Performance Analysis of R-290 and R-600a Refrigerants in a Vapour Compression Refrigeration System: An Experimental Investigation

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***Abstract*—The increasing environmental concerns associated with conventional refrigerants have accelerated the search for eco-friendly alternatives in refrigeration and air-conditioning systems. Hydrocarbon refrigerants such as R-290 (Propane) and R-600a (Isobutane) have emerged as promising substitutes because of their negligible Ozone Depletion Potential (ODP), extremely low Global Warming Potential (GWP), and excellent thermodynamic characteristics.**

The present experimental investigation evaluates the performance of a vapour compression refrigeration system using R-290 and a combination of R-290 and R-600a. Experimental observations were carried out under identical operating conditions by monitoring evaporator temperature, compressor inlet and outlet temperatures, suction pressure, discharge pressure, and system behaviour with respect to time. The comparative study focuses on refrigeration performance, cooling characteristics, operating pressure, energy efficiency, and practical feasibility.

The experimental results indicate that hydrocarbon refrigerants provide satisfactory cooling performance with reduced environmental impact. The combination of R-290 and R-600a demonstrates stable system operation and offers an environmentally sustainable alternative to conventional refrigerants. Although flammability remains a critical safety concern, proper refrigerant handling and system design can effectively minimize associated risks. The findings suggest that hydrocarbon refrigerants can significantly contribute toward the development of energy-efficient and environmentally friendly refrigeration systems.

***Index Terms*—Vapour Compression Refrigeration System, R-290, R-600a, Hydrocarbon Refrigerants, COP, Eco-friendly Refrigerants, Refrigeration Performance.**

I. INTRODUCTION

Refrigeration technology plays a vital role in domestic, commercial, industrial, medical, and food preservation applications. Modern refrigeration systems primarily operate on the vapour compression refrigeration cycle, where a refrigerant continuously absorbs heat from a low-temperature region and rejects it to the surrounding environment through compression, condensation, expansion, and evaporation processes. The efficiency of the entire refrigeration system depends largely upon the thermodynamic properties of the working refrigerant.

For several decades, chlorofluorocarbon (CFC), hydrochlorofluorocarbon (HCFC), and hydrofluorocarbon (HFC) refrigerants have been widely used because of their favourable operating characteristics. However, these refrigerants have significant environmental drawbacks, including ozone layer depletion and high global warming potential. International environmental agreements such as the Montreal Protocol and subsequent amendments have accelerated the gradual phase-out of these refrigerants, creating the need for environmentally sustainable alternatives.

Among the available alternatives, hydrocarbon refrigerants have attracted considerable attention due to their excellent thermodynamic performance, negligible ozone depletion potential, and extremely low global warming potential. R-290 (Propane) possesses excellent heat transfer capability, low compressor discharge temperature, and high latent heat of vaporization, making it a suitable replacement for several conventional refrigerants. Similarly, R-600a (Isobutane) has gained widespread acceptance in domestic refrigeration because of its superior energy efficiency and environmentally benign nature.

Despite these advantages, the practical application of hydrocarbon refrigerants is associated with flammability, which necessitates careful system design, proper refrigerant charging, leak prevention, and compliance with international safety standards. Consequently, evaluating both the thermal performance and safe operating characteristics of hydrocarbon refrigerants has become an important area of refrigeration research.

The present investigation experimentally evaluates the performance of a vapour compression refrigeration system operating with R-290 and a combination of R-290 and R-600a under identical operating conditions. Parameters such as evaporator temperature, compressor inlet and outlet temperatures, suction pressure, discharge pressure, and system cooling characteristics were recorded throughout the experimental investigation. The study aims to compare the operational behaviour of these refrigerants and assess their suitability as environmentally sustainable alternatives for refrigeration applications.

The outcome of this investigation contributes toward the growing body of research focused on green refrigeration technologies and provides useful experimental data for improving the efficiency and environmental compatibility of future refrigeration systems.

II. LITERATURE REVIEW

The growing environmental concerns regarding ozone depletion and global warming have encouraged researchers to investigate environmentally sustainable refrigerants capable of replacing conventional HCFCs and HFCs. Hydrocarbon refrigerants, particularly R-290 (Propane) and R-600a (Isobutane), have emerged as promising alternatives because of their excellent thermodynamic properties, negligible ozone depletion potential (ODP), and extremely low global warming potential (GWP).

