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COMPARATIVE ENERGY ASSESSMENT OF LPG AND CONVENTIONAL REFRIGERANTS IN DOMESTIC REFRIGERATION SYSTEMS

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ABSTRACT

Purpose: This study investigates the feasibility of using Liquefied Petroleum Gas (LPG) as a sustainable refrigerant for off-grid refrigeration systems. It aims to address the challenge of preserving food and medicine in areas with limited or no access to reliable electricity by evaluating the performance and environmental benefits of LPG as an alternative to conventional refrigerants.
Design/Methodology/Approach: An experimental research design was adopted. The conventional compressor-condenser setup was replaced with an LPG cylinder, which leveraged its high pressure to induce cooling without external mechanical input. The experiment measured the system's cooling performance by measuring the pressure differential between the inlet and outlet. Comparative analysis was also conducted between LPG and traditional refrigerants, particularly R134a, to evaluate efficiency and environmental impact.
Research Limitation: The study was conducted under controlled laboratory conditions and does not incorporate long-term field data. Additionally, it focuses primarily on technical viability and does not include economic modelling or safety risk assessments in real-world domestic settings.
Findings: The study found that LPG can serve as an effective refrigerant, achieving a notable cooling effect without electricity. The system demonstrated environmental advantages, including zero Ozone Depletion Potential (ODP) and low Global Warming Potential (GWP).
Practical Implication: It offers a low-energy, environmentally friendly alternative that can be deployed in health, agriculture, and disaster response sectors.
Social Implications: Deploying LPG-powered refrigeration in underserved regions can reduce post-harvest food losses and improve access to temperature-sensitive medical supplies.
Originality / Value: This study contributes novel insights into non-electric cooling technologies and highlights the untapped potential of LPG in decentralised refrigeration applications. It offers a foundation for future research into cost-effective, closed-loop, and scalable off-grid refrigeration systems.

Keywords: *Energy. global warming potential, LPG. ozone depletion potential. refrigeration*

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INTRODUCTION

The refrigeration industry stands at a critical juncture where energy efficiency must be balanced with environmental sustainability. Conventional refrigerants like R134a, while widely used in domestic refrigerators, have a Global Warming Potential (GWP) of 1430, making them significant contributors to climate change (Mohamed, 2015). In response to this environmental challenge, researchers have identified Liquefied Petroleum Gas (LPG) as a promising alternative due to its zero Ozone Depletion Potential (ODP) and low GWP (Adelekan et al., 2017). LPG, a byproduct of petroleum refining consisting primarily of propane (24.4%), butane (56.4%), and isobutane (17.2%), possesses thermodynamic properties particularly suited for refrigeration applications (Akash & Said, 2003).

The shift toward alternative refrigerants has been driven by international environmental agreements. The Montreal Protocol mandated the phase-out of ozone-depleting refrigerants like R12, while the Kyoto Protocol addressed the reduction of high-GWP fluids such as R134a (United Nations Environment Programme, 2020). LPG offers several advantages beyond environmental benefits; its high latent heat of vaporisation enables smaller refrigerant charges compared to synthetic alternatives, potentially reducing overall energy consumption (Fatouh & El Kafafy, 2006). Experimental studies have demonstrated that LPG-based systems can achieve superior Coefficients of Performance (COP) compared to R134a systems, with one study reporting an 11.1% reduction in energy demand and 13.2% decrease in compressor runtime (Adelekan et al., 2017).

The application of LPG in refrigeration systems presents particularly promising opportunities for off-grid and energy-scarce regions. In areas with unreliable electricity access, LPG offers a compressor-free cooling solution by utilising its high-pressure storage in cylinders (Chandra, 2012). When expanded through a capillary tube, LPG undergoes an isoenthalpic phase change, absorbing latent heat and producing refrigeration effects without mechanical compression (Fatouh & El Kafafy, 2006). Experimental results have shown impressive performance, with one modified domestic refrigerator using LPG achieving a temperature reduction from 14.7°C to 0°C in a 30L compartment within just 30 minutes (Muzaffar et al., 2023).

