IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 20, Issue 2 Ser. I (Mar. – Apr. 2023), PP 34-42
www.iosrjournals.org

Performance Evaluation of Water Chiller Using R1234yf/R134a Blend

M.Madhu Nayak[1*] B.Hadya[2] Md.Azizuddin[3]
[1](*Research Scholar, Mechanical Department, Engineering College/ Osmania University, India)*
[2](*Professor, Mechanical Department, Engineering College/ Osmania University, India)*
[3](*Professor, Mechanical Department, Deccan Engineering College/ Osmania University, India)*

Abstract
This paper seeks to determine a comparative study between Hydrofluoroolefin (HFO) and Hydro fluorocarbons (HFC) by considering three different refrigerants R1234yf/R134a in a mass proportion of 60/40%, R134a, R410a. The performance of the system is evaluated in a water chiller of 1TR capacity, to achieve a low GWP refrigerant as the HFC group refrigerants are possessing high GWP of R134a (1430), R410a (2088). The experimental set up was built up with suitable requirements considering the compressor compatibility and insulated with polymer foam inside the evaporator. The comparisions are made considering the R134a and R410a as a base, to find alternative refrigerant with low GWP. The evaluation was based on various factors, including Flow rate, Refrigerant effect (RE), Power Consumption, net COP, Condenser and Evaporator temperatures. With the help of UNEP Ozone fact sheet the blend's GWP is calculated which is 574(appreciable), while its COP of 2.94 is adequate when compared to considered refrigerants. The study concludes that using HFO combined with HFC group refrigerant can be a potentially effective remedy.

Key Word*: HFO, R1234yf, COP, VCRS, GWP, ODP, BLEND.*

Date of Submission: 25-02-2023 Date of Acceptance: 10-03-2023

I. Introduction

Refrigeration**,** the process of removing heat from an enclosed space or from a substance for the purpose of lowering the temperature. To run this process a refrigerant with low GWP is more suggestible. But know a days the refrigerants used are based on the performance not in the view of GWP. For example, R134a, an HFC group refrigerant that is frequently used in field of R&AC, has a GWP of 1430. In order to lower the GWP, it is necessary to look for an Ecofriendly refrigerant. R1234yf has good thermo physical properties which fit to R134a with almost same properties and it will be the most viable replacement. R1234yf is mildly flammable with A2L level, while R134a has no flammability with A1 level. Flammability is the only problem with HFO group refrigerant R1234yf; in order to reduce the flammability blending is the necessary action and R134a is suitable. Investigation is carried out to find the performance which a important parameter. So, before studying the flammability characteristics with a combination of R134a by varying the percentages, the performance evaluation is to be done for the blend. R1234yf is one of the promising replacements for high GWP refrigerant by considering the boiling point (-29˚C), critical temperature (95˚C), critical pressure (3400Kpa), zero ODP and very less GWP for R134a the boiling point (-26˚C), critical temperature (101˚C), critical pressure (4060Kpa), zero ODP and high GWP [1]. R1234yf is considered as alternative fluid not only because of its low GWP and also its low levels of Toxicity. According to Kyoto Protocol, a global agreement passed in 1997 with the goal of limiting the emissions of gases that cause global warming, in the point of concern with GWP and ODP. This work is purely carried out in search of a new alternative refrigerant in view of sustainable development.

