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An Experimental Study on Eco-Friendly Refrigerants as a Sustainable Alternative to Traditional Refrigerants

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Abstract

R134a, also known as 1,1,1,2-tetrafluoroethane, has found extensive use in both domestic and commercial vapor compression refrigeration systems. The focus of present article is to explore potential replacements for R134a within vapor compression refrigeration systems. The replacement strategy involves an in-depth analysis of an ice plant that currently utilizes R134a as its refrigerant. As an alternative to R134a, a carefully proportioned mixture in a mass ratio of 0.1:0.4:0.5 for C1 and 0.1:0.5:0.4 for C2 after trial experiments were prepared with three refrigerants R32, R152a, and R245a to test for variations in density, enthalpy, entropy, global warming potential (GWP) and ozone depletion potential (ODP). Notably, the mixtures C1 and C2 were found to have GWP of 902 and 791 while a zero ODP value respectively as compared to GWP and ODP of 1296 and zero respectively of R134a. The mixture C2 has shown a significant reduction in density while enthalpy was seen increased for mixture C2 as compared to R134a. Coefficient of performance (COP) of C2 is increased by around 11% to 6.54 as compared to COP of R134a. The proportioned mixtures have been prepared to test the impact of different refrigerants on environment by measuring the parameters GWP and ODP. It is always an essential criterion to check the impact of refrigerants on environment before implementing it into the product. Moreover, the technical parameters like density, enthalpy, entropy and COP measurements are performed to analyze the advantages of prepared mixtures over the existing refrigerant. Due to comparatively lower GWP, higher COP and better heat extraction, C2 is recommended as the preferred replacement choice between the two options, C1 and C2.

Key words: Refrigerant, Density, Enthalpy, Entropy, Global warming potential

1. Introduction

Refrigeration is a crucial technology that plays a significant role in modern life, impacting various industries, households, and the global economy. It is the process of cooling or maintaining low temperatures in a controlled environment, typically used to preserve perishable goods, create comfortable living conditions, and support various industrial processes. Refrigeration systems operate based on the principles of heat transfer.

Various international regulations, such as the Montreal Protocol and the Kigali Amendment, set guidelines for phasing out harmful refrigerants and promoting the use of environmentally friendly alternatives. Additionally, energy efficiency standards and labeling programs help consumers make informed choices when purchasing refrigeration appliances. The refrigeration industry continues to evolve, driven by a growing emphasis on sustainability and energy efficiency. Innovations in refrigeration technologies, including magnetic cooling and solid-state refrigeration, show promise in revolutionizing the field. Refrigeration assumes a pivotal part in different parts of our regular routines, like food conservation and guaranteeing open to living and working circumstances. As worldwide worries about the climate and energy productivity develop, the refrigeration business is supposed to adjust to these difficulties. Babarinde and associates led research on R600a, a harmless to the ecosystem refrigerant, improved with TiO2, Al2O3, and SiO2 nanolubricants. They evaluated its reasonableness as a swap for R134a in a fume pressure fridge framework by observing the cooler's power utilization with a computerized wattmeter. The discoveries demonstrated that utilizing R600a with TiO2, Al2O3, and SiO2 nanolubricants brought about lower evaporator temperatures and quicker pull-down times contrasted with R134a and unadulterated R600a [1]. T. O. Babarinde and group investigated upgrading melted petrol gas (LPG), explicitly a propane and butane blend (60:40), with graphene nanolubricant (GN) in a family cooler framework. They fostered a computerized reasoning model consolidating Counterfeit Brain Organization (ANN) and Versatile Neuro-Fluffy Deduction Framework (ANFIS) to foresee and approve the LPG's presentation with graphene nanolubricant. This study utilized graphene nanolubricant in LPG refrigerant charges going from 50 to 70 grams. The outcomes exhibited better Coefficient of Execution (COP) with fluctuating centralizations of graphene nanolubricant [2]. The consideration of graphene nanolubricant prompted power utilization decreases and expanded cooling limit by 16.3% to 20.1% and 6.4% to 19.6%, separately. Scientists overall have investigated how refrigerant blends can upgrade COP, ozone consumption potential (ODP), and a worldwide temperature alteration potential (GWP), subsequently making refrigeration frameworks more productive and harmless to the ecosystem [3-8]. Zafar et al. featured that nanorefrigerants have improved framework efficiency, influencing thermophysical properties and COP. As nanoparticle focus rises, warm conductivity, thickness, and consistency increment while explicit intensity limit diminishes. Notwithstanding, unreasonable nanoparticle focus can decrease explicit intensity limit, possibly influencing cooling limit. This equilibrium highlights the significance of ideal nanoparticle fixation for ideal execution [9]. In spite of these contemplations, nanorefrigerants and nanolubricant-refrigerants have shown superior COP because of improved warm conductivity of nanoparticles [10]. Nanolubricant-refrigerants in light of R152a and Polyester (POE) grease are especially encouraging for refrigeration, offering superior execution and ecological advantages that outperform R134a concerning effectiveness and energy utilization.

