dielectric strength, easy leak detection and low cost.

2.2 Theoretical Analysis of the Refrigeration System

The effect of the evaporator temperature and compressor speed on the performance of the air conditioning system of an automobile has been investigated for various refrigerants such as R154a, R134a, R12 and R22 at an constant condenser temperature (T_c=60 ^{0}C) with the help of the commercial software. The P-h diagram of the refrigeration cycle is presented in Figure 1.

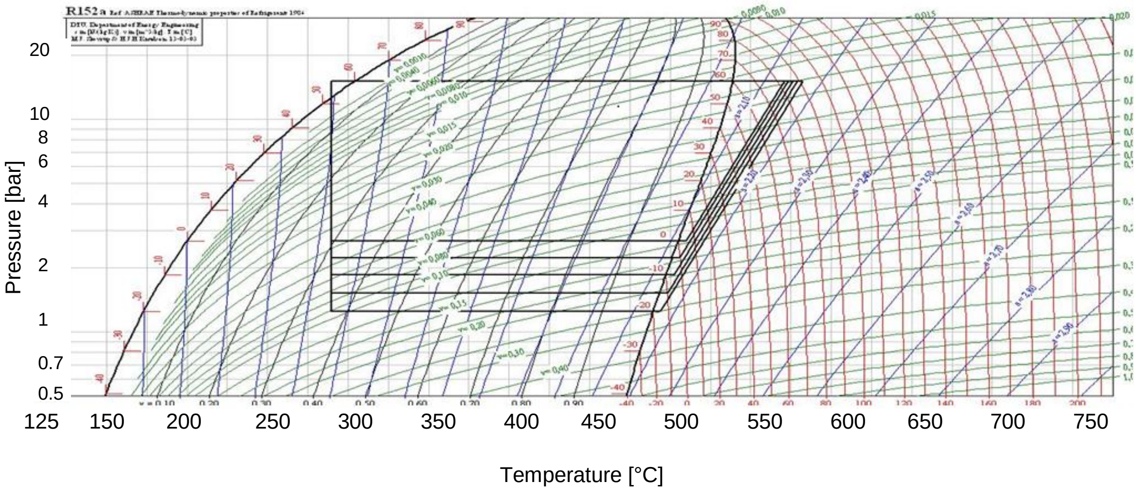

Figure1 P-h diagram of the R152a refrigeration cycle for various evaporator temperatures

3. Results and Discussion

If we examine whether an alternative refrigerant is compatible with the present refrigeration system or not, firstly we need to focus on the compressor pressure ratio (Pr) of the refrigerant in question. Any difference between the compressor pressure ratios may bring significant modifications on the system even all the