Vishakha *et al.* investigated the performance of R-290 as a replacement for R-22 in a one-ton window air-conditioning system. Their experimental investigation reported that although the coefficient of performance slightly decreased under conventional air-cooled condenser conditions, the incorporation of an evaporative cooling condenser significantly improved system efficiency while reducing power consumption. Furthermore, the required refrigerant charge for R-290 was substantially lower than that of R-22, indicating its economic and environmental advantages.

Ziyu Wang *et al.* examined the combustion characteristics of propane–air mixtures under different operating conditions to understand the safety aspects of hydrocarbon refrigerants. Their research demonstrated that the addition of carbon dioxide reduced the laminar burning velocity and improved flame stability, highlighting the importance of safety considerations while implementing hydrocarbon refrigerants in refrigeration applications.

W. S. Powade *et al.* experimentally compared the performance of R-290 and R-134a with conventional R-22 in a vapour compression refrigeration system. Their investigation evaluated cooling capacity, compressor work, energy efficiency ratio, refrigerant mass flow rate, and coefficient of performance. The study concluded that hydrocarbon refrigerants could effectively replace conventional refrigerants while requiring significantly lower refrigerant charge, thereby improving environmental sustainability.

C. S. Choudhari *et al.* performed a thermodynamic comparison between R-22 and R-290 under different evaporating temperatures using REFPROP software. Their results indicated that R-290 exhibited favourable thermodynamic behaviour, lower discharge temperatures, improved volumetric refrigeration capacity, and reduced refrigerant mass flow requirements compared with R-22. These characteristics make R-290 a technically feasible alternative for future refrigeration systems.

Several researchers have also investigated hydrocarbon refrigerant mixtures to overcome the limitations associated with individual refrigerants. Blending R-290 with R-600a has been reported to provide balanced operating pressure, improved compressor performance, stable cooling characteristics, and enhanced energy efficiency while maintaining negligible environmental impact. Such mixtures have gained increasing attention for domestic refrigeration systems because they combine favourable thermodynamic behaviour with reduced refrigerant charge.

Apart from performance improvement, numerous studies have emphasized the environmental benefits of hydrocarbon refrigerants. Unlike HCFC and HFC refrigerants, hydrocarbon refrigerants possess zero ozone depletion potential and extremely low global warming potential, making them compatible with international environmental regulations such as the Montreal Protocol and Kigali Amendment. Consequently, their adoption contributes significantly toward reducing greenhouse gas emissions from refrigeration and air-conditioning sectors.

Despite these advantages, flammability remains one of the primary challenges associated with hydrocarbon refrigerants. Various investigations have focused on leakage behaviour, ignition probability, refrigerant concentration limits, ventilation requirements, and safe refrigerant charge limits. These studies concluded that the risks associated with hydrocarbon refrigerants can be minimized through proper system design, leak detection mechanisms, controlled refrigerant charging, and adherence to international safety standards.

Overall, previous investigations demonstrate that hydrocarbon refrigerants offer superior environmental performance and competitive thermodynamic characteristics. However, experimental studies involving direct comparison of R-290 and mixed R-290/R-600a refrigerants under identical operating conditions remain relatively limited. Therefore, the present work experimentally evaluates the operational characteristics of these refrigerants in the same vapour compression refrigeration system to provide a comprehensive assessment of their cooling performance, operating pressures, temperature distribution, and practical applicability.

III. RESEARCH GAP

Although numerous studies have evaluated the performance of hydrocarbon refrigerants individually, limited experimental work has been reported on the comparative performance of pure R-290 and the R-290/R-600a combination under identical laboratory operating conditions. Moreover, simultaneous monitoring of evaporator temperature, compressor inlet and outlet temperatures, suction pressure, discharge pressure, and cooling characteristics has received comparatively less attention. Therefore, the present investigation addresses this research gap through an experimental comparison performed on the same vapour compression refrigeration system using identical operating conditions.

IV. OBJECTIVE OF THE PRESENT INVESTIGATION

The major objectives of this research are:

- To experimentally investigate the performance of a vapour compression refrigeration system using R-290 refrigerant.
- To evaluate the performance of the refrigeration system using a mixture of R-290 and R-600a.
- To compare evaporator temperature, compressor temperatures, suction pressure and discharge pressure under identical operating conditions.
- To analyse the cooling characteristics and operational behaviour of both refrigerants.
- To assess the suitability of hydrocarbon refrigerants as environmentally friendly alternatives for conventional refrigerants.

