Chittaranjan Beshra, 2025, 13:3
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science, Engineering and Technology

An Open Access Journal

Experimental Study on effect of R134a Refrigerants in a Domestic Vapour Compression Refrigeration System

Chittaranjan Beshra, Lalatendu Paul, Chinmaya Behera, Aman Anand, Bidyut Ranjan Rout, Amar Kumar Das
Department of Mechanical Engineering, GIFT Autonomous, Bhubaneswar

Abstract- This study presents a comparative performance analysis of a vapor compression refrigeration system using two different refrigerants: R134a and hydrocarbon refrigerants (R600a/R290). The experiment was conducted on a standard domestic refrigerator setup under identical environmental and operational conditions. Parameters such as coefficient of performance, refrigeration effect, and environmental impact were used to evaluate performance. The results showed that the hydrocarbon refrigerant demonstrated a significantly higher COP and refrigeration effect than R134a. This improved performance is attributed to the lower molecular weight and superior thermodynamic compatibility of hydrocarbons, which resulted in faster temperature pull-down and greater energy efficiency. The study also highlights the environmental advantages of hydrocarbons, including zero ozone depletion potential and negligible global warming potential, in contrast to R134a's higher GWP of approximately 1430.Despite flammability concerns associated with hydrocarbons, their performance and environmental benefits suggest they are promising alternatives to conventional refrigerants for domestic refrigeration applications. The findings support the suitability of hydrocarbon refrigerants in simple VCR systems as energy-efficient, eco-friendly replacements for high-GWP refrigerants.

Keywords- Vapor Compression Refrigeration; Hydrocarbon Refrigerants; Refrigeration Effect; Global Warming Potential; Ozone Depletion Potential

I. INTRODUCTION

The rising demand for energy-efficient and environmentally sustainable refrigeration has intensified the global search for alternative refrigerants. R134a, a hydrofluorocarbon (HFC), has been widely used in domestic vapor compression refrigeration (VCR) systems due to its favorable thermodynamic properties and zero ozone depletion potential (ODP). However, its high global warming potential (GWP ≈ 1300–1430) makes it a target for phase-out under current environmental protocols.Hydrocarbon refrigerants such as R600a (isobutane) and R290 (propane) have emerged as leading eco-friendly alternatives. These substances offer comparable or superior thermal performance, zero ODP, and negligible GWP (<5), making them highly suitable for replacing R134a in domestic applications (Bolaji & Huan, 2012; Kadhim, 2024). Several experimental studies confirm that systems operating with hydrocarbon refrigerants consistently demonstrate a higher coefficient of performance (COP), with observed gains of up to 31% depending on the blend ratio and configuration (Harun-Or-Rashid et al., 2021; Kalambate et al., 2015). In addition, hydrocarbon refrigerants reduce power consumption by 12–20%, making them more energy-efficient than R134a under identical conditions (Babarinde et al., 2015).While hydrocarbon refrigerants are mildly flammable, their integration into domestic refrigeration systems is increasing, especially when supported by proper design and safety measures (Siddegowda et al., 2019). The thermodynamic compatibility of hydrocarbons with existing compressor systems also allows for minimal system modification, facilitating practical adoption (El-Morsi, 2015; Ghanbarpour et al., 2021).This study experimentally investigates and compares the performance of R134a and hydrocarbon refrigerants (R600a/R290) in a domestic VCR system. Parameters such as refrigeration effect, coefficient of performance (COP), and environmental impact are analyzed under the same ambient and operating conditions. The results contribute to understanding the practical viability of hydrocarbon refrigerants as energy-efficient, low-GWP alternatives to conventional HFCs in household refrigeration.

II. METHODOLOGY

1. VCR System Overview

The experimental investigation was conducted on a standard domestic VCR system, based on the Clausius statement of the second law of thermodynamics. The working principle involves four key processes:

- Isentropic compression of the low-pressure refrigerant vapor in the compressor.
- Constant pressure heat rejection in the condenser.
- Isenthalpic expansion through the expansion device.
- Constant pressure heat absorption in the evaporator.

These processes are represented schematically in the line diagram (Fig. 1) and P-h (pressure-enthalpy) diagram (Fig. 2), both used to identify key thermodynamic properties and evaluate system performance.

