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Research Article

Theoretical exploration of low GWP refrigerant mixtures as replacement to HFC-134A in a vapour compression refrigeration system

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ABSTRACT

Hydro-fluorocarbons (HFCs) that are not harmful to ozone layer and are used in many applications, including as refrigerants, aerosols, solvents and blowing agents for insulating foams replace chlorofluorocarbons and hydro chlorofluorocarbons (HCFCs). However, some HFCs have a high GWP, which stands for "Global Warming Potential(GWP)." Because of the growing concern over global climate change, researchers are paying closer attention for alternatives to these HFCs. The main focus of this work was on the theoretical analysis of the refrigerant mixtures namely AC5, R430A, and R440A as direct replacements for HFC-134a in a refrigerator. The performance of the refrigerator may be enhanced using heat exchanger. The compressor discharge temperature, COP, VCC, refrigerant mass flow rate, power consumption of a compressor and pressure ratio were used to measure the performance of a home refrigerator. The typical COP of R440A and R430A was about 2.5% and 1.4% higher than that of HFC-134, while the average COP of AC5 was 6.1% lesser than that of HFC-134a. R430A almost has the same VCC (Volumetric Cooling Capacity) as HFC-134a. The results also show that HFC-134a uses more power than AC5, R440A, and R430A. R440A and AC5 have higher compressor outlet temperatures than HFC-134a, which affects the life span of the compressor. In comparison with all the above refrigerants, R430A gives the best overall performance and used as replacement to HFC-134a in a VCR.

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INTRODUCTION

The emission of ozone-depleting refrigerants is the primary mechanism by which air conditioning and refrigeration systems contribute to the destruction of stratospheric ozone. Their contributions to global warming are due to the release of refrigerants as well as the emission of greenhouse gases (GHGs) associated with energy use. When chlorine-containing refrigerants are released into the atmosphere, it has a damaging effect on the ozone layer. These substances are referred to as ODS refrigerants (ozone

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depleting substances). Because of this, the potentially harmful ultraviolet radiations are making their way to the surface of the earth. The second contributor to global warming is greenhouse gas emissions into the atmosphere, which began around one hundred years ago as a direct result of a rise in the amount of households using air conditioners and refrigerators. GWP is a measure that can be used to express the impact of these greenhouse gases (Global warming potential). Researchers who study climate change have coined the term "GWP," which stands for "global warming potential. "It is a measurement of the proportional amount of heat that is trapped by the greenhouse gases that are present in the environment. The global warming potential (GWP) of a gas is measured by comparing the total amount of heat that is retained by that gas to the total amount of heat that is retained by the same mass of carbon dioxide. The GWP of a given gas is typically computed over a predetermined period of time, most frequently 20 years, 100 years, or 500 years. It has been determined that R134a has a warming potential of 3,790 over a period of 20 years, and that this number drops to 1,550 over a period of 100 years. HFCs are being referred to as "Super greenhouse gases" because of the effect that is caused by the combination of high GWP and massive usage.

When the Du Pont De Company developed the Freon group of refrigerants, which were also known as chlorofluorocarbons, the refrigeration industry entered a new era (CFCs). This was a commercial success that has never been seen before. In a broad sense, a group of halocarbon products are all referred to collectively under the brand name Freon. It was around this time that the refrigeration industry started to prioritise particular characteristics of refrigerants, such as the fact that they should be liquids, be odorless and colorless, and have boiling points that are only slightly above room temperature. The hydrofluorocarbon (HFC) refrigerant R134a was intended to serve as a replacement for the traditional R12 in domestic refrigerators. Due to the fact that R134a refrigerants have fluorine in their molecular structure, it has only recently been found that these chemicals speed up the rate of global warming. As a result of its significant influence on the progression of environmental change, HFC134a has been categorized as a substance that is harmful to the ozone layer. The emission of these greenhouse gases has an unpredictable effect on the thermal balance of the earth, one of which is an increase in the temperature of the surrounding air. When compared with carbon dioxide, the GWP of HFC refrigerants is significantly higher. When considering the possibility of replacing halogenated refrigerants, it is widely believed that there is an immediate requirement to discover alternative refrigerants that have a low ODP and GWP.

