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Investigating Eco-Friendly Alternatives to Traditional Refrigerants: Addressing Global Warming and Ozone Layer Depletion

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Abstract

CFCs and HCFCs have been scientifically proven to significantly contribute to ozone layer depletion in the stratosphere. In accordance with international protocols such as the Montreal and Kyoto Protocols, these refrigerants should have been phased out over the last decade. The refrigeration and air-conditioning industries are now shifting towards chlorine-free refrigerants, as chlorine is a primary agent in ozone depletion.

HCFC-22, a widely used refrigerant, is scheduled to be phased out by 2030 in developed countries and by 2040 in developing countries. Research has identified potential substitutes for HCFC-22, primarily classified under Hydrofluorocarbons (HFCs) and Hydrocarbons (HCs). Despite their advantages, HFCs and HCs come with their own set of limitations. For instance, HCs are highly flammable and subject to strict safety regulations limiting their use in domestic air conditioners. HFCs, while less flammable, are incompatible with traditional mineral oils, requiring the use of polyolester (POE) oil, which is hygroscopic and can lead to moisture-related issues in the system.

The global impact of refrigerants extends beyond ozone depletion to contributing significantly to global warming. Although traditional refrigerants offer desirable thermodynamic properties such as high energy efficiency and stability, their detrimental effects on the environment necessitate the search for suitable eco-friendly alternatives. This issue requires urgent attention due to its global implications.

In India, HCFC-22 is predominantly used in Vapor Compression Systems (VCS). Due to its high Ozone Depleting Potential (ODP) and Global Warming Potential (GWP), it is set to be completely phased out by 2020 according to the Montreal and Kyoto Protocols. Developed countries have already limited and banned its use in air conditioning systems. Global research efforts are focused on identifying appropriate alternative refrigerant mixtures for residential air conditioners and heat pumps.

The Montreal Protocol has successfully banned CFCs, and it is anticipated that HCFCs will also be phased out within the next half-decade due to their adverse environmental impacts. Post-2020, all countries are expected to adopt eco-friendly refrigerants for refrigeration and air-conditioning systems to mitigate global warming and improve the energy efficiency of these systems.

Keywords:*Chlorofluorocarbons, Hydrochlorofluorocarbons, Ozone Layer Depletion, Global Warming, Eco-Friendly Refrigerants, Montreal Protocol, Kyoto Protocol, Hydrofluorocarbons, Hydrocarbons, Vapor Compression Systems.*

1. Introduction

Refrigeration and air conditioning systems are integral to modern society, enabling food preservation, medical storage, and providing comfort in various environments. However, the refrigerants used in these systems have raised significant environmental concerns. Traditional refrigerants, particularly hydrofluorocarbons (HFCs), have been identified as potent greenhouse gases that contribute to global warming, while others, like chlorofluorocarbons (CFCs), have been phased out due to their detrimental effects on the ozone layer. The increasing awareness of climate change and the importance of protecting the ozone layer have prompted international agreements such as the Montreal Protocol and the Kigali Amendment. These agreements aim to phase out substances that deplete the ozone layer and reduce the use of HFCs, which have high global warming potential (GWP). As a result, there is an urgent need to identify and implement ecofriendly alternatives to these harmful refrigerants.

This paper aims to explore sustainable refrigerant alternatives that can mitigate the environmental impact of refrigeration and air conditioning systems. It will examine the characteristics and benefits of natural refrigerants, such as ammonia, carbon dioxide, and hydrocarbons, as well as newer synthetic refrigerants like hydrofluoroolefins (HFOs). By assessing their effectiveness, feasibility, and safety, this research seeks to provide a comprehensive overview of viable options for reducing the carbon footprint of the refrigeration sector while addressing the challenges of global warming and ozone layer depletion. Through this investigation, the paper will highlight the importance of transitioning to ecofriendly refrigerants and offer recommendations for facilitating this critical shift.

2. Background

2.1. Traditional Refrigerants

Historically, refrigerants like chlorofluorocarbons (CFCs) and hydrofluorocarbons (HFCs) have been the backbone of refrigeration technology. CFCs were widely used due to their efficiency and stability, but their ozonedepleting potential became a major environmental concern. The recognition of their harmful effects led to the adoption of the Montreal Protocol in 1987, which aimed to phase out CFCs and other ozonedepleting substances.

