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Original Article

An Experimental Study on the Effectiveness of Propane and its Blends with Isobutane in Hermetically-Sealed Refrigerating System

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Abstract *- Research into alternate alternatives has been prompted by worries about the environmental impact of conventional refrigerants. Despite the potential flammability risks of hydrocarbon-based refrigerants, a large body of associated literature exists. This work comprises a comparative study between propane (R290) and its blends with isobutane (R600a) in varying proportions (2% to 50% of the isobutane). Important information about the possibility of employing these blends as environmentally benign substitutes for conventional refrigerants is provided by the observation. In particular, it takes almost half an hour for the evaporator temperature to reach 2.9°C when R290 is utilized alone. On the other hand, under the same ambient temperature of 31°C, the evaporator temperature lowers to -3.2°C in just 24 minutes when R290 and an equivalent amount of R600a are combined.*

Keywords *- Climate change, Isobutane, Flammability, Refrigerants, Sustainability.*

1. Introduction

Alternative alternatives are being researched as a result of worries about the environmental impact of conventional refrigerants. [1, 2, 6] Based on its advantageous thermodynamic qualities, [2] propane (R290) has been recognized as a possible alternative; nonetheless, safety concerns are raised by its flammability. [16–20, 23] Despite favorable thermodynamic properties, such as high efficiency and low negative impact on the environment, related literature essentially highlights the potential risks associated with propane use, mainly due to its flammability. [3, 5, 7]. Therefore, further research is imperative to fully comprehend the benefits and risks of implementing propane in refrigeration systems. [1, 2, 4, 6, 8-10, 23-24]

1.1. Problem Statement and Objective

Literature thoroughly investigates the performance, efficiency, and long-term implications of using propane with specific blends. [10] Developing robust strategies and guidelines for safe and sustainable implementation-related research outcomes is vital. [12, 13] With the development of refrigerant mixtures with the admissible magnitude of flammability that abides by the stringent safety standards related to flammability, the range of applications in which propane can be employed widens considerably. [14, 15] The primary objective of this work is to lay forward the preliminary observations related to the thermodynamic performance of propane blended with isobutane as a refrigerant relative to neat propane (commercially available composition), mainly focusing on the time taken to reach the particular evaporator temperature.

2. Materials and Methods

Notably, specific choices and concentrations of additives can fluctuate reliant on application, system requirements, and regulatory considerations. [2-5, 7-11] literature typically conducts extensive testing and evaluations to estimate the optimal blend amount for propane-based refrigeration systems. [4] Isobutane (R600a) is a hydrocarbon refrigerant commonly used in household refrigerators and air-conditioning systems. [2, 16] In this work, initially, the set-up is charged with a 100 gram of R290 to observe the refrigeration-related thermodynamic data, e.g., coefficient of performance (COP), rate of work input to the compressor (W), flammability and heat capacity of refrigerants etc. Afterwards, the same set-up was charged with R290 that was blended with R600a in varying proportions such that the concentration of R600a varies between 2% to 50% to observe the change in values of thermodynamic data associated with neat R290. Please note that the mass of blended refrigerant is also 100 grams. The experiment set-up, as shown in Figure 1, comprises a modified domestic refrigerator using a zoetrope blend of R290/R600a instead of R134a. The compressor is a reciprocating hermetic sealed type that spins at 50 Hz (about 2900 rpm) and has a 12.11 cm^3 cubic capacity. The compressor specifications are designed to work using 350 ml of POE ISO22 lubricating oil with refrigerant R134a. While considering the variable capacity refrigeration systems (VCRS), it is highly desirable to follow the standard safety protocols. Namely, (a) compliance with the International Electro-Technical Commission (IEC) standard for flammable refrigerants, (b) installation of leak detection gauges, (c) proper ventilation, (d) system design and equipment selection, (e) emergency shut-down, (f) operation training along with awareness, (g) installation of fire suppression systems, and (h) proper maintenance. It is worth noting that the specific steps and needs may vary depending on local regulations, intended application, and complexity of the VCRS. Charging and discharging of the refrigerants have been undertaken under controlled conditions with flammable gas detectors in the vicinity.