On a heat pump, Kim et al. [1] conducted an experiment in which alternative refrigerant mixtures were used. These mixtures included R134a/R290, R134a, and HC-600a. It was determined that the systems using a combination of R134a and HC-290 had a COP that was lower than that of systems using either R22 or HC-290 combinations. In contrast to the other refrigerants, HFC-134a and HC-600a have a higher coefficient of performance (COP) value. In order to discover a suitable alternate to R12, Halimic et al. [2] conducted a performance test with R401a, R290, and HFC-134a individually. They found that out of all the different refrigerants they tested, HC-290 had the highest capacity for cooling, and its COP was comparable to that of R12. Although the R134a achieved test results that were comparable to those of the R12, the R290 has an advantage over the R134a due to its lower impact on the environment. Dalkilic et al. [3] performed a hypothetical examination of a refrigerator using a variety of elective refrigerants and refrigerant blends as a potential option for R12 and R22. The objective of this study was to find a replacement for the refrigerants R12 and R134a. They reached the conclusion, based on that hypothetical investigation, that R134a, HC1270, R152a, R32, HC290, HC600 and HC600a are all viable alternatives to the refrigerants listed above and could be used instead.

Mohan Raj et al. [4] conducted theoretical research on the possibility of utilizing hydrocarbon refrigerants in home refrigerators as a stand by refrigerant to HFC-134a. These hydrocarbon refrigerants include R152a, R600, R290, R1270, and R600a. As a performance parameter, a compressor's COP, power consumption, compressor pressure ratio and outlet temperature were all taken into consideration in this investigation. According to the findings, it was discovered that using pure HC refrigerants causes a mismatch in saturation properties, which may require a change in the compressor. As a result, these are not suitable to replace R134a because they are not compatible with it. Because the properties of saturation that the refrigerant R152 exhibits are the same as those that R134a exhibits, there is no need to replace the compressor.

Lee et al. [5] suggested that the combo of HFO1234yf/HFC134a can be used as different applications with some adjustments, where R134a is used as a refrigerant. This was in reference to the fact that the combination can be used in different applications. As a result of their findings, they concluded that the mixture of HFO1234yf and HFC134a has a comparable compressor outlet pressure COP, and refrigeration effect as R134a. Meng et al. [6] conducted a thermodynamic investigation of a refrigerator with various refrigerant mixtures namely R1234ze (E) and a combination of R1234ze (E) & R152a in different proportions and R152a without any modification in the system. The mixtures were tested in the refrigerator. Following that investigation, they came to the conclusion that R152a and R152a combined with R1234ze (E) in a ratio of 50:50 produced the best results in their work. In a VCR system, Sánchez et al. [7] conducted an investigation using refrigerants like HFO refrigerants R1234ze (E),R1234yf HC refrigerants like 290 and 600a, HFC-152a. In the course of those experiments, they came to the conclusion that the direct substitute refrigerants are HFO-1234yf and HFC-152a. An investigation into R450A's use in experiments was directed by Makhnatch et al. [8]. R450a is a standby refrigerant that is made up of R1234ze (E) and R134a in the percentage of 58:42 by mass. It is used in place of HFC-134a134a. It was observed that the cooling effect and the COP of these mixtures shows a decremental value in comparison with HFC-134a by approximately 10% and 3%.

An experiment was carried out by Rastil et al. [9] in which HFC-134a was substituted with the refrigerants R600a and R436a in a home refrigerator. These refrigerants, respectively, are composed of 46% and 50% isobutane and propane. After conducting that experiment, the researchers came to the conclusion that the power consumption of different refrigerant compressors at different charges had decreased by approximately 15% and 8%, respectively. M.M. Joyba et al. [10] performed a second law analysis of HC-600a as a substitute for HFC-134a to calculate the peak load. They found that the peak load for HC-600a was 0.050kg, which was 65% lower than the load required for HFC-134a. In order to find substitutes for HFC-134a, Bilen et al. [11] conducted research on the theoretical examination of an AAC (Automobile air conditioning) system that utilized R152a, R22, and R12. According to the results that they reported, there is not a significant difference in performance between using R152a and using R134a.

