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Effect of Evaporator Temperature on VCRS for Water Chiller Using HFO and HFC Blend

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Abstract
This paper aims to investigate the potential use of Hydrofluoroolefin (HFO) blended with Hydro fluorocarbons (HFC) as a less GWP refrigerant in a water chiller system. An experimental setup of water chiller with a capacity of 1TR was used to evaluate the effect of Evaporator temperature with R1234yf/R134a blend of 60/40% ratio. The evaluation was based on several characteristics such as the condenser temperature, evaporator temperature, work done by the compressor, coefficient of performance (COP), and Refrigerant flow rate. The Test results showed that the blend's evaporator temperature is adequate when compared to R134a, R410a. While the Blend's low GWP of 574 was better than R134a and R410a. The study concludes that the use of HFO blend with HFC group refrigerant can be a promising solution to achieve low GWP refrigerants in the field of refrigeration systems.

***Keywords**: HFO, HFC, R1234yf, COP, ODP, GWP, BLEND.*

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I. Introduction

HFCs are one of the refrigerants that are most frequently used worldwide in the field of refrigeration. In the year 1997, as a global agreement kyotoprotocol passed with the goal of limiting has taken decision for limiting the emission of gases that cause global warming. For example, R134a, an HFC group refrigerant that is frequently used in the R&AC industries, has a GWP of 1430. In order to lower the GWP, it is necessary to look for an Ecofriendly refrigerant. The HFO group refrigerant R1234yf, which is emerging as fourth generation refrigerant, has similar Thermo Physical and chemical properties to R134a, will be the most viable replacement. Compared to carbon dioxide's lifespan of more than 500 years and R134a's 13 years, R1234yf has an atmospheric lifetime of just 11 days. R1234yf does not persist in the atmosphere for decades like HFCs and CFCs do. Vehicles using the incredibly R1234yf refrigerant will simply use less fuel and produce less emission than many of the alternatives currently available. R1234yf falls within safety zone A2L. This suggests that it falls under the less-serious category of refrigerants that are somewhat flammable.

II. Literature Review

After reviewing numerous research articles, Pabon et al. proposed cycle optimization and suggested R1234yf as a substitute for R134a in small-scale systems. [1]. Aprea et al., compared and analyzed experimentally with the pure R1234yf with the combination of R1234yf /R134a in a proportion of (90%/10%), with this combination there is a reduction in the power consumption during the tests [2]. Al-Sayyab et al., compared three refrigerants R513A, R516A, and R1234yf experimentally in vapour compression cycle, R1234yf gives highest flow rate in cooling mode, i.e 33% to 61% than R134a[3]. Gaurav et al., analyzed nearly 31 refrigerants taking R134a as reference and RM 40%R134a/22%R1234yf/38%R1234ze has the capacity of cooling which is nearly similar to R134a, and suggested as the best alternative of R134a[4]. Li et al., compared the performance of R134a and R1234yf. Mass flow rate of R1234yf decreases with increasing condenser temperature [5]. Fuentes et al., conducted experiment on display refrigerator with three different refrigerants among them R1234yf with a difference in cooling capacity of 18.7% [6]. Nayak et al., had reviewed the previous works on alternative refrigerants and suggested R1234yf will be the best suitable alternative for R134a with minor modifications [7]. Saibhargav et al., conducted experiment on a water chillers performance to replace R134a with R600a and R290 blended refrigerants. Author suggested water chiller is the best experimental setup for testing blended refrigerants. In order to test the blended refrigerant like R1234yf water chiller is best suitable in the point of operation and system modifications [8]. Hadya et al., conducted experiment on a one ton air conditioner in search of alternate refrigerants in order to reduce the GWP, the idea is more useful in search of advanced refrigerant of R1234yf in different combinations [9]. Bell et al., reviewed different hydrocarbon refrigerant and hydrofluoroolefin refrigerants and identified GWP reduction with the blended R1234yf of 23 combinations and suggested R1234yf blend as alternative to R134a [10]. Paula et al., considered a small scale vapour compression system and tested with refrigerants of different groups, also compared various parameters like TEWI etc [11]. Kuwar et al., developed a experimental test rig and obtained both experimental and numerical test results of R134a and R1234yf [12]. Alhendal et al., investigated experimentally and theoretically with the low-GWP refrigerants. The COP of R1234yf observed is 3.96, 3.36, 2.88, and 2.48 [13]. Hmood et al., suggests R1234yf as the best alternative for the refrigerants R134a but the flammability issues should be sorted to the low global warming potential refrigerant R1234yf [14]. Mishra et al., compared HFO group refrigerants with R134a in a VCRS, and suggests a heat exchanger in order to attain better COP with R1234yf[15]. Prabakaran et al., studied with a thermodynamic approach in Automotive Air conditioning system the R1234yf/R134a Mix is suggested for use [16].

