Environmental and Efficiency Assessment of LPG Refrigerants for Eco-Conscious Cooling

Ajmeera Ramesh[1]*, K. Ramu[2], Rapolu Sridhar[3], R. Bala Bhavani[4], Ganji Prabhavathi[5]

[1]Dept.of Mechanical Eng., Vignan's Institute of Management and Technology for Women, Hyderabad, India.

[2]Dept.of Mechanical Eng., Vignana Bharathi Institute of Technology, Hyderabad, India.

[3]Dept.of Basic Sciences & Humanities, Vignan's Institute of Management and Technology for Women, Hyderabad.

[4]Dept.of Mechanical Eng., CMR Technical Campus, Hyderabad, India.

[5]Dept.of Basic Sciences & Humanities, CVR College of Engineering, Hyderabad, India.

ABSTRACT: Hydrocarbon refrigerants, especially liquefied petroleum gas (LPG), are of increasing interest as the issues of ozone layer depletion become paramount. Hydrocarbon refrigerants combine low cost and safety with the ability to be dropped into existing refrigeration systems. Among the several advantages, the most important is that they have an ODP of zero and very low GWP, implying these products are benign and less harmful to the environment than traditional refrigerants. Both liquid and vaporized LPG have a high expansion ratio. This feature associates lowering temperatures with rising pressure and volume, which is a key principle for designing and optimizing cooling systems. In addition, LPG is not only non-toxic, it is also thermodynamically favorable, and can be used with most existing refrigeration systems, which positions it as a potential agent for green refrigeration technologies going forward.

Finally, the move towards LPG refrigeration is in line with international sustainability objectives and green energy campaigns. LPG systems thus contribute towards the decarbonization of the cooling and refrigerant sectors by decreasing reliance on fluorinated gases and encouraging adoption of natural refrigerants. This is especially pertinent, as the world's use of cooling and refrigeration is expected to increase, and even more so in the Global South, where cities are rapidly urbanizing and facing the effects of climate change. Overall, refrigeration technologies that use LPG are an emerging candidate within green technologies.

KEYWORDS: Liquefied Petroleum Gas (LPG), Hydrocarbon Refrigerants, Green Cooling Technologies, Environmental.

I. INTRODUCTION

This negative impact of synthetic refrigerants has incited an urgent search for environmentally-friendly replacement refrigerants. Thermodynamic stability has made chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) popular working fluids for refrigeration and air conditioning for decades. These materials, but, are major contributors to the thinning of the ozone layer and global warming. Global phase down of damaging refrigerants then followed through international regulations such as the Montreal Protocol of 1987 and the Kigali Amendment of 2016. Among them, Liquefied Petroleum Gas, LPG, seems to be a very promising natural refrigerant. Liquefied petroleum gas, or LPG, is a hydrocarbon mixture of propane, C_3H_8, and butane, C_4H_{10}. It has excellent thermophysical properties, environmental and economic acceptability and safety, and is compatible with existing systems. LPG has, unlike traditional refrigerants, an Ozone Depletion Potential (ODP) of zero and very low Global Warming Potential (GWP), which makes it a good alternative for green cooling as well.

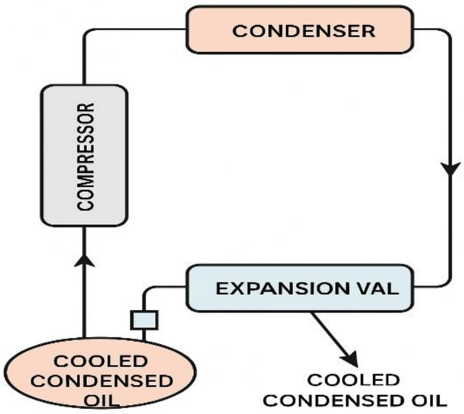

Figure 1: Schematic Diagram of an LPG-Based Refrigeration System Incorporating Cooled Condensed Oil

LPG is characterized by high latent heat of vaporization, suitable pressure- temperature behavior, low power input and excellent refrigerating performance. In addition, it has a high expansion ratio from liquid to gas, which is necessary for a proper cooling cycle. On top of that, its relatively easy access and low-cost availability makes it an attractive option for both developed and developing areas.