Meng et al. [12] directed an investigation into the AAC system using refrigerants such as HFC-134a and a blend of HFC-134a and HFO-1234yf with a mass ratio of 11:89. Their work stated that the new refrigerant mixture has a COP that is approximately 5-15% lower in the heating mode and that it is 5-10% lower in the cooling mode. In a home refrigerator, Aprea et al. [13] conducted an experiment to compare the performance of HFC-134a, HFO-1234yf, and a combination of HFO1234yf and HFC134a at a weight ratio of 90% to 10%. In light of these findings, the researchers came to the conclusion that HFO-1234yf shows a reduction time and electricity consumption are reduced by approximately (-14%, -9%) and (7.5%, 10%) respectively in comparison to the HFC-134a. In addition, they arrived at the conclusion that the refrigerant blend HFO1234yf/ HFC134a (90/10% by weight) is a superior option to HFC-134a in a household refrigerator. In a system for air conditioning, the researchers Golzari et al. [14] came to the conclusion that R1234yf demonstrates a higher exergetic efficiency compared to HFC-134a. This was determined through comparative research. Hasheer et.al [15] led an investigation on different mixtures of refrigerants that could replace R-134 in refrigerator and concluded that R152A/HFO-1234ze (E) could be used as a direct replacement for HFC-134a.

Agrawal et al. [16] explored the theoretical behaviour of various refrigerants in a mechanically Subcooled VCR System as a substitute to R134a, and their results depict that the COP and exergetic efficiency of subcooled VCR cycles are superior in comparison to simple VCR cycles. Thermodynamic Performance Analysis was carried out by Shaik Mohammad Hasheer et al [17] on a refrigerator by making use of different refrigerants as a replacement for R134a. After conducting that investigation, they came to the conclusion that R1234yf is a superior alternative to HFC-134a. Agrawal et al. [18] investigated the First and second law analysis of a domestic refrigerator that uses R1234yf and R1234ze refrigerants as a replacement to R134a. The global warming potential of HFO-1234ze (E) has decreased, and it has a higher COP, so it is suitable to use in chillers [19-20] and heat pumps [21]. Mixtures of HFOs and HFCs have the potential to serve as an effective replacement for HFC-134a. It would appear that HFO-1234yf and 1234ze (E), [22], are potential replacements for HFC-134a. In some mobile air conditioning applications, HFO-1234yf has been used instead of HFC-134a as a standby for HFC-134a [23]. In recent years, a number of researchers have been working on various refrigerants, such as R290, R744, R410A, and R513A, in an effort to find a replacement for R134a in domestic refrigerators [24-26].

According to a review of the existing papers, a significant amount of investigation has been placed into the search for suitable alternative refrigerants from each of the different groups. However, the previous researchers have not yet attempted to combine two or more different types of refrigerants, specifically those belonging to the HC, HFC, and HFO groups. Additionally, the performance evaluation of the heat exchanger was not carried out to a significant degree. In this research article, an attempt is made to overcome the drawbacks of earlier works done by researchers by examining those works and comparing them to this one.

Impact of Alternative Refrigerant Mixtures and its Impact on Environment

Pure hydrofluorocarbons and hydrofluoroolefins are the two types of coolants that have less GWP. The chemistry world is not new to hydrofluoroolefins. They are made up of hydrogen, fluorine, and carbon, just like regular Hydrofluorocarbons (HFCs). The only disparity is that one has at least one double bond and the other does not. These type of molecules are known as olefins or alkenes, so it is worth to call them HFC, HFA, and HFO. Most people call carbon-carbon double-bond refrigerants by the name that comes next. Hydrofluoroolefins can be put into three groups: HFO-1225, HFO-1234, and HFO-1243. Because R1243 isomer is flammable, it is not used, and HFO-1225 isomer has not been made because it is dangerous. So, in a home refrigeration system, HFO-1234ze (E) and 1234yf can be thought of as possible alternatives. From the HFC group, the different refrigerants are HFC 134a, HFC 32, HFC 426A, 428A, 434A, 442A, and HFC-152a. All of the HFC refrigerants except for HFC-152a have a very high GWP value. The natural refrigerants R290 and R600a are made of HC, which stands for hydrocarbons. The GWP value of these refrigerants is zero, and they are very good at cooling and working well.

