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EXPERIMENTAL EXPLORATION ON AIR CONDITIONER WITH HC BASED REFRIGERANTS BLEND

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Abstract

Researchers are looking for long-lasting refrigerators for residential and industrial use due to the changing global climate over the use of zero ODP and high GWP of existing refrigerators. After the Montreal Protocol was revised in 1987, HFCs (hydro fluorocarbons) were identified as potential replacements for CFCs as long-term refrigerants. Due to the high GWP, HFCs gained dominance after the Kigali settlement in 2016 (1300). Therefore, finding long-lasting refrigerants to replace HFCs in room air conditioners is necessary. Commercial LPG is recommended as an emergency room air conditioner (Hydrocarbon Blend of R290/R600a (50%/50%) (by weight)). Commercial LPG has no ODP and low GWP. This mixture has a lower specific volume and flow rate than HFC-134a. Heat emission power consumption vs compressor in a vapor compression refrigeration system. In the present work, two different hermetic compressors are tested in a compatibility test, one with HFC-134a and POE (Polyolester) oil and the other with HC-290 / HC- 600a (commercial LPG) mixture of refrigerant and mineral oil. This test rig runs for 2000 hours continuously under the same conditions. After the specified time, a test to determine the balance and a test of the oil was carried out. After carrying out these tests, conclusions are made in the form of compatibility testing of the hermetic compressor with HC-290/HC-600a (c-LPG) refrigerant mixture, and a comparison is made with the results obtained with HFC-134a. Based on the results, the compatibility of commercial LPG (hydrocarbon mixture) with mineral oil and compressor parts is found to be better than HFC-134a/POE. Further, a simulation study and an experimental study were conducted to evaluate the performance of a 1 Ton window air conditioner with commercial LPG (hydrocarbon blend) as a substitute for HFC-134a. Initially, HFC-134a refrigerant was tested in the first window air conditioning system as recommended by the interior and. The external test conditions in IS 1391-part 1 (1992) are standard without system modification, and the performance of the system was evaluated with different amount of refrigerant charge. Later, LPG sales were charged for charge optimization in the same window air conditioning system during the same test conditions. Commercial LPG achieves 0.4% - 15.58% higher cooling capacity, 0.62% -8.9% lower energy consumption, and 10.49% -16.4% higher COP than the original HFC134a in low and high test conditions with improved capillary length (900mm) and sufficient charging. Weight (0.45 kg).

1.INTRODUCTION

For both home and commercial applications, refrigeration and air conditioning are crucial to daily living. Room air conditioners, which are categorized based on their capacity and type of use, are necessary for the comfort of occupants in residential applications. Room air conditioning typically uses window or split-type air conditioners. Window air conditioners are preferred for small-capacity residential applications because of their affordability and simplicity of installation. Split air conditioners are employed for greater capacity due to their reduced noise and aesthetic appeal. (2017) Althouse et al.

Global usage of refrigerants is rising as a result of the rapid growth in the number of room air conditioners. Before, room air conditioners used HCFC refrigerants like R22. After the Montreal Protocol was amended in 1987, less R22 was used, and HFC refrigerants including R134a, R407c, R404a, and R410a were swapped out for R22 in air conditioners. Due to their great potential to cause global warming, the Kigali amendment to the Montreal Protocol placed restrictions on the use of HFCs in air conditioning applications in 2016. (GWP). The second flaw of HFCs is their miscibility. The utilization of HFC/HC mixes like R433, R431, R422, and R432a by various researchers came later. However, these refrigerant mixes are not sold on a global scale.

KIGALI AMENDMENT TO MONTREAL PROTOCOL

HFCs are used instead of CFCs in refrigeration and air conditioning systems since they have no ozone depletion potential (ODP). But HFCs have a great potential for global warming (GWP). HFCs' GWP ranges from 12 to 14800. Greenhouse gases include HFCs. The Kigali amendment to the Montreal Protocol was approved by 170 nations on October 15, 2016 in Kigali, Rwanda, to regulate the use of compounds with high global warming potentials, including HFCs in the refrigeration and air conditioning sector. By 2050, the Kigali Amendment projects a reduction in emissions of 70 billion tonnes of CO2 equivalent. Additionally, it will contribute to a 0.5°C drop in global temperature. (Ozone-UNIDO, 2017)

1.0 HYDROFLUOROCARBON (HFC)

HFC-134a (1,1,1,2 tetrafluoroethane, CH2FCF3), a member of the hydrofluorocarbon family, is a non-flammable, chlorine-free refrigerant with zero ODP. HFC-134a can be charged in compressors that are similar in size to R12. The fundamental benefit of HFC-134a's nonflammability (Atmospheric Exposure Level (AEL) of 1000 ppm) is that it has zero ODP. However, it still boasts an impressive GWP. The vapour pressure properties resemble those of HCFC. Compared to R12, HFC-134a is said to have better heat transmission properties. (1996, Devotta)

HFC-134a and mineral oils are not miscible. For HFC-134a systems, specialised synthetic lubricants such as polyol ester (POE) lubricants were chosen. However, certain POEs are only moderately miscible with HFC-134a, whereas others are completely miscible (like HCFC-22 and mineral oil).

POEs' hygroscopicity, sensitivity to hydrolysis, and incompatibility with some elastomers are drawbacks. With HFC-134a/POE, contamination and material compatibility are the main problems. POEs have a 100-fold higher hygroscopicity than typical mineral oils. Despite the fact that this rules out the possibility of ice crystal formation at low temperatures leading to a capillary blockage, the system still needs to be kept exceptionally dry. With heat and suction, it is more difficult to eliminate moisture at this level. The majority of commercial POE lubricant manufacturers require 100 ppm of moisture in their products. The water content in the POE lubricant can typically rise from 50 ppm to 1200 ppm in 200 hours in an environment with a RH of 85%. Therefore, handling POE demands the utmost caution.

As both HFC-134a and POEs have a higher propensity to hold moisture, it is imperative for any HFC-134a/POE system to maintain it as dry as possible. In the presence of moisture, POEs are also likely to hydrolyze, which can result in the creation of acids. Desiccant kinds made of silica gel are incompatible with HFC-134a.

