Research on Environment Friendly Alternatives for R22, R12 and R409A Refrigerants

R. Hari Sankar, S. Basnth, K.J. Ajay Ghosh, Manu Sivan, K. Vyshak Dileep

Abstract--- The paper analyses the comparative performance of vapour compression refrigeration of environmental friendly alternatives for the commonly used refrigerants - R22 as well as R12 and R409A. The compared refrigerants are R438A, R407C, R410A and R454C as R22 replacements. The alternatives for R12 and R409A examined are R513a, R134a and R1234yf. The performances of refrigerants are tested in two refrigeration cycles - single stage vapour compression cycle and single stage vapour compression cycle with heat exchanger. The results indicated that among the R22 alternatives, up to condensation temperature of 20°C R454c has the highest coefficient of performance (COP) and above condensation temperature of 30°C R407c has the highest COP. Among R12 and R409 replacements R134a provides the highest COP for all practical values of condensation temperature.

Keywords--- Refrigerant, COP, R22, R12, R409A.

I. INTRODUCTION

Refrigeration is an important field where there is a large scope for research with regards to environmental protection. A lot of refrigerants are commercially available for industrial as well as household applications. But most of the refrigerants used today are highly polluting and ozone depleting in nature. Hence there exists the need of the hour to replace ozone depleting chemicals with environment friendly substances like Hydro Fluro Olefins (HFOs) and other such refrigerants.

A lot of energy is being used for industrial as well as household applications. The lion's share of this energy is being used by refrigerating devices. Hence it is important to use refrigerant that helps to achieve better coefficient of performance and low energy consumption.

II. LITERATURE SURVEY

Charles C Allgood et al (2010) in his paper analyses the usage of R438a as an alternative for R22 refrigerant [1]. He proposes R438a as a reliable, versatile and low cost non ozone depleting replacement for direct expansion (DX) refrigeration and air conditioning systems. It is observed that it provides similar cooling and efficiency to R22 in lower compressor discharge temperatures. It can be used in R22 systems without any change of lubricant type during the retrofit.

Namaz Khan et al (2015) in his paper compare R12, R134A, R407A and R717 for vapour compression system applications [2]. He uses Cool pack software to determine COP, mass flow rate and discharge temperature for various evaporator and condenser temperatures.

Derya Ozkan et al (2007) in his paper performs the comparative study of R600a, R134a, R290, R1270, R32, R22 and R152a refrigerants in vapour compression cycles and heat pumps [3]. The evaporation temperature is varied between -40°C and -10°C while the condensation temperature is held constant at 40°C. It is observed that R152a even though a hydroflurocarbon (CFC) has close to zero ozone depleting potential.

B. Hadya et al (2012) in her paper compares environment friendly refrigerants in lower capacity air conditioning system [4]. She summarizes that R290 is an excellent alternative to R22. She also suggests that in order to prevent the environmental damage and to reduce the harmful effects the refrigeration industry must shift towards the natural refrigerants.

Suri Rajan (2011) in his thesis provides a perspective for comparison of Refrigerant R410 with R404a. The thesis is motivated by the need for efficient and environmental friendly refrigerants in low temperature applications [5].

A. Baskaran et al (2012) in his paper examines the performance of a vapour compression refrigeration system with various refrigerants blend of R152a, RE170 and R290A their outcomes are contrasted with R134a as possible alternative replacement [6]. The outcomes demonstrate that the alternative refrigerants considered in the analysis RE170, R152a and R600a have a somewhat higher performance coefficient (COP) than R134a for the condensation temperature of 50°C and evaporating temperatures ranging from -30°C to10°C.

Bukola Olalekan Bolaji et al (2014) in his paper presents a theoretical investigation concerning the performance of R432A and R433A refrigerants as options against the ozone depleting R22 refrigerant [7].

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It is noticed that the average COPs obtained for R432A and R433A were lesser by just 4.5 and 5.4%, respectively, than those of R22, but the two alternative refrigerants have equally shown better pressure ratios, discharge temperatures and pressures in comparison to R22.