As CFCs were phased out, HFCs emerged as a popular alternative because they do not deplete the ozone layer. However, HFCs are powerful greenhouse gases, with global warming potentials thousands of times greater than carbon dioxide (CO2). This has made HFCs a target for regulatory action, notably under the Kigali Amendment to the Montreal Protocol, which seeks to phase down HFC use globally.

2.2. Environmental Impact

The environmental impact of traditional refrigerants is twofold: global warming and ozone layer depletion. The Intergovernmental Panel on Climate Change (IPCC) highlights that HFC emissions contribute significantly to climate change, with projections indicating that if left unregulated, HFC emissions could account for up to 20% of global greenhouse gas emissions by 2050. Additionally, while HFCs have a low ozone depletion potential (ODP), their cumulative effect on the atmosphere remains a pressing concern.

As the world faces the escalating impacts of climate change, there is an urgent need to reduce the reliance on traditional refrigerants. The search for alternative refrigerants that are environmentally benign, energyefficient, and safe for human health is essential for aligning the refrigeration and air conditioning sectors with global sustainability goals.

2.3. Regulatory Landscape

International agreements have laid the groundwork for phasing out harmful refrigerants. The Montreal Protocol and its subsequent amendments emphasize the importance of transitioning to more sustainable alternatives. Additionally, various countries have implemented their own regulations and incentives to encourage the adoption of ecofriendly refrigerants. For instance, the European Union's FGas Regulation sets limits on HFC usage and promotes the use of natural refrigerants.

This regulatory landscape presents both challenges and opportunities. While it drives the need for innovation in refrigerant technology, it also creates barriers for manufacturers and endusers who must adapt to new systems and practices. Understanding the current regulatory environment is critical for facilitating the transition to ecofriendly alternatives.

3. Objectives

1. To study the performance of HFC152a/HC290/HC600 refrigerant mixture and compare the same with that of HCFC- 22 to attain an optimal mixture composition.

2. To investigate experimentally the performance of R- 152a/HCs refrigerant mixture with various compositions of HC blend and to optimize the same in the aspect of retrofitting and energy efficiency in a window air conditioner.

3. To carry out an economic study to analyse the effects of replacing R-22 with M3 in terms of energy savings and cost benefits.

4. Methodology

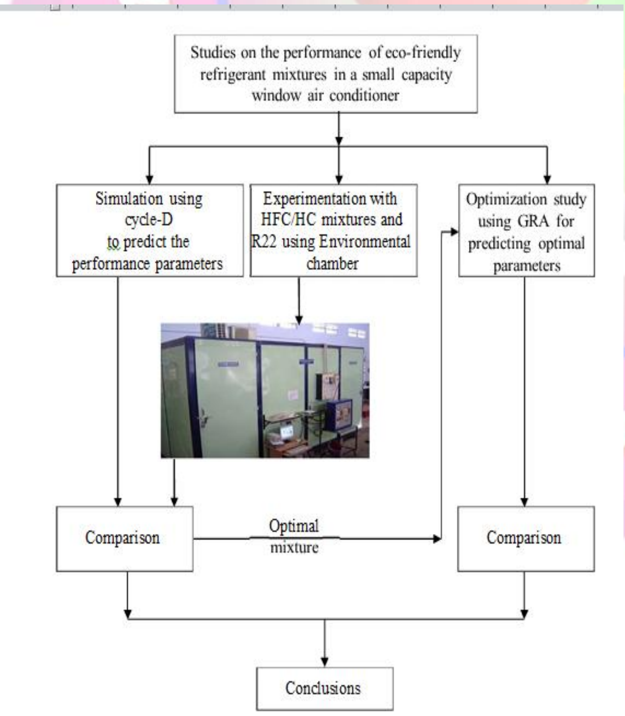

Figure 4.1 Methodology of the total Investigation

Table 4.1 Refrigerant mixture compositions and corresponding to COP and temperature glide

Refrigerant Mixtures	R152a (%wt.)	R290 (%wt.)	R600 (%wt.)	COP	Temperature glide (°C)	
					T_{eva}	T_{cond}
M1	60	20	20	3.26	6.8	7.6
M2	20	20	60	3.33	10.8	14.2
M3	10	10	80	3.32	6.3	10.6
M4	10	80	10	3.18	5.4	4.9
M5	80	10	10	3.31	2.5	2.2