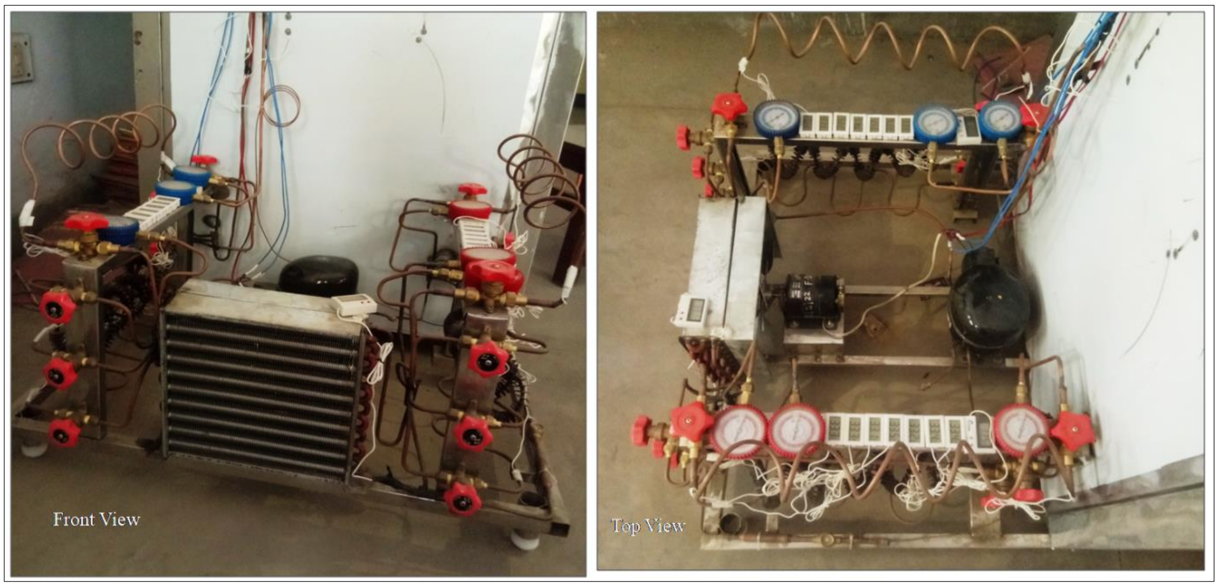

Fig. 1 Experimental set-up (modified domestic refrigerator)

3. Results and Discussion

In the present study, an experimental investigation has been carried out on VCRS, specifically focusing on the utilization of R-290 and its blends with R-600a. The objective was to assess the refrigerating performance of these refrigerants and draw inferences based on the observations. Following are the observations recorded during the experimental runs utilizing a modified domestic refrigerator. The formula created by Kline and McClintock has been used to associate the uncertainty in the results. A maximum uncertainty of ±3.5% is ascribed to each of the examined parameters. [27]

3.1. Refrigeration-Related Thermodynamic Data Associated with Neat R290

Table 1 shows the thermodynamic data, namely, time interval (t), evaporator temperature (T_E(°C)), the temperature of the refrigerant at the compressor inlet (T_C^i(°C)) and outlet (T_C^o(°C)), the temperature of the refrigerant at the evaporator inlet (T_E^i(°C)) and outlet (T_E^o(°C)), the temperature of the refrigerant at the condenser inlet (T_{Cd}^i(°C)) and low-pressure side (LPS) and high-pressure side (HPS) pressures, recorded when the experimental set-up is charged with neat 100 g of R-290. In reference to Table 1, the following observations have been made: The evaporator temperature gradually decreases over time, indicating effective cooling performance. The temperature of the refrigerant at the compressor inlet (T_C^i(°C)) initially decreases and then remains relatively stable throughout the observation period.

The temperature of the refrigerant at the compressor outlet (T_C^o(°C)) shows an increasing trend, suggesting the transformation of compressor work input into heat energy. The temperature of the refrigerant at the condenser inlet (T_{Cd}^i(°C)) increases over time, owing to the heat dissipation from the refrigerant.

