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Experimental study on refrigerant mixing as a drop-in substitute for R134a in a domestic refrigerator

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ABSTRACT

This research aims to find ways to use different mixtures instead of R134a refrigerants that are more efficient and better for the environment. The Kyoto Protocol states that hydrofluorocarbon refrigerants must be replaced due to their high Global Warming Potential values, contributing to environmental damage. The two mixtures tested in this research were both types of refrigerants with different performances, temperatures, and pressures. The first mixture comprises R 134a and R1234yf (10:90% by weight), while the second mixture is R600a and R290 (60:40% by weight). The study revealed that the coefficient of performance of the first and second mixture is higher than R134a by 20.44% and 16%, respectively. Also, the power input of R134a is higher than that of the first mixture by 15.3%, while the second mixture is lower than R134a by 25.8%.

1. Introduction

The energy consumption of domestic refrigerators is significantly higher than that of other household appliances [1]. After international regulations were issued in response to the effects of refrigerant emissions on the environment, the refrigeration industry is currently undergoing change, as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) have such a negative impact on the ozone layer, the Montreal Protocol emphasized the need to replace them[2]. Thus, promoting HFC refrigerants that are safe for the ozone layer is important. As a result of the HFC refrigerants' increased GWP values, the Kyoto Protocol was later formed, calling for their replacement. R134a is the principal component responsible for greenhouse gas emissions, according to the Kyoto Protocol[3]. Many studies have been conducted to improve performance through the direct use of new alternative mixtures and work to develop systems to serve the main goal [4]. Research also dealt with the study of adding nanoparticles to refrigerants and testing their results[5]. This study will look at studies that looked at direct alternatives to hydrocarbon and Hydrofluoroolefins refrigerants. Many studies have been carried out that have taken upon themselves to improve performance through the direct use of new alternative mixtures and work to develop systems to serve the main goal. Research also dealt with the study of adding nanoparticles to refrigerants and testing their results. This research will address studies that deal with the use of direct alternatives to hydrocarbon and hydrofluoroolefin refrigerants. According to F-gas guidelines, the findings stated that residential coolers and refrigeration equipment, as well as freezing and commercial freezers, should be banned as of January 1, 2015, and January 1, 2022, respectively, for hydrocarbons (HFC) with a GWP estimation of more than 150. The majority of nations are drastically reducing their HFC consumption and manufacturing. Therefore, there is increased interest in substituting HFC-134a for potential system upgrades of both existing and incoming systems [6]. HFO-1234yf has no chlorine; therefore, its ozone depletion potential (ODP) is zero[7], and R1234yf has a low global warming potential (GWP) of about 4. HFO-1234yf shares