The motivation present study is derived by the impact of prepared refrigerant mixtures to analyze their impact on environment along with the enhancement in COP, heat extraction and a lesser density to minimize the size of compressor. This study addresses the study of mixtures of different refrigerants in various proportions to carry out the experiments. The experimental studies on different refrigerant mixtures include the performance evaluation of enthalpy, entropy, density, ozone depletion potential and global warming potential when compared to conventional R-134a. The results reveal that the mixtures composition 1 (C1) composition 2 (C2) performed better than R-134a. Coefficient of performance (COP) was also enhanced for C1 and C2 when compared to R-134a. The study focuses on environmental impacts of the refrigerants which is an essential part to achieve better living conditions for mankind and utilize the technology available in a sincere way.

2. Methodology

2.1. Criterion for refrigerant selection

Selection of refrigerant for a selected application is broadly predicated on the subsequent necessities: thermo dynamic and thermo-physical properties, environmental and safety properties, economics.

Table 1 Pressure (Bar) and temperature (^{0}C) reading of ice candy plant

Pressure (P_1) (bar)	Pressure (P_2) (bar)	Temperature (T_1) (^{0}C)	Temperature (T_2) (^{0}C)	Temperature (T_3) (^{0}C)	Temperature (T_4) (^{0}C)
2	11.9	20.10	79.80	29.90	-11.20

Where, P1 = Suction Pressure of Compressor (Bar), P2 = Discharge Pressure of Compressor (bar), T1 = Suction Temp of Compressor (^{0}C), T2 = Discharge Temp of Compressor (^{0}C), T3 = Temp of Condenser exit (^{0}C), T4 = Temp (^{0}C) after Expansion valve.

2.2. Refrigerant property and its mix preparation

Table 2 Refrigerant Properties

Refrigerants	Mol. Wt.	Critical temp (°C)	GWP	ODP
R134a	102	101.06	1296	0
R32	52.02	78.11	650	0
R152a	66.05	113.26	120	0
R245a	135	174.42	950	0

Table 3 Refrigerants to prepare C1 and C2 compositions

Refrigerant	R32	R152a	R245a	Mol wt	GWP
C1	10%	40%	50%	96.6	902
C2	10%	50%	40%	92.8	791

From Table 3 it can be concluded that composition R32, R152 and R245a in a ratio of 10%, 40% and 50% by mass for mixture C1 while 10%, 45% and 40% for mixture C2 can be taken as possible replacement of R134a in vapour compression refrigeration cycle. Below table shows the composition and have been named as C1 and C2 respectively. Performance of both the mixtures C1 and C2 were analyzed along with the properties of R134a on the basis of density, enthalpy, entropy, molecular weight and global warming potential.