Table 4.2 Thermodynamic Properties of Refrigerant and Refrigerant Mixture

Refrigerant	Molecular Weight (g/mol)	Boiling Point (°C)	Freezing Point (°C)	Critical Temperature (°C)	Critical Pressure (°C)
R22	86.46	-40.81	-151.41	96.14	49.9
R152a	66.05	-24.02	-118.59	113.26	45.16
R290	44.09	-42.09	-187.67	96.67	42.47
R600	58.12	-0.055	-138.28	151.98	37.96

4.1 Preparation Of Refrigerant Mixture

In the present study, the proposed ternary mixture of HFC (R152a)/ HC (R290/R600) are zoetrope in nature. Therefore, mixing of the refrigerants, charging, and handling should be done cautiously. Many strategies have been reported in the published literature concerning with characteristic and procedure of the zoetrope mixtures (David et al. 1997; Yanho et al. 1997; Per 1998).

The five mixtures designated as mixture-1(M1), mixture-2(M2), mixture-3(M3), mixture-4(M4) and mixture-5(M5) were prepared in isolated cylinders before they were charged into the compressor. To control the concentration shifts, the required minimum liquid charge quantity level in the mixture cylinder should not be less than 10% volume while charging the system. Therefore, the quantity of the mixture has been prepared necessarily to maintain the level of 10%. To have a correct quantity the mixtures weight was prepared in small cylinders with capacity of 1kg.

The cylinders were cleaned initially and flushed with HFC 152a twice. Then they were evacuated to 0.1

mbar. While filling to avoid pressure accumulation inside the cylinders they were retained in a low temperature bath. Since the vapor pressure of R290 and R600 are lower than R152a, initially the cylinders were filled with the required quantity of R290 and R600. Weighing scale with an accuracy of 0.1 gram was used. In order to maintain the desired mass percentage in the total filled quantity the required mass of R152a was calculated and filled. The cylinders were properly designated to indicate the name and quantity of charged mixture.

5. Experimental Procedure

The experimental setup was subjected to heat infiltration test to evaluate the infiltration rate of both the chambers as a preparatory measure before conduction of the experiment. All experiments were carried out under the condition of adding indoor chamber’s infiltration heat load to the evaporator load. The refrigerant R22 was used for conducting the tests. For all the experiments, the readings were taken only after running the system at least for an hour under required test conditions thereby allowing the system to reach steady state condition and attain stability. The conditions maintained for first setof experiments include condenser temperature constant at 50oC and varying evaporator temperatures at different levels such as 2oC, 4oC, 6oC,8oC, 10oC and 12oC.

An interval period of 20 minutes was maintained to take each reading ensuring the steady state condition of the system. The experiments were repeated thrice for each test condition and the average values were utilized for calculation purposes. Maintaining the same test conditions, three different trial runs were conducted on three different days. Now the tests were repeated by maintaining evaporator temperature constant at 7oC and varying the condenser temperatures at different levels such as 45oC, 47oC, 49oC, 51oC,53oC and 55oC. The indoor chamber heat load and the surrounding conditions in the outdoor chamber were adjusted to maintain condenser and evaporator temperatures within an accuracy range of ±1oC. After completing all the experiments using R22, the air-conditioning system is retrofitted with series of refrigerant mixtures (M1-M5)

The steps involved in the retrofitting procedure are discussed below:

Procedure for retrofitting operations

- R22 refrigerant was completely drained from the air- conditioning system
- The oil was drained by taking out the compressor from the air-conditioning system
- The quantity of the drained mineral oil was measured
- The compressor taken out from the air-conditioning system was charged with polyol ester oil of very small quantity and a dry run conducted. Then the oil was drained. This process of oil charging- system running- oil draining was repeated twice.
- The compressor was then reinstalled into the air-conditioner
- Leakage test of the system was carried out using dry nitrogen at 12.41 bar pressure.
- The system was kept in evacuation condition roughly for an hour
- Then the system was charged with 950 ml of fresh polyol esteroil
- The air-conditioning system was then evacuated to a vacuum. Finally, the system was charged with refrigerant mixtures with help of separate cylinders and repeated the experimental procedure followed and readings are recorded.

5.2 Data Reduction With Sample Data

Performance parameters were calculated by using the measured data with refrigerant side and air side measurements for the refrigerants R22 and mixtures (M1-M5). Measurements at evaporator temperature 7oC and condenser temperature 50oC were taken as the sample data. Tables 3 show the measured and calculated air side and refrigerant side parameters and the COP calculations, using the average of air and refrigerant side values.