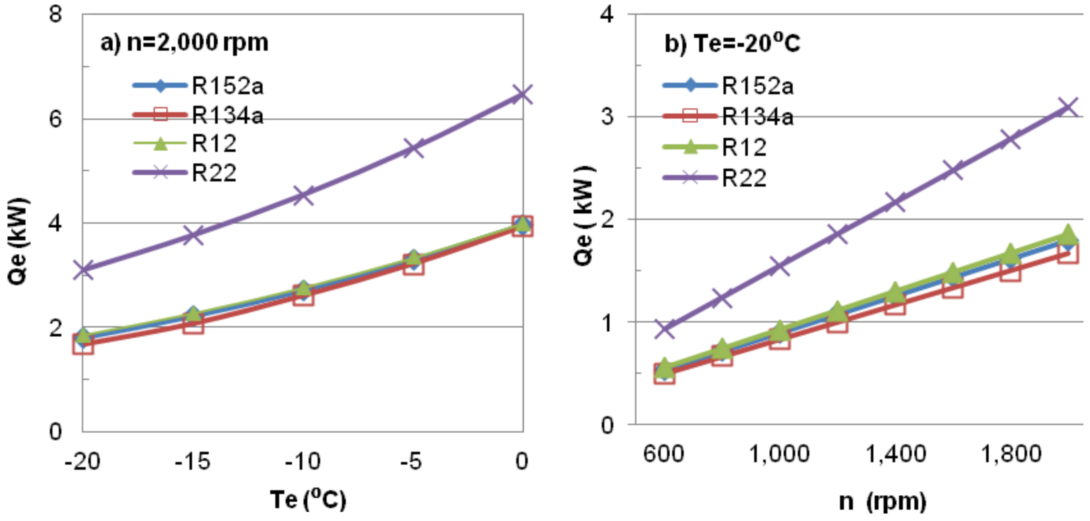

Figure 2.The variation of the evaporator head load at T_c=60 ℃ with a) the evaporator temperature for constant n=2,000 rpm, b) the compressor rotation speed for constant T_e= -20 ℃

properties of an alternative refrigerant except its compressor pressure ratio are similar to present one or better. Therefore, it will not be preferred due to above fact that.

The variation of evaporator heat load with increasing evaporator temperature for constant compressor rotation speed of 2,000 rpm is shown in Figure 2a. It is clear that the evaporator heat load (cooling load) for all refrigerants investigated similarly increases as the evaporator temperature increases. All the refrigerants investigated show the same trend, and almost the same heat transfer load, except R22. At the lower evaporator temperatures, only there is a little difference among them. At a constant evaporator temperature, i.e. T_e=0 ^{0}C, the cooling rate is the same for the refrigerants R134a, R152a and R12. As the relevant of compressor speed, Figure 2b shows the variation of evaporator cooling load with various compressor speeds. The evaporator cooling load of R22 refrigerant is higher than the other three refrigerants over the conditions studied. It can be concluded that the evaporator cooling load increases with an increase in the compressor speed, giving the same increase with compressor speed for all refrigerants, except for R22. For all cases, the cooling rate of R22 is higher than the other three refrigerants for various evaporator temperatures and compressor speeds.

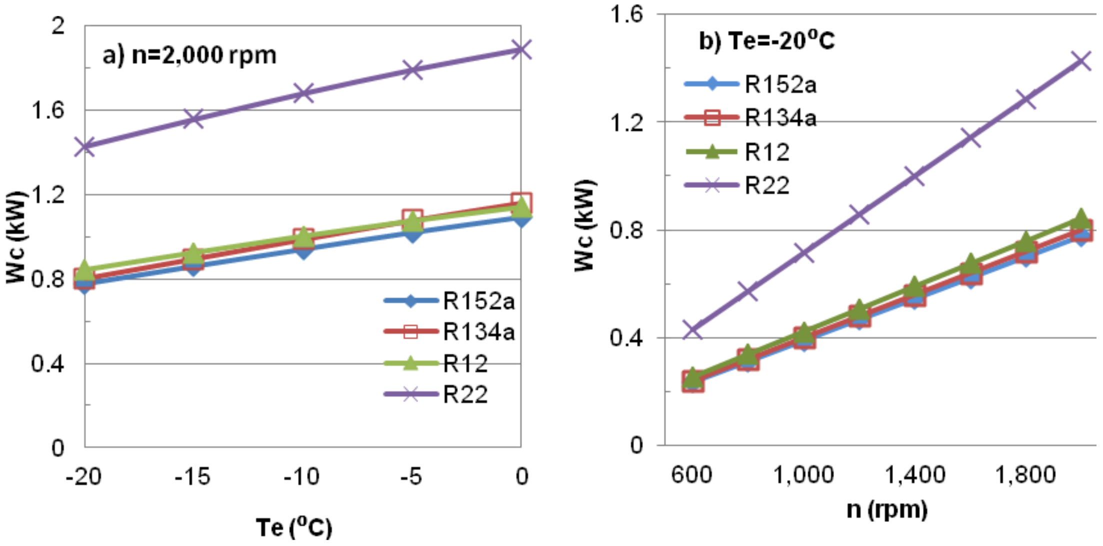

Figure 3.The variation of the compressor work at T_c=60 ℃ with a) the evaporator temperature for constant n=2,000 rpm, b) the compressor rotation speed for constant T_e= -20 ℃