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HFC-134a's low toxicity. Taking into account the extra environmental effects of HFO-1234yf, R1234yf completely transforms into permanent trifluoroacetic acid when exposed to the environment. Therefore, HFO-1234yf has no negative environmental effects. With HFC134a, Spatz and Minor have noticed the physical characteristics of HFO-1234yf. R1234yf is thus a suitable HFC-134a substitute in the refrigeration industry [8]. Mohan Raj et al. (2009) conducted a study in a refrigerator using an HC-600/290 blend (54.6/45.4%). This mixture reduces compressor work consumption while raising COP [9]. As a theoretical study by Fatouh and El Kafafy [10] for using propane/commercial butane mixture as an alternative refrigerant for R134a found, under normal, subtropical, and tropical operating conditions, the propane/iso-butane/n-butane mixture with 60% propane is the optimum drop-in substitute for R134a in household refrigerators. The pressure ratio of the hydrocarbon mixture containing 50%, 60%, and 70% propane is about 6.3 percent, 11.1 percent, and 15.3 percent lower than that of R134a, respectively. The compressor input power requirements for R134a and the ternary hydrocarbon blend of 60% propane are practically identical. The volumetric cooling capabilities of the hydrocarbon mixture with 70% propane are almost 15.5 percent greater than those of R134a. However, R134a and R404a have different volumetric cooling capabilities. Also, Kathar and Surushe [11] conducted an experimental investigation to evaluate the performance of a 220-litre home refrigerator employing (R290/R600a, 50:50 by weight) to replace R134a. The refrigerant mass charge of R290/R600a was nearly 50%, with refrigeration effect higher by 35.29 percent and 12.5 percent, compressor operation lower by 9.12 percent and 14.68 percent, COP larger by 46.92 percent and 31.91 percent, and discharge compressor temperature lower by 8K and 5K than R134a, respectively. R134a/R1234yf (10:90, by weight) was used in an experimental study by Hmood et al. [12] to replace R134a in a refrigerator. The electrical energy consumption was reduced by 7.5 percent, and the pull-down time was reduced by 14 percent in the binary mixture R134a/R1234yf. The amount of energy saved was reduced by 16%. The refrigerant charge was 116 g, which was higher by 16 percent. In the same way, as an alternative to R134a, another mixture used R134a/R1234yf (R513A) (44:56 by weight). The study by Yang et al. [13] found that energy consumed was reduced by 3.5 percent and the refrigeration capacity was increased, while the excellent mass of charge, which was 80 grams, decreased to 5.9%. Hasheer et al. [14] performed energy analyses of R-152a, R-1234yf, and HFC/HFO blends as a direct alternative to R-134a in a domestic refrigerator. They used blends of R134a/R152a/R1234yf like ARM42 (in the ratio of 8.5/14 /77.5 by mass) and ARM42a (in the ratio of 7/11/82 by mass) as alternatives to R134a and theoretically analysed them. In comparison to R-134a, R-152a has a higher COP and volumetric cooling capacity, making it the ideal option; nevertheless, R-152a has a very high compressor discharge temperature, causing a high level of uncertainty in household refrigerators. So, R152a should not be used as a straight replacement for HFC-134a. When compared to R134a, R1234yf has nearly identical volumetric cooling capacity, refrigerating impact, energy consumption, and coefficient of performance. As a result, it can be considered a proper alternative to R-134a. ARM42 and ARM42a are refrigerant mixes that use less energy than HFC-134a at condenser temperatures of 300 °C. At 500 °C, however, the situation is totally flipped; the ARM42a consumes approximately 10% more power at this temperature. ARM42 has the least cooling capability of the three refrigerants, with ARM42a being essentially identical to R134a. As a conclusion, ARM42a was a better choice as a direct substitute for R134a in a household refrigerator. Previous research has not satisfied the study of replacing R134a refrigerant with gaseous mixtures for operating in tropical conditions with the selection of mixtures that achieve the lowest value of GWP, as the applications are often covered by large volumes of domestic refrigerators. In this study, a small volume with a capacity of 92 litters was used, and the study was applied in tropical conditions in the month of August in Baghdad / Iraq.

2. Parameters of mixture refrigerant selection

There are many different factors to consider when choosing a refrigerant for a particular application. GWP is the parameter that guides this research, but other aspects must also be taken into account. This comprises expenditures associated with development and production, as well as flammability, toxicity, and material compatibility. The full environmental impact, not just the GWP, must be evaluated using a technique like the Life Cycle Climate Performance (LCCP). The refrigerant's direct and indirect climate effects are taken into consideration by the LCCP. The refrigerant itself was released into the atmosphere during production, use, and end-of-life disposal, which is what is responsible for the immediate consequences. The indirect effects are ascribed to emissions from power plants as a result of the energy needed to run the refrigeration system over its lifetime. Refrigerant leakage during the refrigerator's useful life is not a concern because home refrigerators have a hermetically sealed system. They also feature a small charge of refrigerant, so it is presumed that production losses and end-of-life disposal losses are negligible. Therefore, compared to the indirect consequences of lifetime energy usage, the direct effects of domestic freezers are quite minor. Climate performance mostly depends on the energy efficiency of the refrigerator because indirect effects account for the majority of the warming effect. Therefore, the primary consideration when contrasting various refrigerants in household refrigerators should be energy performance, assuming that they satisfy the necessary standards for compatibility, safety, and reliability.

