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DESIGN AND EXPERIMENTAL INVESTIGATION OF A VAPOR COMPRESSION REFRIGERATION SYSTEM USING LPG–R134A BLENDED REFRIGERANTS

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Abstract
This experimental study evaluates the performance of a vapor compression refrigeration (VCR) system operating with pure R134a and blended R134a/LPG refrigerants under identical operating conditions. The objective is to assess the feasibility of LPG–R134a mixtures as an energy-efficient and environmentally friendly alternative to conventional R134a. Experiments were conducted by varying the mass fraction of LPG in the refrigerant mixture while maintaining constant and reduced total charge quantities. Key performance parameters, including compressor power consumption, pull-down time, and coefficient of performance (COP), were experimentally determined using an adiabatic calorimetric method. The results indicate that the R134a/LPG blended refrigerant significantly enhances system performance compared to pure R134a. At a reduced total charge of 400 g, a mixture containing 60% LPG and 40% R134a achieved a maximum COP of 0.902, representing an improvement of approximately 14% over the baseline R134a system. In addition, the blended refrigerant demonstrated lower compressor power consumption and improved cooling performance due to its higher latent heat characteristics. The reduction in total refrigerant charge further contributed to enhanced system efficiency. These findings suggest that R134a/LPG blends can serve as a promising alternative refrigerant for domestic refrigeration systems, offering improved energy efficiency with reduced environmental impact while mitigating safety concerns associated with the use of pure hydrocarbons.

INTRODUCTION

Vapor compression refrigeration systems (VCRSs) represent the most prevalent cooling technology used in household, commercial, and light industrial applications. Domestic refrigerators, in particular, operate on the conventional vapor compression cycle and typically employ a single refrigerant as the working medium. Because these systems function continuously over long periods, even marginal improvements in refrigerant selection can lead to significant gains in energy efficiency and reductions in environmental impact. Consequently, the identification of safe, efficient, and environmentally acceptable refrigerants remains a key research priority.

In earlier decades, chlorofluorocarbon-based refrigerants were extensively used in domestic refrigeration owing to their excellent thermodynamic behaviour, chemical inertness, non-toxicity, and non-flammable nature. Among these, CFC-12 was widely regarded as a benchmark refrigerant due to its favourable pressure ratios, stable operation, and compatibility with system components. However, scientific evidence later confirmed that CFCs contribute substantially to stratospheric ozone depletion. This led to global regulatory actions, most notably the Montreal Protocol, which enforced the elimination of CFCs from refrigeration and air-conditioning applications.

To replace CFCs, the refrigeration industry initially adopted hydrochlorofluorocarbons and later transitioned to hydrofluorocarbon refrigerants such as R134a. R134a became a dominant choice in domestic refrigeration because it exhibits zero ozone depletion potential and performance characteristics comparable to those of CFC-12. Despite these advantages, R134a is associated with a relatively high global warming potential, raising concerns regarding its long-term sustainability. As international climate policies continue to tighten, the environmental limitations of HFC refrigerants have driven the search for alternatives that can deliver both reduced emissions and high system efficiency.

Hydrocarbon refrigerants, including isobutane (R600a) and propane (R290), have emerged as strong candidates due to their excellent thermophysical properties. These refrigerants are characterized by high latent heat of vaporization, low molecular weight, and favourable heat transfer behaviour, which often result in improved cooling performance and reduced compressor power requirements. Furthermore, hydrocarbons possess negligible global warming potential and zero ozone depletion potential, making them attractive from an environmental perspective. Numerous experimental studies have demonstrated that hydrocarbon refrigerants can outperform conventional HFCs in terms of coefficient of performance and energy consumption.

Despite these advantages, the direct use of hydrocarbon refrigerants in domestic refrigeration systems is constrained by safety considerations. Hydrocarbons are inherently flammable and may operate at elevated pressures, which introduces risks in the event of refrigerant leakage. Although domestic refrigerators typically contain only a small refrigerant charge, concerns related to ignition and regulatory compliance have limited the widespread adoption of pure hydrocarbons in household appliances. As a result, hydrocarbons are often regarded as technically efficient but practically challenging refrigerants for conventional domestic use.

A promising strategy to overcome these limitations involves the use of refrigerant mixtures that combine hydrocarbons with conventional HFCs. Blended refrigerants are designed to capitalize on the high efficiency and low environmental impact of hydrocarbons while moderating flammability and maintaining acceptable operating pressures. Partial substitution of R134a with hydrocarbon-based components has been shown to reduce global warming impact while enhancing system performance. Such blends offer the potential to achieve a balanced compromise between safety, efficiency, and environmental responsibility.

Previous investigations have indicated that refrigerant blends containing hydrocarbons can lead to lower compressor energy consumption, improved coefficient of performance, and faster cooling response compared with pure R134a. However, system behaviour is highly dependent on blend composition, refrigerant charge quantity, and operating conditions. Furthermore, while CFC-12 remains a reference point due to its ideal operational and safety characteristics, its environmental drawbacks preclude further use. Comparisons with HCFC-22 and R134a reinforce the need for alternative refrigerants that can match historical performance standards without violating environmental regulations.

Although domestic refrigeration systems employ relatively small refrigerant quantities, the trade-off between efficiency and safety remains critical. If blended refrigerants containing limited proportions of flammable components can demonstrate reliable performance under controlled conditions, they may represent a feasible replacement for non-flammable but environmentally harmful refrigerants. However, comprehensive experimental data examining the combined influence of blend ratio and refrigerant charge on system performance remain limited.

Accordingly, the present study conducts an experimental evaluation of a vapor compression refrigeration system operating with R134a/LPG blended refrigerants under controlled laboratory conditions. Performance indicators such as coefficient of performance, compressor power consumption, cooling effectiveness, and overall energy efficiency are analysed for different blend compositions and refrigerant charges. The results aim to assess the technical viability of LPG–R134a mixtures and to support their potential application as energy-efficient and environmentally sustainable alternatives to conventional HFC refrigerants in domestic refrigeration systems

2.Literature Review

CFC12 is considered as the best refrigerant as the comparison between available all refrigerants due to possession of the capability of good ratio of pressure, non-flammable, non-toxic properties. In future it may can be compared with HCFC22 and R134-a. In domestic systems very little refrigerator is used. Thus, due to high efficiency and non-flammability CFC12 is good option but if any flammable refrigerant shows good results, then still non- flammable refrigerant can be considered as substitute [1], The production of CFC11, CFC12, CFC115, CFC113 went under decline in 1986 and further was reduced 1998 and was replaced with R134-a which produces the same results as CFC12 due to high impact on ozone depletion. Zero ODP gave the shift of CFC12 to R134-a [2]. If we compare R407-a with R134-a, R134-a shows better results based on coefficient of pressure (COP) temperature of evaporator and condenser, system exergy efficiency and sub cooling of condenser and evaporator [3].

The analysis of R-1234yf in comparison of R134-a reveals based on two methods energy and exergy, mass flow and pressure temperature in domestic refrigerator by variating the load of refrigerant R1234yf not producing good results. In the domestic refrigerator R1234yf (92.2 gm) and 134-a (100gm) reveals that R134-a, is better option [4].