J.M. Belman-Flores et al., reviewed various research articles based VCRS and presented the trending developments in view of sustainability [1]. Zhaohua Li et al., compared various performance parameters of R1234yf with R134a Oil-Free Refrigeration and found the mass flow rate of the refrigerant is more than R134a[2]. Nayak et al., had reviewed various works of different refrigerants to find a alternative refrigerant and suggested R1234yf as best [3]. Saibhargav et al., suggested water chiller as suitable experimental test rig for testing refrigerant blends [4]. Hadya et al., experimentally studied and compared R32, R410a, R22 the performance parameters under sub-cooling and super heating [5]. Pabon et al., presented a brief review on various system parameters like evaporator and condenser temperatures to substitute R1234yf in place of R134a [6]. Vipin Nair et al., discussed a half decade research articles and after studying about flammability and oil compatibility concluded R1234yf as eco friendly alternative refrigerant [7]. Vijay Singh Bisht et al., analyzed experimentally the evaporator temperature of -25˚C for three refrigerants R12, R134a and R1234yf, attained max efficiency for the system [8]. M.Khairul Bashar et al., studied about various condensation effects R1234yf and R134a in small diameter tube [9]. Paula et al., presented a steady state model of VCRS system, at -5˚C, -4˚C, -3˚C evaporator temperatures and the results are compared with the previous works [10]. Ansari et al., developed a mathematical model to calculate the COP of the VCRS at evaporator temperatures 223K to 273K and suggested as R1234yf as a replacement of R134a [11]. J. Navarro-Esbrı et al., conducted 104 tests by varying various performance parameters with the help of internal heat exchanger and concluded R1234yf is close to R134a for substitution [12]. Babiloni et al., compared three refrigerants i.e R1234yf, R1234ze, R134a by conducting 54 tests evaluated the performance [13]. Celil Aral et al., developed a experimental set up for HP and AC by varying compressor speed, evaporator and condenser temperatures made testings for both R1234yf and R134a and preferred a Suction line heat exchanger to compensate the losses in performance [14]. Sharif et al., evaluated the performance with both R1234yf and R134a in AAC and suggested optimization procedure for better output [15]. Yataganbaba et al., selected three refrigerants R1234yf, R1234ze and R134a and experimented in a two evaporator VCRS, and concluded R1234yf as the best replacement for R134a [16].

II. Experimentation

A schematic representation of a vapour compression refrigeration test apparatus with a 30lit capacity for cooling water. The test rig is built to work with R134a and a blend of R1234yf and R134a. The apparatus consists of a reciprocating compressor, an air-cooled cord mesh condenser, and an evaporator. The apparatus is equipped with four pressure gauges, five calibrated temperature sensors, a digital energy meter, an electronic weighing device, and a digital data logger. This paper summarizes the critical specifications and measured quantities of the test rig.

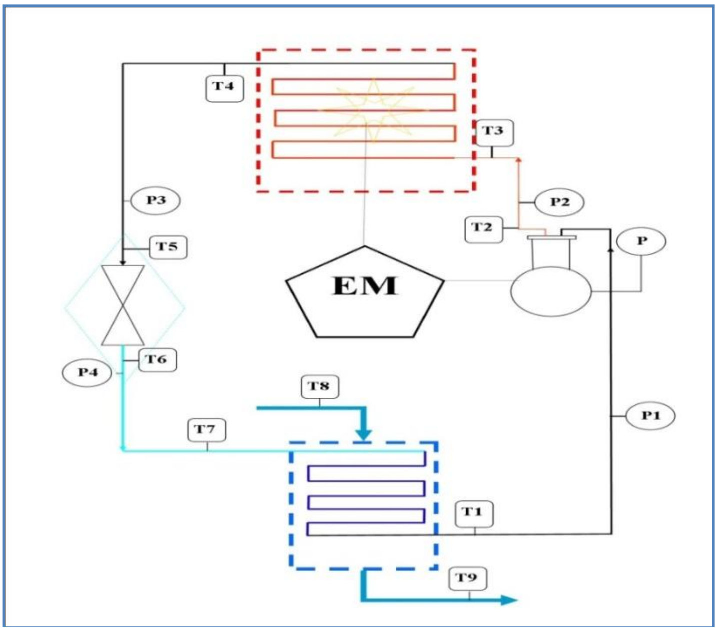

Fig 2.1 Schematic Representation for Test Rig.

EM- Energy meter
P_1- Suction pressure of compressor
P_2- Discharge pressure of compressor
P_3 – Inlet Pressure of expansion valve
P_4 – Outlet pressure of expansion valve
P- Refrigerant injecting pressure
T_1 – Refrigerant exit temp from evaporator
T_2 – Refrigerant exit temp from evaporator
T_3 – Refrigerant inlet temp from condenser
T_4 - Exit temperature from condenser
T_5 - Temperature inlet to the expansion valve
T_6 - Temperature exit from the expansion valve
T_7 - Temperature inlet to the evaporator
T_8 - Water chiller inlet temperature water chiller
T_9 - Water chiller exit temperature

Refrigeration systems have become an essential part of our lives, and their efficiency plays a crucial role in energy conservation. A vapour compression refrigeration system is widely used in domestic and industrial applications due to its high efficiency and low operating cost. This paper presents a schematic representation of a vapour compression refrigeration test apparatus with a 30lit Capacity for cooling water. The apparatus is designed to work with R134a and a blend of R1234yf and R134a. This paper describes the components of the test rig, its critical specifications, and the measured quantities.