3. Calculation of GWP of mixtures

The mass-weighted average of the GWPs of each individual component makes up the GWP of a refrigerant blend since refrigerant blends are simply created by mixing two or more single-component refrigerants together. This means that one may determine the GWP of a mixture by simply adding the GWPs of the constituent components in proportion to their mass; therefore, the following formula 1 [15] is used to compute the GWP of blends:

$$\text{GWP of Blend} = \text{Proportion by \% mass of component A} \times \text{GWP of A} + \text{Proportion by \% mass of component B} \times \text{GWP of B} + \text{Proportion by \% mass of component C} \times \text{GWP of C} \quad (1)$$

4. Test setup

Fig. 1 shows the test rig, which is a refrigerator cooler with a capacity of 92 litters. R134a is used as the working fluid, and the type of refrigerant that is utilized is shown in the figure. The mechanical components of the refrigeration system (compressor, condenser, expansion valve, and evaporator) have not been altered so that the performance of the equipment functioning with a mixture of components inside the drop-in method may be evaluated. Fig. 2 presents the diagram of the refrigerator. The room used can control the temperature and humidity, and the equipment is placed in such a way that it is not affected by direct radiation from other cooling or heating devices.

During the test, the room temperature is kept constant at a constant rate of change of no more than half a degree Celsius (0.5), and humidity levels are kept between 47% and 75%.In addition to the above, the accuracy of reading the temperature gauges must be up to ± 0.6, and the current and voltage meters must be ± 0.5% of the total measured value, while the accuracy of the pressure gauge is ± 0.1% Pa. In this test, the test room is represented by the refrigerator cooler (test chamber), pressure gauges, temperature, power, voltage, a current recording tool, and a stopwatch. The device must be run-in for at least 24 hours prior to the test under typical operating conditions, free of thermal load (test packages), and within the specified temperature range. According to the manual's handbook, the appliance must be ready with all of its baskets, shelves, and attachments (2).

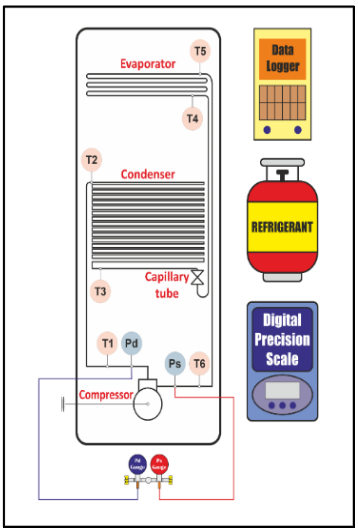

Figure 1. Refrigeration system

Figure 2. Refrigeration diagram

The refrigerator must be left unplugged and with all its doors open for at least 16 hours to allow all its parts to reach temperature equilibrium with the test chamber environment. Appliance doors must be shut, and the unit must be turned on simultaneously with the timer recording the duration of the run. Until steady-state conditions are attained, the device should continue to operate. The temperature test was conducted for the first time using the original refrigerant of the system, which is R134a, with the ideal charge specified by the manufacturer. The other mixtures were then charged individually, and tests were conducted on them. It is worth noting that waiting a sufficient period between tests is necessary to ensure that temperatures return to the initial conditions.

5. Results and discussion

The relationship between the temperature of the evaporator air and the duration of time is depicted in Fig. 3. The amount of time required to bring the air temperature inside the refrigerator down from the ambient state to the intended freezer and cabin air temperatures of 6 degrees Celsius in the cabin is referred to as the "pull-down time." At an ambient temperature of 30 degrees Celsius, pull-down tests were performed. As can be seen in Fig.3, in order to obtain the temperature that was wanted for the R134a baseline test, a pull-down duration of approximately 33 minutes was required. It took 37.5 and 45.8 minutes for the first mixture (M1) and second mixture (M2) to reach the temperature at which they were supposed to be operating. Insufficiency of the refrigerant may cause an extension of the drawing time. At the same time, the high evaporation heat that is characteristic of it is responsible for reducing the drawing time. When choosing between options, it's important to think about the discharge temperature. The stability of the lubricants and compressor parts is affected by the temperature of the discharge. Due to its lower specific heat ratio, the M1 and M2 mixtures' discharge temperature was about 0.5 to 1.5 lower than that of R134a. This is shown in Fig. 4. M1 and M2 have less of an effect on the stability of lubricants and the parts of the compressor. So, when hydrocarbon mixture (HCM) is used instead, you can expect the compressor to last longer. The discharge temperature of R134a is larger than M1 and M2 by 2% and 1% respectively.