A Quantitative approach to evaluate GWP of the Blend.

Blending two or more single refrigerants results in a refrigerant blend; the mass-weighted average of the GWPs of the blend's individual components is the GWP of the blended refrigerant. In other words, one simply sums the GWP of the constituent components in proportion to their mass to determine the GWP of a mix. Hence, the following formula is used to determine the GWP of blends:

Blend's GWP =

Proportion by % mass of component [**A** * GWP of **A + B** *GWP of **B + C** * GWP of **C],** where A, B, C are mass proportions

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

M_1 - Mass Content of R1234yf.
M_2 - Mass Content of R134a.
GWP_1 - R1234yf.
GWP_2 - R134a.

The GWP of Blend after calculation as per UNEP Ozone fact sheet it is 574 for the R1234yf/R134a (60/40%) which is less when compared to R134a (1430). R1234yf blends easily with R134a; because of flammability issues R1234yf is not usable to a maximum extent. By adding the R134a with R1234yf the flammability levels are reduced when compared to standard R1234yf, because R134a is categorized as the non flammable refrigerant.

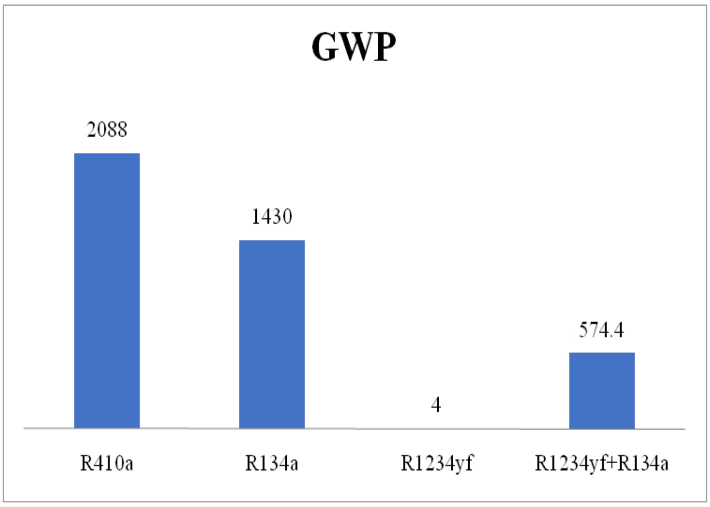

Fig no 2.1 Comparison of GWP for HFC and HFO group refrigerants**.**

Experimental Procedure

A schematic representation of a vapour compression refrigeration test apparatus with a 30litre capacity. It is made up of a reciprocating compressor, an air-cooled cord mesh condenser, and an evaporator. Capacity for cooling water is shown in Figure 3.1. Water in a metal container with polymer foam insulation surrounds the evaporator coil [8]. As a part of the working principle, the compressor compresses the vapour refrigerant to the condenser where heat is rejected and the phase transfer takes place by losing its latent heat after that the liquid refrigerant enters through capillary tube hence temperature reduced. The evaporator is immersed in the water chiller. The three selected refrigerants i.e R134a, R410a and the blend of R1234yf/R134a are used for experimental study.