Fig 2.2 shows the charging setup of refrigerants by mass proportion

The test rig consists of a reciprocating compressor, an air-cooled cord mesh condenser, and an evaporator. The evaporator coil is surrounded by a metal container with polymer foam insulation, which holds the cooling water. The refrigerant that has been condensed inside the condenser is directed through a filter-drier and into a capillary tube without any intermediary storage. A filter-drier is installed before the capillary tube to remove any moisture that might be present in the refrigerant circuit. The charging process for the equipment involves the use of a charging machine, followed by an evacuation step with a vacuum pump to attain a pressure of -30mm of Hg. To start, moisture evacuation within the device is performed via the carrier port. The system is then purged with nitrogen gas to eliminate air, impurities, moisture, and other particles that may affect its overall performance.

Table 2.1 Water chiller Specifications

Parameters	Specification
Storage volume	30 L
Current rating	1.1 max
Voltage	220-240 V
Frequency	50Hz
Refrigerant type	R134a + R1234yf
Mass of charge	150 gms
Capillary tube size	1.5 m
Inner diameter of Capillary tube	1.2 mm
Cooling Capacity	1TR

Fig 2.3 Water Chiller for Experimentation

The apparatus is equipped with four pressure gauges, five calibrated temperature sensors (thermocouples), a digital energy meter, an electronic weighing device, and a digital data logger. The experiment is equipped with pressure gauges and temperature sensors at various points in the refrigeration system. The pressure gauges are installed at the compressor inlet and outlet, condenser outlet, and evaporator inlet. The temperature sensors are positioned at the evaporator inlet, evaporator outlet, compressor outlet, condenser outlet, and inside the water container. The display unit measures the supply voltage and current. An electronic weighing device with a 1-gram resolution is utilized to measure the quantity of refrigerant charged into the rig during the experiment. The experimentally measured values are collected using a digital data logger and HMI device.

Table 2.2 Quantities for Measurement

Quantity	Range	Accuracy
Temperature	-0.1°C - 35°C	+0.1°C
Power	0 - 1000 watt	1w
Voltage	0 - 240Volt	0.1V
Current	0 - 10Amp	0.1amps
Pressure	0 - 21bar	+0.7bar

2.1 GWP for the Refrigerant Blend

Refrigerant blends are an important development in the field of R&AC, as they provide better environmental performance than traditional single-component refrigerants. These blends are created by mixing two or more single-component refrigerants to create a new blend with improved properties. One of the key factors in assessing the environmental impact of refrigerants is their GWP, which is a measure of the amount of heat that a particular refrigerant traps in the atmosphere compared to carbon dioxide over a given time period.

The GWP of a refrigerant blend is calculated by determining the mass-weighted average of the GWPs of the individual components in the blend. This means that each component's GWP is multiplied by its mass proportion in the blend and then added together. For example, if a blend contains two components, R1234yf and R134a, with mass proportions of 60% and 40%, respectively, and GWP values of 4 and 1430, respectively, the GWP of the blend can be calculated using the formula:

GWP of Blend=

Proportion by % mass of component [**A** * GWP of **A** + **B** *GWP of **B** + **C** * GWP of **C]**

$$= \frac{(M_1 \times GWP_1) + (M_2 \times GWP_2)}{M_1 + M_2}$$

M_1- Mass proportion of R1234yf.

M_2- Mass proportion of R134a.

GWP_1 - Global warming potential of R1234yf.
GWP_2 - Global warming potential of R134a.
GWP of Blend = ((0.6 x 4) + (0.4 x 1430)) / (0.6 + 0.4) = 574

The UNEP Ozone fact sheet confirms that the GWP of a blend containing 60% R1234yf and 40% R134a is 574, which is significantly lower than the GWP of R134a alone (1430). This highlights the importance of refrigerant blends in reducing the environmental impact of refrigeration and air conditioning systems.

While R1234yf is a promising refrigerant due to its low GWP, it has limitations due to its flammability. However, by blending it with R134a, which is classified as a non-flammable refrigerant, the flammability level of the blend can be reduced. This makes it a safer and more viable option for use in refrigeration and air conditioning systems.

In conclusion, the development of refrigerant blends has provided an effective solution to address the environmental impact of traditional single-component refrigerants. The calculation of the GWP of a blend is an important consideration in the selection of refrigerants, and the use of blends like R1234yf/R134a can significantly reduce the environmental impact of refrigeration and air conditioning systems while maintaining their efficiency and safety.