Despite these advantages, several challenges must be addressed for widespread adoption. The flammability of LPG necessitates stringent safety measures, and the current inability to recirculate the gas in closed-loop systems presents scalability limitations for household applications (Kumar & Elansezhian, 2019). Recent technological innovations have shown promise in overcoming these challenges.

The incorporation of nanoparticle-enhanced lubricants, such as titanium dioxide (TiO_2), has demonstrated significant performance improvements in LPG systems, yielding 18.74-32.72% higher cooling capacity and COP improvements of up to 61.49% compared to conventional R134a systems (Tipole et al., 2023). Furthermore, optimisation techniques such as the Taguchi method have been successfully applied to refine critical parameters, including capillary tube dimensions and evaporator temperatures, thereby enhancing system efficiency (Kumar & Elansezhian, 2019).

LITERATURE REVIEW

Refrigerant Properties and Thermodynamic Characteristics

Conventional Refrigerant Properties

R-134a (1,1,1,2-tetrafluoroethane) became the predominant replacement for R-12 in domestic refrigeration following the CFC phase-out (Sinche Chele et al., 2024). R-134a exhibits zero ODP, moderate GWP of 1,430, and favourable thermodynamic properties, including appropriate evaporation and condensation pressures for household applications (Savitha et al., 2022). The refrigerant demonstrates good compatibility with common lubricating oils, particularly polyolester (POE) lubricants, and is non-toxic and non-flammable under normal operating conditions (Xu et al., 2022).

However, R-134a has thermodynamic limitations that affect energy efficiency. Comparative studies show that R-134a has lower volumetric refrigeration capacity than R-12, requiring a larger compressor displacement for equivalent cooling capacity (Alsouda et al., 2023). Additionally, R-134a's thermophysical properties, including specific heat, thermal conductivity, and latent heat of vaporisation, differ from those of R-12, thereby affecting heat transfer characteristics in evaporators and condensers (Kumar et al., 2023).

Isobutane (R-600a) represents another widely adopted alternative to R-12, particularly prevalent in European and Asian domestic refrigeration markets (Yana Motta & Domanski, 2022). R-600a has excellent environmental credentials, with zero ODP and a negligible GWP of approximately 3, addressing both ozone-depleting potential and climate change concerns (Ebenezer, 2021). The refrigerant exhibits favourable thermodynamic properties, including high latent heat of vaporisation (367.1 kJ/kg at 0°C compared to R-134a's 217.1 kJ/kg), enabling smaller refrigerant charge requirements (McLinden et al., 2020).

R-600a demonstrates compatibility with mineral oils and alkylbenzene lubricants traditionally used with CFC refrigerants, simplifying retrofit applications and reducing system costs (Uddin & Saha, 2022).

R-404A and R-410A are HFC blends used in some commercial refrigeration applications, though they are less common in domestic systems (Guilherme et al., 2022). R-404A (GWP 3,922) comprises 44% R-125, 52% R-143a, and 4% R-134a, while R-410A (GWP 2,088) contains 50% R-32 and 50% R-125 (McLinden et al., 2020). Both refrigerants face phase-down pressures under the Kigali Amendment due to high GWP values (Piette et al., 2021).

LPG Refrigerant Properties

Propane exhibits superior environmental credentials with zero ODP and GWP of 3, representing one of the lowest-impact refrigerants available (Ilangovan et al., 2025). Thermodynamically, propane demonstrates excellent properties, including high volumetric refrigeration capacity, favourable pressure-temperature relationships, and good heat transfer characteristics (Ramesha et al., 2018). Propane's critical temperature (96.7°C) and pressure (4.25 MPa) fall within appropriate ranges for domestic refrigeration applications (Meng et al., 2024).

Propane's thermophysical properties, including thermal conductivity (0.105 W/m·K at 25°C), viscosity, and specific heat capacity, facilitate efficient heat transfer in evaporators and condensers (Savitha et al., 2022). The refrigerant's latent heat of vaporisation (426.4 kJ/kg at 0°C) exceeds both R-134a and R-12, enabling reduced charge quantities for equivalent cooling capacity (Abas et al., 2018). Propane demonstrates excellent miscibility with mineral oils, eliminating requirements for expensive synthetic lubricants (Owuna et al., 2020).