6. Results and Discussion

6.1 Range Of Experiments

Experiments are conducted using R22. The condenser temperature (Tc) is maintained constant at 50oC with varying their evaporator temperatures (Te) as 2oC, 4oC, 6oC, 8oC, 10oC and 12oC during first sequence of tests. In the second sequence of tests the condenser temperatures are varied, as 45oC, 47oC, 49oC,51oC, 53oC, 55oC but the evaporator temperature maintained at 7oC. After all the tests are over with R22, the air conditioner is retrofitted with proposed refrigerant mixtures from M1 to M5 and the same set of experimental procedure is repeated for each. The performance parameters analyzed during the experimentation
are:

i) Pressure ratio
ii) Compressor discharge temperature
iii) Refrigerant mass flow rate
iv) Refrigeration effect
iv) Compressor power
v) Coefficient of performance

Comparisons on performance parameters of the window air- conditioner for different test mixture are carried out. Results for both R22 and refrigerant mixtures (M1-M5) are analyzed. Capacity of refrigeration is calculated based on refrigeration side measurements and air side measurements. Previously, the capacity of refrigeration is determined using the energy supplied to the heater and heat infiltration load. But in present case, the refrigerant load is measured by using the pressure, temperature, and mass flow rate values of the refrigerant. Also, these measured values at significant points are used for the calculation of refrigerant side power. The energy meter is connected to the compressor to measure compressor power at air side. The average values (between air side measurements and refrigerant side calculations) of compressor power and refrigerating capacity are used for calculating the coefficient of performance.