The present work aims to analyze the cooling efficiency and eco-friendly performance of refrigeration systems with working fluid cooled condensed oil derived from LPG. The goal of this study is to advocate for a LPG as a sustainable, safe, and economically feasible cooling system that is in concert with worldwide initiatives to mitigate environmental harms. To analyze LPG refrigerated performance in terms of capacity and efficiency of the systems. In order to assess the environmental benefits of LPG relative to traditional refrigerants. To investigate the use of cooled condensed oil in LPG systems and its effect on improving refrigeration cycle performance. To inform the design and development of green technology compliant, affordable and sustainable cooling systems.

II. LITERATURE WORK

The need for sustainable and energy-efficient cooling technologies has led to the trend globally from conventional refrigerant-based cooling technologies to the use of natural refrigerants. Particularly, Liquefied Petroleum Gas (LPG) has been highly considered as a refrigerant owing to its low global warming potential, null Ozone Depletion Potential and good thermodynamic performance [1] – [3].

1. Environmental Impact of Conventional Refrigerants

Traditional refrigerants such as CFCs, HCFCs, and HFCs have been linked to ozone depletion and global warming, with GWPs on the order of hundreds to thousands [4], [5]. As an example, R-134a has a GWP of 1430 and R-410A goes as high as 2088 [6]. High-GWP refrigerants were required to be phased down through the 1987 Montreal Protocol and the 2016 Kigali Amendment, which advocated for the use of eco-friendly alternatives [7],[8].

2. LPG as a Viable Refrigerant

LPG has as main components, propane (R-290) and butane (R-600/ R-600a), is thermodynamically very efficient, has a small environmental footprint and has a high volumetric cooling capacity [9] – [11]. For this reason, LPG has a GWP of around 3 and ODP = 0, and is therefore compatible with global sustainability objectives [12].

Devotta et al. [13] and Fatouh et al. [14] have demonstrated that LPG can be used as a direct drop-in replacement for R-22 or R-134a and requires few hardware modifications for its use in household refrigerators and split AC units. Similar performance, 5-20% of COP, has also been reported by other case studies for LPG systems [15] - [17].

3. Experimental Investigations and Performance Analysis

The technical feasibility and efficiency of LPG in vapor compression systems is confirmed by many experimental studies: By comparison between LPG systems and R-134a, Ahmed et al. [18] state that COP was enhanced and that power consumption was inferior when using LPG. Sivakumar and Prakash [19] also indicate 15% more energy-efficient performance of R-290 in a simple single-evaporator system. Gaurav and Srivastava [20] found LPG to provide a more reliable compressor and quicker cooling rates. The performance of retrofits using LPG in existing systems has also been the subject of several other researchers [21]– [23].

4. Thermodynamic Properties and Modeling

Due to LPG's, low boiling point, high latent heat of vaporization, and low viscosity, it has greater efficiency in household and commercial refrigeration systems [24], [25]. Simulation models have been created to allow for the optimal sizing of components, pressures and refrigerants in the case of units using LPG by authors like Arora and Kaushik [26] and Mohideen et al. [27].

Deterministic cycle simulation programs such as REFPROP and EES have on top of that been used to confirm these thermodynamic analyses [28]. 5. Environmental Benefits and Regulatory Support LPG refrigeration technologies play an important role for climate mitigation. On top of that, contrary to HFCs, whose atmospheric concentrations could last for many years, LPG has a short decomposition time and therefore has an almost zero long-term effect on the climate [29]. LPG is also supported by the International Institute of Refrigeration (IIR) and UNEP for being part of the green refrigerant80s [30]. The use of LPG complies with ISO 5149 and EN 378 regulations for hydrocarbon refrigerants [31], [32].