The temperature of the refrigerant at the evaporator inlet (T_E^i(°C)) remains relatively stable throughout the observation period. The temperature of the refrigerant at the evaporator outlet (T_E^i(°C)) is parallel to the trend of evaporator temperature, indicating effective cooling. The low-pressure side pressure (LPS) remains relatively constant at a low level, indicating stable system operation. The high-pressure side pressure (HPS) initially increases and then stabilizes at a more or less constant level, suggesting consistent system performance. Figure 2 summarizes the major observation with respect to neat R-290 as a refrigerant.

Table 1. Observed thermodynamic data regarding the 100 g of R290 as a refrigerant

$t(min)$	T_E(℃)	T_C^i(℃)	T_C^o(℃)	T_{Cd}^o(℃)	T_E^i(℃)	T_E^o(℃)	$LPS\ (psi)$	$HPS\ (psi)$
0	31	30.7	30.5	30.9	30.2	31	65	80
2	30.1	29.3	33.1	32.4	28.3	28.2	10.1	189.9
4	28.1	29.1	35.1	34.1	26.5	28.1	10.1	190
6	25.1	27.7	37.1	36	23.3	26.1	10.2	179.9
8	23.2	20.3	39.1	37.7	20.7	22.1	9.1	180
10	20.2	16.2	40.5	38.1	21.5	19.7	9.2	180.1
12	18.2	13.1	40.7	38.1	17.1	15	7.1	170.1
14	15.5	11.1	41.2	38.2	12.7	12.6	6.1	170
16	13.3	9.1	41.5	38.2	10.4	12.4	6.1	170.1
18	11.1	4.4	42.3	38.7	10.1	12.3	6.2	170
20	10.1	6.1	42.2	39.1	9.7	11.9	6.1	170.2
22	8.1	5.5	43.1	39.5	9.7	10.7	6.1	170.2
24	6.2	5.5	43.7	39.7	9.2	10.1	6.1	170.1
26	5.1	5.2	43.4	39.8	9.1	10.2	6.1	170.2
28	4.1	5.1	44.1	39.8	8.6	9.7	6.2	180.1
30	2.9	5.1	44.5	39.9	8.2	9.9	6.2	180

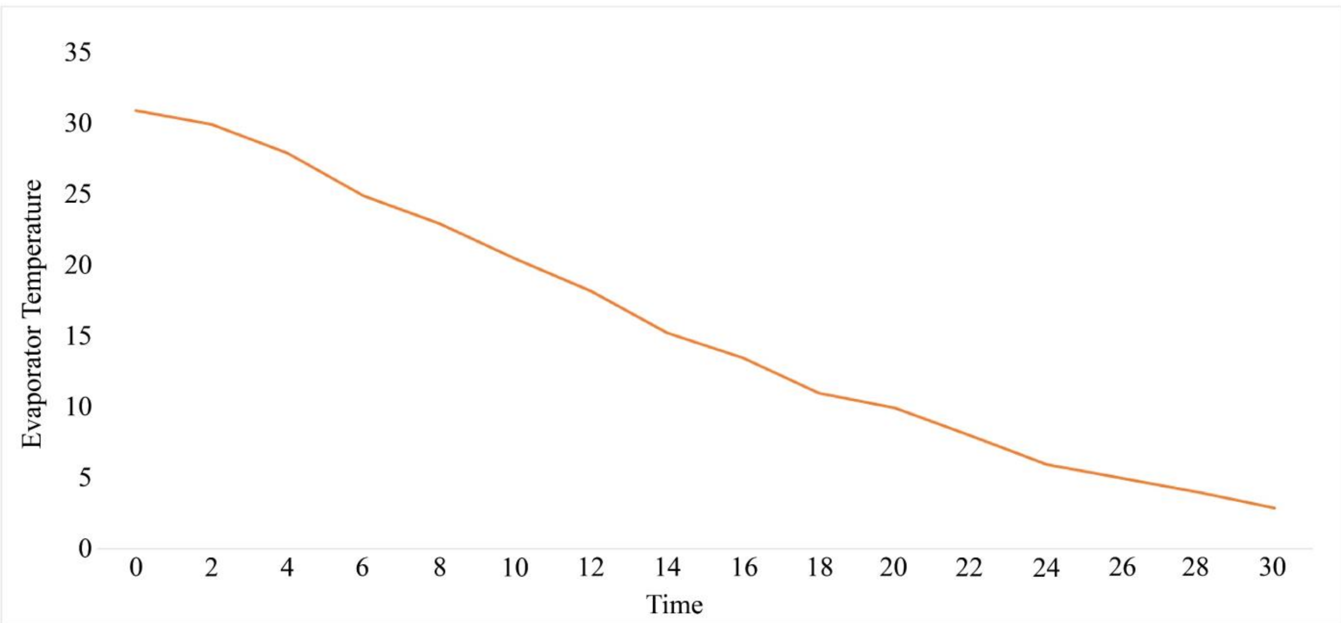

Fig. 2 Evaporator Temperature versus Time regarding the 100 g of R290 as a refrigerant