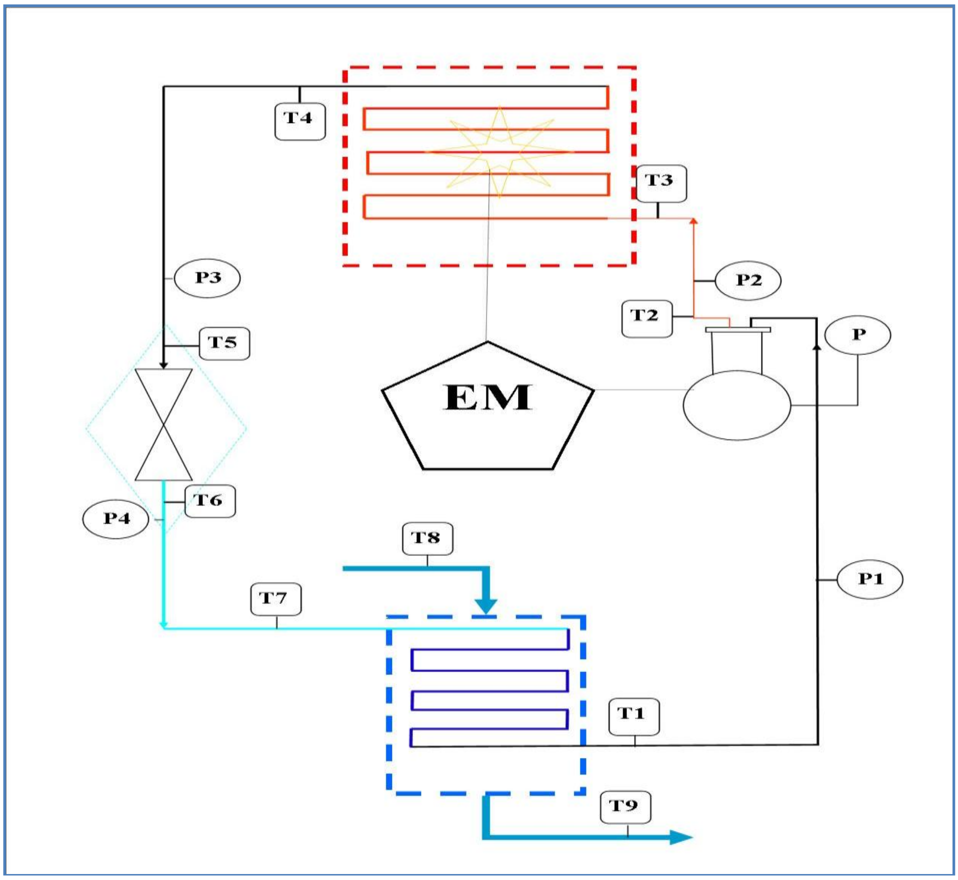

Fig no 3.1 Schematic Representation for Test Rig.

EM- Energy Meter
P_1- Pressure at suction of compressor
P_2- Pressure at discharge of compressor
P_3 – Pressure at inlet of expansion valve
P_4 – Pressure at outlet 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

To eliminate air, impurities, moisture, and other particles that can adversely affect the system's overall efficiency, the equipment is purged with nitrogen fuel. Four pressure gauges are attached at the compressor inlet and outlet, condenser outlet, and evaporator inlet. Five thermocouples are placed at the evaporator inlet, evaporator outlet, compressor outlet, condenser outlet, and inside the water container. The display unit is employed to determine the input voltage and current, while actual power consumption is monitored using a digital energy meter. Service ports are provided at the compressor's top for charging and retrieving refrigerant, while the carrier port is initially used to evacuate the equipment's internal moisture

Fig no 2.2 Shows the charging setup of refrigerants by mass proportion

The charging machine is used to charge the rig, and the vacuum pump is used to evacuate it to a pressure of -30 mm Hg. The key specifications of the test rig are summarized in the table below. The measured quantities, along with their range and accuracy, are listed in the table below. An electronic weighing device with a precision of 1 gram was used to calibrate the amount of refrigerant to be charged to the rig during the test. The experimentally measured values were recorded using a digital data recorder and an HMI device.