3. Results & Discussion

3.1. Density, enthalpy and entropy v/s Temperature results with Pressure constant for R134a, C1 and C2

A density vs. temperature plot (see figure 1a) provides valuable insights into the behavior of refrigerants under various temperature and pressure conditions, helping engineers and technicians design and analyze refrigeration systems.

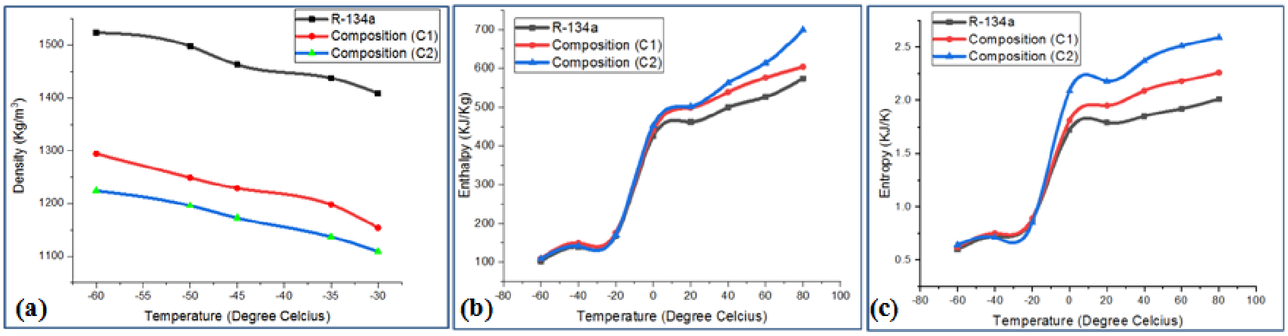

Figure 1 (a) Density v/s Temperature (b) Enthalpy v/s Temperature (c) Entropy v/s Temperature for R-134a, Composition (C1) and Composition (C2)

At the point when thickness is high, the particular volume is low, showing that a more modest blower size is required for a given mass of stockpiling. Figure 1a represents a diagram plotting thickness against temperature, contrasting R134a, C1, and C2. It's apparent from the diagram that R134a has the most elevated thickness, C2 has the least, and C1 falls somewhere in the range of C2 and R134a. Subsequently, R134a would require a more modest blower size for a given mass of stockpiling.

The enthalpy of a refrigerant is a critical mark of its intensity extraction or retention limit. A higher enthalpy implies the refrigerant can remove or ingest more intensity. Figure 1b shows a diagram of enthalpy versus temperature for R134a, C1, and C2, in light of information from REFPROP at explicit strain and temperature readings. C2 has the most elevated enthalpy, R134a has the least, and C1 in the middle somewhere in the range of R134a and C2. Therefore, C2 requires less refrigerant mass contrasted with C1 and R134a.

The entropy versus temperature chart in Figure 1c, likewise got from REFPROP information, uncovers that C2 has the most elevated entropy among C1, R134a, and C2.

3.2. COP results of R134a, C1 and C2

The calculation of the theoretical Coefficient of Performance (C.O.P) is conducted through either the utilization of a pressure-enthalpy chart or the application of REFPROP software, utilizing the pressure and temperature conditions obtained from the recorded readings. The results revealed a COP of 5.86 for R134a while 6.32 and 6.54 for C1 and C2 respectively. A higher COP indicated an enhanced performance of the refrigeration system.