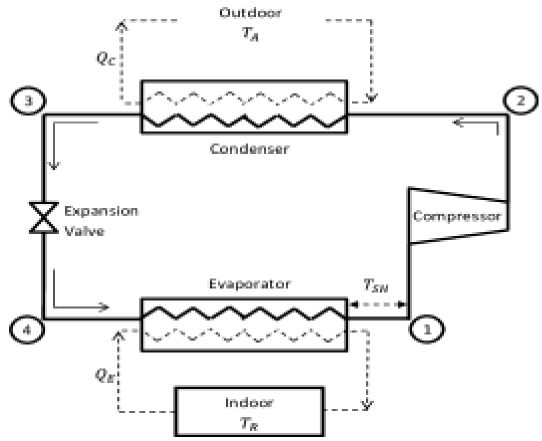

Figure 1. Simple VCR System

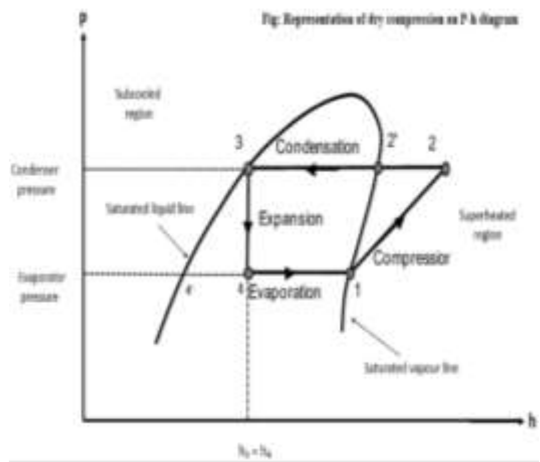

Figure 2. P-h diagram of simple VCR cycle

2. Experimental Setup

The setup includes all the standard components of a domestic refrigerator:

- **Compressor:** Electrically powered, used to compress low-pressure vapor into high-pressure vapor.
- **Condenser:** Located at the back of the refrigerator, facilitates heat rejection to the surroundings.
- **Expansion Valve:** Reduces pressure and temperature of the liquid refrigerant before entering the evaporator.
- **Evaporator:** Absorbs heat from inside the refrigerator and cools the internal space.

Instrumentation included

- Pressure gauges and thermocouples to measure refrigerant pressure and temperature at key points.
- Current and voltage meters to assess power consumption.

All tests were conducted under identical ambient conditions to ensure consistency.

3. Testing Procedure

Initially, the system was charged with R134a, and experiments were carried out at constant condenser and evaporator temperatures. After recording the baseline performance, the system was evacuated and then charged with hydrocarbon refrigerants (R600a/R290). The same set of tests was repeated using identical operating conditions.

For each refrigerant, data was collected for the following:

- Evaporator and condenser temperatures
- Compressor inlet and outlet pressures
- Electrical power consumption
- Temperature readings across components
- The primary performance metrics evaluated were:
- Refrigeration effect
- Coefficient of Performance (COP)

Environmental impact assessment based on known GWP and ODP values of the refrigerants used. The system was designed and operated to directly compare the thermodynamic and environmental performance of the selected refrigerants without modifying core hardware, ensuring fair and consistent analysis.

III. RESULTS AND DISCUSSION

1. Refrigeration Effect

The refrigeration effect, representing the system's capacity to absorb heat in the evaporator, was evaluated for both R134a and the hydrocarbon refrigerants under the same ambient conditions. The experimental results showed that the refrigeration effect was significantly higher for R600a/R290 compared to R134a. This improvement can be attributed to the better thermodynamic compatibility and heat absorption characteristics of hydrocarbons, which enhanced their ability to maintain lower evaporator temperatures and quicker temperature pull-down during operation. This is shown in Figure 3.

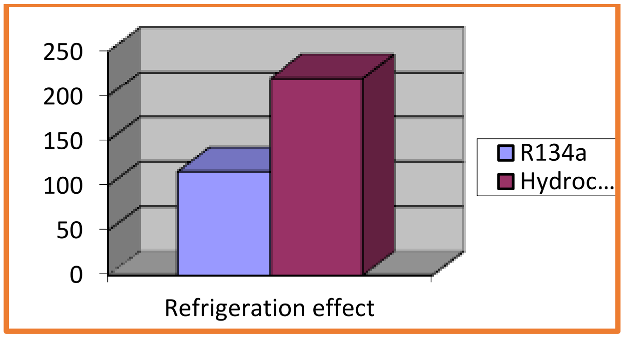

Figure 3. Graph representing Refrigeration effect

2. COP

The COP, which indicates the system's energy efficiency, was found to be higher for hydrocarbon refrigerants (R600a/R290) than for R134a. The increase in COP reflects lower compressor work and a higher refrigeration effect, confirming the superior performance of hydrocarbons in a domestic VCR setup. Experimental data revealed a consistent trend of improved energy efficiency when using R600a, in agreement with findings from prior studies comparing hydrocarbon and HFC refrigerants. The result is shown in Figure 4.