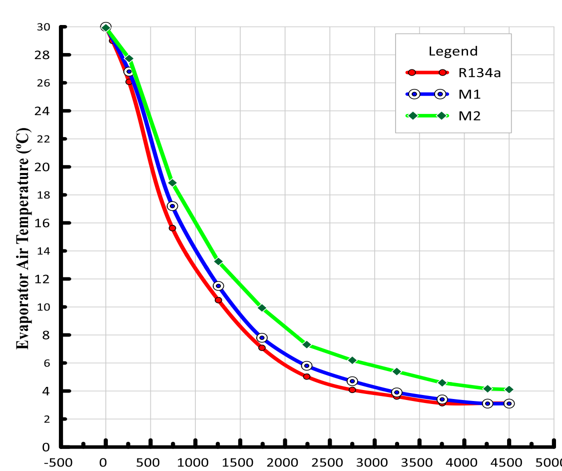

Figure 3. Evaporator air temperature vs time

Fig. 5 presents the GWP value of each mixture of the mixtures used as well as the value of the pure and constituent refrigerants of these mixtures. It is noted from the diagram that the value of R134a is the highest value in pure refrigerants, its value is 1430, for mixtures, the value is the lowest 13.2 for M2, while in the pure refrigerants used, it is the lowest value of GWP for refrigerant 1 for R1234yf. The warming of the Earth may be affected differently by various greenhouse gases (GHGs).

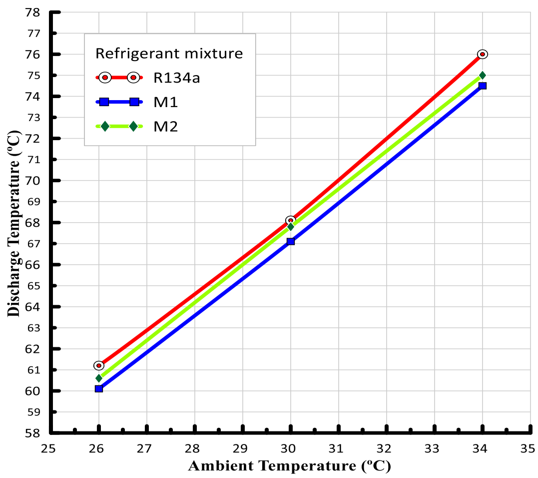

Figure 4. Discharge temperature vs Ambient temperature

The capacity of these gases to absorb energy (radiative efficiency) and how long they remain in the atmosphere (lifetime) are two important ways in which they vary from one another. The GWP values for the pure refrigerants were also adopted from the data presented in the Montreal Protocol and from the Fourth Assessment Report adopted by the Intergovernmental Panel on Climate Change. The GWP values of mixtures generally depend on the GWP values of their components and according to the proportion of components in the mixture, so the refrigerants with small, relatively insignificant values were selected.

Fig. 6 illustrates how the COP changes as a function of the evaporator temperature for a combination of M1, M2, and R134a. It has been noticed that the COP increases as the evaporator's temperature rises for both refrigerants. This is because there is a reduction in the work of compression that occurs whenever there is a smaller temperature difference between the evaporator and the ambient. The decrease in the temperature differences leads to a decrease in the pressure of the compressor. According to the findings, COP of M1 and M2 is higher than R134a by 20.44% and 16% respectively. Using R134a in a refrigerator result in a much lower COP, which necessitates a larger amount of consumed electrical power in order to achieve the same level of cooling. It is worth noting that the increase in energy consumption means an increase in environmental pollution, directly and indirectly. The COP of the refrigerator was calculated by dividing heat extracted from the evaporator by the work done by the compressor. Fig. 7 compares the compressor work of the selected blends and R134a with the evaporator temperature. It shows that the power input of R134a is higher while the power input of M2 is lower. R134a is higher than M1 by 15.3%, while M2 is lower than R134a by 25.8%. This relationship can be considered an important parameter influencing the life of the compressor, its components, and the safety of the lubricant. This figure shows that the working ratio of the compressor increases as the temperature rises. Because of the temperature difference, the compressor needs more energy to operate. This behaviour is consistent with the findings of Mohanraj, M. et al.[9].