The GWP value of the alternative refrigerants needs to be lower, and they also need to protect the ozone layer. The low GWP mixtures of refrigerants are R440A (0.6:1.6:97.8

by mass of R290, R134a, and R152a), R430A (76:24 by mass of R152a and R600a), and AC5 (R32:5:83 by mass of R152a, R1234ze (E), and R32) as possible replacements for HFC-134a. Using equation (1), the GWP of the above mixtures of refrigerants was found [5].

$$\mathbf{GWP_m = GWP_k \times W_k + GWP_\mathit{l}\, X \times W_\mathit{l} + GWP_m \times W_m} \quad (1)$$

Where GWP_k= GWP value of refrigerants k,
GWP_l= GWP value of refrigerant l,
GWP_m= GWP value of refrigerant m, Wk, Wl and Wm are to be k, l and m refrigerants mass fraction

Thermodynamic investigation of a Refrigerant Blends

Theoretical modeling is one of the most widely accepted practices to study the household refrigerator performance. This research deals with the performance of a domestic refrigerator operating on VCR system with the conventional refrigerant R134a and with different mentioned alternative refrigerants. The entire analysis is carried out by providing different the condenser and evaporator temperatures and also with the use of heat exchanger as shown in Figure 1.

Calculations

Some assumptions are taken for the calculation of thermodynamic cycle analysis in the vapor compression system, and these are based on the literature [6]. Table 2 depicts the operating conditions for the thermodynamic analysis. Based on these values results are plotted and are depicted in Figure 3 to 8. In this Analysis the compressor receives the refrigerant in the superheated vapor condition. In the compressor the refrigerant is compressed to a higher pressure and from there it passes through the condenser. The pressure losses take place in the condenser, at the end of the condenser the refrigerant in liquid state. From the condenser the refrigerant passes to expansion valve where the pressure is dropped and then passed through evaporator.

These pressure losses in the both condenser and evaporator are clearly shown in Figure 2. To figure out the thermodynamic properties at different states REFPROP software is used. For replacement of various refrigerants as a direct substitute to R134a in a domestic refrigerator, the Performance characteristics such as power consumption,

Table 1. Properties of the Refrigerant Mixtures

Properties	Refrigerants			
	R134a	**AC5**	**R440A**	**R430A**
Composition	-----	R32 (12%) R152a (5%) R1234ze (E) (83%)	R290 (0.6%) R134a (1.6%) R152a (97.8%)	R152a (76%) R600a (24%)
Molar mass (kg/kmol)	102	96.7	66.22	63.97
Critical temperature (^{0}C)	101.01	103.19	112.65	106.97
Boiling point, BP (^{0}C)	- 26.1	-34.3 to -23.3	- 25.4	-27.6
Liquid density at 35^{0}C (kg/m^3)	1207.6	1101.1	897.62	759.78
Vapor densityat 298K (kg/m^3)	32.35	28.92	18.68	19.69
ODP	0	0	0	0
GWP	1430	92	150	104

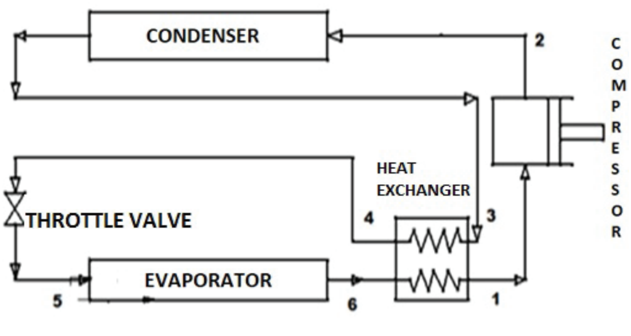

Figure 1. Refrigerator with Heat Exchanger.