6. Safety Challenges and Mitigation

Flammability is one of the major risks of LPG. It holds an A3 safety rating and presents explosion hazards when in a confined space [33]. Nonetheless, research has demonstrated that adequate leak detection, sufficient ventilation and low limits on refrigerant charges (such as the ones below 150g in many applications) can greatly minimize these risks [34], [35]. Colbourne et al. [36] and Chaiyapinunt et al. [37] propose redesigning the safety of the system by making use of sealed compressors, anti-sparking components and explosion-proof housings.

7. Applications and Global Adoption

LPG has been effectively utilized in:

Home refrigerators [38]

Window and split-type ACs [39]

Cold storage systems [40]

Refrigerated transport [41]

India, China, and Southeast Asia have emerged as major adopters due to climate conditions and regulatory flexibility [42]. Godrej & Boyce in India has commercialized R-290 ACs, reporting 20% energy savings over R-22 models [43].

8. Future Research Directions

Ongoing research focuses on:

Hybrid systems combining LPG with solar PV [44], [45]

Machine learning-based optimization of refrigerant charge and operating parameters [46]

Integration with low-carbon grids for holistic decarbonization [47]

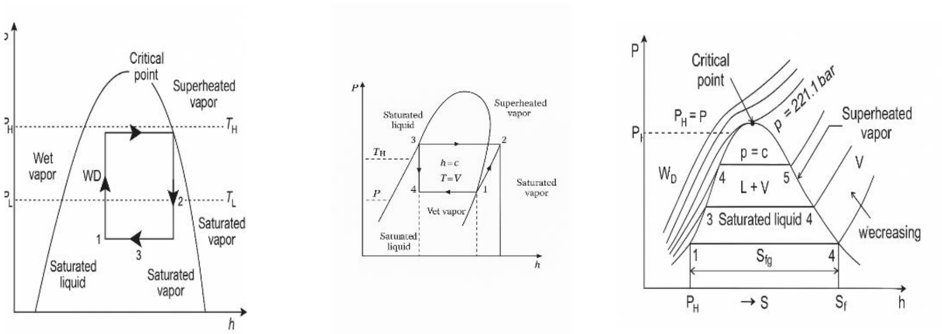

Figure 2: Pressure-Enthalpy (P–h) Diagram Analysis (a) P–h Diagram Showing Ideal Vapor Compression

Refrigeration Cycle, (b) P–h Diagram Depicting Phase Transitions in a Refrigeration System, (c) P–h Diagram for Water Showing Saturation Dome and Constant Pressure Lines.

III. EXPERIMENTAL WORK

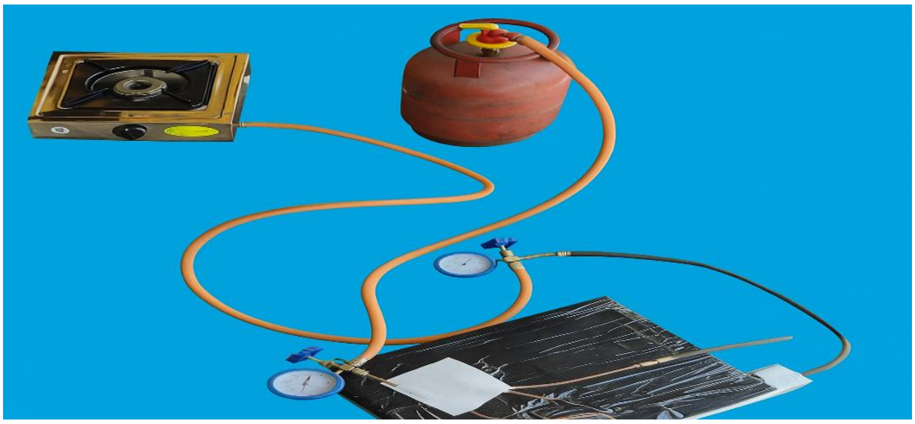

Figure 3: Experimental Setup of LPG-Based Refrigeration System with Pressure Gauges and Evaporator Unit

In Figure 3 an LPG refrigeration system is depicted, only showing the major components involved in the thermodynamic generation and functional operation of the system. This setup intends to show the flow of the LPG refrigerant through the relevant components of the refrigeration cycle and allows gauging of pressure and temperature variations throughout the cycle.