A non-flammable refrigerant, HFC-134a is categorised as such by ASHRAE's test procedures. According to Underwriters Laboratory (UL), HFC-134a is essentially non-flammable. HFC-134a becomes flammable at low pressure (5.5 psig and 17.7 0C) after mixing with greater air concentrations (60%). For combustibility at low temperatures, a higher pressure is needed. For leak testing, HFC-134a and air shouldn't be mixed. Therefore, high concentration air should be present at absolute pressure (above atmospheric).

1.1 LOW GWP REFRIGERANTS

Researchers are looking for long-term refrigerants for residential and industrial uses due to changes in the global environment about the use of zero ODP and high GWP of the present refrigerants. After the Montreal Protocol was revised in 1987, HFCs (hydrofluorocarbons) were viewed as a potential replacement for CFCs as long-term refrigerants. Due to their high GWP, HFCs have gained control after the 2016 Kigali amendment (1300). Finding long-term refrigerants to replace HFCs is therefore necessary. With some use restrictions, a number of natural refrigerants such as carbon dioxide, ammonia, hydrocarbons, and HFOs are thought to be an alternative to HFCs. These natural refrigerants have low to little or no GWP and no ODP. The ODP and GWP of particular refrigerants are shown in Table 1.3.

ODP and GWP of refrigerants (Devotta and Gupta, 2002)

Refrigerant	ODP	GWP (100 years)
R11	1	4600
R12	0.82	10,600
R22	0.034	1700
R123	0.012	120
HFC-134a	0	1300
R152a	0	120
R407C	0	1700
R410a	0	2000
R290	0	~ 20
R600a	0	~ 20
R717	0	< 1
R718	0	< 1
R744	0	1

ODP and GWP

ODP and GWP are two factors that are currently the key environmental concerns under consideration. Due to the disintegration of some other synthetic fluids, acid rain may one day be a factor in refrigerant selection. Since HFCs can breakdown into fluoric acid in the lower atmosphere and will be washed away extremely quickly to the earth, it has already been mentioned that expanded use of HFCs may generate more acid rain. Table 1.3 demonstrates that when compared to CFCs, HCFCs, and HFCs, all-natural refrigerants have a very low GWP and no ODP.

HFCs appear to have solved the ODP issue, thus for the time being, attention will turn to global warming and acid rain.

TEWI (Total Equivalent Warming Impact)

The refrigerant released into the environment has a direct impact on global warming, as measured by the GWP. However, the biggest effect (the direct impact) typically results from CO2 emissions during the generation of electricity using fossil fuels needed for plant operation. The direct and indirect components of the effect are added together to form the TEWI. A definition of the TEWI is:

TEWI = GWP x M + Z x B

where : GWP = GWP of the fluid relative to CO2 (GWPCO2 = 1) M = Total mass of the refrigerant released to the environment

Z = Amount of CO2 released in the generating electricity (kg of CO2/kWh) B = Energy consumption of the system in its lifetime (kWh)

The TEWI varies from nation to country, and in a huge country like India, it may also vary from region to region depending on the form of power generation. It is highly reliant on the energy production method and the efficiency of the refrigeration plant. The indirect influence may account for up to 99% of the total impact in some circumstances. Since HFCs (HFC-134a) and their mixes (R410a and R404a) often have high GWPs, ranging from 600 to 4000, they are increasingly widely employed to replace CFCs and HCFCs. As a result of their greatly expanded consumption in the RAC industries in developing nations, HFC emissions are expected to considerably increase up until 2050. The Montreal Protocol's Kigali amendment from 2016 requires that high GWP HFCs be phased out in accordance with the established timeline. In India, the phase down of HFC began in 2019.

Isobutane (R600a)

The standard boiling point of R600a is higher (-11.85°C). Because isobutane is a single substance, it eliminates differential leakage issues, which simplifies charging and troubleshooting duties. In particular at high ambient temperatures, recent research have demonstrated that freezers using R600a offer superior efficiency than those using HFC-134a. Additionally, R600a provides low discharge pressure, low stress, and refrigerant pulsations on the discharge side with potentially lower noise levels.

The suction side of the compressor with R600a operates under vacuum leading to the possibility of air ingress, which is not desirable. Proper vacuum conditions can handle this hurdle without any risk. To achieve better energy efficiency, the modification in capillary length and quantity of refrigerant charge is necessary. In general, Isobutane technology does not require any changes in manufacturing except for safety precaution.

Utilizing mineral oils isobutane. It is common knowledge that isobutane and mineral oils mix well and result in a decrease in the viscosity of the mixture. As a result, oil needs to have a higher kinematic viscosity index (10cSt). In India, these mineral oils are easily accessible in contrast to the HFC-134a-specific proprietary synthetic lubricants.

All conventional metals and non-metals used in air conditioning systems, such as mineral oil, sealing materials, and a compressor motor, are compatible with iso butane refrigerant. Silicone and natural rubber are not compatible with iso butane. Such materials are not likely to be utilised in hermetic systems, nevertheless.

Iso butane has higher latent heat, lower density, better thermal conductivity compared to that of HFCs. In addition, due to lower density, the charge required is lower than that of HFCs for the same capacity of the system. The hydrocarbon charge is approximately 40-50% of HFC refrigerant by weight resulting in cost savings.

The behavior of the hydrocarbon with the materials and oil is nearly the same as HFC. There is no specific requirement to concern hydrocarbon production regarding its cleanliness other than specific flammability precautions. Service technicians should be trained to handle hydrocarbon safely to avoid explosion, specifically during soldering

Hydrocarbon refrigerant tubes in the system. Service technicians should follow prescribed safety standards and procedures to handle hydrocarbon refrigerants. In principle, retrofitting of HFC-134a by hydrocarbon does not create any problem concerning the system's reliability if there is no problem with ignition sources presence causing safety issues by leakages. Ultimately, the same charging unit can be used for hydrocarbons (except the charging valve). So, servicing refrigeration and air conditioning systems in developing countries becomes more effortless and safer.