The designed VCR system to operate R12 was dosed with R290 and R600-a refrigerant then compared their output results with R12, and R134-a. Experiments revealed the results that R290 and R600-a, has better output for refrigeration. The R12 refrigerant produced bit higher refrigeration in comparison with R134-a further R12 showed more energy efficiency (6.8 percent to 17.4 percent) as compared to the mixture of R290/R600. The coefficient performance of R12 is reduced by 3.9% to 25.1% at lower conditions of evaporating temperature and 11.8 percent to 17.6 percent at higher conditions of evaporating temperature respectively [5]..The latest mixtures of refrigerants that are being used in the vapor compression-based refrigeration and air conditioners (AC) and heat pump (HP) are being segregated in to major six groups 1-Ammonia (R717) 2-hydroflourocarbons (HFC) 3-Carobon dioxide (R744) 4- Hydrocarbon (HC) 5-HC/HFC 6-Hydrocholorflurocarbon (HCFC) [6]. R12 was found to be closely related to R600-a/R290 mixture in the sense of discharge temperature. R600-a/R290 (88/32 by weight percentage) can replace HFC134-a.

Research conducted in 2010 on R12 and related CFC refrigerants were banned almost due to depletion in the ozone layer. The two refrigerants are 134-a, and R152-a as compared to R12 refrigerants were found environment friendly. The analysis based on experiment between R134-a, R12 and R152-a showed that COP of R12 is 1.4 percent higher than R152-a, and also 18.2 percent higher than R134-a. it is observed that the countries which are underdeveloped are still using the refrigerants based on the halogens due to its very low cost and highly efficient thermodynamic and physical properties. The refrigeration agents based on halogens are impacting on the environment by majorly causing the ozone depletion (ODP) and creating the phenomena of global warming. so, there is a big gap to bring up the non-halogenated refrigerants that can fill the gap. the studies based on the experiments and theories for environmentally friendly alternatives revealed that HC and HFC and heir mixtures can be the choice in future that can last for a long span of time as alternative [7]. The refrigerant mixtures under the HC are pointed out as the long-term substitute to eliminate the current refrigerants under the halogen in the vapor compression systems. The mixtures of HFC/HC (R430a) and HC mixtures e.g., R290/R600a, R600a/R600 and R290 etc. are good alternatives to R13A and R134a.The application of HC/HFC mixtures will be restricting the application of synthetic lubricants, and are leaving low environmental impacts. One can observe that the use of environmentally friendly refrigerants is important in minimizing the environmental effects brought about by halogenated refrigerants to protect the environment [8].

There is a feasibility study of LPG (60 % propane and 40 % comm. butane) is a good alternative R134a in a domestic refrigerator. The study of performance based on experiment for VCR system with LPG was conducted and compared 134a. The performance of a domestic refrigerator was tested by using LPG while the compressor was designed to perform 105g 134a was able to perform on LPG. The analysis of consumption of energy revealed that there should be a replacement of HFC compressor with HC compressor for HC refrigerants. The consumption of energy was observed to be reduced while was charged with modest amount of LPG as compared with core refrigerant. It is observed that LPG is the best candidate until date which can replace R134a with a limitation of capillary tube and initial charge [9]. Approximately 17,500 Metric tons of HFC and HC are being used in traditional refrigerants which adds a big share for the depletion of ozone layer and causing the high contribution to global warming. LPG is the mixture of isobutane, propane and with the maximum ratio with 56.4% butane. LPG is a good alternative to HC and HFC as its eco-friendlier and uses less energy [10].

The experiment that was conducted on the refrigerator with LPG 60g and capillary tube in the length of 5m produced favorable results compared to R134a and capillary tube in 4m and the experimental results were recorded as follows; Pull down time, energy consumption and power consumption 7.6, 4.3 and 5.5 respectively. Besides the COP of LPG was nearly 7.6% greater than that of R134a energy consumption and Lower on time ratio of LPG refrigerator is 10.8% and 14.3% accordingly. While conclusively talking the LPG is a better alternative to R134a in refrigeration except capillary tube system. In tropical conditions the ongoing test on LPG with 60%propane and 40 comm. butane as the alternative of R134a in a unit-evaporator framework of a domestic refrigerator showed that 12C can be effortlessly accomplished by using 50g of LPG or somewhat further with capillary tube having a length between 4 to 6 m. As we tend to increase the charge of LPG the cabinet and freezer temperature and pull-down time goes down and on the other hand refrigerant mass flow, discharge temperature and energy consumptions ratio gets high with the increased cooling capacity [11].

The results extracted from the experiments on the LPG as considered as alternative to R12 are presented as the charge of LPG (50,80 and 100) were used in a refrigerator designed for R12 showed that the LPG showed very comparable results and COP was higher for all charges at below 15c evaporator temperature. While talking about overall results that 80g charge of LPG at 47c constant temperature showed the best results. While during experiments no operational issue or degradation of lubricant was observed and results were higher than R12. The alternative LPG can help in curbing global warming, ODP and greenhouse effect. The only related issue with LPG is that it is highly flammable and requires additional care but it is also an everyday domestic fuel meaning that the masses are familiar with the use of this gas [12]. The LPG mixture while producing the good results for refrigeration. There is another specific mixture with the composition ratio of HC600a (0.0397%), HC290 (98.95%) and HC170 (1.007%) proven to be the better performer than the unblended mixture of HC290 and was proven to be the safe combination for the parts of the system. These HCs refrigerants show elevated COPs as compared to HCFC22 but showed a tiny lag in sense of capacity of condenser. ISO categorized HC refrigerants as 3rd group hazardous material. While performing the operational tests, it was proven that if we take proper operational precautions, they are found to be safe. The performance perspective shows that LPG and HC290 mixture showed the elevated COP hp of 12% as well as 18% in sequence on temperature T=3°C and T=35°C. Under such used conditions the capacity of condenser was reduced by 10 and 15 percent respectively. Moreover, the mass flow rates of LPG and HC 290 were almost 44% and 50% lower than the HCFC22. For the both HCs the temperature of discharge were low evidently lower than HCFC22 in all conditions. The LPG and mixture of LPG produced the better output at higher temperature values. The combination of LPG was confirmed as the great substitute of the HCFC22 in the refrigeration and heat pump systems [13].

The theoretical studies related to VCR while using the various blends of HCs and HFCFs as refrigerating agents. Genetic algorithm induction method was adopted to solve an approach of a nonlinear limited optimization technique in the process of selecting the best blend. Comparison of the operational output of HCs and HFCs refrigerants with the R134a revealed that the new optimum blend shows an improvement of 11.9% of the case of COP. This optimization was conducted on the software-based MATLAB model intended to the HCs and HFCs and HCs refrigerants mixtures of the process which consisted of propane(R290), Isobutane (R600a) and butane (R600a). On the other side the refrigerants applied in optimization process are R134a, R32 and R152a and the combination of these mixtures exhibited the highest COP. While the sole R134a is being inducted the value of COP is 1.7992 and the blend of R134a (6.61%), R32 (5.64%) and R152a (87.75%) produced the maximum COP ranged to 11.93% in comparison with R134a. The findings indicate that they could be used in its place in domestic refrigeration and no modifications were needed in the system constituents and the blend exhibited the 0% ODP and extremely small GWP (242) and extremely low inflammability (LFL =6.0153) and performance even greater than the R134a [14].