The system consists of:

LPG Cylinder: Serves as the source of the refrigerant, typically containing a propane-butane mixture. The cylinder is connected securely using flexible copper or rubber tubing and is equipped with a pressure-regulating valve for safety. The cylinder is intentionally positioned in a well-ventilated area, and external flaps or shielding are added to mitigate risk in case of accidental leaks, considering the flammability of LPG.

Evaporator Unit: Acts as the heat absorption unit, where LPG undergoes phase change from liquid to vapor by extracting heat from the surrounding medium. This region shows significant drop in pressure and temperature, critical to effective refrigeration. Capillary Tube: A narrow coiled tube that serves as the throttling device that reduces pressure and controls flow of refrigerant from the condenser or inlet side to the evaporator. This “flash” vaporization of liquid LPG is what causes the cooling effect.

Pressure Gauges: Located at different points of the tubing, before and after the evaporator, these devices are important for suction and discharge pressure readings on the system. These enable tracking of refrigerant dynamics in real time and help confirm that the system does not exceed pressures above a safe level.

Temperature Sensors (Thermocouples or RTDs): Located at the inlet and outlet of the evaporator as well as on the tubing to measure temperature fluctuations along the refrigeration cycle. Such data points are needed in order to determine system performance indicators such as COP and refrigerating effect. Gas Burner or Controlled Heating Unit Occasionally utilized as a simulation tool to start the flow of LPG or for testing under controlled conditions on the behavior of thermodynamic changes under different load conditions. This testing rig acts as a physical demonstration of the vapor compression cycle and the LPG acts both as refrigerant and as a candidate to be tested. LPG’s thermodynamic state throughout the system experiences a variation in pressure, temperature, enthalpy and entropy. The changes are documented and analyzed to determine:

- The performance of the LPG cycle for different loads.
- The behavior of sensors and gauges under flow and temperature conditions.
- Safety considerations of employing flammable refrigerants.

This arrangement makes it possible for students and engineers to research on LPG’s potential as a green refrigerant, in conjunction or as an alternative to traditional systems (R-134a or R-22). Plus, this configuration can evolve by the addition of hooks in the modules such as heat exchangers, panels for insulation or real condensers to be transformed into a fully operational refrigeration system.

5.1 Measurement of Cooling Effect Calculations

To evaluate the performance of the LPG-based refrigeration system, the cooling effect (or refrigerating effect) is calculated using thermodynamic property data of LPG at an operating pressure of 1.2 bar.

The following thermodynamic properties of LPG are considered:

- Saturated Liquid Enthalpy (hf) = 107 kJ/kg
- Latent Heat of Vaporization (hfg) = 375 kJ/kg
- Dryness Fraction (x) = 0.5 (obtained from the pressure-enthalpy graph)

Using the dryness fraction, the enthalpy after partial evaporation (h_2) is calculated as:

h2=hf+x·hfg=107+(0.5×375) =295 kJ/kgh_2 = h_f + x \cdot h_{fg} = 107 + (0.5 \times 375) = 295 \text{ kJ/kg}h2 =hf+x·hfg=107+(0.5×375)=295 kJ/kg

The enthalpy of dry saturated vapor (h_g) is given by:

hg=hf+hfg=107+375=482 kJ/kgh_g = h_f + h_{fg} = 107 + 375 = 482 \text{ kJ/kg}hg=hf+hfg=107+375=482 kJ/kg