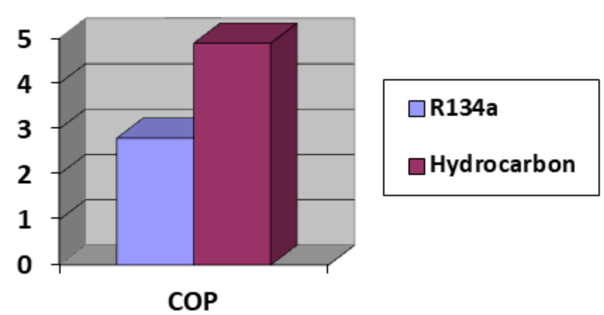

Figure 4. Graph representing COP

3. Environmental Considerations

In addition to performance metrics, the environmental impact of the refrigerants was considered. R134a, while having zero ODP, carries a high global warming potential (GWP ≈ 1300–1430). In contrast, R600a and R290 are natural refrigerants with zero ODP and negligible GWP (<5), offering substantial reductions in long-term climate impact. This aligns with international environmental protocols pushing for the phase-out of high-GWP refrigerants and supports the case for hydrocarbon-based alternatives in household applications.

4. System Compatibility and Limitations

Despite the performance and environmental benefits, the use of hydrocarbon refrigerants comes with certain limitations, primarily flammability risks, which require adherence to strict safety measures. However, the system used in this study did not require significant hardware modification, as the vapor pressure characteristics of R600a and R134a are similar, allowing both refrigerants to be tested using the same compressor and system layout. This compatibility is critical for practical replacement in existing domestic systems.

IV. CONCLUSION

This study conducted a comparative experimental evaluation of a domestic VCR system using two refrigerants: R134a and hydrocarbon refrigerants (R600a/R290). The results indicate that hydrocarbon refrigerants deliver superior performance, with both a higher refrigeration effect and greater COP than R134a under identical operating conditions. In addition to improved thermal performance, R600a and R290 offer significant environmental advantages, featuring zero ODP and negligible global warming potential (GWP < 5) compared to the high GWP of R134a. These attributes make hydrocarbon refrigerants strong candidates for replacing high-GWP refrigerants in domestic refrigeration systems. While flammability remains a concern, the hydrocarbon refrigerants used in this study were compatible with the existing VCR setup, requiring no significant changes to the compressor or system design. Based on these findings, R600a and R290 represent environmentally friendly and energy-efficient alternatives to R134a in household refrigeration applications. Their adoption could contribute significantly to climate change mitigation efforts while maintaining system performance.

REFERENCES

1. M. Harun-Or-Rashid, K. M. Rashid Shahrier and Farzana Alam Shakila. "Performance Analysis of a Domestic Refrigerator Using R134a and R600a Refrigerant." 2021 International Conference on Automation, Control and Mechatronics for Industry 4.0 (ACMI) (2021): 1-4. https://doi.org/10.1109/ACMI53878.2021.9528273
2. Saif Ali Kadhim. "Thermodynamic and Environmental Analysis of Hydrocarbon Refrigerants as Alternatives to R134a in Domestic Refrigerator." International Journal of Thermodynamics (2024). https://doi.org/10.5541/ijot.1368985
3. T. O. Babarinde, O. Ohunakin, D. Adelekan, S. A. Aasa and S. Oyedepo. "Experimental Study of lpg and R134a Refrigerants in Vapor Compression Refrigeration." International Journal of Energy for a Clean Environment, 16 (2015): 71-80. https://doi.org/10.1615/INTERJENERCLEANENV.2016015644
4. M. Ghanbarpour, A. Mota-Babiloni, Bassam E. Badran and Rahmatollah Khodabandeh. "Energy, Exergy, and Environmental (3E) Analysis of Hydrocarbons as Low GWP Alternatives to R134a in Vapor Compression Refrigeration Configurations." Applied Sciences (2021). https://doi.org/10.3390/APP11136226
5. Parashurama Siddegowda, G. Sannappagowda, V. Jain and S. Gowda. "Hydrocarbons as Alternate Refrigerants to Replace R134a in Domestic Refrigerators." Revue des composites et des matériaux avancés (2019). https://doi.org/10.18280/RCMA.290204
6. Bukola Olalekan Bolaji and Z. Huan. "Energy performance of eco-friendly RE170 and R510A refrigerants as alternatives to R134a in vapour compression refrigeration system." 2012 Proceedings of the 9th Industrial and Commercial Use of Energy Conference (2012): 1-8.
7. Saurabh P. Kalambate, Rajaram N. Gawade, S. B. Khandekar, D. D. Jadhav and Naveed M.H. Bhatkar. "Performance Analysis of Vapour

Compression Refrigeration System by using R134a and blend of R290 and R600a.", 2 (2015): 76-80.
8. M. El-Morsi. "Energy and exergy analysis of LPG (liquefied petroleum gas) as a drop in replacement for R134a in domestic refrigerators." Energy, 86 (2015): 344-353. https://doi.org/10.1016/J.ENERGY.2015.04.035