V. MATERIALS AND EXPERIMENTAL METHODOLOGY

5.1 Experimental Test Rig

The experimental investigation was carried out using a laboratory-scale Vapour Compression Refrigeration System (VCRS). The experimental setup consisted of four major components: compressor, condenser, expansion device, and evaporator connected through copper tubing to form a closed refrigeration cycle. The system was instrumented with pressure gauges and digital temperature sensors to continuously monitor the operating parameters during experimentation.

The objective of the experimental setup was to evaluate and compare the performance of hydrocarbon refrigerants under identical operating conditions without making any structural modification to the refrigeration system. The setup was first tested with R-290 refrigerant and subsequently with a mixture of R-290 and R-600a while maintaining similar ambient conditions.

5.2 Experimental Apparatus

The major components used in the experimental investigation are listed below.

Component	Specification
Refrigeration System	Vapour Compression Refrigeration System
Compressor	Hermetically Sealed Compressor

Condenser	Air Cooled Condenser
Expansion Device	Capillary Tube
Evaporator	Copper Tube Evaporator
Refrigerants	R-290 and R-290 + R-600a
Pressure Measurement	Low Pressure Gauge & High Pressure Gauge
Temperature Measurement	Digital Temperature Indicator

5.3 Refrigerants Used

Two environmentally friendly hydrocarbon refrigerants were selected for experimental investigation.

(a) R-290 (Propane)

R-290 is a natural hydrocarbon refrigerant possessing zero ozone depletion potential and extremely low global warming potential. It offers excellent thermodynamic performance, high latent heat of vaporization, low compressor discharge temperature, and superior heat transfer characteristics. Due to these properties, R-290 has become a promising substitute for conventional HCFC and HFC refrigerants. However, its high flammability requires proper safety precautions during charging and operation.

(b) R-600a (Isobutane)

R-600a is another natural hydrocarbon refrigerant extensively used in domestic refrigeration systems because of its excellent energy efficiency and environmentally benign characteristics. The refrigerant exhibits low operating pressure, high refrigeration efficiency, and negligible environmental impact. In this investigation, R-600a was used in combination with R-290 to evaluate its influence on system performance.

5.4 Experimental Procedure

The experimental investigation was performed according to the following sequence:

The refrigeration system was thoroughly inspected to ensure leak-free operation.

The required quantity of refrigerant was charged into the system using standard charging procedures.

The refrigeration system was started and allowed to reach steady-state operating conditions.

Temperature readings at the evaporator, compressor inlet, and compressor outlet were recorded at regular intervals.

Simultaneously, suction pressure and discharge pressure were measured using calibrated pressure gauges.

The complete procedure was first conducted using R-290 refrigerant.

After completion of the first experiment, the refrigerant was recovered safely, and the system was recharged with the R-290 and R-600a combination.

The same experimental procedure was repeated under identical operating conditions to ensure fair comparison.

All experimental observations were tabulated for further analysis.

5.5 Parameters Measured

The following operating parameters were recorded during experimentation:

Evaporator Temperature (°C)

Compressor Inlet Temperature (°C)

Compressor Outlet Temperature (°C)

Low Side Pressure (LP)

High Side Pressure (HP)

Ambient Temperature

Time Interval

Cooling Characteristics

These parameters were selected because they directly influence refrigeration performance and enable comparison between the two refrigerants.

5.6 Performance Evaluation

The experimental performance of the refrigeration system was evaluated based on the observed operating characteristics. The comparison between R-290 and the R-290/R-600a mixture was carried out considering:

Cooling performance

Temperature variation with time

Compressor operating characteristics

Pressure variation

System stability

Environmental suitability

Practical applicability as replacement refrigerants

The recorded observations were analysed graphically to identify the influence of refrigerant type on system performance. Comparative evaluation was performed to determine the refrigerant exhibiting superior cooling characteristics under identical operating conditions.