3.2. Refrigeration-related thermodynamic data associated with zoetrope blend of R290/R600a

Table 2 shows the analogous thermodynamic data as shown in Table 1. In reference to the Tab. 2, the following observations have been made: Evaporator temperature (T_E(℃)) decreases gradually from 31 ℃ at starting to -3.2 ℃ within 24 minutes.

The temperature of the refrigerant at the compressor inlet shows little deviation from the mean value throughout the observation period, ranging between 30.5 ℃ to 17.2℃. The temperature of the refrigerant at the compressor outlet increases initially and then stabilizes around 44.5 ℃ to 44.7 ℃ after 10 minutes onwards. The temperature of the refrigerant at the condenser outlet (T_{Cd}^o(℃)) decreases consistently from 30.2 ℃ at the start to 35.2 ℃ within 24 minutes. The evaporator inlet temperature shows a decreasing trend that varies between 30 ℃ to 14.7 ℃. The evaporator outlet temperature shows an analogous decreasing pattern that drops from 30.7 ℃ to 20 ℃ within 24 miniutes. The low-pressure side (LPS) pressure has been observed to be at constant around 6 to 7 psi throughout the observation period. The high-pressure side (HPS) remains constant at 120 psi, except for the initial value of 130 psi at 2 and 4 minutes. Figure 3 summarizes the major observation with respect to neat R-290/R600a as a refrigerant.

Table 2. Observed thermodynamic data regarding the 100 g of zoetrope blend of R290/R600a as a refrigerant

t(℃)	T_E(℃)	T_C^i(℃)	T_C^o(℃)	T_{Cd}^o(℃)	T_E^i(℃)	T_E^o(℃)	LPS (psi)	HPS (psi)
0	31	30.5	30.6	30.2	30	30.8	40	45
2	29.1	29.8	34.8	32.9	29.5	30.5	7.1	130.1
4	27.4	28.4	35.8	33.5	26.5	29.1	7	130
6	23.8	27.1	38.1	33.8	24.5	28.5	6.1	120
8	20.1	25.3	39.1	33.9	22.3	27.1	6	120.1
10	16.4	23.5	40.5	33.8	20.1	26.1	5.1	110
12	12.2	22	41.1	34.1	19.1	24.9	5	110
14	9.1	20.4	42.5	34.2	18.3	23.5	5.2	120.2
16	6.3	19.2	42.5	34.4	17	23.1	6	120.1
18	4.1	18.5	43	34.7	16.7	22.8	6.1	120
20	1.2	18.2	43.5	34.8	16.1	22	6	120.1
22	-1.4	18	43.7	35	15.2	21	6.1	120.3
24	-3.2	17.2	44.5	35.2	14.8	20	6	120