Table 2.1 Specifications of VCRS Test Rig

Parameter	Specification
Storage capacity	30 Litres
Current	1.10 MAX
Voltage Regulation	220-240 V
Frequency Rating	50hz
Refrigerant	R1234yf /R134a
Charge of refrigerant	150 gms(mass)
Capillary Length	1.5 m
Capillary tube inner diameter	1.2 mm
Capacity	1 TR

Fig no 2.3 Experimental Test rig of water chiller

Table no 2.2 Measured Quantities

Quantities	Range	Accuracy
Temperature(˚C)	-0.1°C to 35°C	+0.1°C
Power consumption(W)	0 to 1000 watts	1watts
Voltage(V)	0 to 240Volts	0.1Volts
Current(Amps)	0 to 10Amps	0.1Amps
Pressure (Amps)	0 to 21bars	+0.7bars

For this test, the freezer is fully loaded and the thermostat is functioning properly. Thermocouples are placed in predetermined locations, and a few additional thermocouples are used until a steady state is achieved with the aid of the digital temperature control unit. It takes a long time for the loaded product to reach the desired temperature. The system's performance is evaluated based on the interior temperature and time of the cabinet, which indicates how the machine operates when fully loaded and how long it takes to unload the load. During the load cycling test, the thermostat is connected to the circuit when there is a full load. When the temperature inside the cabinet reaches the lowest set freezing temperature, the compressor starts running, which is referred to as the reduce-in time, and takes the energy required to maintain the temperature stable. When the temperature inside the cabinet reaches the maximum set freezing temperature, the compressor stops, which is referred to as the cut-off time. The purpose of this test is to determine how long it takes a loaded product to reach the desired temperature under full load conditions, and to assess the compressor's energy needs during the reduce-in and cut-off points. The experimental system used to study the refrigeration effect, COP, and work done on the system may yield the above information. The resulting experimental values are presented to visualize the behaviour of the simple vapor compression cycle with and without low receiver.

II. Results

3.1 Effect of Evaporator Temperature and Power Consumption

Fig 3.1 shows the variation of compressor power consumption with respect to evaporator temperature, for the blend refrigerant the evaporator temperature is 7.6˚C, for R134a it is 8˚C and for R410a it is 10˚C, power consumption for blend is 0.58kw, for R134a it is 0.57kw, R410a it is 0.61kw. The power consumed during the cycle is almost similar for the blend and R134a; it is slightly high when compared with R410a. Hence the blend refrigerant is suitable for the cycle.

Table no 3.1 measured values of Evaporator temperature and Power consumption

Evaporator Temperature(˚C)			Power Consumption(Kw)		
R1234yf/R134a	R134a	R410a	R1234yf/R134a	R134a	R410a
-11	-11	-10	1.10	1.00	1.20
-9.1	-9	-5	0.96	0.95	1.00
-1.5	-1	0	0.78	0.77	0.82
2.8	3	5	0.68	0.66	0.72
7.6	8	10	0.58	0.57	0.61