R.K Dreepaul (2017) in his work presents the consequences of the Montreal protocol which was successfully administered in Mauritius. HFC refrigerants such as R134a, R404a, R407C and R410 are the commonly used refrigerant in the Mauritian RAC field.The paper also indicates that stake holders on the business have good understanding of the consequences of ozone depleting refrigerants and the advantages of using new generation refrigerants instead of the conventionally used ones. The stake holders are aware of the high energy efficiencies and excellent thermodynamic properties of these chemicals as refrigerants [8].

III. METHODOLOGY

For the analysis of the performance characteristics of the refrigerants, two cycles are being utilized: a single stage compression cycle and another single stage compression cycle with heat exchanger.

In the single stage compression cycle there is a compressor, an evaporator, expansion valve and condenser. While the cycle with heat exchanger has an addition of a heat exchanger to the above mentioned cycle.

Figure 1 portrays a typical, single-stage vapour-compression system. Every single such systems have four components: a compressor, a condenser, a thermal expansion valve and an evaporator. Circulating refrigerant gets into the compressor as saturated vapour and is compressed to an elevated pressure, resulting in an elevated temperature as well. This superheated vapour can be condensed with either cooling water or cooling air flowing across the coil or tubes. This is where the circulating refrigerant rejects heat from the system and the rejected heat is carried away by either the water or the air.

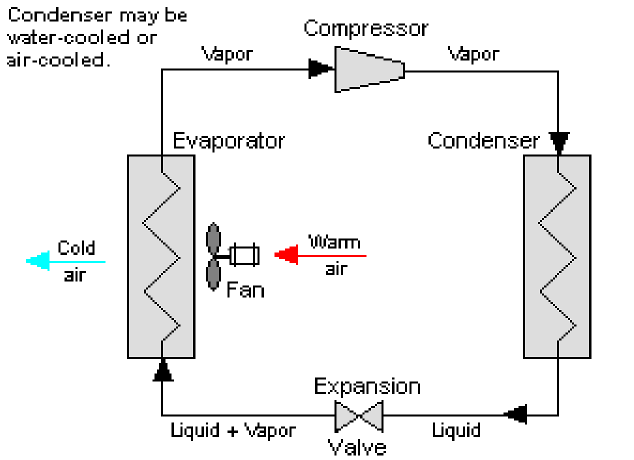

Figure 1: Single stage compression cycle

The analysis is done with the help of Chemours Refrigerant Expert 1.0 software. This software assists in computing P-v-T data as well as different refrigeration cycle performance data for numerous refrigerants.

The volumetric as well as isentropic efficiencies both are set as 100% for the single stage compression cycle. The volumetric as well as isentropic efficiencies are set as 100% and 70% respectively for the single stage compression cycle with heat exchanger. The evaporation temperature is varied between -40°C and -10°C while the condensation temperature is held varied between 10°C and 40°C. Refrigeration capacity is kept as 100 kW. The calculations are computed with the required refrigerants given as input. Various properties like COP, mass flow rate volumetric efficiency are noted down and tabulated. Graphs are plotted. The results obtained for various refrigerants are analyzed and compared.

IV. REFRIGERANTS USED

A. R22

Chlorodifluoromethane also known as R22 is a Hydro Chloro Fluoro Carbon (HCFC). Figure 2 shows an R22 molecule. This colourless gas performs well in the roles of refrigerants and propellants. Its usage has been banned in developed countries owing to its high Ozone Depletion Potential (ODP) as well as high Global Warming Potential (GWP). However, developed countries still continue the practice of R22 use [9].

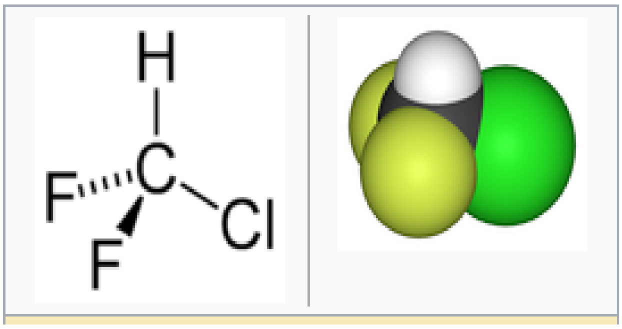

Figure 2: R22 molecule

B. R438A

Refrigerant R-438A is an environment friendly option against R-22. It exposes the latter's pressure-enthalpy characteristics with mineral oil compatibility.