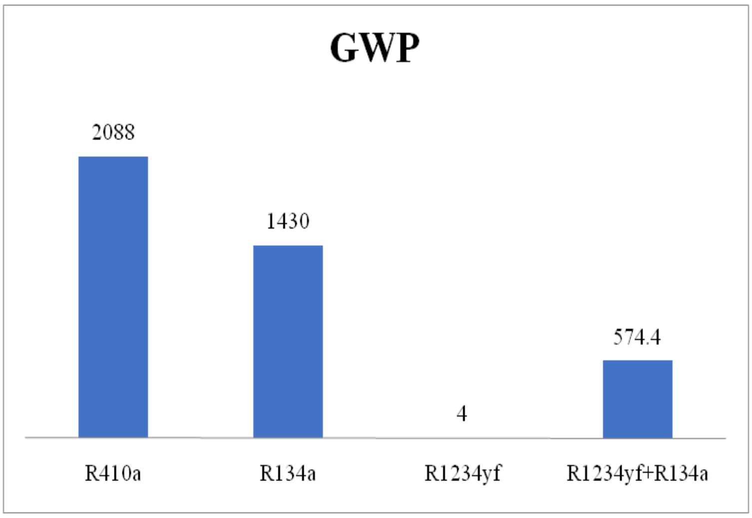

Fig 2.4 Comparison of GWP of considered refrigerants

2.3 PERFORMANCE ANALYSIS

The performance characteristics of the VCR system were analyzed with respect to alternative condensers and refrigerants. One of the key parameters studied was the refrigeration effect, as defined by Equation (1), which quantifies the amount of heat removed from the water when input energy is provided to the compressor.

$$Q_{evap} = m_r (h_2 - h_4) \quad (1)$$

$$P_{com} = m_r (h2 - h_1) / \eta_{isen} \quad (2)$$

$$m_r = \frac{Vst * N * \eta_{VOL}}{V4} \quad (3)$$

Where, m_r represents mass flow rate of Equation (3), h_1 and h_4 refers enthalpy of refrigerant at inlet and outlet of evaporator , η_{isen} and η_{VOL} means the isentropic efficiency and volumetric of the compressor respectively and h_2 refers to the enthalpy of refrigerants at outlet of compressor. N is speed of compressor and V_4 is the specific volume of the refrigerant at compressor inlet.
COP in Equation (4).

$$COP = \frac{Qevap}{Pcom} \quad (4)$$

III. EXPERIMENTAL COMPARISION

3.1 Effect of COP and Evaporator Temperature

The COP of the system for the blend is 2.94 with evaporator temperature 7.6˚C, for R134a it is 2.91 with evaporator temperature 8˚C and for R410a it is 2.90. The COP of blend is high when compared to the other two refrigerants. The data provided suggests that R134a+R1234yf is the most efficient refrigerant among R134a, R410A, and R134a+R1234yf, with the highest COP values at all evaporator temperatures. The trend of increasing COP values with increasing evaporator temperature is observed, indicating a higher heat transfer rate at higher evaporator temperatures. However, it's important to note that the relationship between evaporator temperature and COP can vary depending on the specific refrigerant and the operating conditions of the refrigeration system.

Table 3.1 Measured values of Evaporator temperature and COP

Evaporator Temperature(˚C)			COP		
R134a+R1234yf	**R134a**	**R410A**	**R134a+R1234yf**	**R134a**	**R410A**
-11	-11	-10	2.76	2.75	2.75
-9.1	-9	-5	2.77	2.76	2.77
-1.5	-1	0	2.85	2.82	2.81
2.8	3	5	2.88	2.87	2.88
7.6	8	10	2.94	2.91	2.90