In another study conducted on the refrigerator that was designed to perform on R134a was used as a test device where the experiment was conducted to check the possibility of using HCs and their blends which are pure isobutane, butane and propane and their blends as refrigerants. The efficiency was studied and then compared with R134a. The study revealed that compressor consumed the lesser energy as compared to R134a and less than the HFC 134a when Butane and ISO butane was used 3% and 2% less at the base temperature of 28C. The COP of HCs and their mixtures evidenced as positive indicators that these can be used as refrigerants in domestic refrigerators. The undergone project studied the Efficient, Ozone friendly, safe, and cost- effective alternative over HFC134a. The successful experiments on HCs and their blends showed the below given results. The consumption of energy for HCs and mixtures is almost close to the consumption of HFC134a and further the butane and iso butane tended to use lesser energy 2% and 3% respectively at 28C. Further the HCs and their mixtures produce lower inlet temperature that property make them fit for lower temperature application. In another instance the compressor was loaded with the charge of 140g of HFC134a and 70g of HCs, the output was same that shows the better image of performance [15]

Another set of experiments with different load of charges 40-60-80-100g for LPG and R134a were compared where the results showed that pull down time and designed temperature were achieved earlier by LPG as compared to R134a and COP was increased by 9.5% and energy consumption felled by 12%. That proved that LPG is a better substitute of R134a. The discovery of R134a as a chlorine free refrigerant and went as a replacement for R12 based on its thermodynamic & Physical properties. However, due to its high ratio of ODP and adverse effect on environment in future its production will be halted permanently and further LPG is arising as rival of R134a with better COP and energy efficiency [16].

The comparison of the performance of the refrigeration systems in terms of their energy consumption was carried out by comparing the refrigeration capacity, compressor power consumption, the COP, compressor discharge temperature, and the pull- down time. The main conclusions of the paper are provided below. R134a/LPG (28:72) substitution of the refrigerant facility in R134a will have higher capacity of refrigeration than a similar refrigerant in all comparable capillary tube lengths and charge of refrigerant. The corresponding refrigeration of about 4.8, 10.6 and 8.2 percent is larger than the refrigeration of R134a at the capillary length of tube 5.1 m and refrigerant charge of 108,118 and 128 g respectively due to the high latent heat compared to the R134a. It is also noted that the compressor power consumption of the vapor compression refrigeration system using R134a/LPG (28:72) mixture is reduced by 8.2, 4.9 and 2.2 percent of capillary tube length of 5.1m and refrigerant charge of 108, 118 and 128. g. The COP values between R134a/LPG (28:72) and the ones of R134a are between 2.2-15.2 percent higher. Optimal level of COP is achieved at 118 g of R134a/LPG and at 5.1m of the capillary tube length and is 15.2 percent higher than that of R134a.This system has already operated 90 days with no fluctuation of the oil level and this test is testament to the fact that the mineral oil is miscible and the mixture performance in the R134a system is reliable [1].

Leakage of hydrocarbon a long-time problem which responsible of hazards. Two tests were conducted to test limits of explosion hydrocarbon and air mixture conditioned (rectangle shock tube) and unconditioned (plastic bag) test. Various hydrocarbons explosion hazards and fire compare with two-dimensional parameter. Confined test (rectangular shock tube) finds out the effects of some hydrocarbons and air mixture explosive hazard and fire's chemical additives. Safety measurement of HC is primary thus reactivity and flammability test performed [18].

For replacing hydrofluorocarbons HCFC, the composition of HC and HFC refrigerant used. Performance, thermodynamic properties, equipment compatibility, cost, and toxicity of HFC same as HCFC. By mixing the refrigerant's potential fractionation behavior, flammability does not ignore. The proportion of flammable and non-flammable refrigerant is referred to as flammability ratio. Thus, threshold value of flammable and non-flammable blend can find out by the formulation of FR (flammability ratio) of several blends. CFR (critical flammability ratio) is a threshold between a mixture of refrigerant flammable and non-flammable. However, several methods are used to find out the FR (flammability factor) and CFR (critical flammability factor of the refrigerant blend). CFR find out the potential of refrigerant mixture. The following method can perform any refrigerant blend with only the limitation of the number of the refrigerant present [19]. Substitution of R22 with non-azeotropic blend of R152a, R134a, R32, R290 and R1270 name as M40 at various proportions determine the thermodynamic values and flammability. RF (refrigerant flammability) used to determine the flammability of refrigerant blend. M40 has 0.51% more COP then the baseline R22 furthermore temperature of compressor discharge of R22 is 11.60C is greater than M40.according to study flammability of blend is weak flammable class. The overall performance of blend M40 is higher than R22 can be a good replacement [20].

High potential halogenated hydrocarbons were banned on Montreal protocol (1987) due to its negative effects to the ozone layer that shields the earth against the ultraviolet radiations. The greenhouse gases (GHG) that are used in the existing refrigeration, air conditioning, and heat pumping systems are within the time-barred Kyoto Protocol (1997) permit. The European Union law (2014) and the Paris Accord (2016) are desperately demanding the phase out of using harmful synthetic refrigerants in order to fight the loss of the ozone and overturn the consequences of the climate change. The choice of natural refrigerants is such that the net contribution of the greenhouse gases (GHG) to the environment is nonexistent [21].

Application of the natural refrigerant R290 can be crucial in achieving the goals of the international provisions such as Montreal and Kyoto. Urgently, R22 should be phased out because of ozone depletion and global warming because of environmental problems. Analytical calculation was done on the potential of R290 as a possible substitute of R22 in the refrigerants in terms of thermodynamic performance of fridges at standard vapor compression cycle with a range of evaporating temperature of -250C to 100C as the condensing temperature is 45C. The ref properties like, discharge temperature, volumetric refrigerating capacity and mass flow required by refrigerant have been observed to be lower in case of R290 than in case of R22.However, it is possible to expect higher COP in regard to the properties of R290 in terms of environmental and thermophysical property [22].