6.2 Pressure Ratio

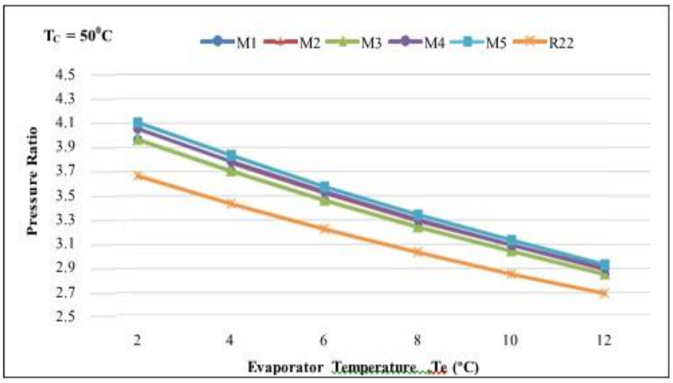

Figure 6.1 Effect of Evaporator Temperature on Pressure Ratio

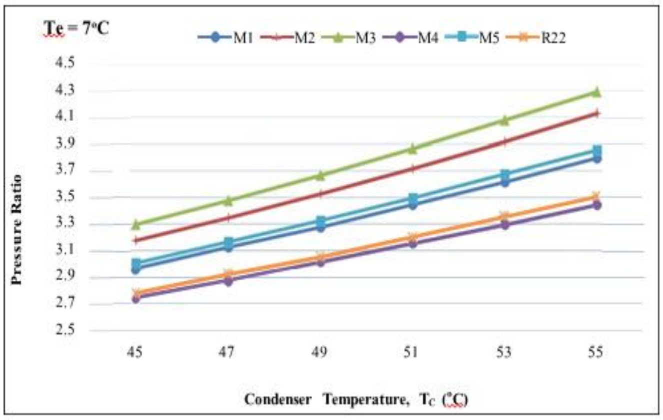

Figure 6.2 Effect of Condenser temperature on Pressure ratio

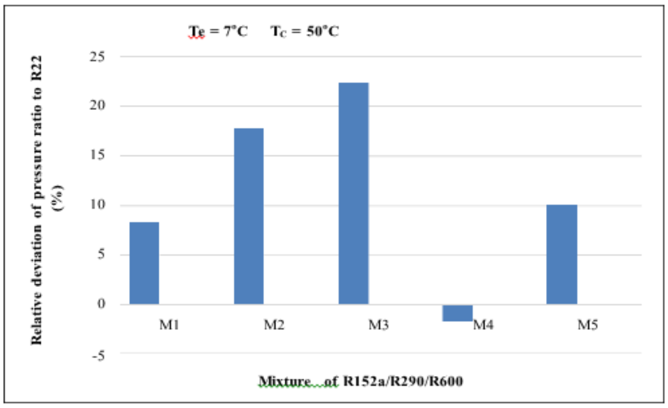

Figure 6.3 Deviation of pressure ratio compared with R22

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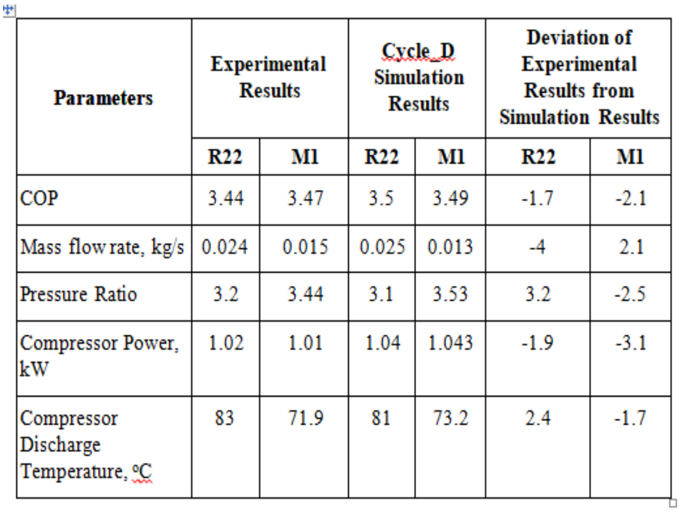
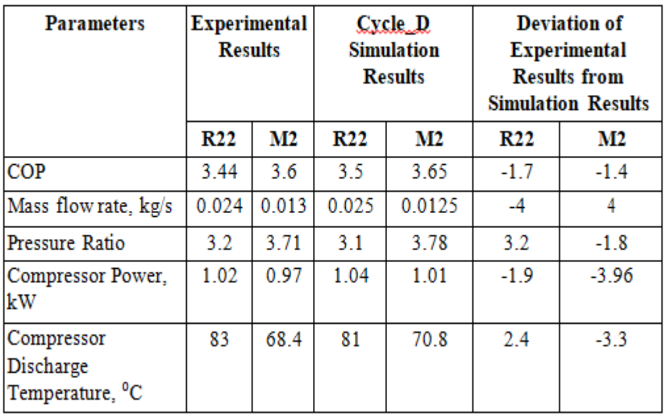
Table 6.1 Comparison of Experimental results and Cycle_D simulation results of R22 and M1 (for the runs with Te = 7^0 C and Tc = 50^0 C)



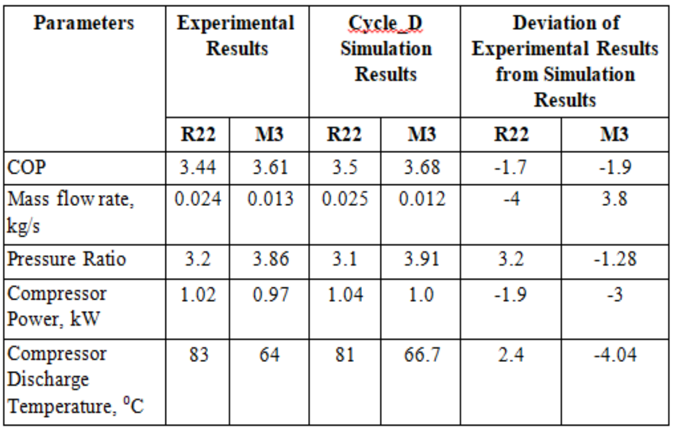
Parameters	Experimental Results		Cycle_D Simulation Results		Deviation of Experimental Results from Simulation Results	
	R22	M1	R22	M1	R22	M1
COP	3.44	3.47	3.5	3.49	-1.7	-2.1
Mass flow rate, kg/s	0.024	0.015	0.025	0.013	-4	2.1
Pressure Ratio	3.2	3.44	3.1	3.53	3.2	-2.5
Compressor Power, kW	1.02	1.01	1.04	1.043	-1.9	-3.1
Compressor Discharge Temperature, °C	83	71.9	81	73.2	2.4	-1.7

Table 6.2 Comparison of Experimental results and Cycle _D simulation results of R22 and M2 (for the runs with Te = 7^0 C and Tc = 50^0 C)