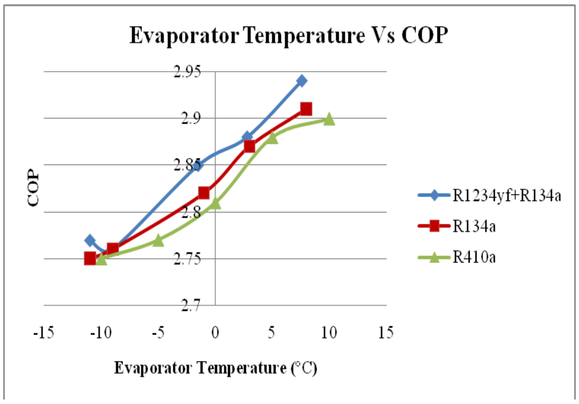

Fig 3.1 Comparison of COP and Evaporator temperature

3.2 Effect of COP and Refrigeration Effect.

The refrigerating effect is the amount of heat absorbed throughout the system, from the Fig 3.2 for the blend it is high with a value of 213.1(J/sec) when compared to the other refrigerants, for R134a and R410a the RE is 208.1 and 207.8 is less. The refrigeration effect values indicate the amount of heat being removed by the refrigerant at each data point. Again, it appears that R134a+R1234yf shows the highest refrigeration effect values across all data points, followed by R134a and then R410A. Overall, the data suggests that R134a+R1234yf is the most efficient and effective refrigerant among R134a, R410A, and R134a+R1234yf.

Table 3.2 Measured values of COP and Refrigeration Effect

COP			Refrigeration Effect		
R134a+R1234yf	**R134a**	**R410A**	**R134a+R1234yf**	**R134a**	**R410A**
2.76	2.75	2.75	184.8	179.8	178.4
2.77	2.76	2.77	188.2	183.2	182.6
2.85	2.82	2.81	190.1	185.1	184.8
2.88	2.87	2.88	198.9	193.9	192.6
2.94	2.91	2.9	213.1	208.1	207.8

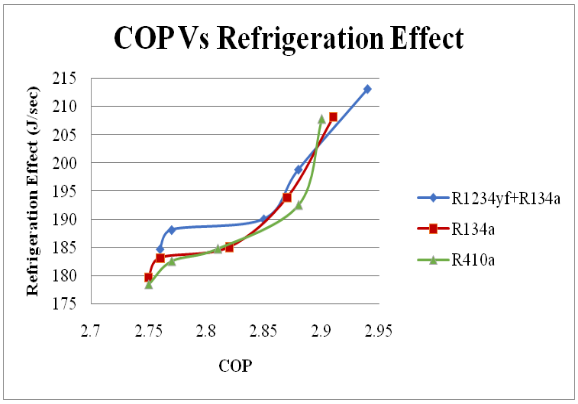

Fig 3.2 Comparison of COP and Refrigerating Effect

3.3 Effect of COP and Power Consumption

The power required to run the compressor of the system should be as less as possible, for the considered system the power consumed for the blend refrigerant it is 0.58kw, for R134a it is 0.57kw and for R410a it is 0.61kw, the COP of the system for the blend is 2.94, for R134a it is 2.91 and for R410a it is 2.90. From the Fig 3.3 it is observed that the R410a consumes more power when compared to other refrigerants and the desired output is obtained from the blend. The data showing the COP (Coefficient of Performance) and power consumption (in kW) for three different refrigerants - R134a+R1234yf, R134a, and R410A - over five different data points. COP is a measure of the efficiency of a refrigeration system, while power consumption is a measure of the amount of energy consumed by the system. It appears that R134a+R1234yf has the highest COP values, followed by R134a and then R410A. Additionally, R134a+R1234yf have the lowest power consumption values, followed by R134a and then R410A.

Table 3.3 Measured values of COP and Power Consumption

COP			Power Consumption(kw)		
R134a+R1234yf	**R134a**	**R410A**	**R134a+R1234yf**	**R134a**	**R410A**
2.76	2.75	2.75	1.10	1.00	1.20
2.77	2.76	2.77	0.96	0.95	1.00
2.85	2.82	2.81	0.78	0.77	0.82
2.88	2.87	2.88	0.68	0.66	0.72
2.94	2.91	2.90	0.58	0.57	0.61