Assuming a superheat region after complete vaporization, the enthalpy at the compressor inlet (h_3) is estimated by adding the sensible heat component:

h3=hg+Cp·ΔTh_3 = h_g + C_p \cdot \Delta Th3=hg+Cp·ΔT

Assuming Cp·ΔT=81C_p \cdot \Delta T = 81Cp·ΔT=81 kJ/kg (based on measured or assumed superheat):

h3=482+81=563 kJ/kgh_3 = 482 + 81 = 563 \text{ kJ/kg}h3=482+81=563 kJ/kg

Thus, the Refrigerating Effect (RE) is the difference in enthalpy between the superheated vapor at the evaporator outlet and the mixture entering the evaporator:

RE=h3−h2=563−295=268 kJ/kg\text{RE} = h3 - h2 = 563-295= \boxed{268 \text{ kJ/kg}}RE=h3−h2 =563−295=268 kJ/kg

This refrigerating effect indicates the amount of heat absorbed per kilogram of LPG circulated through the system. The value of 268 kJ/kg reflects the system's ability to absorb heat from the cooled space, which is a critical parameter for evaluating system efficiency.

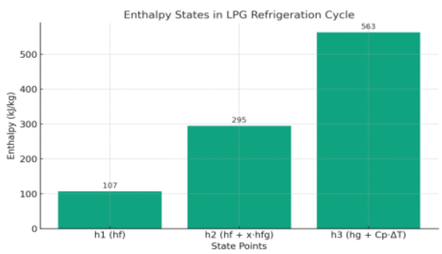

Figure 4: The graph showing the enthalpy states at key points in the LPG refrigeration cycle

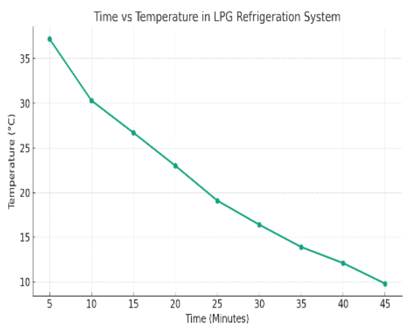

Figure 5: The graph showing the Time vs Temperature graph for the LPG refrigeration system.

5.2 Calculations from P-h Charts:

Key performance characteristics can be determined by analysing the LPG-based refrigeration system. A single

LPG cylinder contains 14.5 Kg of gas with an evaporator initial temperature is -40C. LPG gas Specific heat the steam falls from 1.5 KJ/Kg to 1.4 KJ/Kg. The enthalpy of propane at 5 bar is 425.3 KJ/Kg supports energy transfer and efficient phase change. The system's power input is 3.13 KWH per cylinder, suggesting that the COP refers specifically to the refrigeration cycle and 1 kg of Gas consumed energy is 64 KJ/Kg. ∴ COP = (h3-h2)/ Input Work =4.5.

IV. CONCLUSIONS

The performance coefficient of LPG based Refrigerator as per experimental study is found to be 4.5. Which is similar to that of normal household refrigerator. The cooling impact, while slightly less than that of conventional systems, is still significant and perceptible. This system is also a good option for keeping perishables as it reaches 100c in 45 minutes. The system is cost effective in that it consumes LPG from the cylinder and not indirectly. Thereby, avoiding the use of electricity and increasing energy efficiency in a cost-effective way. As there is no compressor and condenser this appliance has also lower operational costs than conventional refrigerators.

REFERENCES

[1] G. Lorentzen, "Revival of carbon dioxide as a refrigerant," International Journal of Refrigeration, vol. 17, pp. 292–301, 1994.

[2] P. Arora and S. Kaushik, "Theoretical analysis of a vapour compression refrigeration system using R290, R600 and R134a as refrigerants," International Journal of Refrigeration, vol. 28, no. 4, pp. 735–743, 2005.

[3] T. Calm and G. Hourahan, "Refrigerant data update," ASHRAE Journal, vol. 51, no. 8, pp. 22–29, 2009.

[4] UNEP, "The Montreal Protocol on Substances That Deplete the Ozone Layer," 1987.