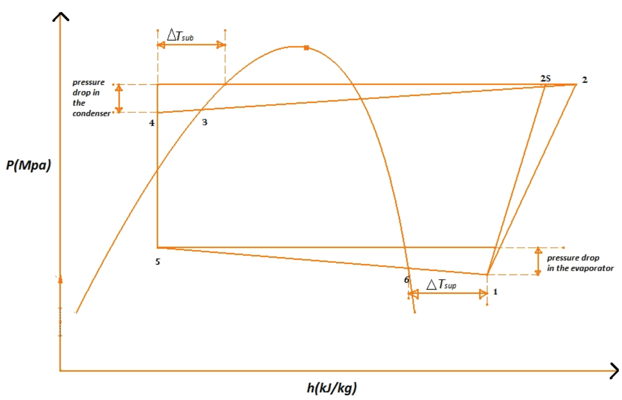

Figure 2. P-h diagram of a Refrigerator.

Table 2. Operating conditions for the thermodynamic analysis

Condensing temperatures	40^0C and 50^0C
Evaporating temperatures	-20^0C to 10^0C
Evaporator pressure loss	0.03MPa
Condenser Pressure loss	0.02MPa
Isentropic efficiency of a compressor	0.70
Volumetric efficiency	0.75
Compressor displacement volume	8.16 cm^3/rev
Speed of the Reciprocating compressor	30 rev/sec
Heat exchanger efficiency	0.6.
Sub cooling temperature(ΔTsub)	5K
Superheating temperature(ΔTsup)	5K

COP, VCC, Compressor discharge temperature and Pressure ratio are evaluated.

The domestic refrigerator pressure ratio can be expressed as:

$$Pressure\ ratio = P_{cond} / P_{evap\_act} \tag{2}$$

The formula for energy consumption is given by:

$$W_{compressor} = h_2 - h_1 \tag{3}$$

Where

$$h_2 = h_1 + (h_{2s} - h_1) / \eta_{is} \tag{4}$$

The formulae for refrigeration effect is given by,

$$Cooling\ capacity = h_6 - h_5 \tag{5}$$

The coefficient of performance (COP) of the refrigerator can be stated as:

$$COP = Cooling\ capacity\ /work\ done\ by\ the\ compressor \tag{6}$$

VCC is given as:

$$Q_{vol} = (h_6 - h_5) \times \eta_{vol} / v_1 \tag{7}$$

Where v_1 be the specific volume at entry to the compressor.

Mass flow rate of a refrigerant (m_r) is given by

$$m_r = RPM \times V_{sv} \times \rho_1 \times \eta_{vol}/60 \tag{8}$$

Where
V_{sv}= Displacement of the compressor
$\rho_{1\,=}$ density of the refrigerant at compressor inlet.

RESULTS AND DISCUSSION

Deviation of Mass Flow Rate of Selected Refrigerants

Figure 3. depicts the alteration of mass flow rate versus temperature of the evaporator.At the same evaporator temperatures, the mass flow rate of AC5 is about 8.59% less than that of HFC-134a. Due to their low Vapour density, the mass flow rates of R440a and R430a are around 30.18 and 25.75 percent lower than those of HFC-134a at an evaporator temperature range of -20^0C to 10^0C. Because of this, we can expect the above refrigerants to use less power than R134a.

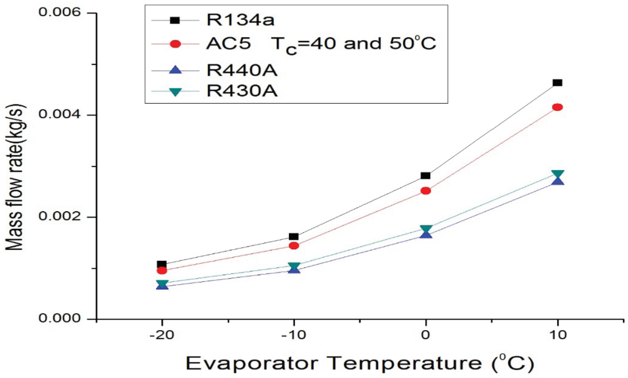

Figure 3. Refrigerant Mass flow rate (kg/s) vs. Evaporator temperature (^{0}C).