The primary constraint on propane adoption involves flammability, with ASHRAE A3 classification indicating high flammability under standard test conditions (ASHRAE, 2019). This necessitates charge limitations, typically restricted to 150 grams in household refrigerators per international safety standards (IEC, 2017; ISO, 2019).

While both hydrocarbons share environmental benefits and flammability concerns, thermodynamic differences affect performance characteristics (Harby, 2017). Propane has a higher volumetric refrigeration capacity than isobutane, requiring a smaller compressor displacement for equivalent cooling (Kulkarni et al., 2023). However, isobutane operates at lower pressures, reducing compressor stress and potentially extending equipment lifespan (Savitha et al., 2022). System performance comparisons reveal context-dependent trade-offs between these hydrocarbons, with optimal selection varying by application requirements and design constraints (Kuyukina et al., 2020).

Some research has examined hydrocarbon blends combining propane, isobutane, and other components to optimise thermodynamic properties while managing flammability (Santos et al., 2020). For example, commercial products like HC-12a (R-414B alternative designation) blend multiple hydrocarbons, achieving property profiles intermediate between those of the pure components (Wang et al., 2021). However, blend composition stability, fractionation concerns, and performance consistency across operating conditions require careful evaluation (Shishkova et al., 2022).

Energy Performance Comparisons

Numerous experimental investigations have directly compared the energy consumption of domestic refrigerators operating with propane versus R-134a. Results demonstrated that R-290 achieved 7.9% lower energy consumption than R-134a under identical operating conditions, attributed to its superior thermodynamic properties and reduced pressure drop (Giménez-Prades et al., 2022). Similarly, Mathias et al. (2023) reported energy savings of 3-8% with propane replacement across multiple household refrigerator models.

Rasti et al. (2013) performed detailed experimental comparisons examining not only overall energy consumption but also component-level performance, including compressor efficiency, heat exchanger effectiveness, and system coefficient of performance (COP). Their findings indicated that propane systems achieved 5-12% higher COP depending on ambient temperature and cabinet loading conditions (Rasti et al., 2013). The performance advantage increased at higher ambient temperatures due to propane's favourable pressure-temperature relationships, reducing compressor work requirements (Alawadhi & Phelan, 2022).

However, some studies report more modest differences or context-dependent results. Abas et al. (2018) found that energy consumption varied by less than 3% between R-290 and R-134a in their tested refrigerator, suggesting that system design optimisation for specific refrigerants significantly influences comparative performance. This highlights that direct refrigerant substitution without system optimisation may not fully realise potential efficiency gains (Bista et al., 2018).

Theoretical and Simulation Studies

Thermodynamic Modelling

Theoretical thermodynamic cycle analyses provide fundamental insights into refrigerant performance potential independent of specific hardware implementations (Choi et al., 2018). Chaturvedi et al. (2025) performed detailed vapour-compression cycle modelling comparing R-290, R-600a, and R-134a under standardised operating conditions. The analysis revealed that propane achieved theoretical COP values 8-12% higher than those of R-134a due to its favourable isentropic compression characteristics and reduced throttling losses (Chaturvedi et al., 2025).

Cui et al. (2022) indicated that hydrocarbon refrigerants exhibited lower exergy destruction in compressor and expansion device components, which explains the observed efficiency advantages. However, the analysis also revealed that heat exchanger effectiveness significantly mediated overall system efficiency, suggesting that refrigerant benefits require appropriate heat exchanger design (Omer, 2022).

Component-Level Modelling

Detailed component modelling enables isolation of refrigerant impacts on specific system elements. Roskosch et al. (2017) developed comprehensive compressor models that incorporate real-gas properties, heat transfer, and mechanical losses to predict performance across various refrigerants. Simulations indicated that propane's lower specific heat ratio and molecular weight reduced compressor discharge temperatures and power consumption compared to R-134a (Roskosch et al., 2017).

Dhamodharan et al. (2024) examined convective heat transfer coefficients, pressure drops, and effectiveness for different refrigerants. Results demonstrated that propane exhibited superior heat transfer characteristics in both evaporators and condensers, enabling size reductions while maintaining thermal performance (Dhamodharan et al., 2024). However, the analysis emphasised that geometry optimisation specific to each refrigerant maximises performance benefits.