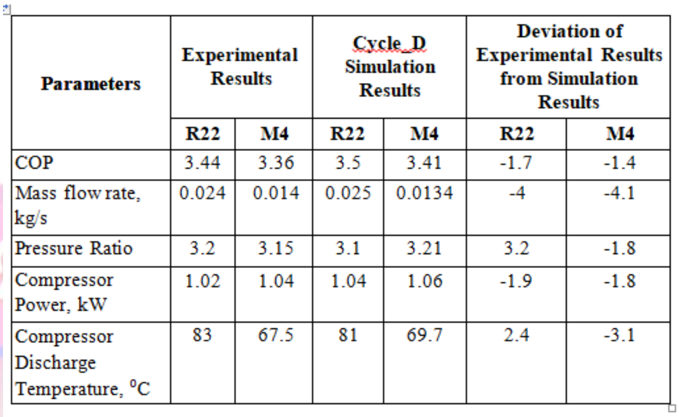
Parameters	Experimental Results		Cycle_D Simulation Results		Deviation of Experimental Results from Simulation Results	
	R22	M2	R22	M2	R22	M2
COP	3.44	3.6	3.5	3.65	-1.7	-1.4
Mass flow rate, kg/s	0.024	0.013	0.025	0.0125	-4	4
Pressure Ratio	3.2	3.71	3.1	3.78	3.2	-1.8
Compressor Power, kW	1.02	0.97	1.04	1.01	-1.9	-3.96
Compressor Discharge Temperature, °C	83	68.4	81	70.8	2.4	-3.3

Table 6.3 Comparison of Experimental results and Cycle _D simulation results of R22 and M2 (for the runs with Te = 7^0 C and Tc = 50^0 C)



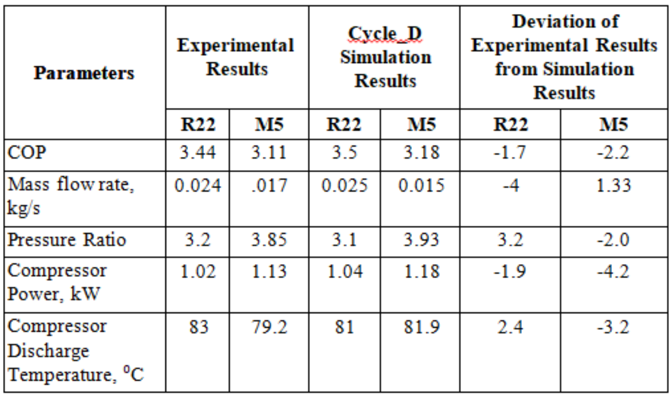
Parameters	Experimental Results		Cycle_D Simulation Results		Deviation of Experimental Results from Simulation Results	
	R22	M3	R22	M3	R22	M3
COP	3.44	3.61	3.5	3.68	-1.7	-1.9
Mass flow rate, kg/s	0.024	0.013	0.025	0.012	-4	3.8
Pressure Ratio	3.2	3.86	3.1	3.91	3.2	-1.28
Compressor Power, kW	1.02	0.97	1.04	1.0	-1.9	-3
Compressor Discharge Temperature, °C	83	64	81	66.7	2.4	-4.04

Table 6.4 Comparison of experimental results and Cycle_D simulation results of R22 and M4 (for the runs with Te = 7^0 C and Tc = 50^0 C)



Parameters	Experimental Results		Cycle_D Simulation Results		Deviation of Experimental Results from Simulation Results	
	R22	M4	R22	M4	R22	M4
COP	3.44	3.36	3.5	3.41	-1.7	-1.4
Mass flow rate, kg/s	0.024	0.014	0.025	0.0134	-4	-4.1
Pressure Ratio	3.2	3.15	3.1	3.21	3.2	-1.8
Compressor Power, kW	1.02	1.04	1.04	1.06	-1.9	-1.8
Compressor Discharge Temperature, °C	83	67.5	81	69.7	2.4	-3.1

Table 6.5 Comparison of experimental results and Cycle_D simulation results of R22 and M5 (for the runs with Te = 7^0 C and Tc = 50^0 C)