Various studies were related with the use of hydrocarbon as alternative refrigerant in refrigeration, air conditioning and heat pump, and automobile air conditioning system. Depending on the findings of the different studies and the above synopsis that can be applied to the hydrocarbon the following can be drawn: Not only is it the best alternative in the event of environment but even it may help save the amount of energy needed and it may even be used as a good drop-in substitute to the existing halogenated refrigeration. The short atmospheric lifetime of hydrocarbons makes the GWP of the hydrocarbons to be near zero. The thermodynamic and thermo-physical convenience of HC is what ensures that the performance of the equipment would be similar to the traditional refrigerants. iv) Hydrocarbons offer intriguing refrigerant to the conventional ones in the view of energy efficiency, COP, refrigerant charges, and the discharge-temperatures of the compressor. The largest part of the studies undertaken has been on low refrigerant charge in big volume systems since the features of flammability that apply to hydrocarbons. The use of artificial lubricant that is hygroscopic in nature will be done away with because of the application of HFC/HC blends. The mixtures of HC/HFC can be used with CFC, and HCFC that will last as long as the current systems. The HC refrigerants that are low volatile are preferable to be used together with the HCFC refrigerant to overcome the flammability of the HC mixture and the issue of oil miscibility. In CFCs and HCFCs replacement, there was a big study found in replacement with completely new system design with minimal research on the resoliciting process. R290 is successfully commercialized in low charge, room, and portable air conditioner to substitute R22. HC mixtures (e.g., R432A/ R433A) and HC/HFC mixtures (e.g., R290/ R470c/ R600a/ R290) are also encouraged as an ecological alternative to the use of R22 in air conditioning and heat pump systems. HC and HC/HC blends are identified to be the good replacements of R12 and R134a in the domestic and commercial refrigeration systems. The air conditioner of automobiles was reported to be interested in the usage of R290/R600/R600a and HC/HFC mixtures (R134a/R290:R600a) instead of R143.

Energy and exergy of a conventional vapor compression refrigeration system using R152a and R290, R600, R600a, R123 and R717 was analyzed theoretically and the result of the analysis was compared with standard refrigerant R134a of the system. This conclusion was reached based on the fact that alternative R600, R600a, R717 and R152a had better COP and efficiency (energetic), R600 was a functional alternative, and others. The other parameter like the type of refrigerant, extent of sub cooling and superheating on energetic efficiency, COP, RE, VRC, PTR, total exergy destruction was also addressed based on different evaporative temperature [24].

The experimental researches of 30g charge of LPG and R600a refrigerant to the refrigerant at the different ambient temperatures promised the advantages as alternative refrigerants of the refrigerant in the modified R134a refrigerator. It was concluded the following: small hydrocarbon-based refrigerant, intentionally small, was safe and cost-effective in comparison with R134a refrigerant. The hydrocarbon-based refrigerants had better energy saving properties. The refrigerants that are made of hydrocarbons had lower discharge temperatures and depressors in the condensing process that means it had high compressor durability [25].

A series of experiments was conducted in this research to examine the effects of liquefied petroleum gas (LPG) mixture of 60 percent propane and 40 percent commercial butane as a drop-in supplement to refrigerant R134a in a domestic refrigerator under the subtropical climate in Bangladesh. They were run in experimental conditions of constant and cyclic operating conditions and constant surrounding air temperature Temp=33±1 o C. Three dissimilar tube length and variable level of charging were taken into consideration. The experiment result determined that the maximum temperature of the air in the freezer was -17.5 C when 65gm LPG was used and a capillary tube of length was 4m. R134a and LPG were compared and the amount of charge was made. After the replacement of refrigerant-R134a with LPG, reduction in pull-down time, discharge temperature and mass flow. The rate of 2.4, 17.8, and 20 percent was found. Finally, one can say that LPG can also be used as an alternative to refrigerant R134a in mini-fridges [26].

The present article is devoted to the thermal performance of a hydrocarbon blend refrigerant in house refrigerator that is going to be retrofitted. Pull-down test and energy consumption test are carried out in terms of the standard test conditions with propane/butane mixture (4951) as the refrigerant. The experiments of R134a and HC blend refrigerant are conducted separately under no-load condition. By conducting experimental research of R134 a and HC blend, comparison of the temperature that is achieved by the freezer is made. It is observed that the HC blend has a. temperature that is lower by 3 due to large latent heat. The refrigerator temperature is also compared with both refrigerant R134a and HC mixture. HC blend system uses less power on a daily basis, and this is 17.86 percentage less than the amount of power used by R134a system. The coefficient of performance of the HC blend system is also determined to be approximately 40 percent more than the R134a system with the same cooling capacity [27].

3. Methodology

The basic design of the project contains all basic vapor compression cycle components and some additional components for testing. A proper mixture of the refrigerants R134a and LPG charged in the system from the mixing chamber. The cycle starts from the compressor which pressurizes the refrigerant. According to the power need to run the system 1/4 hp compressor is optimized for usage. The exhaust of compressor flows to the condenser and the outlet pressure is measured by a pressurized refrigerant and temperature measured by a PT-100 thermocouple installed between compressor outlet and condenser inlet. The refrigerant is rejected and the heat emitted by the refrigerant is discarded into the atmosphere with the condenser. The tube and fine type condenser are employed with a length of 13.2m and the outer diameter of tube is 10mm.

A condenser fan is placed that through the air on condenser which maximizes the heat transfer in the condenser. A high-pressure gauge is fitted at the outlet of the of condenser and the temperature is measured using a thermocouple. Due to the change in pressure and temperature variation, there should be a possibility that refrigerant may change its volumetric properties. To overcome this issue a receiver is placed in the way to the expansion valve that ensures the proper mixture of blend proceed further and convert remaining vapor contents into liquid. After the receiver, a rotameter is used to measure the flow rate of the outgoing refrigerant to the expansion valve. A filter drier is also used here to filter the refrigerant because the expansion valve is basically a narrow tube known as a capillary tube.

Figure 1: Project picture

The optimum length of the capillary tube to be used in this project is 5.1m. As the refrigerant flowsthrough the tube of the capillary the pressure is lowered and abrupt expansion on the outflow of the tube happens creating a cooling effect. A low-pressure gauge measures the pressure there and thermocouple measure the temperature. To produce refrigeration effect refrigerant pass through the evaporator of 3.05m length and tube outer diameter of 10mm. Again, a low-pressure gauge measures the pressure there and the temperature is measured by a thermocouple. Overall, four pressure gauges and four PT-100 thermocouples are placed in the system at different points.

The basic vapor compression system consists of four basic components. Compressor, condenser, expansion valve and evaporator. If the system is working with only one refrigerant it is easy to calculate its COP by using its property charts. As our project is related to use of mixture of two refrigerant so, it is not possible to calculate COP by using property charts. To calculate COP an adiabatic chamber is designed where cooling effect is calculated with the help of adjustable heater. The more detail about components and apparatus is given below.

3.1 Compressor

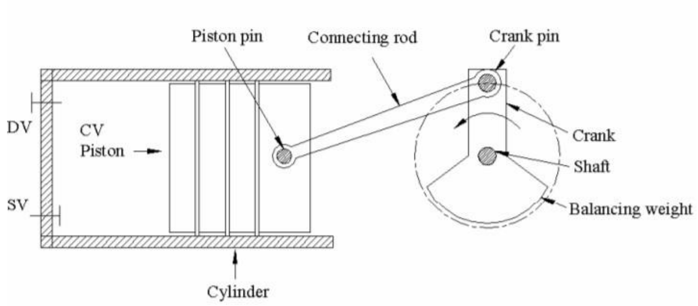


Figure 2: Schematic of a reciprocating compressor

A compressor is a machine that decreases the amount of gas through the increase of its pressure. The gas compressor that is being used is an air compressor. The compressor FR8.5G in the system is the Danfoss compressor FR8.5G with a capacity of 1/4 Hp. Where a compressor is used in a VCR system, it would continuously draw the refrigerant out of the evaporator, such that it would be able to keep the low temperature and low pressure in the evaporator and remove the heat out of the refrigerating chamber by boiling the refrigerant. The reciprocating compressor is the workhorse of refrigeration and air conditioning industry. The reciprocating compressor has few watts to hundreds of kilowatts of cooling capacities. These compressors of modern days have a high speed which is approximately equal to 3000 rpm to 3600 rpm, single or multi-cylinder (up to16 cylinder) and single-acting type.

