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# PERFORMANCE EVALUATION OF REFRIGERANTS: R717, R290, R134A, R22 AND R712

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**Abstract:**

The main focus of the research is analysis of the function of the refrigerants such as R717 (ammonia), R290 (propane), R134a (1,1,1,2- tetrafluoroethane), and R22 (dichlorodifluoromethane). The paper has analyzed and compared the efficiency factors, energy efficiency ratios, thermodynamic properties, and environmental effects. After lots of research, it has been ascertained that R134a has no implication on the depletion of the ozone layer. Furthermore, the high GWP was expressed to attract specific concerns about the ecological significance of this substance. The cause of disappearance of R22 is due to its features such as ODP leading to its elimination from use. Thus, besides having a zero GWP and being even more efficient than R744, R717 had to meet high requirements on safety due to toxicity and flammability factors. On the other hand, R290 while being very efficient as a ''natural'' although flammable refrigerant has now been considered as an optimal choice while exercising certain handling precaution since GWP is low . Altogether, the research has elucidated why the choice of refrigerants or their characteristics should meet specific application requirements and conditions or environmental factors. Last but not the least it has helped to promote a shift towards ecological refrigerants and air conditioning systems.

Keywords- Performance Evaluation of Refrigerants, R717, R290, R134a, R22 and R712.

- GWP- Global Warming Potential
- Qc-heat absorption
- Qe-heat rejected

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- W- Energy input
- COP-Coefficient of Performance
- EER-Energy efficiency ratio
- ODP-Ozone Depletion Potential

## 1. Introduction:

Refrigerants like R134a, R22, R717, R290 and R712 in cooling systems of many different applications. When home refrigerators and automobile air conditioners are considered, they use R134a—a stable as well as innocuous HFC. Numerous concerns have emerged in terms of its high amount of potential to contribute to global warming. Since, R22 is an HCFC that depletes the ozone layer, global agreements including the Montreal Protocol forbid it. Effective though it is, natural refrigerant R717 is also flammable and poisonous, requiring precise handling techniques. Even though combustible, R290 enjoys a wide appeal because of its low global warming potential, proper management is a must. R-172 or Water ($H_2O$) as a refrigerant is from the natural refrigerant group. Mainly used in absorption refrigeration and steam jet cooling, the compound act both as the refrigerant as well as the working fluid, because of its natural abundance, non-toxicity and as it does not affect the environment's ozone depletion potential and global warming potential.

A. **R134a, or 1, 1, 1, 2-Tetrafluoroethane**: has been a fluorinated hydrocarbon refrigerant that has seen wide application in cooling segments since it came onto the market. It exists as a grey, incombustible gas at room temperature and is less toxic than certain other refrigerants.

Key Characteristics:

- Chemical Formula: $C_2H_2F_4$
- Molecular Weight: 102.03 g/mol
- Boiling Point: -26.3°C (-15.3°F)
- Global Warming Potential (GWP): Approximately 1,430 (on a scale where $CO_2$ has a GWP of 1)
- Chemical Structure:

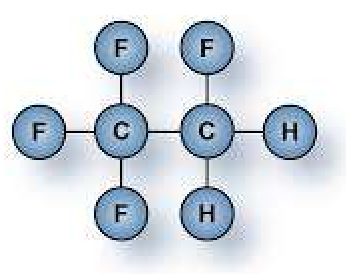


Fig.1. Chemical STructure of R134a

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- Historical Context: R134a was introduced to replace the obsolete refrigerant R12 (dichlorodifluoromethane), the new refrigerant R134a was designed, which, unlike its predecessors, does not affect the ozone layer.
- Applications:
  i. Automobile Air Conditioning: In the 1990s, R134a became a standard refrigerant in the vehicle air conditioning sector mainly because of its reliability and safety performance.
  ii. Household and Commercial Refrigeration: It is used in many domestic refrigerators and freezers, as well as commercial cooling systems.
  iii. Industrial Refrigeration: It is also applied in various industrial cooling processes and cooling appliances.
  iv. Heat Pumps and Refrigerated Transport: R134a is also used in some of the Heat Pump Systems and in the refrigeration system of transport vehicles.

B. **R22 or dichlorodifluoromethane:** is, commonly, a chlorofluorocarbon (CFC) refrigerant found in both air conditioning and refrigeration systems.