Isobutane is present in natural crude oil, which can be extracted by separation and purification. These are readily available in most of the Article-5 countries. However, care has to be taken that unstable and toxic impurities are strictly limited. (Devotta et al, 2001)

Commercial LPG (Hydrocarbon Blend)

Commercial LPG is the hydrocarbon blend of propane and isobutane (50% /50%) by weight emerged as the alternative compound as a substitute to HFC-134a. The refrigerant properties of this mixture are better than that of HFC-134a. It is still not used in air conditioning systems due to the charge limitation of A3 flammable refrigerant. However, after adopting safety regulations as per ASHRAE 34 and permitting A3 refrigerant charge up to 0.5 kg (IEC standard, 2019), It is possible to use this refrigerant mixture in room air conditioners.

Most of the industries in European countries adopted hydrocarbon refrigeration systems. There are three fundamental reasons to adopt hydrocarbon as a refrigerant as follows.

(i) GWP of these mixtures is negligible.

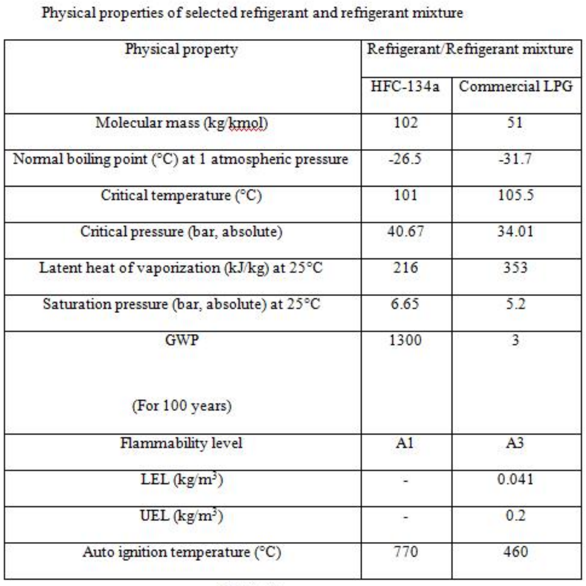
(ii) ODP of these mixtures is zero.

(iii) These mixtures are compatible with mineral oil and are readily available in nature.

In addition to the above, a specific advantage of the hydrocarbon blend is its vapor pressure curve which can adjust to the need of appliances. It is possible to use such a blend in the HFC-134a system without any modification of the compressor. The boiling point (1 bar pressure) of the HC mixture (50%-50%) ranges from -32°C to -24°C, which is very close to HFC-134a (-26.5°C). The specific volume and mass flow rate of this blend is lower than HFC-134a. The latent heat of enthalpy of this mixture is very high (353 kJ/kg). The hydrocarbon mixture is compatible with metals / non-metals, generally used for refrigeration and air conditioning systems. The noise level of the compressor with hydrocarbon blend is found to be 35-40 Db, which is very similar to R12/HFC-134a. (Devotta et al. 1996)

Table 1.4 [ACRIB, 2001]

Physical properties of selected refrigerant and refrigerant mixture



Physical properties of selected refrigerant and refrigerant mixture

Physical property	Refrigerant/Refrigerant mixture	
	HFC-134a	Commercial LPG
Molecular mass (kg/kmol)	102	51
Normal boiling point (°C) at 1 atmospheric pressure	-26.5	-31.7
Critical temperature (°C)	101	105.5
Critical pressure (bar, absolute)	40.67	34.01
Latent heat of vaporization (kJ/kg) at 25°C	216	353
Saturation pressure (bar, absolute) at 25°C	6.65	5.2
GWP (For 100 years)	1300	3
Flammability level	A1	A3
LEL (kg/m^3)	-	0.041
UEL (kg/m^3)	-	0.2
Auto ignition temperature (°C)	770	460

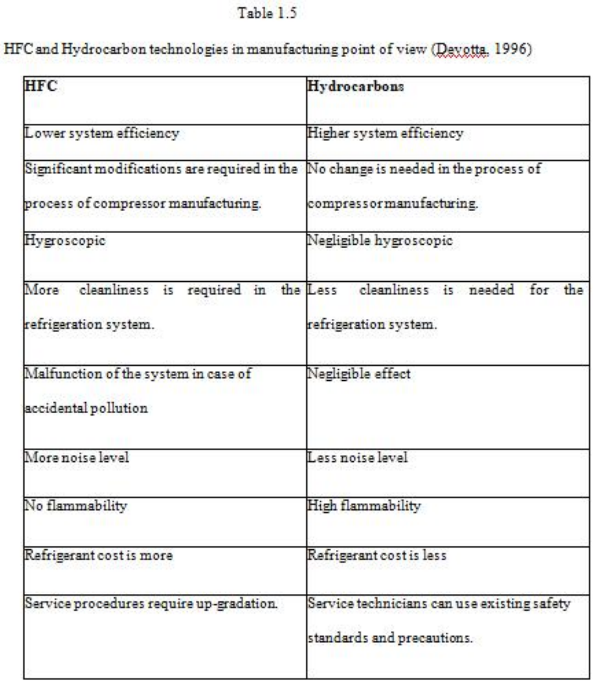


Table 1.5

HFC and Hydrocarbon technologies in manufacturing point of view (Devotta, 1996)

HFC	Hydrocarbons
Lower system efficiency	Higher system efficiency
Significant modifications are required in the process of compressor manufacturing.	No change is needed in the process of compressor manufacturing.
Hygroscopic	Negligible hygroscopic
More cleanliness is required in the refrigeration system.	Less cleanliness is needed for the refrigeration system.
Malfunction of the system in case of accidental pollution	Negligible effect
More noise level	Less noise level
No flammability	High flammability
Refrigerant cost is more	Refrigerant cost is less
Service procedures require up-gradation.	Service technicians can use existing safety standards and precautions.