Figure shows the schematic of a reciprocating compressor. The reciprocating compressor has a piston that moves to and for in a cylinder to facilitate the suction and compression of the refrigerant vapor; and as such, the compressor has suction and discharge valves. Such compressors needed are somehow similar in construction and working to a two-stroke engine since in a single rotation of the crank the suction and compression of refrigeration vapor is had. The condenser inlet is taken to discharge side of compressor and exit of evaporator is taken to suction side of compressor. This is because pressure in the inlet and outlet manifolds differs and inlet and outlet valves are opened and closed respectively. The pressure in the inlet manifold is the same or a little below the evaporator. In the same case, the pressure of the condenser is the same or a little lower than the pressure of the outlet manifold. To have a smooth operation of the valves and space for mounting the valves, these manifolds play a role in stabilizing the inlet-outlet pressure. The valves used are plate or reed type, which is either clamped or floating. For limiting the valve displacement and for smoothing return after opening or closing backstops and springs are usually used. The valve type decides the piston speed. Excessive vapor velocities are caused by the too high speed that will lower the volumetric efficiency and decrease in compression efficiency by throttling loss.

3.2 Condenser

A device or unit which is used to condense a gaseous refrigerant into liquid form through cooling by using heat transfer is called a condenser.

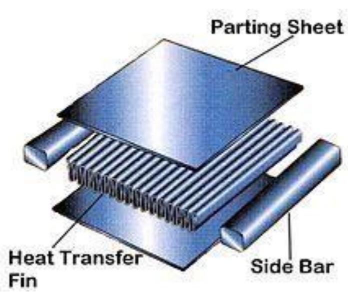


Figure 3: Components of condenser.

The system uses Fin plate type condenser. Tubes have a diameter of 10mm with a overall length of the tube being 13.2m. The purpose of transferring the heat in a working fluid to the surrounding air or a second fluid as in the case of steam power plant condenser is meant. The fact that a phase change occurs and in the process an effective heat transfer occurs is what a condenser depends on, in this case, when the vapor is condensed to liquid. The condenser usually permits the vapor to flow in with a temperature that is higher than the temperature of the secondary fluid. When the vapor starts to cool down it will release a large quantity of latent heat as the vapor condenses into a liquid since the condensing substance reaches a saturation temperature. The amount of liquid grows and the amount of vapors reduces as the process of condensing takes place and only the liquid is left at the out of the condenser. A few condensers are designed to contain additional length to sub-cool this helps us to condense liquid lower than the saturated temperature.

In the design of the condenser there exists so many variations. There exist variables that include geometry, working fluid, the material, and secondary material. Air, water, phase-change materials, or refrigerants are commonly used secondary fluids.

The two advantages of significant design over other cooling technologies of condenser are as follows:

- The efficiency of the latent heat by heat transfer is much more than that of the heat transfer of sensible heat only.
- The temperature difference increases between working and secondary fluid when during condensation, the temperature of working fluid stays relatively constant

Figure 4: Condenser

3.3 Evaporator

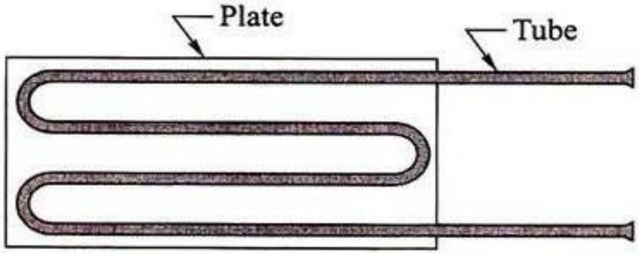


Figure 5: Inside evaporator

A device which is used to change the phase of the liquid state into a chemical substance just like water changes its phase to vapor. Plate and tube type evaporator are used in the system with diameter of tube 10mm and total length of the tube is 3.02m. The fin plate evaporator is a widely used evaporator as shown in the figure. These evaporators consist of tubes; these tubes are in the form of coil and these tubes on one side of the plate are either welded on brazed. An evaporator is made by the combination of plate forms and coiled tubes. In domestic freezers and fridges, the plate type evaporators are used mostly.

In some cases, we set these coiled tubes in the middle of two parallel plates, and in both plates, the coiled plates are implanted in grooves. The refrigerant that flows through these tubes has excellent thermal contact with the plate. Plate freezers are the type of freezers that use such plate evaporators. The evaporator is in contact with the cold reservoir when low pressure and low-temperature refrigerant enters the evaporator. As the refrigerant starts to boil at a low temperature so we must maintain it to low pressure. So, through the cold reservoir, the heat is absorbed by the liquid and evaporates. The refrigerant of low pressure and temperature move towards the compressor again after leaving the evaporator, at the starting point of the cycle.

Figure 6 Evaporator

3.4 Capillary Tube

Figure 7: Capillary Tube

Capillary tube is a pressure reducing device to meter the flow of refrigerant from the condenser outlet to the evaporator inlet.

The inner diameter of the capillary tube is 1.12mm and its length is 5.1m. This kind of tube has an inner diameter that is of the hair like thinness. The mixture is introduced under high pressure and passes through the capillary and the pressure decreases due to resistance in the capillary tube. The more the pressure on the refrigerant the less the boiling point. The tube is charged with thick and liquid mixture of various density and related speed into the tube. Majority of the low-pressure liquid is directed to the evaporator in which it is flashed into an evaporation to convert it to vapor. Any spare liquid would quickly evaporate and generally in the first third or quarter of the evaporator. This relatively thick low-pressure vapor is now sent through the evaporator that gathers the heat on its way.

3.5 Thermocouple

Figure 8: J-type Thermocouple.

A thermocouple is an electrical device consisting of two dissimilar electrical conductors forming an electrical junction.

One of the sensors that are used to measure temperature is a PT100. It is a kind of sensor that is a member to a category of Resistance Temperature Detectors or RTD. Pt100, gives two valuable items of sensor information. Pt is the chemical symbol of Platinum and the first part indicates that the sensor is made of the same, Platinum. The second section of 100 is associated with the opposition of the device at 0°C. In this case **100Ω**. This theme has a number of variations. In the apparatus, J-type PT100 thermocouple is utilized. A Pt100 is a device that measures temperature based on variation in resistance value to indicate temperature. In the case of a Pt100, the resistance at 0 o C is 100 ohms and at 100 o C, the resistance is 138.5 ohms. Thus, each degree Celsius change in resistance has a change of resistance of 0.385 o.

Figure 9: Display of Thermocouple

3.6 Pressure Gauge

Figure 10: Pressure Gauge

Pressure Gauge is a device which shows the pressure of the refrigerant. Basically, four pressure gauges are used in the system to find pressure at different point two of them are high pressure gauges which measure pressure in high pressure area before condenser and after condenser. Remaining two are placed in low pressure area after expansion and after evaporator to find out the pressure drop.