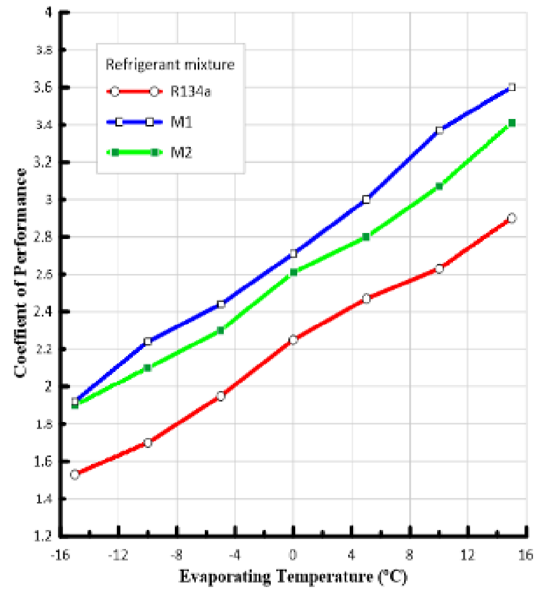

Figure 5. GWP for refrigerant mixtures

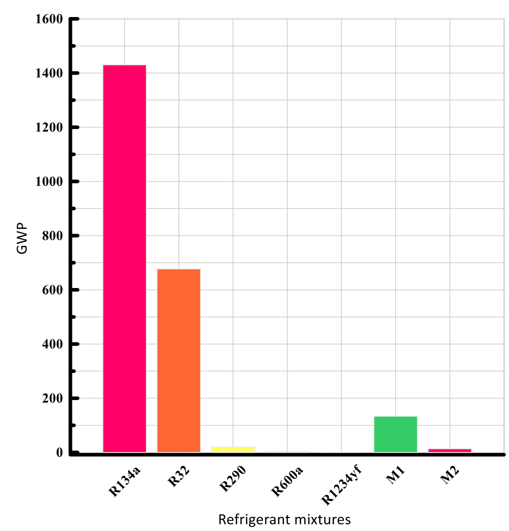

Figure 6. Coefficient of performance vs Evaporating temperature

A very important parameter is the amount of power used right now. Fig. 8 shows how much power R134a used and how many mass charges of HCM it had. It has been seen that the amount of power used goes up as the mass charge of the refrigerant goes up. This is mostly because the amount of refrigerant going through the compressor is getting bigger. The power consumption of M1 and M2 was found to be about 16 and 25 lower than that of R134a. When the temperature outside goes up, the condensing temperature and pressure go up, which makes the refrigerator use more power.

Fig. 9 represents the cost of using different mixtures compared to the basic charge R134a. The clear variation in cost is noted through the chart. The cost of M1 and M2 is higher than that of R134a by 90% and 78%, respectively. Still, the benefits are balanced through efficiency, as well as the difference is not considered relatively large if greater benefits are taken into account.