Parameters	Experimental Results		Cycle_D Simulation Results		Deviation of Experimental Results from Simulation Results	
	R22	M5	R22	M5	R22	M5
COP	3.44	3.11	3.5	3.18	-1.7	-2.2
Mass flow rate, kg/s	0.024	.017	0.025	0.015	-4	1.33
Pressure Ratio	3.2	3.85	3.1	3.93	3.2	-2.0
Compressor Power, kW	1.02	1.13	1.04	1.18	-1.9	-4.2
Compressor Discharge Temperature, °C	83	79.2	81	81.9	2.4	-3.2

CONCLUSION

The objective of this study is to find an eco-friendly refrigerant mixture with good performance parameters to replace R22 in vapour compression refrigeration system. Theoretical study for the ternary mixture is carried out by changing the proportions of R22 and refrigerant mixtures (M1-M5) using REFPROP 7.0 software. The ternary refrigerantsR152a/R290/R600 with five different mass proportions are taken for study and compared their thermal performances with that of R22 to find the optimal combination among the test mixtures. CYCLE _D software is used for simulation and analysis.

Experimental study was carried out on a window air conditioner with the five selected refrigerant mixtures and the impact of the new mixtures were analyzed. The desirable performance parameters such as coefficient of performance, compressor power, refrigeration effect, mass flow rate, compressor discharge temperature and pressure ratio etc., were studied and compared with the base refrigerant R22. The composition designated as Mixture-3 has given better performance among the five selected alternative mixtures.

The performance characteristics of the test fluids along with R22 are measured for study and the major conclusions drawn from the analysis are given below.

- The optimized charge quantity of the mixture (M3) is about 9.52% lower than the optimized mass of R22 this is due to the reason that M3 has lower vapour density compared to R22.
- The Coefficient of Performance of M3, M2,M5 and M1were found to be higher than that of R22 by 5.25%, 4.92%, 1.96% and 0.98% respectively and M4 gave 2.95% lower COP than R22.
- The pressure ratios of M3, M2, M5, M1 were higher than that of R22 by 22.28%, 17.7%, 10%, and 8.28% respectively and that of M4 was 1.7% lower than R22.
- The compressor discharge temperatures for M3, M4, M2, M1 and M5 were found to be lower than that of R22 by 23.71%, 19.01%, 18.56%, 13.98%, and 11.41% respectively.
- The compressor power of M4 was 2.6% higher than that of R22 whereas where as that of M2, M3, M5, M1 were found to be lower by 5.22%, 5.22%, 1.74%, 0.87% respectively.
- The performance of M3 and M2 were significantly higher compared to R22 whereas, the temperature glide was poor. The temperature glide value of M5 was appreciably better and also its performance was higher than that of R22.Hence from the experimental results it can be observed that M5 shows the required properties to become a potential replacement candidate to R22.

References

1. Intergovernmental Panel on Climate Change (IPCC). (2021). Climate Change 2021: The Physical Science Basis. Retrieved from [IPCC] (https://www.ipcc.ch/report/ar6/wg1/)

2. United Nations Environment Programme (UNEP). (2016). Kigali Amendment to the Montreal Protocol. Retrieved from [UNEP] (https://www.unep.org/resources/report/kigaliamendmentmontrealprotocol)

3. European Commission. (2020). Regulation (EU) No 517/2014 on fluorinated greenhouse gases. Retrieved from [European Commission] (https://ec.europa.eu/clima/policies/fgas_en)

4. Bhan, A., & Kuppuswamy, R. (2020). A review of natural refrigerants: Current status and future prospects. *International Journal of Refrigeration*, 112, 114. DOI: 10.1016/j.ijrefrig.2020.02.012

5. Mavromatidis, G., & Sethi, V. (2021). The role of natural refrigerants in sustainable refrigeration: A review of recent developments and future prospects. *Renewable and Sustainable Energy Reviews*, 135, 110160. DOI: 10.1016/j.rser.2020.110160

6. M. H. A. M. Fadhl, M. K. (2020). Transitioning from HFCs to Natural Refrigerants: The Need for Education and Training. *Sustainable Cities and Society*, 60, 102242.
DOI: 10.1016/j.scs.2020.102242

7. United Nations Environment Programme (UNEP). (2018). *The 2018 Report of the Montreal Protocol*. Retrieved from [UNEP](https://ozone.unep.org/resources/publications/montrealprotocolreport2018)

8. Kauffeld, M., & S. G. (2018). Carbon dioxide as a refrigerant: Opportunities and challenges. *Energy Efficiency*, 11(2), 235252. DOI: 10.1007/s120530179555y