3.7 Adiabatic Chamber

Adiabatic chamber is the type of chamber in which no heat is enters or leaves the system. Adiabatic chamber in the apparatus is an insolate box which consist of heaters with a total power of 600 watts, evaporator, and water. This component is mainly used to find out the COP. When the cooling effect produced by evaporator is canceled out by adjusting the power of heaters placed in the chamber power of heater is noted that is used to calculate COP. This whole process is done adiabatic where no external heat effects the system.

3.8 Voltmeter

Figure 11: Voltmeter

It is a measuring device which is used to measure voltage or potential difference.

3.9 Ampere Meter

It is a measuring device which is used to measure ampere in a device.

Figure 12: Ampere Meter

4. Results And Discussion

In this chapter all the experimental results are mentioned from experiment 1 to 6 respectively. All the readings are noted by trying to keep the environmental conditions same. Further results are mentioned in the tables below.

4.1.1 Experiment 1

In this experiment 100% R-1334A is charged to system. The main objective of this experiment is to form a base line for other experiments to compare results. By following the procedure R134A is charged in the system and after system reaches to steady state condition values are noted. Total charged weight is 585g.

The values we note are given in the table below.

Table 1: Experiment 1 Data

Suction Temperature T1 (^{0}C)	26
Suction Pressure P1 (Psi)	5
Compressor Discharge Temperature T2 (^{0}C)	66
Compressor Discharge Pressure P2 (Psi)	154
Condenser Outlet Temperature T3 (^{0}C)	43
Condenser Outlet Pressure P3 (Psi)	154
Evaporator Inlet Temperature T4 (^{0}C)	-1
Evaporator Inlet Pressure P4 (Psi)	5
Compressor Ampere I1 (A)	0.9
Compressor Volt V1 (V)	220
Heater Ampere I2 (A)	0.7
Heater Volt V2 (V)	225
Chamber temperature (^{0}C)	20

These values are then plotted to P-h chart for R134a to get enthalpy of the system.

From P-h chart the values of enthalpy at different points are noted that are required to calculate COP of the system. For COP of a system formula is mentioned below.

$$\text{COP} = \frac{h1-h4}{h2-h1}$$

Table 2: Enthalpy Data

h1 enthalpy at suction	240 KJ/kg
h2 enthalpy at compressor discharge	300 KJ/kg
h4 enthalpy at evaporator inlet	190 KJ/kg

COP calculated from the enthalpies is 0.8 this value is used as a theoretical value that will be used as a base line to check the accuracy of the system by calculating COP with adiabatic chamber.

4.1.2 Experiment 2

In this experiment 100% R134A is charged to system. The main objective of this experiment is to form a base line for other experiments to compare results. By following the procedure R134A is charged in the system and after system reaches to steady state condition values are noted. The value of the COP calculated in previous experiment is compared with the COP of this experiment to check the accuracy of the chamber. The data for this experiment is mentioned in the table.

Table 3: Experiment 2 Data

Suction Temperature T1 (^{0}C)	26
Suction Pressure P1 (Psi)	5
Compressor Discharge Temperature T2 (^{0}C)	66
Compressor Discharge Pressure P2 (Psi)	154
Condenser Outlet Temperature T3 (^{0}C)	43
Condenser Outlet Pressure P3 (Psi)	154
Evaporator Inlet Temperature T4 (^{0}C)	-1
Evaporator Inlet Pressure P4 (Psi)	5
Compressor Ampere I1 (A)	0.9
Compressor Volt V1 (V)	220
Heater Ampere I2 (A)	0.7
Heater Volt V2 (V)	225`
Chamber temperature (^{0}C)	20

Power consumes by compressor I1 x V1 (W)	198
Power consumes by heater I2 x V2 (W)	157.5

Keeping the camber temperature constant at 20 ^{0}C when the heat absorption from the evaporator becomes equal to the heat rejection by heater.

$$\mathrm{COP} = \frac{\text{power consume by heater}}{\text{power consumes by compressor}}$$

Calculated COP in experiment 2 is 0.79.

4.1.3 Experiment 3

In this experiment 60% LPG and 40% of R134A is charged to the system keeping total weight of charged gas constant which is 585g. Both gasses are charged side by side to get a proper mixture of gases. After system reaches to steady state condition values are noted. The data for this experiment is mentioned in the table.

Table 4: Experiment 3 Data

Suction Temperature T1 (^{0}C)	17
Suction Pressure P1 (Psi)	25
Compressor Discharge Temperature T2 (^{0}C)	91
Compressor Discharge Pressure P2 (Psi)	357
Condenser Outlet Temperature T3 (^{0}C)	43
Condenser Outlet Pressure P3 (Psi)	357
Evaporator Inlet Temperature T4 (^{0}C)	-8
Evaporator Inlet Pressure P4 (Psi)	26
Compressor Ampere I1 (A)	1.1
Compressor Volt V1 (V)	220
Heater Ampere I2 (A)	1.0
Heater Volt V2 (V)	225`
Chamber temperature (^{0}C)	20
Power consumes by compressor I1 x V1 (W)	242
Power consumes by heater I2 x V2 (W)	216

Keeping the camber temperature constant at 20 ^{0}C when the heat absorption from the evaporator becomes equal to the heat rejection by heater.

$$\text{COP} = \frac{\text{power consume by heater}}{\text{power consumes by compressor}}$$

Calculated COP in experiment#3 is 0.897.

4.1.4 Experiment 4

In this experiment 80% LPG and 20% of R134A is charged to the system keeping total weight of charged gas constant which is 585g. Both gasses are charged side by side to get a proper mixture of gases. After system reaches to steady state condition values are noted. The data for this experiment is mentioned in the table.

Table 5: Experiment 4 Data

Suction Temperature T1 (^{0}C)	17
Suction Pressure P1 (Psi)	27
Compressor Discharge Temperature T2 (^{0}C)	91
Compressor Discharge Pressure P2 (Psi)	357
Condenser Outlet Temperature T3 (^{0}C)	43
Condenser Outlet Pressure P3 (Psi)	357
Evaporator Inlet Temperature T4 (^{0}C)	-10

Evaporator Inlet Pressure P4 (Psi)	28
Compressor Ampere I1 (A)	1.2
Compressor Volt V1 (V)	220

Keeping the camber temperature constant at 20 ^{0}C when the heat absorption from the evaporator becomes equal to the heat rejection by heater.

$$COP = \frac{\text{power consume by heater}}{\text{power consumes by compressor}}$$

Calculated COP in experiment 4 is 0.83.

4.1.5 Experiment 5

In this experiment 60% LPG and 40% of R134A is charged to the system keeping total weight of charged gas constant which is 400g. Both gasses are charged side by side to get a proper mixture of gases. After system reaches to steady state condition values are noted. The data for this experiment is mentioned in the table. In this experiment total weight of charged gases is reduced to 400g.