1.2 SAFETY STANDARDS

The search for alternatives to HCFCs and HFCs simultaneously is much more compounded than the earlier search for alternatives to CFCs. Currently, there are HCFCs, HFCs, HFOs (unsaturated HFCs), natural refrigerants including R717 (Ammonia), Hydrocarbons (HC-600a and HC-290), R744 (CO2) in use as a refrigerant in a variety of applications, globally as well as in India. Most of the low GWP refrigerants, including HFC-32, HFO-1234yf, HFO-1234ze, HC-290, and R 717, are flammable. It introduces safety factors to consider by the HVAC & R community in the design, construction, operation, and service and decommissioning systems using flammable and toxic refrigerants. In India, earlier, there were no safety codes or standards, and no safety regulations were available to address the safe use of flammable refrigerants adequately. Presently, ISHRAE published safety guidelines to use flammable refrigerants. (ISHRAE,2017)

As per ASHRAE 34 and EN 378, A3 refrigerants are listed (Table 1.6) as the highest flammable refrigerants. Flammable refrigerants are regulated strictly by the International Electrochemical Commission (IEC) and European standard EN 378, which control the permissible quantity of these refrigerants. IEC 60335-2-40 standard allows using A3 hydrocarbon refrigerant up to 0.5 kg. (International Electrochemical Commission, 2019) Safety guidelines and safety standards for safe use of A3 flammable and toxic refrigerants are prescribed in ASHRAE 15, EN 378, and European standards. Charge limits of these flammable refrigerants are 20% as per ASHRAE 15/BS 4434 or 25% as per DIN 7003. It helps to decrease the flammability limit of flammable refrigerants in case of leakage within a confined area. As per EN 378 standard, charge limitations depend upon two factors; maximum charge and permitted charge. Maximum charge quantity depends upon the location and categories of occupancy. The permitted charge limit depends upon the room size where the charge could leak.

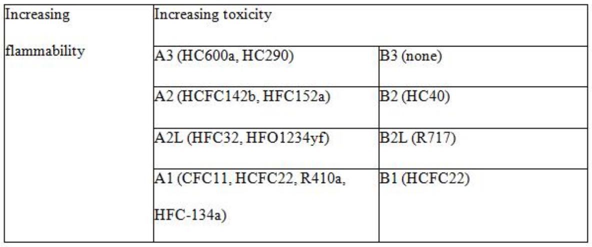
Grob (1998) investigated that system design modification can avoid the risk of using flammable refrigerants. Colbourne and Ritter (2002) developed a model to assess risk for room air conditioners using flammable refrigerants. They investigated that a high concentration of flammable refrigerants at floor level and failure of installed safety components enhances overall risk.

1.3.1 SAFETY CLASSIFICATION

Besides energy efficiency, thermal and chemical stability, the most significant aspect of refrigerant selection is safety. Classification of refrigerants is based on two safety aspects flammability and toxicity. Both parts are covered under IS 16656: 2017 standard (Table 1.6).

Table-1.6

Safety classification of refrigerants (ISHRAE 2015)



Increasing flammability	Increasing toxicity	
	A3 (HC600a, HC290)	B3 (none)
	A2 (HCFC142b, HFC152a)	B2 (HC40)
	A2L (HFC32, HFO1234yf)	B2L (R717)
	A1 (CFC11, HCFC22, R410a, HFC-134a)	B1 (HCFC22)

The following parameters are affected due to the flammability of refrigerants and require modification of equipment design.

(i) Safety of technicians and occupants.

(ii) Material handling activities

(iii) Service activities

Refrigerants' flammability properties are the lower explosive limit, upper explosive limit, ignition temperature, flame propagation velocity, and heat of combustion.

1.3.2 SAFETY CONSIDERATIONS

For using flammable refrigerants, various safety precautions should be followed to protect against injury to occupants and harm to property. So, safety begins with prescribed basic safety precautions and following safety procedures. Before dealing with any refrigerant, the properties of the flammable refrigerant should be known. The manufacturer generally provides flammability properties of refrigerant and safety precautions required.

Safety hazards also apply to different materials used with refrigerants. These materials are lubricating oil, oxy-acetylene (for brazing), nitrogen gas (for leak testing), etc.

Whenever handling flammable refrigerants, consequences and order of potential risk should be assessed to address necessary safeguards and safety precautions required to ensure the system's safe working.

In general, refrigerants are kept in highly pressurized cylinders. At atmospheric pressure, these refrigerants have an affinity for rapid expansion, resulting in explosion and injury to occupants and property. So, high-pressure refrigerant cylinders should be handled with safety procedures. Manufacturer's guidelines should be followed in handling refrigerant cylinders.

During releasing pressurized refrigerant liquid in the atmosphere, refrigerant liquid vaporizes fast and extracts heat from the atmosphere. In case of a liquid spill on body skin, it will lead to frostbite. So, one should have safety gloves and safety glasses or personal protective equipment during handling refrigerants. In case of any spill or skin contact, the manufacturer's guidelines should be followed.

In all refrigerants, if released, asphyxiation of people (and also animals) occurs due to decreased oxygen levels in atmospheric air. As most refrigerants (except ammonia) are denser than air, leaked refrigerants tend to settle in rooms below ground and enclosed spaces. Due to the odorless property of refrigerant, occupants may suffer asphyxiation without any notice of oxygen displacing problem. In general, proper ventilation is required in areas of highly accumulated refrigerant vapor regions. In case of a significant leak, blowers or fans flow high-speed air at the lowest floor level for evacuating and ventilating areas. Respiratory protection or breathing apparatus for occupants is required in these areas to avoid any accidents/fatalities due to asphyxiation in the field of RAC.

The system should be designed considering the properties of flammable refrigerants and the impact of ignition. It is necessary to adopt safety precautions during working on a flammable refrigerant system. (ISHRAE, 2017)

LITERATURE REVIEW

According to Spatz et al. (2014), high GWP refrigerants have yet to be replaced with low GWP refrigerants under the Kyoto Protocol. HFO was introduced as an unsaturated fluid with a low flammability and GWP. However, due to its lower latent heat capacity, it requires the highest mass flow rate of any refrigerant. It has the highest power requirement and the lowest COP when compared to HFCs. As the temperature of the evaporator drops, so does its power consumption. As a result, HFOs do not provide a long-term solution because they produce toxic byproducts and decompose. It is also costly. A low GWP hydrocarbon refrigerant/blend is a potential substitute for air conditioners with safety parameters. Hydrocarbons are more energy efficient.

Domestic refrigerators with LPG as a replacement for HFC-134a were investigated experimentally by Fatouh and Kfafy (2006) and Mani et al. (2008). The power consumption and pressure ratios of the LPG system were found to be 4.3% and 5.5% lower, respectively, than those of the HFC-134a system. Cooling capacity and COP, on the other hand, were 28.6% and 7.6% higher, respectively, than HFC-134a. As a result, LPG was discovered to be a long-term solution for domestic refrigerators.