Deviation Of Pressure Ratio W.R.T Change in Evaporator Temperature

Figure 4 depicts the Alteration of pressure ratios Vs evaporator temperature. Pressure ratio is the ratio of a compressor's outlet pressure to its intake pressure. It goes down when the temperature of the evaporator goes up and up when the temperature of the condenser goes up. At certain condenser temperatures, the results show that AC5 has a better pressure ratio than R134a by about 1.15 percent. However, the pressure ratio of R440A and R430A refrigerant mixtures is about 1.19 and 5.78 percent lower than that of HFC-134a. Pressure ratio affects how well a compressor uses its volume. Compared to HFC-134a, the pressure ratio of the mixtures of R440A and R430A is lower. So we can expect these refrigerants to have a good volumetric efficiency.

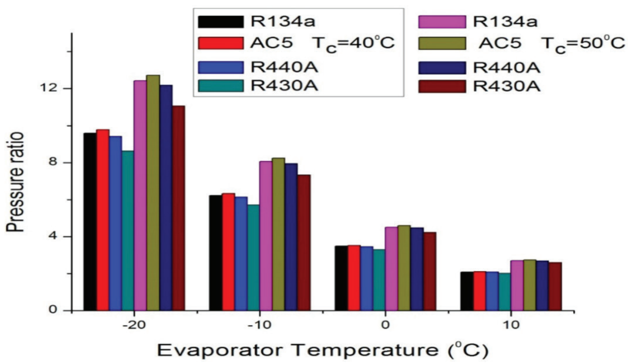

Figure 4. Pressure ratio vs. Evaporator temperature (^{0}C).

Deviation of Volumetric Cooling Capacity with Respect to Change in Evaporator Temperature

Figure 5 depicts the deviation of volumetric cooling capacity in comparison to the evaporator temperature. It has been found that AC5 refrigerant has a lower volumetric cooling capacity than R134a by 9.91%, 10.10%, and 10.35%, respectively, at the condenser temperatures of 40°C and 50°C. R440A has a lower VCC by 6.4%, 5.1%, and 3.4% than R134a. At the mentioned condenser temperatures, the VCC of R430a is lower than that of R134a by 1.12%, 0.4%, and 0.4%, respectively, within the range of -200C to 100C for the evaporator temperature. When it comes to alternative refrigerants, the volumetric cooling capacity is a key factor that affects the dimension of the compressor. The volumetric cooling ability of alternatives to the original refrigerant should be between -8% and 8% of that of the original. Due to its low VCC value, AC5 refrigerant is not at all a good direct replacement for R134a. Because the VCC value is between -8% and 8%, R440A and R430A are better alternatives to HFC-134a that don't require changes to the compressor.

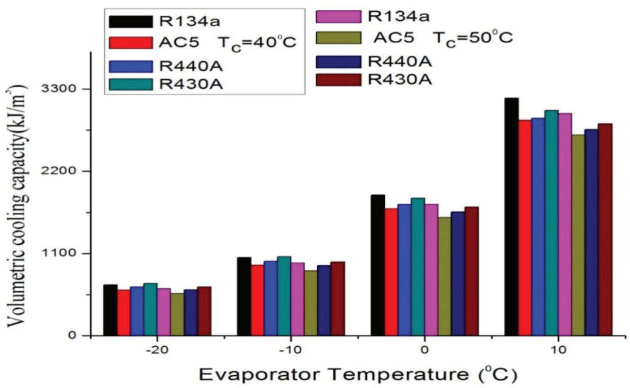

Figure 5. VCC vs. Evaporator temperature.

Change in Compressor Power with Respect to Change in Evaporator Temperature

Figure 6 depicts the variation of consumption compressor power versus evaporator temperature. At condenser temperatures of 40°C and 50°C, the power consumption of alternative refrigerants R440a, AC5, and R430a is about 7.6%, 4.1%, and 1.4% less than that of HFC-134a whereas compressor power usage goes up with the evaporator temperature because the mass flow rate goes up. It also goes up with the condenser temperature because the enthalpy variance between the compressor inlet and outlet goes up.