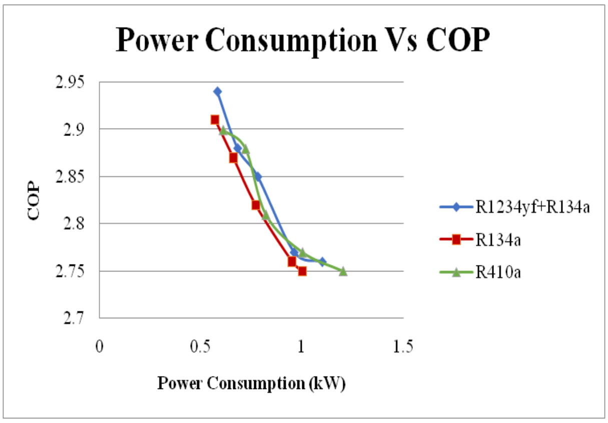

Fig 3.3 Comparison of power consumption and COP

3.4 Effect of COP and Condenser Temperature

The Condensing temperature is the saturation temperature at which the vapour changes from vapour to liquid, while it can change depending on ambient temperature. Fig 3.8 shows the variation in condenser temperature at 44˚C the maximum COP is obtained for the blend whereas for R410a, R134a at 55˚C and 45˚C it is less. From the plot the heat rejection in the condenser is done at low temperature when compared to the other refrigerants. So the load on the compressor is less. This implies that the blend refrigerant compressor requires lower pressure lift in comparision with other compressors.

Table 3.4 Measured values of COP and Condenser Temperature (˚C)

COP			Condenser Temperature(˚C)		
R134a+R1234yf	**R134a**	**R410A**	**R134a+R1234yf**	**R134a**	**R410A**
2.77	2.75	2.75	36	38	35
2.76	2.76	2.77	38	40	40
2.85	2.82	2.81	39	42	45
2.88	2.87	2.88	41	43	50
2.94	2.91	2.90	44	45	55

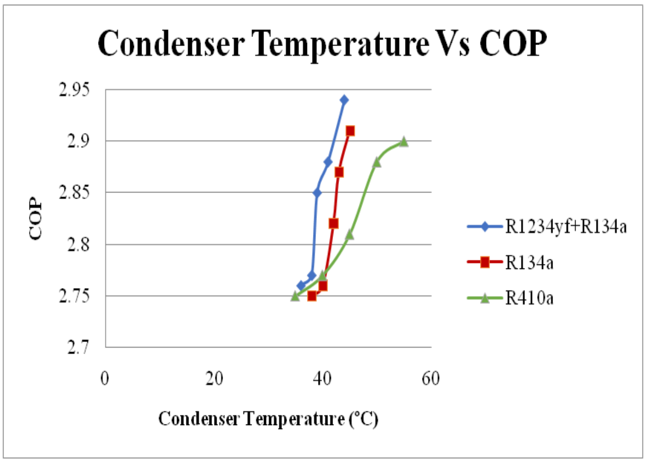

Fig 3.4 Comparison of COP and condenser temperature

IV. CONCLUSIONS

This paper presents an experimental analysis of a VCRS using R1234yf/R134a as a drop-in replacement for R134a. The goal of the study is to investigate the COP of the VCRS for water chiller, using a blended mixture of R1234yf/R134a. To achieve this, the test rig was modified by adopting different design parameters.

The experimental analysis showed that the combination of R1234yf /R134a in a 60/40 blend is superior in performance when compared to R134a. Furthermore, the system was checked to withstand a peak pressure for the compressor, as previous studies have failed due to compressor compatibility when there is a change in refrigerant.

The study also recorded a lower scale of refrigerant charge for the 60/40 blend of R1234yf and R134a, at 150 g, which is considerably lower than the charge required for R134a in the considered configuration. Additionally, the COP for the 60/40 blend was observed to be higher when compared with R134a. According to the findings of the study, the blended refrigerant of R1234yf/R134a exhibited a higher cooling capacity than R134a. This indicates that the VCRS system using the blended refrigerant was more effective in removing heat and providing cooling than the system using R134a.The experimental test results were compared with previous works of R410a under various parameters like evaporator temperature, condenser temperature, COP, Power consumption etc.

Furthermore, the GWP for the blend was 574, which is less compared with R134a (1430). It was also suggested that the addition of flame retardants to the proposed blend could further reduce flammability issues in the cycle. Therefore, the blended refrigerant is the best alternative for the HFC group refrigerants, after considering all the parameters.

REFERENCES

[1]. J.M. Belman-Flores, J.M. Barroso-Maldonado, A.P. Rodríguez-Muñoz, G. Camacho-Vázquez, Enhancements in domestic refrigeration, approaching a sustainable refrigerator – A review, Renewable and Sustainable Energy Reviews 51, pp: 955–968 , (2015).

[2]. Zhaohua Li, Kun Liang, Hanying Jiang, Experimental study of R1234yf as a drop-in replacement for R134a in an oilfree refrigeration system, Applied Thermal Engineering 153 646–654, (2019).