Computational Fluid Dynamics (CFD)

Advanced CFD modelling provides detailed insights into local heat transfer phenomena and flow distributions affecting refrigerator performance (Moraveji & Toghraie, 2017). Prasad et al. (2023) employed CFD to analyse evaporator performance with R-134a and R-600a, revealing differences in refrigerant distribution, local heat transfer coefficients, and temperature profiles. The simulations indicated more uniform refrigerant distribution with R-600a due to lower mass flow rates, potentially explaining experimental observations of improved temperature homogeneity (Prasad et al., 2023).

Cabinet Air Circulation

Refrigerator cabinet design influences energy consumption through thermal insulation and air circulation patterns (Heidinger et al., 2018). Sun et al. (2023) examined cabinet temperature distributions with different refrigerants, finding that superior evaporator performance with hydrocarbons improved temperature uniformity, reducing compressor cycling requirements. However, cabinet design characteristics, including insulation thickness, door seal quality, and interior organisation, affected the magnitude of refrigerant-dependent performance variations (Sun et al., 2023).

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METHODOLOGY

The study employs a comparative experimental approach to evaluate the performance of an LPG-based refrigeration system against a conventional domestic refrigerator. Two identical refrigeration units with 132-litre capacity are used - one modified to operate with LPG and the other maintaining its original R134a refrigerant system. The experimental setup includes precision instruments for temperature measurement (±0.5°C accuracy), pressure gauges (0-500 psi range), power meters, and gas flow meters, all connected to a digital data acquisition system for continuous monitoring.

System Modification for LPG Operation

The test refrigerator undergoes careful modification to accommodate LPG refrigerant. The conventional compressor-condenser unit is replaced with a 15kg LPG cylinder equipped with a high-precision pressure regulator. A capillary tube expansion device is installed, and the system is thoroughly checked for leaks using gas detectors. Safety features, including pressure relief valves and emergency shut-off mechanisms, are incorporated. The modified system maintains all original insulation properties to ensure a valid comparison.

Working Principle of LPG Refrigeration System

The LPG refrigeration system operates through a carefully engineered thermodynamic process that leverages the phase-change properties of liquefied petroleum gas to generate cooling. At the heart of this system lies a pressurised LPG cylinder containing gas stored at approximately 80 psi, which serves as both the refrigerant and energy source. When the regulator valve is opened, high-pressure LPG begins its journey through the system, first flowing through a reinforced gas line designed to withstand the substantial internal pressure.

The critical transformation occurs as the LPG passes through the capillary tube, an expansion device that creates a deliberate pressure drop. This isentropic expansion process reduces the pressure to about 15 psi while maintaining constant enthalpy, resulting in a significant decrease in temperature. The now low-pressure, low-temperature LPG enters the evaporator coils located within the refrigerated compartment, where it absorbs heat from the surrounding environment. This heat absorption causes the LPG to undergo a complete phase change from liquid to vapour, thereby producing the desired refrigeration effect that cools the storage space.

Following its passage through the evaporator, the low-pressure LPG vapour can be directed to a burner for productive utilisation, creating a dual-purpose system that maximises energy efficiency. Alternatively, in simpler configurations, the vapour may be safely vented. This innovative design eliminates the need for conventional electric compressors, instead relying on the inherent pressure energy stored in the LPG cylinder. The system's simplicity, featuring no moving parts beyond the

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regulator valve, enhances its reliability and makes it particularly suitable for off-grid applications where electricity access is limited or unavailable. The schematic diagram is shown in Figure 1.