Gill and Singh (2017, 2018) investigated and compared the performance of a vapour compression refrigeration system with an HFC-134a/LPG (28:72) refrigerant mixture to that of HFC-134a. Variable condenser and evaporator temperatures were used in trials with regulated ambient conditions. The results showed a 2.10-13.86% lower compressor discharge temperature and a 15.1-17.82% higher COP with the refrigerant mixture than HFC-134a. Furthermore, the miscibility of the refrigerant mixture with mineral oil was found to be appropriate in the refrigeration system. He et al. (2014) investigated the high-performance freezer performance with R290 and HFC-134a experimentally and theoretically. Theoretical study results showed that R290 increased refrigeration capacity by 54.2% when compared to HFC-134a. Furthermore, when R290 was used instead of HFC-134a, the power consumption of the freezer was reduced by 26.7%.

Qiqi et al. (2015) tested a room air conditioner with components compatible with R410a refrigerant using a refrigerant mixture of R32 (68%) and R290 (32%). The mixture's performance was compared to that of R410a. The GWP of the refrigerant mixture is 22% that of R410a. The gliding temperature of the mixture was discovered to be the same as that of R410a. Compressor power and discharge temperature were both increased by 14% to 23.7% and 0.61% to 4.76%, respectively. Cooling capacity was increased by 6.1% to 16.4%. The COP was raised by 6%-7%. Shaik and Ashok Babu (2017) theoretically investigated room air conditioners with various combinations of HFC-134a, R290, RE170, R1270, and R32 refrigerant mixtures. Furthermore, this mixture has a GWP of 716, which is lower than R22 (GWP 1760).

Moham et al. (2020) compared R600a/R22 refrigerant blend with TiO2 nanomaterial and mineral oil to R22/POE oil in a split type air conditioner. The results showed that the blend's discharge temperature decreased by 15% and its COP increased by 10-9.5% when compared to R22/POE oil. The researchers discovered that using a hydrocarbon refrigerant blend with nanomaterial improved the system's COP.

Jung et al. (2020) used R1234yf refrigerant to test a 2-4 kW capacity air conditioning system. The system performed better with R1234yf than with HFC-134a, according to the results. Navarro et al. (2013) investigated the open piston compressor using HFC-134a, R1234yf, and R290. R290 has higher compressor efficiency and lower heat losses than other refrigerants, according to the results. The discharge temperature of R1234yf is lower than that of R290. To work with R1234yf refrigerant, additional system modifications are required.

Teng et al. (2012) investigated the effect of charge level and outdoor temperature conditions (26°C to 32°C) on a room air conditioner using R290 as a substitute for R22. The results showed that the EER of R290 increased as the outdoor temperature increased. For the given outside temperature range, the optimal R290 charge quantity was 50% of R22. R290's EER should ideally be 20% higher than R22's.

3. METHODOLOGY

3.1 PROBLEM STATEMENT

According to a recent amendment to the Montreal Protocol in Kigali, Rwanda, in 2016, to control the consumption of high GWP working fluids such as HFCs in the global air conditioning industry. As a result, adopting a low GWP environmentally friendly refrigerant/refrigerant mixture is critical. Several refrigerants, including hydrocarbons, hydrocarbon refrigerant mixtures, HFO, and natural refrigerants, are being actively considered as HFC replacements. Millions of HFC-based compressors are already in use in room air conditioners. To assess the reliability of old compressors, the compatibility of these existing compressors with alternative working fluid and lubricant oil is required. . In the current work, hermetic compressor compatibility testing and performance evaluation with hydrocarbon refrigerant mixture (commercial LPG) are performed to evaluate the performance of this refrigerant mixture in the window air conditioner, and experimental results are compared with HFC-134a.

3.2 OBJECTIVES

Determine the compatibility of commercial LPG with hermetic compressor and lubricating oil components, as well as compare it to HFC-134a.

Set up a psychrometric test chamber to assess the performance of a 1 Ton window air conditioner powered by HFC-134a and commercial LPG.

Conduct performance baseline tests to determine the feasibility of replacing HFC-134a with commercial LPG and lowering the charge quantity.

Create a simulation model to evaluate the performance of the window air conditioning system as capillary tube length changes are made for charge reduction with commercial LPG while maintaining cooling capacity and COP.

To compare the performance of the window air conditioning system with a modified capillary tube length and the optimum charge quantity of commercial LPG to the baseline test results with HFC-134a.

3.3 APPROACH

Two hermetic compressors were tested in a compatibility test rig, one with HFC-134a and POE and the other with a mixture of HC-290/HC-600a (50%/50%) (commercial LPG) refrigerants and mineral oil. Under the same conditions, this test rig ran for a total of 2000 hours. The following observations were made after the time limit was reached.

1. Visual rating: Before the test, photographs of compressor parts such as pistons, piston pins, cylinders, and so on were taken, and after the test, photographs were taken.

2. Petrography was used to perform surface finish tests on critical components. Both working fluids were compared before and after the test.

COOLING CAPACITY AND COP CALCULATION

The cooling capacity and COP were calculated using the equation as follows.

q_C = m_a Δh

COP = q_c/W

where ,

qc = Cooling capacity (kW)

ȝ 2 = Outlet air density at indoor (kg/m3) vm = Air volumetric flow rate (m3/s)

Δh = h1 – h2

h1 = Inlet enthalpy of air in kJ/kg h2 = Outlet enthalpy of air in kJ/kg W = Power consumption in kW ma = Mass flow rate of air in kg/s

Moiler chart was used to calculate the enthalpies of moist air at the evaporator's entry and exit state points, as well as the air density at the outlet. The volumetric air rate through the evaporator was measured using the airflow measuring duct.

3.5 MEASUREMENT UNCERTAINTIES

The measurement uncertainties for the experimental results with both working fluids were calculated. Moffat's method was used to assess performance parameters such as cooling effect and COP based on measured elements (1998). Uncertainty was calculated using the instrument's accuracy as well as some engineering intuition. Table 3.1 displays the uncertainties in significant parameters. For uncertainties, test results were calculated using the following equations.