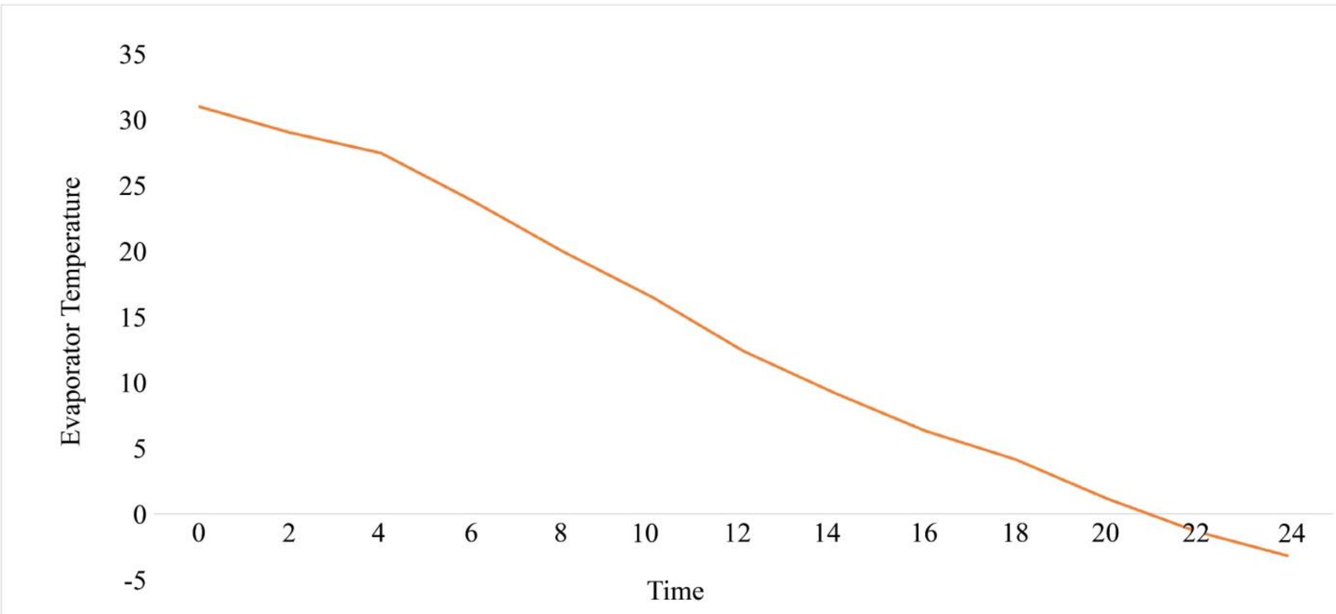

Fig. 3 Evaporator Temperature versus Time regarding the 100 g of zoetrope blend of R290/R600a as a refrigerant

Utilization of the R290/R600a (50%/50%) zoetrope blend as a refrigerant, the mass of refrigerant needed is significantly reduced, amounting to approximately one-third of the original charge of R134a. In summary, the observations indicate that the refrigeration system is functioning properly, with efficient cooling at the given pressure limits of the experimental set-up. The refrigerating effect of zoetrope blend R290/R600a (50%/50%) is relatively better than that of neat R290. By introducing R600a to R290, the mixture's flammability is reduced, and its heat capacity is increased. Literature has also shown that the addition of R600a to R290 significantly improves the safety aspects while maintaining the desirable refrigeration aspects. Associated literature can be found elsewhere. [2, 16, 21-22, 25-29] Literature hints at the independence of R290/R600a mixture flammability concerning the relative concentration of constituents. However, further in-depth studies on the flammability of the hydrocarbon mixtures are required. [2] As such, the results reported in this work are limited with respect to flammability constraints. [5, 7, 9-15, 21-22, 26-29]

3.3. Future Work

This work is limited by the life cycle assessment of refrigerants tested, along with their overall sustainability in terms of global warming potential and ozone depletion potential. It forms the potential for further research, such as exploring additional blends, testing refrigerants under varied operational conditions or evaluating the refrigerating capacity of tested refrigerants in particular refrigerating applications.

4. Conclusion

This preliminary work demonstrates that propane and its particular zoetrope blend with isobutane (probably in equal proportions) can be efficiently used as a refrigerant in hermetic-sealed vapor-compression systems. Notably, it takes almost half an hour for the evaporator temperature to reach 2.9°C when using neat propane. In comparison, at an ambient temperature of 31°C, the evaporator temperature lowers to -3.2°C in just 24 minutes when propane and isobutane are mixed in an equal amount. In summary, the results hint at the refrigerating potential of the blends that are particularly characterized by relatively reduced flammability in comparison to neat propane.

Statements and Declarations

Data and Material Availability

The publication contains all the data needed to replicate the findings that have been presented.

Author's Contribution

Each of the authors contributed to the study's idea and design. Data collection, analysis, and material preparation were done by Swayam Prakash Kutar.

Swayam Prakash Kutar wrote the first draft of the manuscript, and all contributors offered input on previous iterations. The final text was reviewed and approved by all authors.

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The findings herein reflect the work and are solely the responsibility of the authors.

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