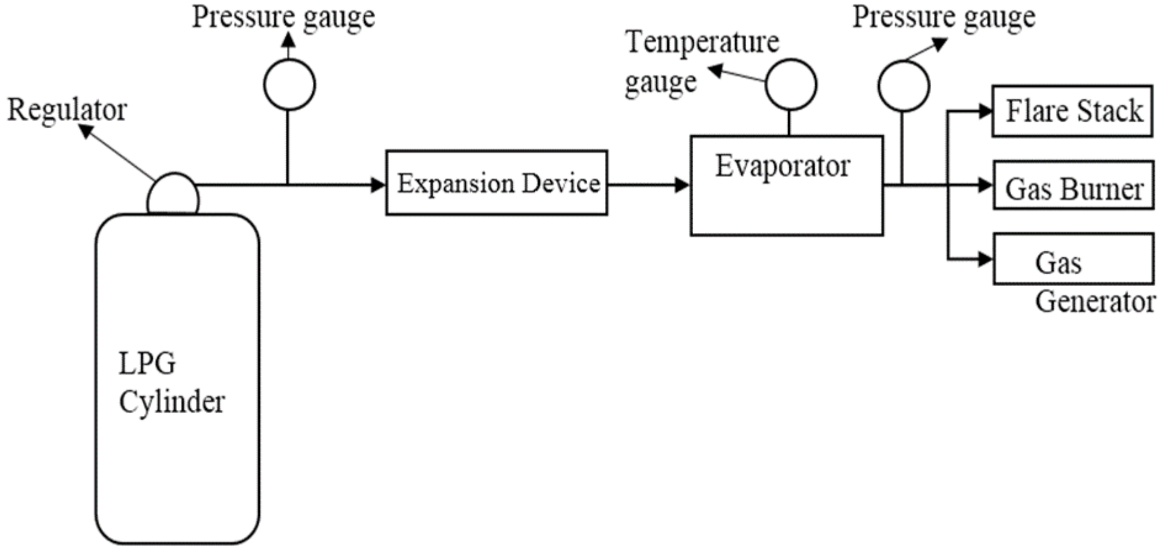

Figure 1: Schematic Diagram of an LPG Refrigeration System

Experiment Procedure

For the experiment to proceed, all equipment must be installed. The outlet of the cylinder is connected to the expansion device, with a pressure gauge installed between the expansion device and the cylinder to measure the inlet pressure. The expansion device is connected to the evaporator inlet. The burner is also connected to the outlet of the evaporator, with a pressure gauge installed between the evaporator and the burner to take the outlet pressure reading. The LPG cylinder is inverted to ensure that liquid LPG comes out at high pressure. The high-pressure valve on the cylinder is partially opened to allow refrigerant (LPG) to flow through the system. The parameters used in the experiment are stated below:

- A 132-litre domestic electric refrigerator rated at 100W and consuming 0.48 kWh/24 hours.
- An LPG-powered refrigerator connected to a 15 kg LPG cylinder with an energy content of 735 MJ.

For the LPG refrigerator, usage is assumed to be 18 hours per day for 30 days, while the electric refrigerator is assumed to consume energy at the stated rate under the same duration. The test was also conducted under the following conditions: The inlet pressure of the system was set at 6 bar, while the outlet pressure was 1.37 bar. The ambient (surrounding) temperature at the time of the test was 27°C.

During the test, the evaporator temperature was set to 29°C. This temperature was recorded every 10 minutes over a 60-minute period to monitor its changes.

Figure 2: The Complete Setup of the LPG Refrigeration System

RESULTS AND DISCUSSION

Five experiments were conducted with varying inlet and outlet pressures to analyse their impact on cooling performance. Table 1 summarises the recorded temperature and pressure data. The results demonstrate how pressure variations influence the refrigeration effect, with detailed trends visible in the tabulated data.

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Table 1: Pressure Variations Influence the Refrigeration Effect

Time (mins)	Pressure at inlet (bar)	Pressure at outlet (bar)	Temperature (°C) of evaporator
0	6	1.02	33.2
10	6	1.02	29.3
20	6	1.02	24.1
30	6	1.02	19.6
40	6	1.02	13.3
50	6	1.02	6.9
60	6	1.02	2.5