Table 6: Experiment 5 Data

Suction Temperature T1 (^{0}C)	25
Suction Pressure P1 (Psi)	10
Compressor Discharge Temperature T2 (^{0}C)	68
Compressor Discharge Pressure P2 (Psi)	240
Condenser Outlet Temperature T3 (^{0}C)	42
Condenser Outlet Pressure P3 (Psi)	240
Evaporator Inlet Temperature T4 (^{0}C)	-15
Evaporator Inlet Pressure P4 (Psi)	11
Compressor Ampere I1 (A)	0.8
Compressor Volt V1 (V)	216
Heater Ampere I2 (A)	0.7
Heater Volt V2 (V)	222`
Chamber temperature (^{0}C)	20
Power consumes by compressor I1 x V1 (W)	172.2
Power consumes by heater I2 x V2 (W)	155.4

Keeping the camber temperature constant at 20 ^{0}C when the heat absorption from the evaporator becomes equal to the heat rejection by heater.

$$COP = \frac{\text{power consume by heater}}{\text{power consumes by compressor}}$$

Calculated COP in experiment#5 is 0.902.

4.1.6 Experiment 6

In this experiment 80% LPG and 20% of R134A is charged to the system keeping total weight of charged gas constant which is 400g. Both gasses are charged side by side to get a proper mixture of gases. After system reaches to steady state condition values are noted. The data for this experiment is mentioned in the table. In this experiment total weight of charged gases is reduced to 400g.

Table 7: Experiment 6 Data

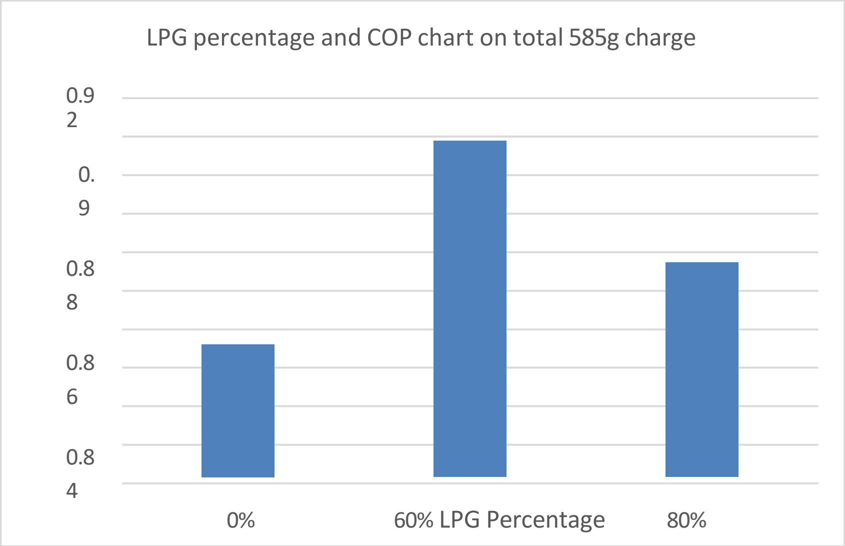
Suction Temperature T1 (^{0}C)	24
Suction Pressure P1 (Psi)	13
Compressor Discharge Temperature T2 (^{0}C)	70
Compressor Discharge Pressure P2 (Psi)	260
Condenser Outlet Temperature T3 (^{0}C)	42
Condenser Outlet Pressure P3 (Psi)	260
Evaporator Inlet Temperature T4 (^{0}C)	-16
Evaporator Inlet Pressure P4 (Psi)	14
Compressor Ampere I1 (A)	0.9
Compressor Volt V1 (V)	220
Heater Ampere I2 (A)	0.8
Heater Volt V2 (V)	220`
Chamber temperature (^{0}C)	20
Power consumes by compressor I1 x V1 (W)	198
Power consumes by heater I2 x V2 (W)	176

Keeping the camber temperature constant at 20 ^{0}C when the heat absorption from the evaporator becomes equal to the heat rejection by heater.

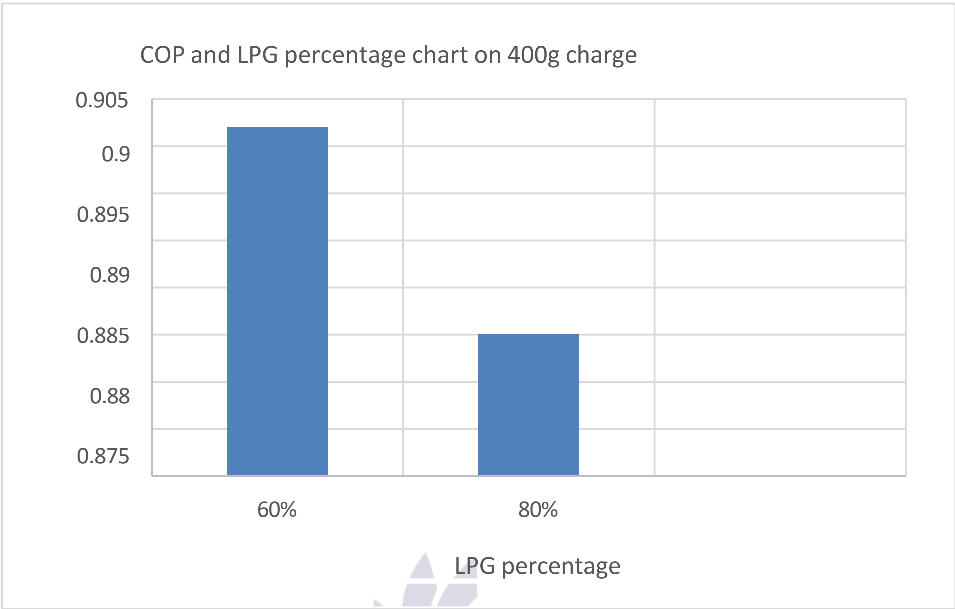
$$COP = \frac{\text{power consume by heater}}{\text{power consumes by compressor}}$$

Calculated COP in experiment 6 is 0.88.

4.2. Discussion



Experiment no. 1 gives the theoretical value of COP from P-h chart. That is compared with the experimental value of COP after performing the experiment on the same charge. While the calculated relative error was 0.5% the proofs the validity of results. Then the results are taken on different ratios of LPG with R134A keeping the charge constant which is 585g. the overall results on 585g of charge is shown in the table.



After performing the experiments on the same charge, the value of total charge reduced to 400g. Again, system is tested on the different percentages of LPG with R134A. Reducing the total charge increase the COP of the same system, under ambient temperature. All the experiments are taken in the same time to reduce the effects of environmental temperature.