The compressor work for various evaporator temperatures and compressor speed is presented in Figure 3a and 3b. It is obvious that compressor work increases with increasing compressor speed. Although, the compressor work for all refrigerants is nearly the same along with the increasing value of the compressor speed, except for R22, which is higher than the others, the work of R152a is a little smaller than those of R134a and R12 at a constant compressor speed. As a result the compressor work for all refrigerants approaches more to each other as the evaporator temperature decreases. The compressor work increases with increasing the compressor speed for all gases investigated. From the lower compressor speed to higher one, the work of R152a is getting bigger.

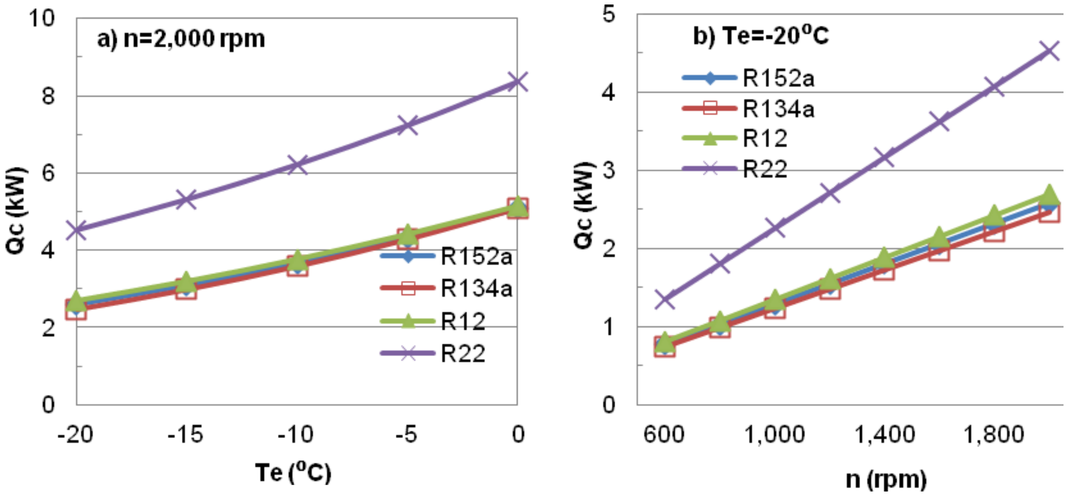

Figure 4. The variation of the condenser heat load at T_c=60 ℃ with a) the evaporator temperature for constant n=2,000 rpm, b) the compressor rotation speed for constant T_e= -20 ℃

Figure 4a shows the amount of heat rejected from the condenser as a function of evaporator temperature for n=2,000 rpm. It is seen from the figure that the amount of heat rejected from the condenser for the refrigerants R152a, R134a and R12 indicates very similar behavior, but that for R22 having higher values than others. Since, the condenser heat load is the sum of the evaporator heat load and compressor power, similar trend is observed for the compressor work as well. Figure 4b illustrate the variation of condenser heat load with various compressor speeds for Te=-20 ^{0}C. It can be expressed that the heat load trends for all the refrigerants are similar, but as expected for R22 has higher values than others.