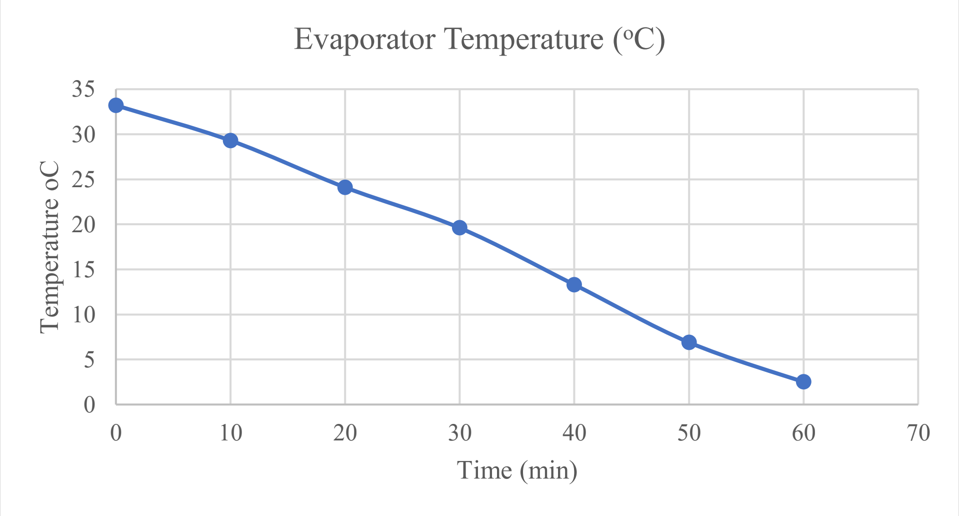

Figure 3: Effective Cooling Capability of the LPG Refrigerant

The temperature-time plot in Figure 3 demonstrates the LPG refrigerant's effective cooling capability. As the system operates, the evaporator temperature decreases steadily, confirming that LPG effectively absorbs heat from the refrigerated space.

Table 2: System Performance adjusted inlet pressure to 4.5 bar

Time (mins)	**Pressure at inlet (bar)**	**Pressure at outlet (bar)**	**Temperature (°C) of evaporator**
0	4.5	0.97	32
10	4.5	0.97	28.7
20	4.5	0.97	21.3
30	4.5	0.97	16.6
40	4.5	0.97	9.9
50	4.5	0.97	4.7
60	4.5	0.97	1.4

Table 3: System Performance

Time (mins)	**Pressure at inlet (bar)**	**Pressure at outlet (bar)**	**Temperature (°C) of evaporator**
0	4.5	0.72	31
10	4.5	0.72	28.1
20	4.5	0.72	23.2
30	4.5	0.72	18.6
40	4.5	0.72	12.5
50	4.5	0.72	6.3
60	4.5	0.72	1.3

The experimental results from subsequent trials are systematically documented in Tables 2 and 3, providing a comprehensive comparison of system performance under varying operating conditions. In the second experimental run, the inlet pressure was carefully adjusted to 4.5 bar, resulting in an outlet pressure of 1.25 bar, while maintaining an ambient temperature of 32°C throughout the testing period.

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The third experiment featured different operational parameters: the system operated at a reduced inlet pressure of 3 bar, yielding an outlet pressure of 0.96 bar, under slightly cooler ambient conditions of 31°C. These deliberate variations in both inlet pressures and environmental temperatures were implemented to thoroughly investigate the LPG refrigeration system's response to different thermodynamic states and its ability to maintain stable cooling performance across a range of operating scenarios. The collected data corroborate the findings of Babarinde et al. (2022), demonstrating the system's pressure-dependent characteristics and providing valuable insights into the relationship between operating parameters and refrigeration efficiency.