Key Characteristics:

- Chemical Formula: $CCl_2F_2$
- Molecular Weight: 120.91 g/mol
- Boiling Point: -40.8°C (-41.4°F)
- Global Warming Potential (GWP): Approximately 1,810 (on a scale where $CO_2$ has a GWP of 1)
- Chemical Structure:

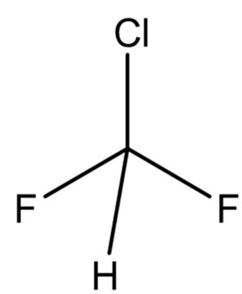


Fig.2. Chemical Structure of R22.

- Historical Context: Created in the 1950s, R22 became the choice for refrigeration and air conditioning due to its ability to cool and its solid stability. The usage comprised air conditioning in homes and offices as well as in building and generic industrial tasks.
- Applications:
  i. Air Conditioning: Residential and commercial air conditioning systems frequently used R22.
  ii. Refrigeration: This material served in multiple refrigeration systems, specifically in supermarket refrigeration, food refrigeration, and industrial cooling regions.
  iii. Heat Pumps: A number of heat pump systems have also relied on R22 for their refrigerant features.

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C. **R-717 or ammonia ($NH_3$):** is a refrigerant that has been in use for many decades within the industrial and commercial refrigeration systems. This is so due to its high efficiency and effectiveness in heat absorption and transfers hence its widespread use.

Key Characteristics:

- Chemical Formula: $NH_3$
- Molecular Weight:17.03 g/mol
- Boiling Point:-33.34°C (-28.03°F)
- Global Warming Potential (GWP): Ammonia has no impact on global warming, making it a climate-friendly choice compared to many synthetic refrigerants
- Chemical Structure:

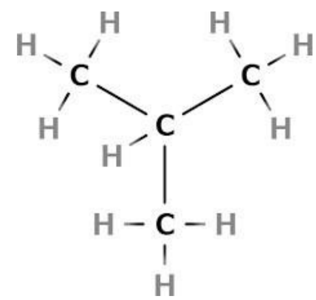


Fig.3. Chemical Structure of R717.

- Historical Context: Utilized since ancient history, ammonia has been largely for fertilization purposes in agriculture.. Significant growth in its industrial application took place in the 19th and 20th centuries, particularly for refrigeration technology and chemical manufacturing, principally because of its efficiency and practicality.
- Applications:
  i. Refrigeration: Used as a refrigerant in large-scale industrial systems such as food processing and cold storage due to its high efficiency and effective heat transfer properties.
  ii. Agriculture: A key component in fertilizers, ammonia supplies essential nitrogen to crops, enhancing agricultural productivity.
  iii. Chemical Industry: Integral in the production of chemicals like nitric acid, urea, and other nitrogen-based compounds.

D. **R290 or Propane:** is the designation to use propane ($C_3H_8$) as a refrigerant. It is a member of the hydrocarbon family and is well acclaimed for its environmental and efficiency advantages in many uses.

Key Characteristics:

- Chemical Formula: CH3CH2CH3
- Molecular Weight**:** 44.10 g/mol

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- Boiling Point**:** -42.1°C (-43.8°F)at atmospheric pressure
- Global Warming Potential (GWP**)**: R290 has an extremely low GWP compared to many synthetic refrigerants, making it a more environmentally friendly option
- Chemical Structure:

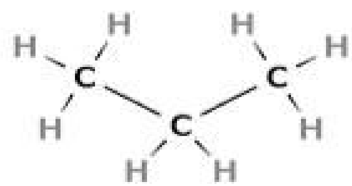


Fig.4. Chemical Structure of R290.

- Historical Context: Propane has been used as a fuel in heating and cooking for many decades. It was widely used as a refrigerant in the late twentieth and early twenty-first century as part of measures to come up with better substitutes for high GWP refrigerants.
- Application:
  i. Refrigeration**:** R290 is used in commercial refrigeration systems such as display cabinets, refrigerated counters, cold rooms and ice machines, cold storage and small commercial refrigerators because of its effectiveness as well as energy consumption environmental impact.
  ii. Air Conditioning: It is also used in some air conditioning systems, especially in small-scale and residential applications.