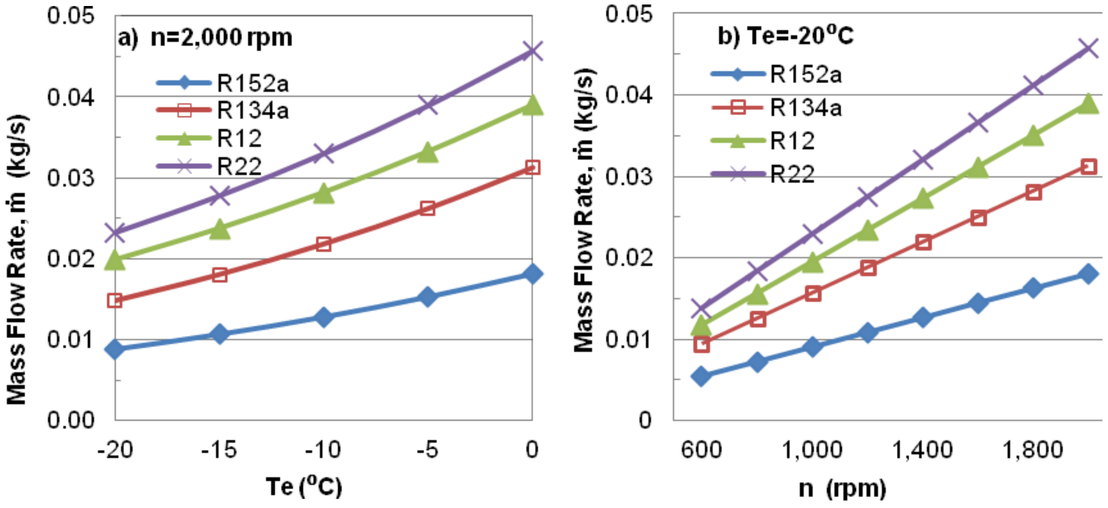

Figure 5. The variation of the refrigerant mass flow rate at T_c=60 ℃ with a) the evaporator temperature for constant n=2,000 rpm, b) the compressor rotation speed for constant T_e= -20 ℃

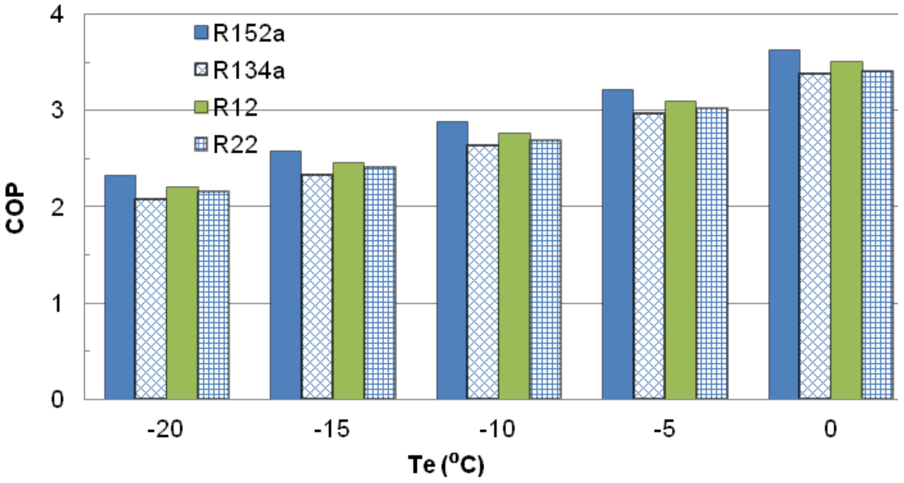

Figure 6. The effect of the evaporator temperature on the coefficient of performance (COP) for all compressor speeds and constant T_c=60 °C