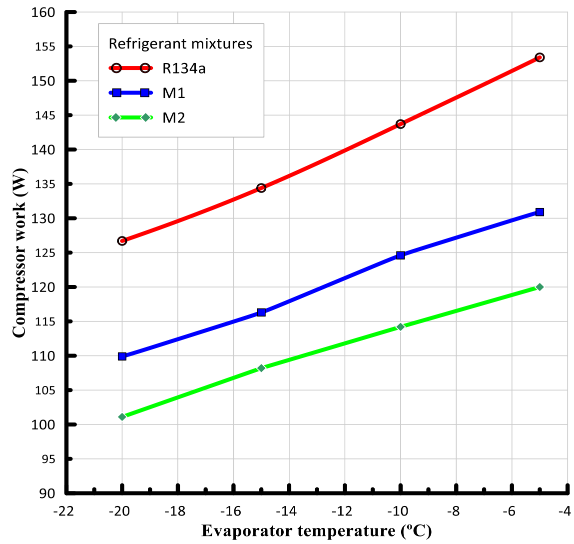

Figure 7. Compressor work vs. Evaporator temperature

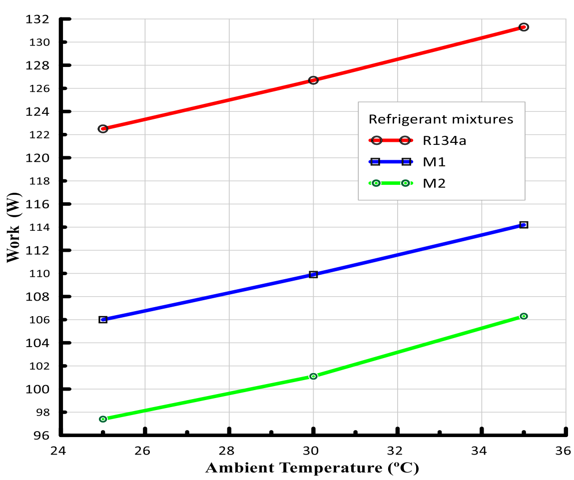

Figure 8. Work vs. Ambient temperature

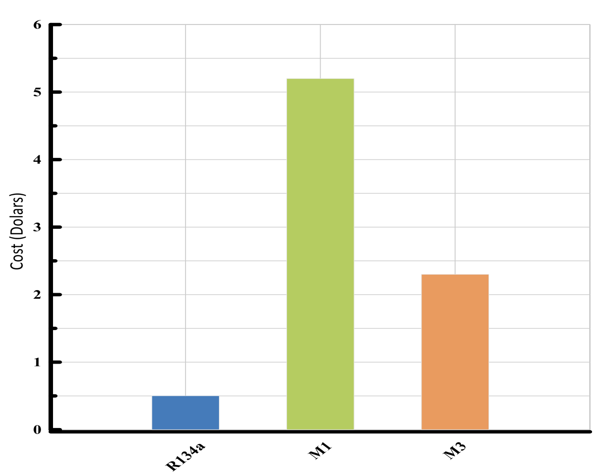

Figure 9. Costs for used mixtures

6. Conclusions

This paper conducts an experimental study between HFC134a and HFO1234yf, and a refrigerant mixture of HFC134a and HFO1234yf (10:90% weight) is introduced into a household refrigerator. When 10% HFC134a is added to HFO1234yf, the mixture is no longer flammable and has a much lower potential to warm the planet than R134a. In the second experimental mixture, R600a refrigerants and R290 refrigerants were mixed in a ratio of 60:40, respectively. The experimental research was carried out in a commercial refrigerator that had been specifically constructed to be compatible with HFC-134a, and the following conclusions can be drawn:

- The best charge of the refrigerant mixture M1 was 45 g, about 11% greater than that of HFC-134a.
- The pull-down time of the refrigerant mixture was reduced with respect to HFC134a.
- The GWP of a mix of hydrocarbons made up of 45% HC290 and 55% HC600a is almost nothing.
- The hydrocarbon mixtures (HCMs) yield desired performance characteristics, such as a higher COP of 6.4% for an evaporator temperature of -15 ºC.
- The HCM will also reduce the indirect effects of global warming because it will reduce the amount of electricity that goes into the compressor because it is more energy efficient.
- It was discovered that synthetic oil is miscible with HCM refrigerant and that this miscibility is excellent.
- Compared to HFC134a, the pull-down time was cut by about 20% in percentage terms.
- It was discovered that the daily energy consumption of 50 g of HCM mass charges was approximately 1.9 percent less than that of HFC134a.
- Researchers have found that HCMs have discharge temperatures that are about 18 degrees Celsius lower than HFC134a.
- It can be considered that M1 is the ideal drop-in refrigerant fluid for HFC-134a in existing plants after taking into account all of the factors that were discussed earlier in this paragraph.

Authors' contribution

All authors contributed equally to the preparation of this article.

Declaration of competing interest

The authors declare no conflicts of interest.

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