3.3. Environmental characteristics and molecular weight of R134a, C1 and C2

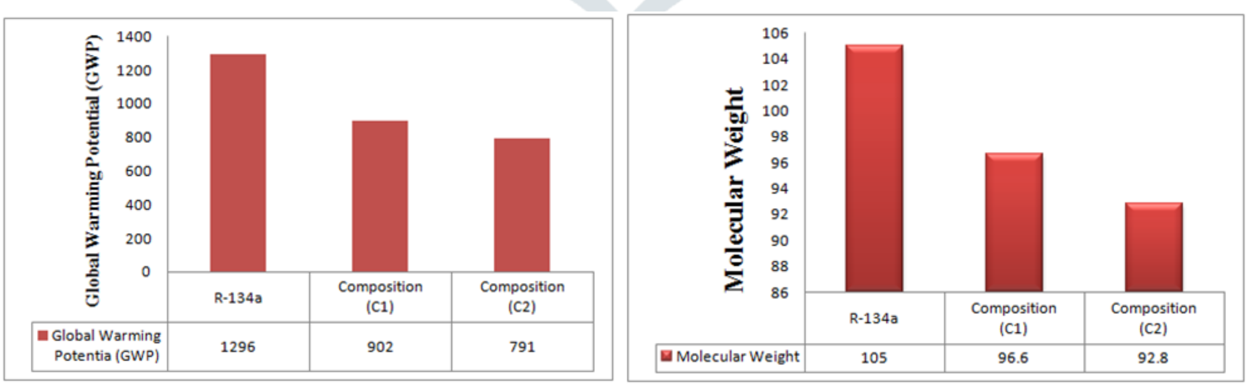

Figure 2 Global warming potential (GWP) and molecular weight of R134a, C1 and C2

R134a, with a significantly high global warming potential of approximately 1296 necessitates a phase-out strategy. To identify a potential replacement for R134a, the approach involves evaluating the performance of existing refrigeration systems operating with R134a and comparing it with an environmentally friendly refrigerant. Data for pressure and temperature readings were collected from an ice plant utilizing a vapor compression refrigeration cycle with R134a. The results as shown in figure 2 reveal that the global warming potential (GWP) of refrigerant C1 is 791 which is effectively lesser than the GWP of R134a and C1. Hence refrigerant C2 will have minimum impact on global warming as compared to other two refrigerants. Furthermore, when molecular weights of 3 different refrigerants taken into study were compared, C2 was found to have a minimum molecular weight of 92.8 as compared to 105 and 96.6 of R134a and C1 respectively. Moreover, ozone depletion potential (ODP) of all the refrigerants tested was zero.

Refrigerant mixtures C1 and C2 may be used against R134a since both the mixtures have higher COP than R134a, Moreover, GWP was found to be lesser for both C1 and C2 as compared to R134a. It was also observed that all the refrigerants have zero ODP.

4. Concluding remarks

In conclusion, the interplay of factors such as density, enthalpy and entropy with respect to temperature, enhanced GWP and reduced molecular weight highlights the intricate relationship between these thermodynamic properties and their implications for various applications. Following are the conclusions drawn from the experimental investigation performed:

1. The density-temperature plot revealed that R134a has the highest density, while C2 has the lowest, and C1 falls between C2 and R134a. Therefore, C1 would require a smaller compressor size for a given mass of storage.
2. Looking at the enthalpy-temperature graph for R134a, C1, and C2, it's clear that C2 has the highest enthalpy, R134a has the lowest, and C1 is in between them. This means that C2 requires less refrigerant mass compared to C1 and R134a.
3. Analyzing the entropy-temperature graph for R134a, C1, and C2 shows that C2 has the highest entropy among them.
4. A refrigerant with a lower molecular weight will have a higher latent heat of vaporization. Additionally, a higher molecular weight results in a lower specific volume, meaning less refrigerant is needed to achieve the desired refrigeration effect.
5. All the refrigerant compositions prepared and R134a have zero ozone depleting potential.
6. Comparison of global warming potential (GWP) of R134a, C1 and C2 shows a higher value of GWP for R-134a and a decreasing value for C1 and C2 respectively.

It was observed from study, that along with efficiency, environmental characteristics are also an essential part of refrigerant selection. A more efficient refrigerant cannot be selected by ignoring its hazardous impacts on the environment thus it becomes necessary to check the global warming potential and ozone depletion potential of the refrigerants.

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