9. P. G. Leck, E. B. (2020). Exploring the Economic and Environmental Impact of Hydrocarbon Refrigerants in Household Refrigerators. *Journal of Cleaner Production*, 256, 120426.
DOI: 10.1016/j.jclepro.2020.120426

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10. U.S. Environmental Protection Agency (EPA). (2021). *Hydrofluorocarbons (HFCs) Overview*. Retrieved from [EPA] (https://www.epa.gov/ghgemissions/overviewhydrofluorocarbonshfcs)

11. Adrián Mota-Babiloni, Joaquín Navarro-Esbrí, Ángel Barragán- Cervera, Francisco Molés & Bernardo Peris 2015, 'Analysis based on EU Regulation No 517/2014 of new HFC/HFO mixtures as alternatives of high GWP refrigerants in refrigeration and HVAC systems', International Journal of Refrigeration.

12. Adriano Greco, Mastrolla, R & Palombo 2003, 'R-407C as an Alternative to R-22 in Vapour Compression Plant: An Experimental Study', International Journal of Refrigeration, vol. 21, pp. 1087-1098.

13. Agarwal, RS & Bhatia, P 1998, 'Energy Consumption of Indian Domestic Refrigeration under Field and Laboratory Conditions A Step Towards Energy-Efficiency Standards', IIf-IIR Commissions, New Delhi, pp. 342-352.

14. Agarwal, RS 1998, 'Hydrocarbon Refrigerants for Domestic and Commercial Refrigeration Appliances', IIF-I1R Commissions, New Delhi, pp. 270-284.

15. Aprea, C & Greco, A 2013, 'Performance Evaluation of R-22 and R- 407C in a Vapour Compression Plant with Reciprocating Compressor', Applied Thermal Engineering, vol. 23, pp. 215-227.

16. Aprea, C, Mastrolla, R, Renno, C & Vanoli, GP 2004, 'An evaluation of R-22 Substituents Performance Regulating Continuously the Compressor Refrigeration Capacity', Applied Thermal Engineering, vol. 24, pp. 127-139.

17. Arcaklioglu, E 2005, 'An algorithmic approach towards finding better substitutes of Chlorofluorocarbons in terms of the second law of thermodynamics', Energy Conversion and Management, vol. 46, pp. 1595-1511.

18. Buero of Indian Standards (BIS) 1992, 'Room Air conditioners Specifications', Part I: Unitary Air Conditioners, IS1391, New Delhi, India.

19. Calm, JM & Domanski, PA 2004, 'R22 replacement status', ASHRAE J, vol. 46, no. 8, pp. 29-39.

20. Camporees, R, Bigolaro, G & Bobbo, S 1997, 'Experimental Evaluation of Refrigerant Mixtures as Substitutes for R-12 and R-502', InternationalJournal of Refrigeration, vol. 20, pp. 22-31.

21. Chen, S., Judge, JF, Groll, EA & Radermacher, R 1994, 'Theoretical Analysis of Hydrocarbon Refrigerant Mixtures as a Replacement for R- 22 for Residential Uses', International Refrigeration Conference, Indiana, pp. 225-230.

22. Choi, JM & Kim, YC 2002, 'The Effects of Improper Refrigerant charge on the Performance of a Heat Pump with an Electronic Expansion Valve and Capillary Tube', Energy, vol. 27, pp. 391-404.

23. 'Climate Change 2013: The physical science basis. Contribution of working group I to the fifth Assessment Report of the Intergovernmental panel on Climate Change (IPCC), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

24. Corberan, JM & Segurado, JB 2008, 'Review of standards for the use of hydrocarbons refrigerants (HCs) in air conditioners, heat pump and refrigeration equipment', International Journal of Refrigeration, vol. 3, no. 4, pp. 748-756.

25. Coulbourne, D & Ritter, TJ 1998, 'Hydrocarbon Refrigeration Safety: Standards and Quantitative Risk Assessments', IIF-IIR Commissions Conference, New Delhi, pp. 293-301.

26. David Morrison, J, Stuat Corr & Bruce E Gillbert 1997, 'Production Scale Handling of Zeotropic Blends' ASHRAE Transactions, vol. PH-97-9-2, pp. 756-764.

27. Deng, J 1989, 'Introduction to Grey Theory', Journal of Grey Systems, vol. 1, no. 1, pp. 1-24.