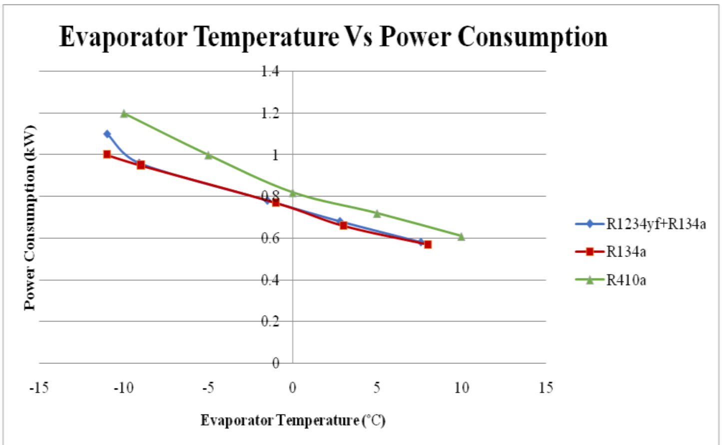

Fig no 3.1 Comparison of Evaporator Temperature and Power Consumption

3.2 Effect of Evaporator Temperature and Power Consumption

Compressor discharge pressure is one of the important parameter for consideration; the Fig 3.2 shows the various ranges of the three refrigerants in which only R134a and the blend are comparable the discharge pressure for R410a at 7.6˚C is around 1100kpa as the evaporator temperature changes, but the observation which draws the attention is both the R134a and Blend have very nearby values of 370 and 380 with Evaporator temperatures 8˚C and 7.6˚C and compressor discharge pressure. Hence by the fig, it is noticed that R134a compressor is compatible to the Blend.

Table no 3.2 Measured values of Evaporator Temperature and Peak Pressure

S.No	Evaporator Temperature(˚C)			Peak Pressure(Psi)		
	R1234yf/R134a	**R134a**	**R410a**	**R1234yf/R134a**	**R134a**	**R410a**
SET 1	-11	-11	-10	210	225	600
SET 2	-9.1	-9	-5	220	235	650
SET 3	-1.5	-1	0	250	255	750
SET 4	2.8	3	5	280	275	950
SET 5	7.6	8	10	380	370	1100

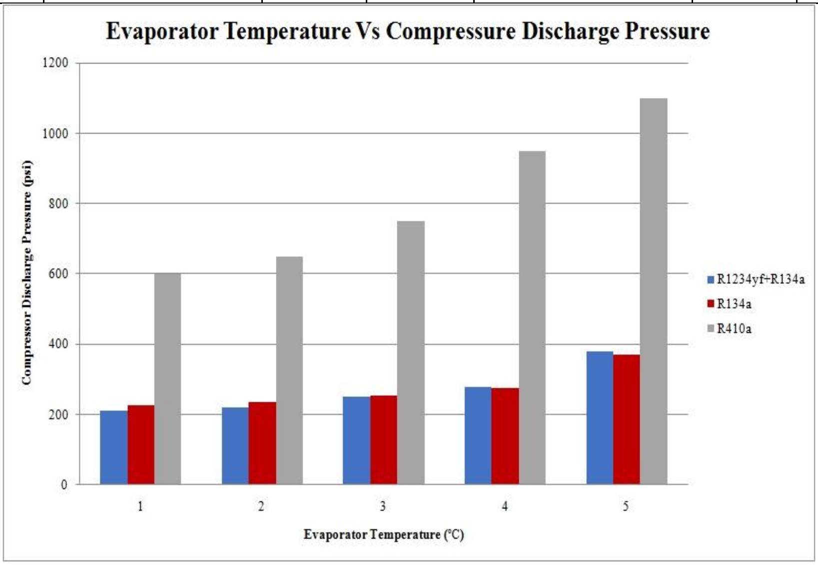

Fig no 3.2 Comparison Evaporator Temperature and Compressor Discharge Pressure

3.3 Effect of Evaporator Temperature and Refrigerant Mass Flow rate

Fig 3.3 shows the variation of mass flow rate in three refrigerants with respect to evaporator temperature of -10˚C to 10˚C for the condenser temperature of 55˚C and the mass flow rate of R410a, R134a and R1234yf are 0.042, 0.040 and 0.038 at the evaporator temperatures of 10, 8, 7.6 from the graph it is observed that the refrigerant mass flow rate is almost similar for both the refrigerant blend and the R134a but slightly varied with R410a in terms of the considered range.