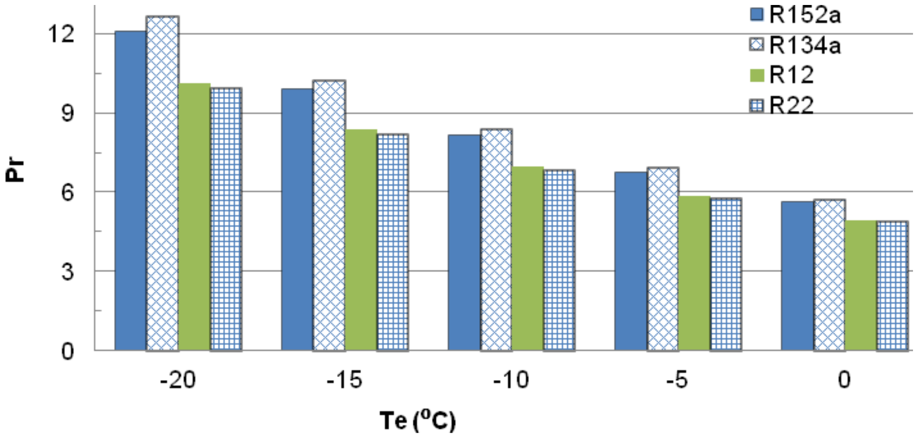

Figure 7. The effect of the evaporator temperature on the pressure compression ratio (Pr) for all compressor speeds and constant T_c=60 ℃

The variation of the mass flow rate with evaporator temperature for n=2,000 rpm is given in Figure 5a. It is clear that the mass flow rate of the refrigerant R152a circulated in the system is less than that of refrigerant R134a and it leads to a higher cooling power. At the same evaporator temperature, while the requirement of refrigerant mass flow rate of the system for R134a is 0.015 kg/s, this is only 0.009 kg/s for refrigerant R152a at constant evaporator temperature of 20 ^{0}C. It can be seen from Figure 6b that, the mass flow rate increment according to increasing value of compressor rotational speeds for R152a is more slowly as it is compared to the other refrigerants and the difference becomes larger when the compressor rotational speed is increased. As a conclusion, it can be said that for constant compressor speed the min mass charge is required for R152a, while max mass charge is required for R22.

The variation of the COP with evaporator temperature for all the refrigerants is presented in Figure 6. Generally, COP value of the system increases as the evaporator temperature is increased and the refrigerant R152a gives better COP value than the other refrigerants at a specified evaporator temperature. The effect of the evaporator temperature on the compressor pressure ratio for various refrigerants is presented in Figure 7. It is clear from the figure that at a constant condenser temperature (T_c=60 ^{0}C), the compressor pressure ratio for both refrigerants (R152a and R134a) over a range of evaporator temperatures considered herein is nearly the same. The compressor pressure ratio decreases with the increasing value of the evaporator temperature for all the refrigerants studied. It can be concluded that refrigerant R152a can be considered possible alternative replacement of refrigerant R134a by without making any significant modifications on the existing AC systems of the automobiles, while having higher COP.

4. Conclusions

In this paper, the effect of operational parameters such as evaporator temperature and compressor speed on the cooling load, the condenser heat load, compressor work, the mass flow rate of refrigerant and performance coefficient of an AC system have been examined theoretically for the refrigerants R152a, R134a, R12 and R22. In addition, possible alternative replacement of R134a used in the AC systems of current automobiles with R152a has been investigated. Based on the results presented above, the following conclusions are drawn:

- For all refrigerants investigated here, the evaporator cooling load, the compressor work, condenser heat load increase as the evaporator temperature or compressor speed is increased.
- The evaporator cooling load, the compressor work, condenser heat load for refrigerants R152a, R134a and R12 are nearly the same but those for refrigerant R22 are higher than the other three refrigerants over the conditions studied.
- The mass flow rate of refrigerant increase with increasing value of compressor speed or evaporator temperature. The mass flow rate of the refrigerant R152a circulated in the system is less than that of refrigerant R134a.
- The refrigerant R152a gives better COP value than the other refrigerants at a specified evaporator temperature.
- The difference between the compressor pressure ratios of the refrigerants R152a and R134a over a range of evaporator temperatures considered is insignificant.

In the frame of above conclusions, R152a can be considered as a good drop-in replacement for R134a in the AC systems of present automobiles since it has the same pressure ratio with R134a and thus, there is no need any considerable modifications on the system.

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