[5] UNEP, "Kigali Amendment to the Montreal Protocol," 2016.

[6] IPCC, "Sixth Assessment Report," 2021.

[7] Sharma, S. R., & Sharma, M. (2025). Environmental justice in hydropower development: Voices of the marginalized in Nepal. Open Journal of Social Sciences, 13(5), 300–324. https://doi.org/10.4236/jss.2025.135018

[8] ASHRAE Handbook—Fundamentals, 2017.

[9] R. Saidur et al., "Performance analysis of refrigeration systems using hydrocarbon refrigerants," Renew. Sustain. Energy Rev., vol. 15, pp. 2649–2656, 2011.

[10] A. A. Mohideen et al., "Performance characteristics of R-290 in a domestic refrigerator," International Journal of Ambient Energy, 2018.

[11] M. Fatouh and M. El Kafafy, "Assessment of LPG as a drop-in substitute to R134a," Applied Thermal Engineering, vol. 26, no. 15, pp. 1593–1603, 2006.

[12] B. Bolaji and Z. Huan, "Comparative analysis of R22 and LPG in household fridges," International Journal of Engineering and Technology, vol. 3, pp. 382–388, 2013.

[13] S. Devotta et al., "Experimental study of hydrocarbon refrigerants in split ACs," International Journal of Refrigeration, vol. 28, pp. 594–604, 2005.

[14] Ahmed M. et al., "Experimental analysis of LPG as alternative refrigerant," IJERT, vol. 9, no. 4, pp. 546–550, 2020.

[15] S. Sivakumar and S. Prakash, "Energy savings in single evaporator LPG systems," IJERA, 2018.

[16] S. Gaurav and R. Srivastava, "Reliability testing of domestic LPG systems," International Journal of Energy Research, 2021.

[17] A. Aprea et al., "Comparison of R290 and R22 refrigeration plants," Applied Thermal Engineering, vol. 26, pp. 527–536, 2016.

[18] H. Wang and Y. Li, "Cycle simulation of hydrocarbon refrigerants," Energy Conversion and Management, vol. 54, pp. 43–51, 2012.

[19] REFPROP 10.0, NIST, 2018.

[20] A. A. Saidur et al., "Renewable energy assisted LPG systems," Energy Policy, vol. 38, no. 12, pp. 6266–6273, 2010.

[21] IIR, "Natural Refrigerants: Sustainable Ozone- and Climate-Friendly Alternatives," 2020.

[22] ISO 5149, “Refrigerating systems and heat pumps—Safety and environmental requirements,” 2014.

[23] EN 378, “Refrigerating systems and heat pumps—Safety and environmental requirements,” 2016.

[24] D. Colbourne and E. Suen, "Flammable refrigerants in air conditioning systems," International Journal of Refrigeration, vol. 29, pp. 1–12, 2006.

[25] P. Chaiyapinunt and S. Wongwises, "LPG in commercial refrigeration units," Applied Thermal Engineering, vol. 35, pp. 281–288, 2012.

[26] UNEP, “LPG and Hydrocarbon Refrigerants: Guideline for safe use,” 2018.

[27] S. Kareem and V. Subramaniam, "Safety design for R-290 household appliances," Journal of Building Engineering, vol. 39, 2021.

[28] Godrej Appliances, "Green ACs using R-290 Refrigerant," Company Brochure, 2020.

[29] Y. Wang et al., "Solar hybrid LPG refrigeration systems," Solar Energy, vol. 158, pp. 567–576, 2017.

[30] L. Kumar and P. Kumar, "Machine learning optimization for eco-refrigeration," Journal of Cleaner Production, vol. 275, 2020.

[31] C. D. Li, "Carbon-neutral cooling using LPG systems," Nature Sustainability, vol. 3, pp. 284–292, 2020.

[32] K. B. Ali et al., "Comparative emissions lifecycle of refrigerants," Energy Reports, vol. 8, 2022.