Table no 3.3 Measured values of Evaporator Temperature and flow rate

Evaporator Temperature(˚C)			Refrigerant Mass Flow Rate(Kg/s)		
R1234yf/R134a	**R134a**	**R410a**	**R1234yf/R134a**	**R134a**	**R410a**
-11	-11	-10	0.015	0.010	0.020
-9.1	-9	-5	0.014	0.012	0.015
-1.5	-1	0	0.027	0.028	0.030
2.8	3	5	0.031	0.032	0.036
7.6	8	10	0.038	0.040	0.042

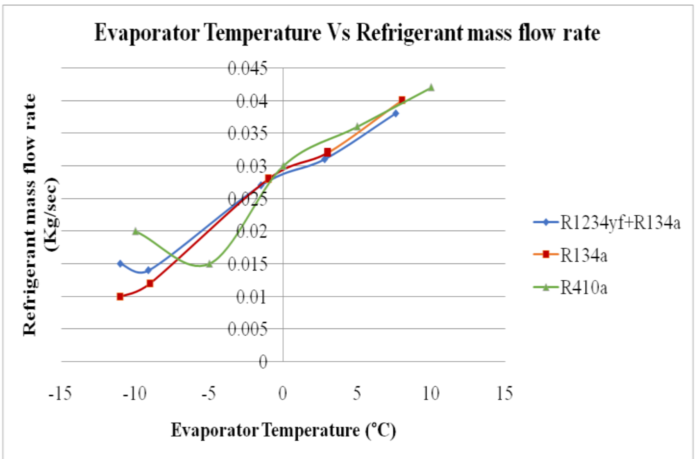

Fig no 3.3 Comparison of Evaporator Temperature and Flow Rate

3.4 Effect of Evaporator Temperature and Coefficient of Performance

For any type of refrigeration the COP of the system is the most important consideration. The COP 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.

Table no 3.4 Measured values of Evaporator temperature and COP

Evaporator Temperature(˚C)			COP		
R1234yf/R134a	**R134a**	**R410a**	**R1234yf/R134a**	**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

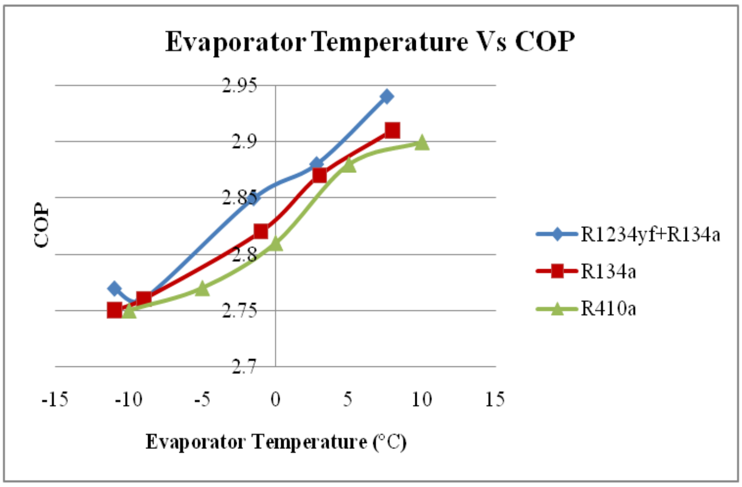

Fig no 3.4 Comparison of Evaporator Temperature and COP

III. Conclusion

In this Experimental analysis of VCRS using R1234yf/R134a as a substitute for R134a has been presented. In the present work to investigate the evaporator temperature variation on various parameters of water chiller of 30 Ltrs capacity and 1TR, with blended mixture of R1234yf and R134a is tested. The test rig is suitably modified by adopting different design parameters.

- It is evident that the combination of R1234yf/R134a in 60/40 percentage as a mix is good at performance than R134a.
- The system is checked to withstand a peak pressure for compressor as many of the case studies have failed because of compressor compatibility when there is a change in refrigerant.
- The Refrigerant charged inside the system is 150gms as per mass ratio of R1234yf/R134a.
- The Evaporator temperatures for the combination of R1234yf/R134a are observed with other parameters like power consumption, compressor discharge pressure, mass flow rate, COP and compared with R134a, R410a.
- The GWP of the blend after calculation as per UNEP Ozone fact sheet it is 574 which is less, when compared with R134a (1430), R410a (2088).
- The Blend refrigerant is considered to be the best alternative for the HFC group refrigerants after considering the evaporator temperatures.

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ABBREVIATIONS,

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