## 2. Literature Review

Refrigerants choice is significant for increasing energy effectiveness and decreasing negative impacts on the environment in cooling systems. This review focuses on the comparative evaluation of four refrigerants: R717 (ammonia), R290 (propane), R134a (1,1,1,2-tetrafluoroethane) and R22 (dichlorodifluoromethane) on the basis of thermodynamics, efficiency or impact on the environment.

Since the beginning, R134a has been widely adopted as an environmentally friendly successor of R12 (Emani et al., 2017). Some concern has been expressed regarding the contribution of Fluorocarbons and they have GWP of approximately 1430 to climate alteration. Based on the analysis, R134a can perform functional use in various applications; however, its high GWP means a transition towards environmentally sensitive options (Padmavathy et al., 2022).

R22, a chlorofluorocarbon compound, was usually utilized in Air condition and Refrigeration applications. Nevertheless, the high ODP (Ozone Depletion Potential) led to its removal in compliance with international agreements like Montreal Protocol. The high GWP of approximately 1,810 of R22

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requires a safer choice (Al-Zahrani, 2023).

Because of its very high efficiency and no GWP, R717 (ammonia) has emerged to be popular in industrial refrigeration. For major applications, the effective properties of heat transfer make it ideal (Yin, J.M et al., 2023). Despite these advantages, ammonia is toxic and flammable; thus, many safety precautions are required when using it (Crolius et al., 2021).

The favorable choice of R290 (propane) is gradually increasing due to its almost three times lower GWP level than R22 and has excellent thermodynamic properties. Since it is combustible, comprehensive adjustment to management methods has brought it to an acceptable standard of residential and commercial usage (Cao and Hwang, 2020). The results of the analysis show that increasing the concentration of R290 in refrigeration systems can improve their energy efficiency and reduce the environmental impact and therefore it can be considered as a leading refrigerant for further use (Mota-Babiloni, 2020).

Research conducted recently demonstrated a new trend shifting in natural refrigerators R290 and R717 due to regulatory constraints and increased focus on environmental friendliness. Comparisons made in this paper indicate that R290 strikes the desired optimization level of efficiency and environmental safety for a wide range of cooling uses.

Conclusions from Literature Reviews are Environmental Pros and Cons: refrigerant R134a Pros: Non-toxic, non-flammable, and relatively efficient. Cons: High global warming potential (GWP). Refrigerant R22 Pros: Effective cooling performance.Cons: Being phased out due to ozone depletion potential; not environmentally friendly. Refrigerant R717 Pros: Highly efficient, low GWP, and low cost. Cons: Toxic and flammable; requires safety precautions. Refrigerant R290 : Excellent thermodynamic properties, low GWP, and environmentally friendly. Cons: Flammable, which requires careful handling.

## 3. Methodology

This study conducts a comparative analysis of four refrigerants—R717 (ammonia), R290 (propane), R134a (tetrafluoroethane), and R22 (dichlorodifluoromethane)—by utilizing CoolPack software for simulation and experimental analysis via a heat pump. The goal is to evaluate the performance and environmental impact of each refrigerant across various operating conditions.

### 3.1. Thermodynamic Property Input

The research begins by gathering the thermodynamic properties of the selected refrigerants. Key properties such as boiling point, critical temperature, specific heat, and latent heat of vaporization are sourced from established databases and literature. These properties are then inputted into the CoolPack software to establish a foundational dataset for simulation.

### 3.2. Setup of Cooling Cycle Scenarios

Using CoolPack, several cooling cycle scenarios are simulated.The Software coolpack with Version Coolpack V.1.5.0 is used. The software enables the modeling of various configurations, including vapor-compression cycles under different temperature ranges.

3.3. Evaluation parameters Metrics

For each refrigerant, the following performance metrics are calculated:

- **Heat Absorption (Qc):** The amount of heat absorbed by the refrigerant during the evaporation process.
- **Heat Rejected (Qe):** The heat expelled by the refrigerant during condensation.
- **Energy Input (W):** The work input required for the compression process.
- **Pressure Ratios:** The ratio of discharge pressure to suction pressure.
- **Coefficient of Performance (COP):** Calculated as COP=QcWCOP = \frac{Qc}{W}COP=WQc.
- **Energy Efficiency Ratio (EER):** Calculated as EER=QcQeEER = \frac{Qc}{Qe}EER=QeQc .