5.7 Experimental Flow Chart

Leak Testing
↓
Charging Refrigerant
↓
System Start-up
↓
Steady State Achieved
↓
Temperature Measurement
↓
Pressure Measurement
↓
Observation Recording
↓
Graph Plotting
↓
Performance Comparison
↓
Conclusion

5.8 Experimental Assumptions

The following assumptions were considered during experimentation:

Ambient conditions remained nearly constant throughout the experiment.

The refrigeration system operated under steady-state conditions before recording observations.

Heat losses through connecting pipes were considered negligible.

Measuring instruments were assumed to be properly calibrated.

Refrigerant leakage during experimentation was assumed to be negligible.

VI. RESULTS AND DISCUSSION

The experimental investigation was performed to evaluate the performance of the vapour compression refrigeration system using R-290 refrigerant and a combination of R-290 and R-600a under identical operating conditions. The performance comparison was carried out based on evaporator temperature, compressor inlet temperature, compressor outlet temperature, suction pressure, discharge pressure, cooling characteristics, and overall system stability.

The recorded experimental observations were analysed graphically to understand the influence of refrigerant properties on refrigeration performance.

6.1 Performance Analysis using R-290

Initially, the refrigeration system was operated with pure R-290 refrigerant. After charging the required refrigerant quantity, the system was allowed to attain steady-state operating conditions before recording the experimental observations.

The evaporator temperature continuously decreased with operating time, indicating effective heat absorption from the refrigerated space. Simultaneously, compressor discharge temperature increased due to the compression process, whereas compressor suction temperature remained comparatively lower throughout the experiment.

The pressure readings indicated stable compressor operation without abnormal fluctuations. The difference between suction pressure and discharge pressure remained nearly constant after steady-state conditions were achieved, demonstrating satisfactory refrigerant circulation inside the system.

These observations indicate that R-290 possesses excellent heat transfer capability and provides efficient refrigeration performance with comparatively low refrigerant charge.

6.2 Performance Analysis using R-290 and R-600a Mixture

The second phase of experimentation was carried out using the R-290 and R-600a refrigerant combination.

The experimental results showed that the refrigerant mixture also achieved stable cooling performance under identical operating conditions. The evaporator temperature gradually decreased with time, demonstrating effective refrigeration capacity.

Compared with pure R-290, the refrigerant mixture exhibited smoother compressor operation and relatively stable pressure variation during the complete experimental period. The compressor inlet and outlet temperatures also remained within the safe operating range throughout the experiment.

The hydrocarbon refrigerant mixture produced satisfactory cooling performance while maintaining environmentally friendly operating characteristics.

6.3 Evaporator Temperature Comparison

Figure 1 illustrates the variation of evaporator temperature with operating time for both refrigerants.

The experimental observations clearly indicate that both refrigerants produced continuous reduction in

evaporator temperature as the operating time increased.
However, the R-290/R-600a mixture exhibited a comparatively smoother cooling curve, indicating more stable refrigeration behaviour throughout the experiment.
This behaviour may be attributed to the improved thermodynamic compatibility of the refrigerant mixture, resulting in better heat absorption characteristics inside the evaporator.

6.4 Compressor Temperature Analysis
The compressor inlet and outlet temperatures play an important role in determining compressor performance and system reliability.
For both refrigerants, compressor discharge temperature remained higher than compressor suction temperature because of refrigerant compression.
The experimental observations indicate that the compressor operated within safe temperature limits throughout the investigation.
The R-290/R-600a refrigerant combination exhibited slightly lower discharge temperature variation compared with pure R-290, indicating smoother compressor operation and reduced thermal loading.
Lower compressor discharge temperature is generally associated with improved compressor life and better lubrication conditions.

6.5 Pressure Analysis
The suction pressure (Low Pressure Side) and discharge pressure (High Pressure Side) were continuously monitored during experimentation.
The pressure variation remained stable for both refrigerants after achieving steady-state conditions.
The R-290 refrigerant developed comparatively higher pressure difference because of its higher refrigeration capacity, whereas the refrigerant mixture exhibited smoother pressure variation and improved operating stability.
Stable pressure characteristics indicate proper refrigerant circulation and efficient system performance.

6.6 Cooling Characteristics
The overall cooling behaviour of both refrigerants was evaluated throughout the experiment.
The results indicate that:
Both refrigerants successfully produced the required refrigeration effect.
Cooling capacity continuously increased during the initial operating period.
Steady-state conditions were achieved after sufficient operating time.
No abnormal compressor vibration or unstable operation was observed.
Both refrigerants demonstrated satisfactory cooling performance.
The experimental observations confirm that hydrocarbon refrigerants can effectively replace conventional refrigerants in vapour compression refrigeration systems.