5. Conclusion

Testing the same system on different charge and different ratio of gases. LPG shows better COP and increased in overall efficiency of the system. Using LPG in the system reduces the total amount of charge to get better results. Pulldown time and cooling capacity of LPG is more than that of single R134A. As the power consumed by the compressor depends on the amount of gas in the system and cooling capacity of the system. By using LPG in the system amount of the gas is reduced that cause in the decrease in compressor power consumption. If only LPG is used in the system, it increases the risk factor of explosion while running of the system or doing its repairing. When the LPG is working with the inflammable gas R134a this risk factor is reduced that makes the use of HC refrigerant safer to use on commercial and domestic level. On the other hand, LPG also have much less effects on the environment. The main concluded points are: Designed a VCR system for both R134A and LPG

- Designed adiabatic chamber for calculation of COP of mixture refrigerants
- Mixture of LPG and R134a gives better COP than only R134a
- Power consumed by the compressor reduces with the use of LPG
- Overall quantity of gas charge reduces with the use of LPG
- Lower temperature is achieved with the use of LPG in the same system

Reference

L. J. M. Kuijpers, J. A. de Wit, and M. J. P. Janssen, “Possibilities for the replacement of CFC 12 in domestic equipment,” *International Journal of Refrigeration*, vol. 11, no. 4, pp. 284–291, 1988.

H. O. Spauschus, "HFC 134a as a substitute refrigerant for CFC 12," *International journal of refrigeration*, vol. 11, no. 6, pp. 389–392, 1988.

V. S. Reddy, N. L. Panwar, and S. C. Kaushik, "Exergetic analysis of a vapour compression refrigeration system with R134a, R143a, R152a, R404A, R407C, R410A, R502 and R507A," *Clean Technologies and Environmental Policy*, vol. 14, no. 1, pp. 47– 53, 2012.

J. M. Belman-Flores, V. H. Rangel-Hernández, S. Usón, and C. Rubio-Maya, "Energy and exergy analysis of R1234yf as drop-in replacement for R134a in a domestic refrigeration system," *Energy*, vol. 132, pp. 116–125, 2017.

K. Mani and V. Selladurai, "Experimental analysis of a new refrigerant mixture as drop- in replacement for CFC12 and HFC134a," *International journal of thermal sciences*, vol. 47, no. 11, pp. 1490–1495, 2008.

B. O. Bolaji, "Exergetic Performance of a Domestic Refrigerator Using R12 and its Alternative Refrigerants," 2010.

M. Mohanraj, S. Jayaraj, and C. Muraleedharan, "Environment friendly alternatives to halogenated refrigerants—A review," *International Journal of Greenhouse Gas Control*, vol. 3, no. 1, pp. 108–119, 2009.

M. Mohanraj, C. Muraleedharan, and S. Jayaraj, "A review on recent developments in new refrigerant mixtures for vapour compression-based refrigeration, air-conditioning and heat pump units," *International journal of energy research*, vol. 35, no. 8, pp. 647–669, 2011.

A. K. Rai, A. Kumar, P. Kumar, and A. A. Ansari, "Experimental Study on A Domestic Refrigerator Using Lpg As A Refrigarant," *Technology*, vol. 6, no. 11, pp. 43–49, 2015.

S. M. Deokate, S. AK, D. AM, and N. A. Uzagare, "A Study Paper on LPG as an Alternative Refrigerant for Refrigeration," 2016.

M. Fatouh and M. el Kafafy, "Experimental evaluation of a domestic refrigerator working with LPG," *Applied Thermal Engineering*, vol. 26, no. 14–15, pp. 1593–1603, 2006.

B. A. Akash and S. A. Said, "Assessment of LPG as a possible alternative to R-12 in domestic refrigerators," *Energy conversion and Management*, vol. 44, no. 3, pp. 381–388, 2003.

B. Purkayastha and P. K. Bansal, "An experimental study on HC290 and a commercial liquefied petroleum gas (LPG) mix as suitable replacements for HCFC22," *International Journal of refrigeration*, vol. 21, no. 1, pp. 3–17, 1998.

E. Khorshid, B. Alshriaan, A. Alsairafi, A. Alazemi, and A. Alhaddad, "Performance investigation on new refrigerant mixture," in *2011 Fourth International Conference on Modeling, Simulation and Applied Optimization*, 2011, pp. 1–5.

M. A. Sattar, R. Saidur, and H. H. Masjuki, "Performance investigation of domestic refrigerator using pure hydrocarbons and blends of hydrocarbons as refrigerants," 2007.

T. O. Babarinde, O. S. Ohunakin, D. S. Adelekan, S. A. Aasa, and S. O. Oyedepo, "Experimental study of LPG and R134a refrigerants in vapor compression refrigeration," *International Journal of Energy for a Clean Environment*, vol. 16, no. 1–4, 2015.

J. Gill and J. Singh, "Experimental analysis of R134a/LPG as replacement of R134a in a vapor-compression refrigeration system," *International Journal of Air-Conditioning and Refrigeration*, vol. 25, no. 02, p. 1750015, 2017.

Y. Lizhong, F. Weicheng, Z. Xiaodong, and W. Qing'an, "Analysis of fire and explosion hazards of some hydrocarbon–air mixtures," *Journal of hazardous materials*, vol. 84, no. 2–3, pp. 123–131, 2001.

F. Girodroux, A. Kusmierz, and C. J. Dahn, "Determination of the critical flammability ratio (CFR) of refrigerant blends," *Journal of Loss Prevention in the Process Industries*, vol. 13, no. 3–5, pp. 385–392, 2000.

S. V. Shaik and T. P. A. Babu, "Thermodynamic performance analysis and flammability study of various new ozone friendly non azeotropic refrigerant mixtures as alternatives to replace R22 used in residential air conditioners," *Journal homepage: http://iieta. org/Journals/IJHT*, vol. 36, no. 4, pp. 1470–1481, 2018.

N. Abas, A. R. Kalair, N. Khan, A. Haider, Z. Saleem, and M. S. Saleem, "Natural and synthetic refrigerants, global warming: A review," *Renewable and Sustainable Energy Reviews*, vol. 90, pp. 557–569, 2018.

C. S. Choudhari and S. N. Sapali, "Performance investigation of natural refrigerant R290 as a substitute to R22 in refrigeration systems," *Energy Procedia*, vol. 109, pp. 346– 352, 2017.

M. Larumbe Gonfaus, "Energetic optimization of lyophilisation," 2017.

R. K. Gond, R. P. Chaudhary, M. A. Khan, and G. Jain, "Performance and exergy analysis of vapour compression refrigeration system using various alternative of R134a," *International Research Journal of Engineering and Technology*, vol. 3, no. 5, pp. 187– 193, 2016.

O. R. Olatunji, O. S. Ohunakin, and D. S. Adelekan, "Performance of a Limited Charge of R600a and LPG Refrigerants in a Domestic Refrigerator Using R134a Refrigerant in Different Ambient Conditions," in *Journal of Physics: Conference Series*, 2019, vol. 1378, no. 2, p. 22101.

R. H. Ahmad *et al.*, "Comparative analysis of refrigerant performance between LPG and R134a under subtropical climate," *Journal of Thermal Analysis and Calorimetry*, vol. 139, no. 4, pp. 2925–2935, 2020.

J. Thavamani and R. Senthil, "Performance analysis of retrofitted domestic vapour compression refrigeration system using hydrocarbon refrigerants," *International Journal of Ambient Energy*, pp. 1–8, 2020.

Cengel, Y. A., & Boles, M. A. (2007). *Thermodynamics: An Engineering Approach 6th Editon (SI Units)*. The McGraw-Hill Companies, Inc., New York. ISBN: 978-0073398174