Each refrigerant's performance is analyzed over a range of temperatures and pressures to observe trends and differences in efficiency.

### 3.4. Experimental Research with Heat Pump

After Simulations in coolpack the refrigerant's performance is tested in actual operating conditions.

#### 3.4.1. Setup and Configuration

A heat pump system with capacity 1 toons is used. It is configured to utilize the refrigerants under controlled conditions. The experimental setup includes measuring instruments for temperature, pressure, and energy consumption.

#### 3.4.2.Data Collection

Data is collected for each refrigerant during operation, focusing on:

- Temperature and pressure at various points in the cycle.
- Energy consumption over time.
- Heat output and input during operational cycles.

#### 3.4.3. Comparative Analysis

The outcomes from the CoolPack simulations and experimental data are analyzed in conjunction with the literature survey results. A comparative framework is established to evaluate each refrigerant's performance and environmental impact:

- Efficiency metrics (COP and EER) are compared across the refrigerants.
- Environmental impact is assessed based on GWP and ODP.

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- Discussions on the suitability of each refrigerant for different engineering applications are included

The methodology culminates in a comprehensive analysis of the refrigerants' performance and environmental sustainability. The findings from simulations, experimental data, and literature review will inform best practices for refrigerant selection in engineering applications, highlighting both efficiency and environmental considerations.

**Fig.5. Experimental Setup.**

**Results and Discussion:**

Table 1: Properties of refrigerant

| Sr No | Refrigerant | COP | Qc(KJ/Kg) | Qe(KJ/Kg) | Qc-Qe (KJ/Kg) | Pressure Ratio | Displacement (m^3/h) | Work (KW) |
|---|---|---|---|---|---|---|---|---|
| 1. | R134a | 4.03 | 168.734 | 135.161 | 33.573 | 5.063 | 31.6749 | 2.686 |
| 2. | R22 | 4.11 | 188.886 | 151.891 | 36.995 | 4.328 | 20.9120 | 2.960 |
| 3. | R717 | 4.29 | 1310.36 | 1062.860 | 247.506 | 5.348 | 133.6632 | 19.801 |
| 4. | R290 | 3.99 | 333.139 | 257.520 | 64.619 | 3.988 | 42.0079 | 5.170 |

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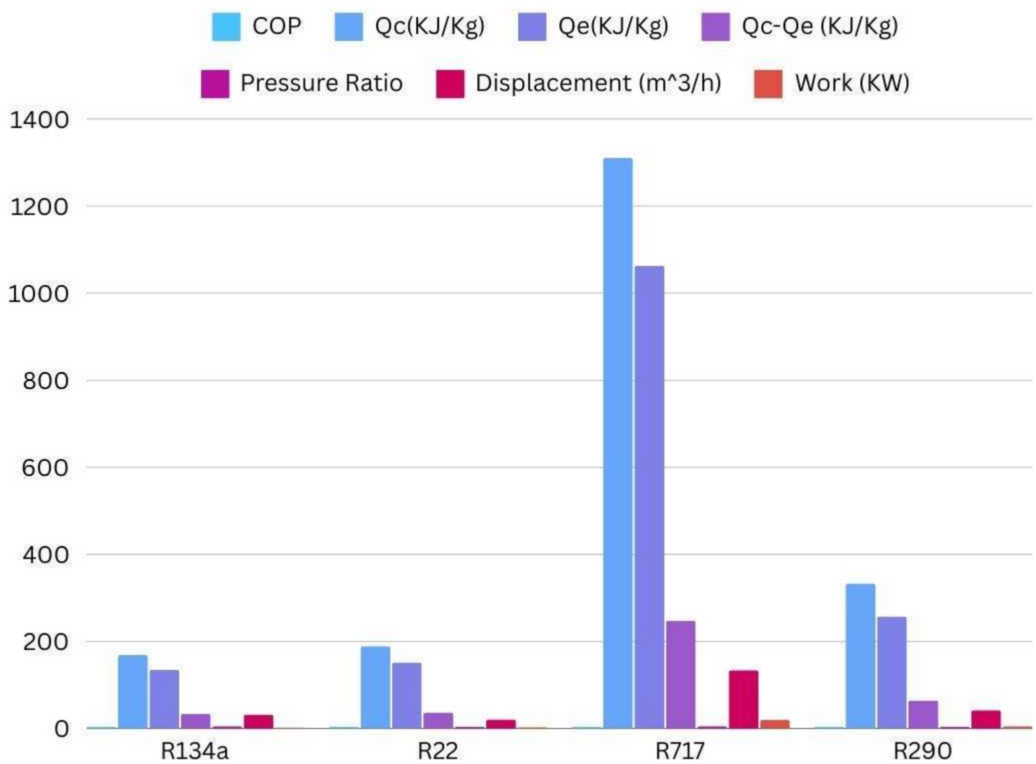