Change of COP with Respect to Change in Evaporator Temperature

Figure 7 signifies the deviance of COP of refrigerant mixtures versus evaporator temperature. At 40⁰C condenser temperature, the COP of a mentioned refrigerant

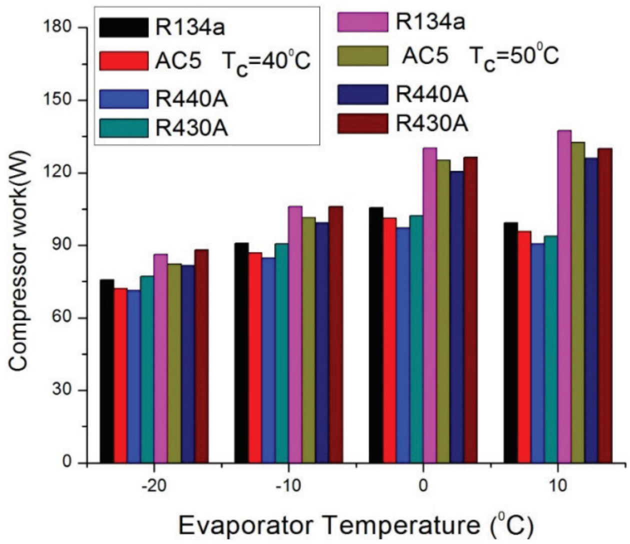

Figure 6. Compressor work (W) vs. Evaporator temperature (^{0}C).

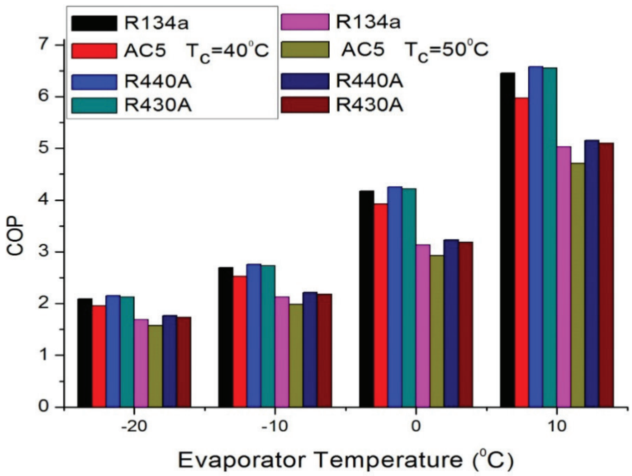

Figure 7. COP vs. Evaporator temperature (^{0}C).

mixtures R440A, R430A shows a greater value than that of HFC-134a by approximately 1.37%, 2.7%.

At a condenser temperature of 500C, R440A, R430A refrigerants shows a higher value than that of R134a by around 2.5%, 3.2% respectively. This is because a refrigerator compressor uses less electricity. AC5 shows a lower COP value as related with HFC-134a by approximately 6.58%, 5.6% at a 400C and 500C of condenser temperature.

Changes in the Discharge Temperature of The Compressor Based on Changes in the Temperature of the Evaporator

Figure 8 depicts the alteration of compressor's outlet and evaporator temperatures. The compressor discharge

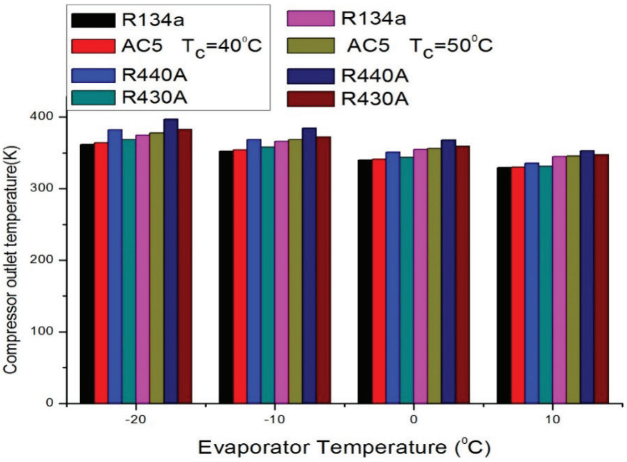

Figure 8. Alteration of Compressor outlet temperature (K) VS Evaporator temperature (^{0}C).