Table 3.1
Uncertainties in major measuring parameters

Parameter	Operating Limit	Uncertainty
Pressure	0 – 40 bar	± 0.4 bar
Temperature	0- 200 (°C)	± 2.2°C
Power	0 – 5000 (W)	± 10W

4. EXPERIMENTATION

The experiment was carried out to evaluate the performance of a 1 Ton window air conditioner using commercial LPG (hydrocarbon blend) as a replacement for HFC-134a. Furthermore, the effect of capillary tube length on c-LPG charge quantity was investigated. Table 4.1 shows the experimental conditions. The HFC-134a refrigerant was initially tested in the original window air conditioning system under standard indoor and outdoor test conditions without system modification. Later, at the same test conditions, c-LPG was charged for charge optimization in the same window air conditioning system. HFC-134a and c-LPG baseline experimental test results were compared in terms of performance parameters such as power consumption, cooling capacity, and COP.

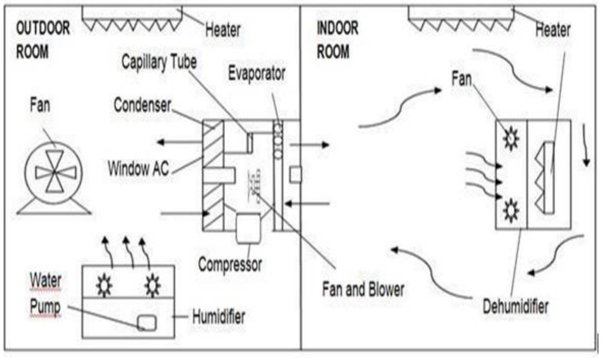


Fig 4.1 Psychrometric test chamber

Based on simulation results for optimum cooling capacity, the room air conditioning system was tested with the optimum c-LPG charge quantity and optimum capillary tube length. Other system components remain unchanged. All of the above-mentioned cases' test results were discussed and compared in terms of various performance parameters such as power consumption, cooling capacity, and COP. The experiments were carried out in a psychrometric test room, as shown in fig 4.1.

4.1 PSYCHOMETRIC TEST CHAMBER

The layout of the psychometric test chamber for performance testing of the window air conditioning system is shown in Fig 4.1. It is divided into two equal-sized rooms (10ft x 10ft x 8ft) (indoor and outdoor). To maintain test conditions, a common partition separates the two rooms. The common partition has an opening for mounting the window air conditioner. In the psychometric test facility, the evaporator side was kept towards the indoor room side, and the condenser side was kept towards the outdoor room side. To maintain the desired IS 1391-part 1(1992) test conditions, various reconditioning equipment such as a spray humidifier, dehumidifier, electric air fan, and two electrical air heaters (each 1 kW) were installed in the indoor and outdoor rooms.

Table 4.1
Test conditions (IS1391 Part 1)

Test	Outdoor		Indoor	
	DBT (°C)	WBT (°C)	DBT (°C)	WBT (°C)
Domestic Test	35	30	27	19
Export Test A	35	24	27	19
Export Test B	46	24	29	19

4.2 EXPERIMENTAL PROCEDURE

In this experiment, cooling capacity was calculated using the enthalpy difference between supply and return air. For experimental results, enthalpies were calculated using the psychrometric calculator. The testing procedure is described below.

The water level in the humidifier was initially checked in psychrometric test rooms. Following that, the control panel's indoor and outdoor test conditions were set in accordance with IS1391 part 1 (1992) test conditions. Then, to achieve steady-state conditions, turn on the air heater, humidifier, dehumidifier, and air fan.

After you've achieved steady-state conditions, turn on the window air conditioner and let it run for an hour before taking readings. With varying loads on the heater, air fan, and humidification/dehumidification, the DBT and WBT in the indoor and outdoor rooms were automatically maintained. In steady-state conditions, readings were taken every 10 minutes for one hour. Each trial was carried out twice. Reading deviation was found to be within a + 2% range.

This experimental setup tested the capacity and power consumption of HFC-134a and commercial LPG with varying charge amounts.

4.2.1 Charge and Capillary Optimization Tests

Three cases were considered in this experimental setup. In case I, the system was charged with HFC-134a with no changes made to the window air conditioning system. In Case II, the same system was charged with commercial LPG with no system changes. Capillary tube length was changed in Case III, and the system was charged with commercial LPG.

The performance of a window air conditioner was evaluated using HFC-134a under various test conditions according to IS 1391 part 1 (1992), as shown in table 5.1 The refrigerant charge was recovered after the HFC-134a test, and commercial LPG was charged with safety precautions. The same experimental method was used for the DT, ETA (low ambient), and ETB (high ambient) test conditions, in accordance with the test standards.

The primary goal of this test was to obtain an optimised refrigerant charge quantity. The charge quantities of the refrigerant HFC-134a tested were 0.82 kg, 0.86 kg, 0.9 kg, 0.94 kg, and 0.98 kg. Based on previous research and recommendations for hydrocarbon refrigerant charge quantity published in the literature (Joudi and Al-Amir 2014, Teng et al. 2012, Padalkar et al. 2010), the commercial LPG charge quantity for the same system was kept at 50% of the HFC-134a charge quantity.

Following the recovery of the HFC-134a charge from the system and leak testing, commercial LPG with a charge quantity of 0.41 kg was charged in the same compressor with safety precautions. This refrigerant is charged in a well-ventilated area away from any source of ignition. An electronic weighing machine is connected to the refrigerant can via a specially designed charging line. The charging valve has been changed. During charging, the can is kept inverted. The commercial LPG charge quantities tested in the experimental work were 0.41 kg, 0.43 kg, 0.45 kg, 0.47 kg, and 0.49 kg.

In this experimental setup, net cooling capacity was determined in the psychrometric test chamber using a capacity rating test under IS 1391-part 1 (1992) test conditions. Using the psychrometric calculator, the air enthalpy method was used to calculate cooling capacity in various cases for these test conditions. During performance tests, an energy metre was used to calculate total power consumption (compressor and fan). The cooling capacity and total power consumption were used to calculate the COP.