Graph 1 : Performance Evaluation of R134a, R22, R717 and R290.

Coefficient of Performance (COP):

$$COP = Qc/W$$

As per the results depicted in Graph 1 and Table 1 The R717 Stand out for highest COP than others.However the Displacement and Work of COmpression is more required compared to R134a, R22 and R290.

Table 2: Energy Efficiency Ratio

To measure the efficiency of cooling equipment, the Energy Efficiency Ratio (EER) is the used. We divide the cool output (measured in BTUs) by the energy Intake (reported in watts) to calculate this.

- Energy Efficiency Ratio (EER):

$$EER = \text{Cooling Output (BTUs)} / \text{Energy Input (watt)}$$

EER= BTUs of Cooling / Energy Input (in watts)

| Refrigerators | Qc(BTU/Hr) | W(watt) | EER |
|---|---|---|---|
| R717 | 159.92 | 2686 | 0.0595 |
| R290 | 179.02 | 2960 | 0.0604 |
| R22 | 1241.96 | 19801 | 0.027 |
| R134a | 305.32 | 5170 | 1.059 |

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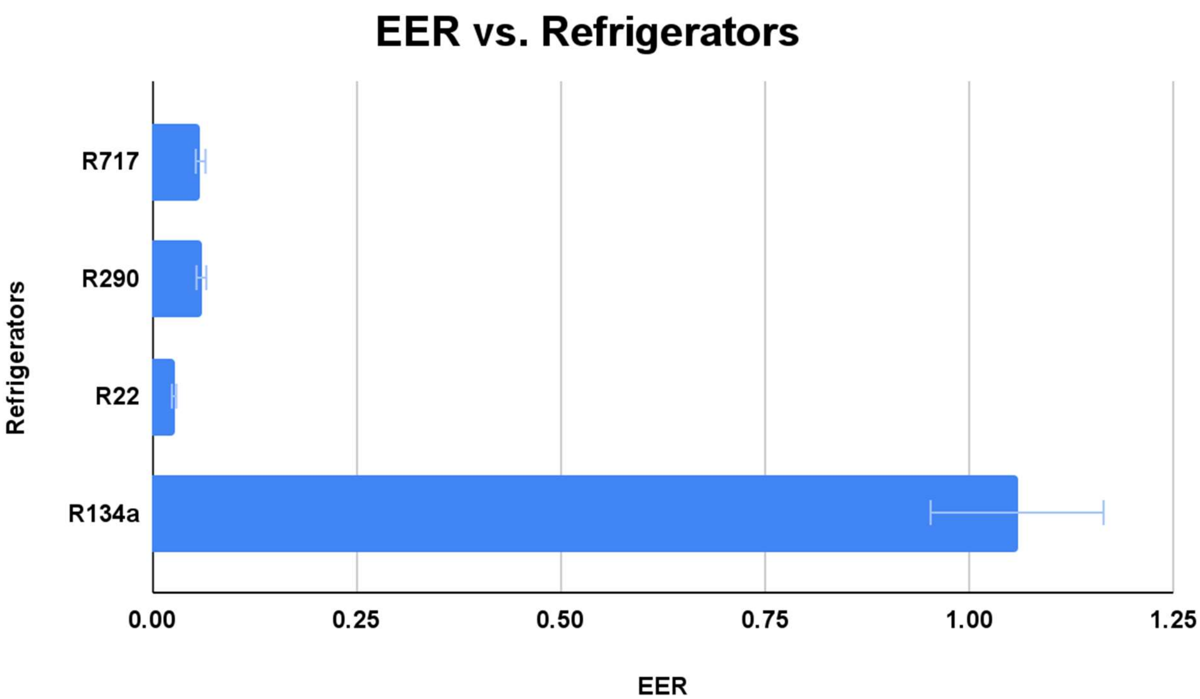
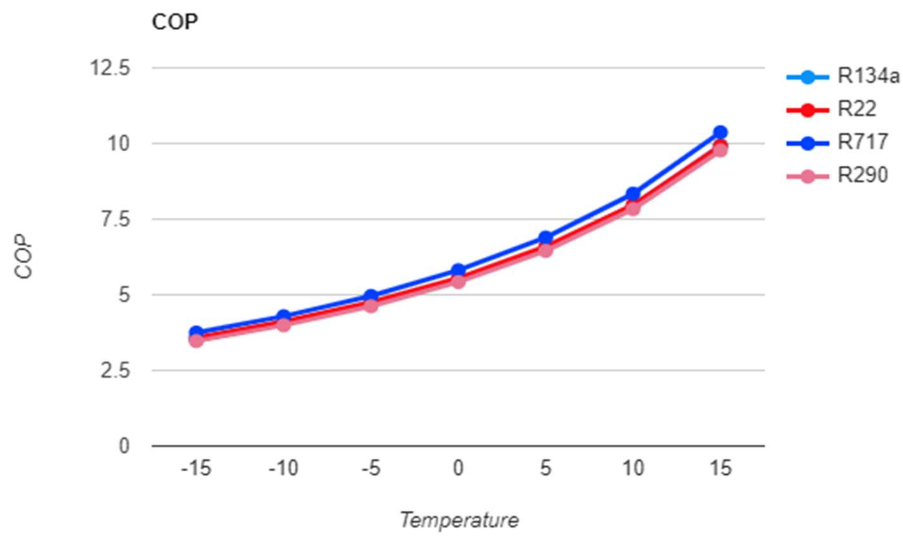