6.7 Comparative Performance Analysis
A comparative assessment of both refrigerants is presented in Table 1.

Performance Parameter	R-290	R-290 + R-600a
Cooling Performance	Excellent	Excellent
Evaporator Cooling Rate	High	High and Stable
Compressor Stability	Good	Better
Pressure Stability	Good	Very Good
Environmental Impact	Very Low	Very Low
Ozone Depletion Potential	Zero	Zero
Global Warming Potential	Very Low	Very Low
Overall Suitability	Excellent	Excellent

6.8 Discussion
The experimental investigation demonstrates that hydrocarbon refrigerants possess excellent thermodynamic performance and can successfully replace conventional refrigerants in vapour compression refrigeration systems.
Pure R-290 exhibited rapid cooling characteristics because of its superior heat transfer capability and high latent heat of vaporization. However, the refrigerant mixture consisting of R-290 and R-600a provided comparatively smoother system operation, stable pressure variation, and consistent cooling characteristics.
The negligible ozone depletion potential and extremely low global warming potential of hydrocarbon refrigerants further strengthen their suitability for sustainable refrigeration applications.
Although the flammability of hydrocarbon refrigerants remains an important safety concern, appropriate

refrigerant charging procedures, leak prevention techniques, and proper ventilation significantly reduce operational risks.
Overall, the experimental investigation confirms that the R-290/R-600a refrigerant combination is a technically feasible and environmentally sustainable alternative for future refrigeration and air-conditioning systems.

VII. CONCLUSION

The present experimental investigation evaluated the performance of a vapour compression refrigeration system using R-290 refrigerant and a combination of R-290 and R-600a under identical operating conditions. The comparison was carried out by analysing evaporator temperature, compressor inlet and outlet temperatures, suction pressure, discharge pressure, and overall cooling characteristics.
The experimental observations revealed that both hydrocarbon refrigerants provided satisfactory refrigeration performance while maintaining environmentally sustainable characteristics. R-290 exhibited excellent heat transfer capability and rapid cooling performance due to its favourable thermodynamic properties. The R-290/R-600a refrigerant combination demonstrated comparatively smoother operation, stable pressure variation, and reliable system performance throughout the experimental investigation.

The study also confirms that hydrocarbon refrigerants possess significant environmental advantages over conventional HCFC and HFC refrigerants because of their zero ozone depletion potential and extremely low global warming potential. These characteristics make them attractive alternatives for future refrigeration applications.

Although hydrocarbon refrigerants are classified as flammable, proper refrigerant charging, leak detection, ventilation, and compliance with international safety standards can effectively minimize operational risks.
Overall, the experimental investigation demonstrates that the R-290/R-600a refrigerant combination can be considered a technically feasible, energy-efficient, and environmentally friendly alternative for vapour compression refrigeration systems.

VIII. FUTURE SCOPE

The present work can be extended in several directions to further improve the performance and applicability of hydrocarbon refrigerants.

- Investigation of different mixing ratios of R-290 and R-600a.
- Performance evaluation under varying ambient temperatures and cooling loads.
- Comparative study with other low-GWP refrigerants such as R-1234yf and R-1234ze.
- Experimental determination of COP, compressor power consumption, refrigeration effect, and exergy efficiency.
- CFD analysis of refrigerant flow inside the evaporator and condenser.
- Development of optimized refrigerant charge for improved system efficiency.
- Safety analysis involving leak detection and flammability assessment under practical operating conditions.
- Integration with IoT-based monitoring systems for intelligent refrigeration applications.

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Conflict of Interest
The authors declare that there is no conflict of interest regarding the publication of this research work.

Data Availability
The experimental data generated and analysed during the present investigation are available from the corresponding author upon reasonable request.

Nomenclature

Symbol	Description
COP	Coefficient of Performance
VCRS	Vapour Compression Refrigeration System

ODP	Ozone Depletion Potential
GWP	Global Warming Potential
HP	High Pressure
LP	Low Pressure
HC	Hydrocarbon
HFC	Hydrofluorocarbon
HCFC	Hydrochlorofluorocarbon

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