[3]. M.MadhuNayak, B.Hadya, Md.Azizuddin, A Comparative Study of Performance of HFC Group Refrigerants and HFO Refrigerants, Gradiva review journal, volume 8 issue 4 2022 , page no: 165 , Issn no : 0363-8057.

[4]. A. Saibhargav, K.Srinivasa Reddy, V.Mukesh Reddy, Performance Analysis of Vapour Compression Refrigeration System Using HC Refrigerant Mixtures for Water Chiller, International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075, Volume-8 Issue-9, July 2019.

[5]. Boda Hadya, A. M. K. Prasad, Suresh Akella. Performance Assessment of HFC Group Refrigerants in Window Air Conditioning System. International Journal of Mechanical Engineering and Applications. Vol. 3, No. 5, pp. 81-85, 2015.

[6]. Juan J.G. Pabon , Ali Khosravi , J.M. Belman-Flores , Luiz Machado , Remi Revellin , Applications of refrigerant R1234yf in heating, air conditioning and refrigeration systems: A decade of researches, International Journal of Refrigeration , 2020.

[7]. Vipin Nair, HFO refrigerants: a review of its present status and future prospects, International Journal of Refrigeration, PII: S0140-7007(20)30459-X, 2020.

[8]. Vijay Singh Bisht, A.K Pratihar, Pradeep Kumar Vishnoi & Parbhakar Bhandari , R1234YF: An Eco-Friendly Drop In Replacement of R12 and R134a, Asian Journal of Applied Science and Technology (AJAST), Volume 2, Issue 4, Pages 36-46, Oct-Dec 2018.

[9]. M. Khairul Bashar , Keisuke Nakamura , Keishi Kariya , Akio Miyara , Condensation heat transfer of R1234yf in a small diameter smooth and microfin tube and development of correlation, International Journal of Refrigeration , 2020.

[10]. Cleison Henrique de Paula , Willian Moreira Duarte, Thiago Torres Martins Rocha, Raphael Nunes de Oliveira, Antônio Augusto Torres Maia, Optimal design and environmental, energy and exergy analysis of a vapor compression refrigeration system using R290, R1234yf, and R744 as alternatives to replace R134a, International Journal of Refrigeration 113 10–20, 2020.

[11]. Naushad A. Ansari, Bipin Yadav, Jitendra Kumar, Theoretical Exergy Analysis of HFO-1234yf and HFO-1234ze as an Alternative Replacement of HFC-134a in Simple Vapour Compression Refrigeration System, International Journal of Scientific & Engineering Research, Volume 4, Issue 8, 137, ISSN 2229-5518, 2013.

[12]. J. Navarro-Esbrı, J.M. Mendoza-Miranda , A. Mota-Babiloni , A. Barraga´n-Cervera, J.M. Belman-Flores, Experimental analysis of R1234yf as a drop-in replacement for R134a in a vapor compression system, International journal of refrigeration 36, 2013 .

[13]. Adrian MotaBabiloni, Joaquín Navarro-Esbrí, Angel Barragan , Francisco Moles , Bernardo Peris, Drop-in energy performance evaluation of R1234yf and R1234ze(E) in a vapor compression system as R134a replacements, Applied Thermal Engineering 71, 2014.

[14]. M. Celil Aral, Mukhamad Suhermanto & Murat Hosoz, Performance evaluation of an automotive air conditioning and heat pump system using R1234yf and R134a, Science and Technology for the Built Environment, 2020.

[15]. M Z Sharif, W H Azmi, N N M Zawawi, R Mamat and A H Hamisa, R1234yf vs R134a in automotive air conditioning system: A comparison of the performance, IOP Conf. Ser.: Mater. Sci. Eng. 863 012049, 2020.

[16]. Alptug Yataganbaba, Ali Kilicarslan, Irfan Kurtbas, Exergy analysis of R1234yf and R1234ze as R134a replacements in a two evaporator vapour compression refrigeration system, International Journal of Refrigeration , 2015.

ABBREVIATIONS,

GWP- Global warming potential
ODP – Ozone Depleting potential
HFC – Hydro Fluoro Carbon
HFO- Hydro Fluoro Olefin
COP- Coefficient of Performance
RE- Refrigeration Effect
SLHX- Suction Line Heat Exchanger

M.Madhu Nayak. "Performance Evaluation of Water Chiller Using R1234yf/R134a Blend." *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, 20(2), 2023, pp. 34-42.