Graph 2 :Energy Efficiency Ratio (EER) Performance Evaluation of R134a, R22, R717 and R290.

As shown in Graph.2. and Table.2. The EER Rating is higher for R134a than other refrigerants R22, R717 and R290. Thus shows that Refrigerants R134a is more efficient than other refrigerants R22, R717 and R290.

Table 3: COP vs Temperature

| Refrigerators | -15 | -10 | -5 | 0 | 5 | 10 | 15 |
|---|---|---|---|---|---|---|---|
| R717 | 3.75 | 4.29 | 4.96 | 5.89 | 6.89 | 8.34 | 10.37 |
| R290 | 3.45 | 3.99 | 4.62 | 5.42 | 6.45 | 7.83 | 9.77 |
| R22 | 3.58 | 4.11 | 4.75 | 5.55 | 6.59 | 7.97 | 9.92 |
| R134a | 3.50 | 4.03 | 4.67 | 5.49 | 6.54 | 7.95 | 9.93 |




Graph 3 : COP Evaluation of R134a, R22, R717 and R290.

As per the results depicted in Graph.3 and Table.3. The R717 stands out for highest COP at all temperature conditions of evaporator at high load and partial load conditions compared to R134a, R22 and R290.While R290 refrigerant resulted in lowest performance at all evaporator temperatures.

**Conclusion**

During the research it was also noted that the use of R-712 (H2O) in industrial and commercial applications is somewhat restricted, because of its lower efficiency or COP, high freezing point (0°C for water) and restrictions in the phase change. R22 is an air-conditioning refrigerant which was once popularly used in home appliances and businesses but was later banned in 2020 due to its maximum contribution to ozone depletion and global warming. R290 (propane) shows superior performance regarding environmental impact thanks to its low greenhouse gas pressure and high efficiency. Although safety measures are needed, R717 proves to be very effective for industrial use. The recommendation for sustainability is R290; however, R134a is still usually employed for common household applications. Industry emphasis on sustainability means that natural refrigerants like R290 and R717 will probably become more prevalent as time goes on. This adjustment not only advances environmental objectives but also cooling system energy efficiency, which is critical given the effects of climate change. However, we concluded that because of its high efficiency and low global warming potential (GWP), R290 (propane) stands out. Because of this, it's a great option for both commercial and domestic refrigeration applications.

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## GRAPHICAL ABSTRACT

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