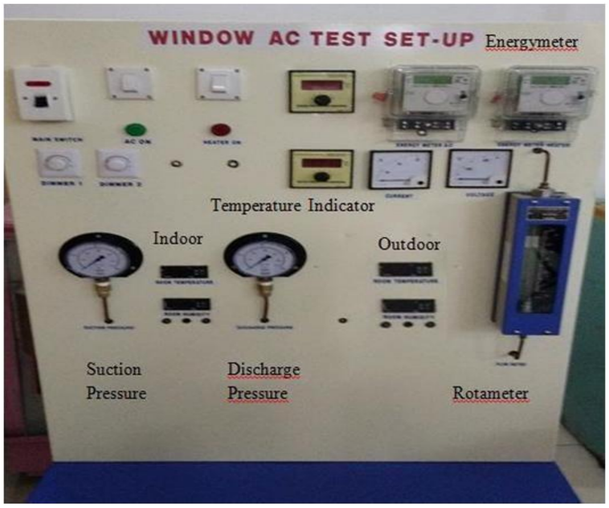


Fig. 4.2 Control panel

5. RESULTS AND DISCUSSION

The experimental results of HFC-134a and commercial LPG in terms of mass flow rate, suction pressure, discharge pressure, total power consumption, cooling capacity, and COP are discussed in this chapter. The results of simulations and experiments are also compared and discussed.

THERMODYNAMIC PERFORMANCE CYCLE ANALYSIS

HFC-134a and commercial LPG thermodynamic cycle analyses have been performed. Operating parameters such as condensing temperature, condenser sub-cooling, evaporator temperature, and evaporator superheat were studied. Furthermore, the impact of these operating parameters on performance parameters such as power consumption, cooling effect, and COP was investigated.

5.1 Effect of Condenser Temperature

Figure 5.1 depicts the effect of increasing the condenser temperature from 35°C to 50°C on the cooling capacity of HFC-134a and commercial LPG. Cooling capacity decreased as condensing temperature rose. Commercial LPG has a higher cooling capacity up to about 45°C. Following that, the cooling capacity of HFC-134a was discovered to be greater than that of commercial LPG. Even though the latent heat of HFC-134a is lower than that of commercial LPG, the cooling capacity of commercial LPG is lower at higher ambient temperatures due to the higher charge quantity and mass flow rate of HFC-134a than commercial LPG.

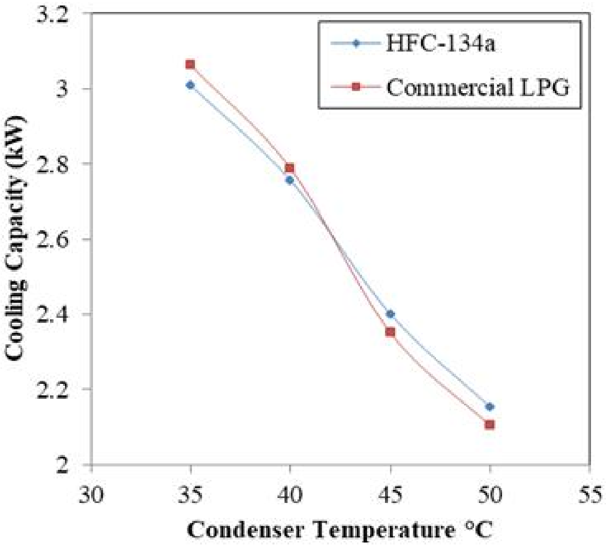


Fig.5.1 Effect of condenser temperature on cooling capacity

Figure 5.2 depicts the effect of changing the condenser temperature on the power consumption of HFC-134a and commercial LPG. 2. As the condensing temperature rose, so did the power consumption. Power consumption is increasing slowly, with an increase in charge quantity due to an increase in mass flow rate and an increase in discharge temperature. With condenser temperature, commercial LPG consumed 2.5% to 5.26% less power than HFC-134a.

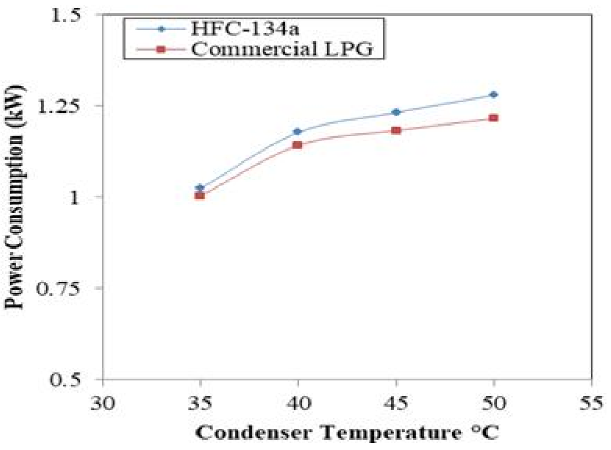


Fig.5.2 Effect of condenser temperature on power consumption

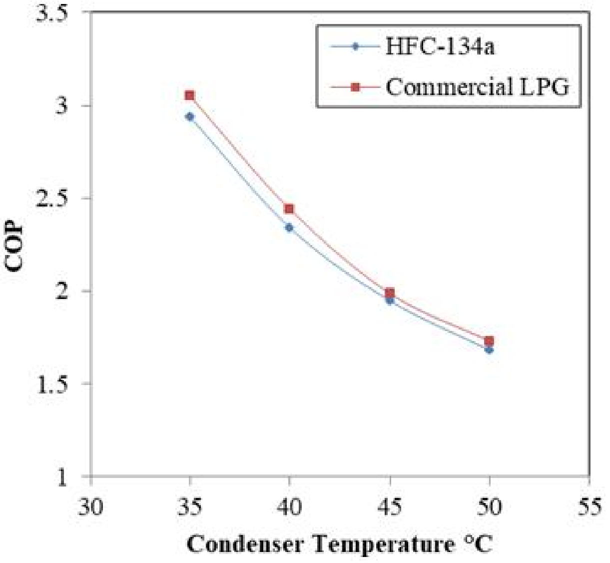


Fig.5.3 Effect of condenser temperature on COP

The variation of COP of HFC-134a and commercial LPG with condenser temperature is shown in Fig 6.3. With increasing condensing temperature, COP decreased. As condensing temperature rises, cooling capacity falls, and power consumption rises due to high discharge pressure, resulting in COP decreases. Due to lower power consumption and higher condenser temperature, the COP of commercial LPG was found to be 2.89% to 3.93% higher than HFC-134a.