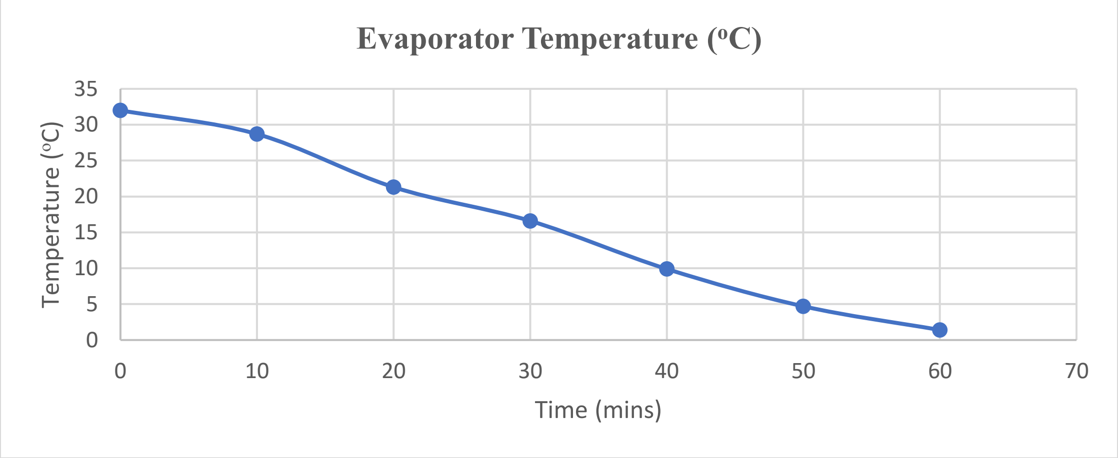

Figure 4: Graph of Experiment Two (Evaporator Temperature)

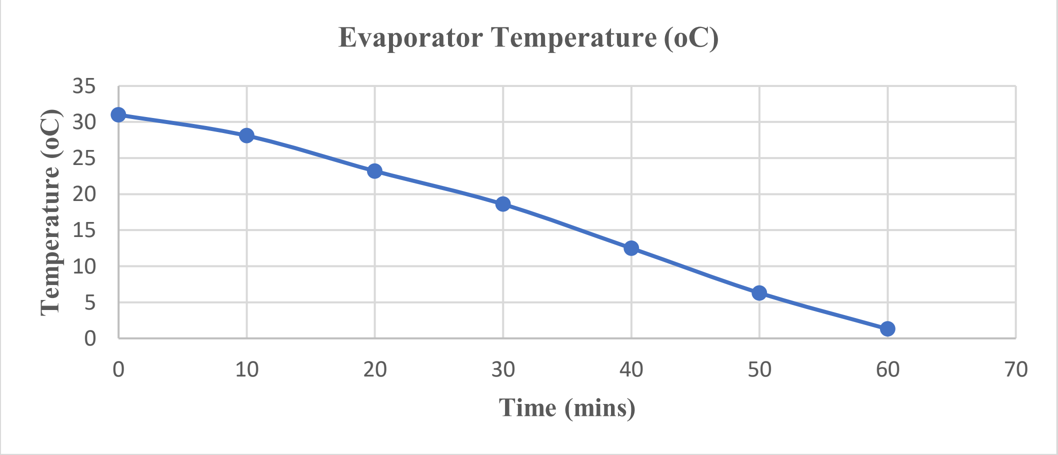

Figure 5: Graph of Experiment Three (Evaporator Temperature)

The results from experiments two and three corroborate the findings of the initial experiment, as clearly illustrated in Figures 4 and 5. Despite variations in inlet pressure across trials, the outlet pressures remained similar because the expansion device maintained a constant diameter. This consistent behaviour demonstrates that the expansion device serves as the primary control mechanism for the refrigeration system's operation.

All three experimental trials conclusively demonstrate that LPG is an effective alternative refrigerant for refrigeration applications. The data consistently shows that, regardless of input pressure variations, the system maintains stable performance characteristics when properly configured with an appropriate expansion device. These findings validate LPG's potential as a viable substitute for conventional refrigerants in refrigeration systems (Kulkarni et al., 2023).

Performance Refrigerator

The conventional refrigeration system used for comparative analysis in this study was a 125-litre Westpoint tabletop refrigerator with an energy rating of 100 kWh per 24 hours. The temperature measurements in Table 4 document the refrigerator's performance at 10-minute intervals under controlled ambient conditions of 31°C. For accurate comparison, the experimental setup maintained identical evaporator dimensions and refrigerated space volume between the conventional refrigerator and the LPG-based system being evaluated. This is consistent with Katoch et al. (2022), who noted that the standardised approach ensured consistent testing parameters across both refrigeration configurations.