temperature is significant as it affects the stability of compressor parts. One can figure out the compressor discharge temperature by using both the condenser pressure and the actual specific enthalpy at the compressor outlet. At condenser temperatures of 40^{0}C and 50^{0}C, it was found that the compressor's outlet temperature was higher with AC5, R440A, and R430A than with HFC-134a by about 6–10^{0}C, 3–7^{0}C, and 2–6^{0}C. The compressor's lubricating oil and motor coil are affected by how hot the outlet is. So, it's important to be careful when using this refrigerant in a VCR.

At condenser temperatures of 40^{0}C and 50^{0}C, it was found that the compressor's outlet temperature was higher with AC5, R440A, and R430A than with HFC-134a by about 6–10^{0}C, 3–7^{0}C, and 2–6^{0}C. The compressor's lubricating oil and motor coil are affected by how hot the outlet is. So, you have to be careful when using this refrigerant in a fridge.

Mota-Babiloni et al. [27] conducted an investigation on R450a (a blend of 52% R1234ze (E) and 48% R134a) and found that its average cooling capacity and coefficient of performance (COP) are 6% and 1% higher than those of R134a. According to Bukola Olalekan Bolaji et al. [28], the mean values of R430A and R440A are 8.75 and 7.24% higher than that of R134a, respectively, while the value of R450A is lower by 4.77% compared to R134a. Current work was prompted by the discovery that R430A's VCC (volumetric cooling capacity) is very close to that of HFC-134a. R430a has a higher COP than HFC-134a by a margin of about 2%-4%. R430A's effectiveness stems from the same factors that make the above refrigerants effective. Mota-Babiloni et al. conducted an experimental analysis of R450a's efficiency. This article has the potential to persuade readers due to the comparison of the theoretical performance of R430A to the experimental performance of R450a.

CONCLUSION

In this study, thermodynamic analysis was done on a number of low GWP refrigerants. The goal was to find a replacement for HFC-134a that could be used in home refrigerators. The research led to the following conclusions, which are summed up below:

The AC5 refrigerant has a volumetric cooling capacity that is about 9.1% lower than that of HFC-134a. The value must be between -8% and 8% for a direct replacement. So, it can't be used as a direct replacement in a home refrigerator.

- At different condenser temperatures, R430A has a VCC that is 1.12%, 0.41%, and 0.44% lower than R134a.
- At different condenser temperatures, the COP of R440A and R430A is about 1.3–2.5%, 2.5–3.4% higher than that of HFC-134a. But R440A shows that the compressor output temperature is high, which changes the way a lubricating oil for a refrigerator compressor works.
- Alternative refrigerants like R440a, AC5, and R430a use less electricity than HFC-134a by about 7.6%, 4.1%, and 1.4%, respectively.
- R440A and R430A had good results for power consumption, volumetric cooling capacity (VCC), coefficient of performance (COP), and pressure ratio.

Based on the work R430A refrigerant is the preeminent choice for replacing R134a in a home refrigerator without any changes to the system. The refrigerant (R440A) is the succeeding best choice for replacing R134a in a home refrigerator. But it can't be used when the condenser temperature is very high without taking some safety precautions. But in contrast to refrigerant R134a, the mixture of refrigerants called AC5 needs a bigger compressor, so it can't be used in a home refrigerator.

NOMENCLATURE

COP	Coefficient of performance
GWP	Global warming potential
LSHX	Heat exchanger
VCC	Volumetric cooling capacity
HCFC	Hydro chlorofluorocarbon
HFO	Hydrofluoroolefins
HC	Hydrocarbons
RPM	Revolution per minute

Subscripts

m, 1, k	Refrigerants
Comp/comp/	compressor
is	isentropic
r	refrigerant
vol	Volumetric
evap_act	actual evaporator
Cond	Condenser
K	Kelvin
(ΔT_{sub})	Sub cooling temperature
(ΔT_{sup})	Superheating temperature

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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