5.2 Effect of Evaporator Temperature

Figure 5.4 depicts the effect of a 5°C increase in evaporator temperature on the cooling capacity of HFC-134a and commercial LPG. The cooling capacity increased as the evaporator temperature increased due to an increase in clearance volumetric efficiency and a decrease in the specific volume of the refrigerant at the compressor inlet. Because of their combined effect, the mass flow rate of refrigerant through the compressor increased, and thus the cooling capacity increased. With evaporator temperature, commercial LPG had a 1% higher cooling capacity than HFC-134a.

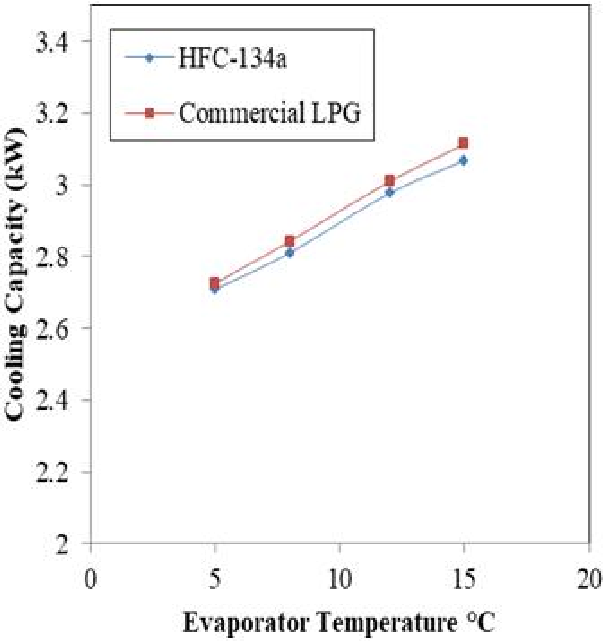


Fig.5.4 Effect of evaporator temperature on cooling capacity

Figure 5.5 depicts the effect of changing the evaporator temperature on the power consumption of HFC-134a and commercial LPG. Power consumption decreased marginally as evaporator temperature increased due to a decrease in discharge temperature. With evaporator temperature, commercial LPG consumed 2.63%-4.4% less power than HFC-134a

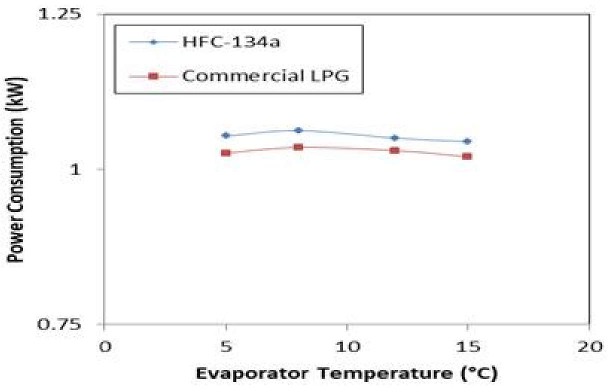


Fig.5.5 Effect of evaporator temperature on power consumption

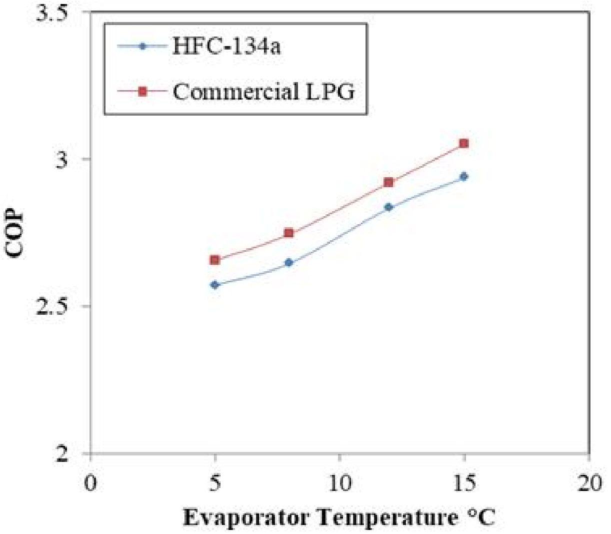


Fig.5.6 Effect of evaporator temperature on COP

The variation of COP of HFC-134a and commercial LPG with evaporator temperature is shown in Fig 5.6. Increased evaporator temperature increased COP due to increased cooling capacity and decreased power consumption. Commercial LPG had a COP that was 3.1%-3.6% higher than HFC-134a due to lower power consumption and higher evaporator temperature.

6. CONCLUSIONS

According to the Montreal Protocol amendment in Kigali, Rwanda, in 2016, HFCs/HCFCs are controlling substances. As a result, environmentally friendly working fluids for air conditioners are required. This research sought the best solution for existing and new room air conditioners. Commercial LPG has been identified as a potential solution for window air conditioners. The performance of a 1Ton window air conditioner with commercial LPG as a drop-in replacement for HFC-134a was evaluated using simulation and experimental work. Significant findings in the compatibility test of hermetically sealed compressors are as follows.

O The optimum conditions in the baseline test with a window air conditioner are as follows.

O The maximum cooling capacity for low ambient (DT and ETA) conditions is 0.9 kg with HFC-134a, while the maximum cooling capacity for higher ambient ETB conditions is 0.86 kg with HFC-134a

O Commercial LPG has an optimum cooling capacity of 0.47 kg at low ambient (DT, ETA) test conditions and 0.45 kg at ETB conditions.

O In comparison to HFC-134a baseline results, a 1 Ton window air conditioner with an optimum charge (0.45 kg) of commercial LPG and a modified capillary length (900mm) achieves the following.

- Cooling capacity rose by 0.4%-15.58%.

- Power consumption has been reduced by 0.62%-8.9%.

- The coefficient of performance (COP) increased by 10.49% -16.4%.

- As a result of the above findings, it is possible to conclude that commercial LPG can be used as a drop-in replacement for HFC-134a in 1 Ton window air conditioning systems. However, the system must incorporate safety parameters in accordance with safety standards.

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