Table 4: Performance Refrigerator

Time (mins)	Evaporator Temperature (°C)
0	31.7
10	22.5
20	14.7
30	4
40	-1
50	-4
60	-9

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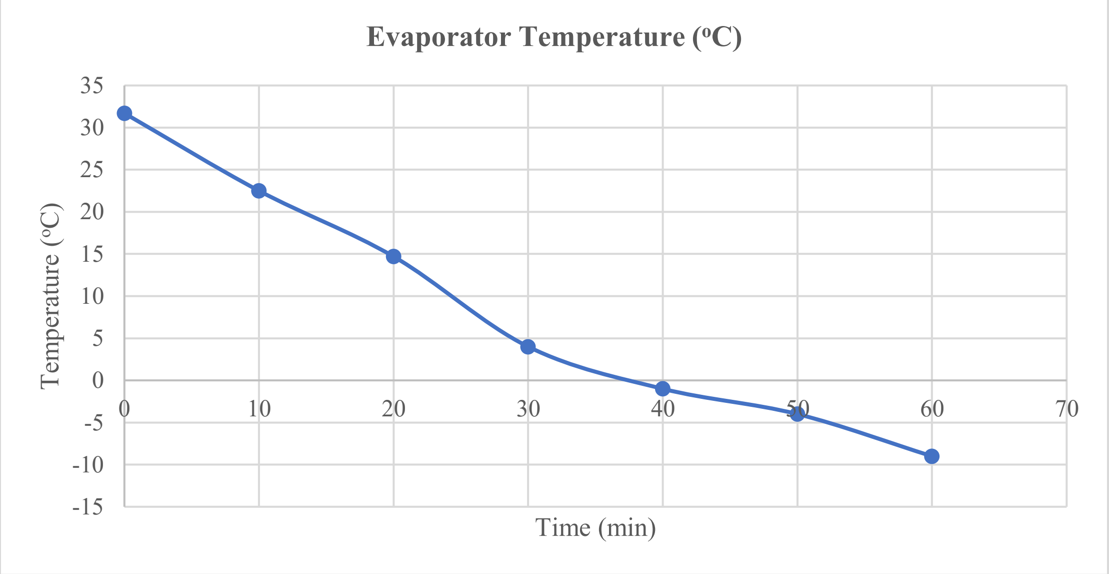

Figure 6: Cooling Rate versus Time for the Conventional and LPG Refrigerators

Figure 6 compares the cooling rate versus time for the conventional and LPG refrigerators. Both systems exhibit similar cooling trends, with an initially gradual temperature drop during the first ten minutes as thermal energy is absorbed by the refrigerant lines and evaporator components.

The analysis reveals two key findings:

1. The conventional refrigerator demonstrates faster cooling performance compared to the LPG system
2. The LPG refrigerator's cooling capacity shows direct pressure-dependence:
    i. Increased inlet pressure enhances the cooling rate
    ii. Reduced inlet pressure diminishes cooling effectiveness

This pressure-sensitive behaviour in the LPG system contrasts with Bohne's (2023) finding that the electrically-driven domestic refrigerator performs more consistently, highlighting an important operational characteristic of pressure-based refrigeration systems. The comparative results provide valuable insights into the thermodynamic differences between the two refrigeration approaches.

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CONCLUSION

Based on the experimental analysis, several key conclusions can be drawn regarding LPG refrigeration systems. First, the study confirms that Liquefied Petroleum Gas (LPG) effectively produces refrigeration and can serve as a viable alternative refrigerant.

This technology offers significant advantages by reducing reliance on electrical power, making it particularly suitable for areas with limited or no access to electricity. Additionally, when the outlet gas is repurposed for cooking, heating, or power generation through a gas generator, the system can achieve near-zero operating costs.

Environmentally, adopting LPG as a refrigerant would decrease reliance on conventional refrigerants, thereby reducing their contribution to global warming. The system's simple design, with no moving parts, ensures minimal maintenance requirements. However, cost analysis reveals that operating the flared LPG refrigeration system for a month is approximately 16 times more expensive than running a traditional refrigerator, suggesting that this technology is most economically viable for industries or sectors already utilising LPG for their process operations. These findings demonstrate that while LPG refrigeration presents promising alternatives for specific applications, its widespread adoption requires careful consideration of both technical and economic factors.

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