C. R407C

R-407C is a zeotropic blend of difluoromethane (R-32), pentafluoroethane (R-125), and 1,1,1,2-tetrafluoroethane (R-134a). Difluoromethane assists in providing the heat capacity, pentafluoroethane diminishes flammability, tetrafluoroethane brings down pressure.

D. R410A

R-410A is a zeotropic, but near-azeotropic mixture of difluoromethane (CH_2F_2, called R-32) and pentafluoroethane (CHF_2CF_3, called R-125. It serves the purpose of a refrigerant in air conditioning systems.

E. R454C

R-454C hydrofluoric-olefin (HFO) based refrigerant alternative for R-404A and R-22. It possess low Ozone Depletion Potential (ODP) as well as low Global Warming Potential (GWP).

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F. R12

R-12 or dichlorodifluoromethane finds its applications as a refrigerant and aerosol spray propellant. Figure 3 shows an R12 molecule.

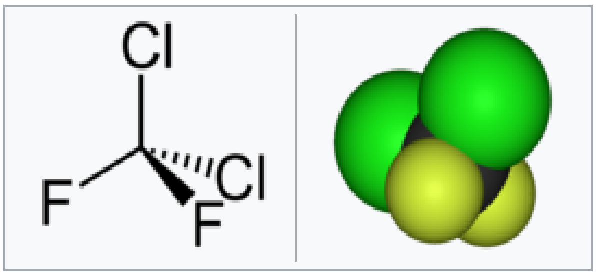

Figure 3: R12 molecule

G. R409A

R409A is an HCFC-based refrigerant, is a retrofit refrigerant for the R-12 stationary positive displacement cooling and refrigeration systems, for example, stroll in coolers, drink containers, candy machines, and grocery store frameworks.

H. R513A

R-513A is an environment friendly Hydrofluroolefin based refrigerant alternative for R-134a. It is an azeotropic refrigerant and is appropriate for new and retrofit of existing systems, offering good capacity and energy efficiency almost equivalent to R12.

I. R134A

1,1,1,2-Tetrafluoroethane is a haloalkane refrigerant with thermodynamic properties equivalent to R-12 (dichlorodifluoromethane) but with negligible ozone depletion potential and a lower global warming potential (1,430, compared to R-12's GWP of 10,900)[10].

J. R1234yf

2, 3, 3, 3-Tetrafluoropropene is popularly known as HFO-1234yf. This Hydro Fluoro Olefin (HFO) possess a chemical formula CH_2=$CFCF_3$. It is also designated R-1234yf as the first of a new class of refrigerants.

Table 1: Refrigerants compared and their global warming potential (gwp) and ozone depletion potential (ODP)

Refrigerant	Global Warming Potential (GWP)	Ozone Depletion Potential (ODP)
R22	1810	.055
R438A	2265	0
R407C	1774	0
R410A	2088	0
R454C	148	0
R12	10900	0.82
R409A	1909	0.046
R513A	573	0
R134A	1430	0
R1234yf	4	0

V. RESULTS AND DISCUSSION

The comparative study of R438a (Freon M099), R407C (Freon 407C), R410A (Freon 410c) and R454C (Opteon XL20) which are environment friendly alternatives for R22 is performed. A comparative study of R513a (Opteon XP10), R134a (Freon 134a) and R1234yf (Opteon YF) which could be replacements for R12 and R409 is also performed

Table 2: COP values for various evaporator temperatures (Te) at various condenser temperatures (Tc) in single stage vapour compression cycle

T_c (°C)	T_e (°C)	COP				
		R438A	*R407A*	*R410A*	*R454C*	*R22*
10	-10	11.68	11.57	11.37	11.74	11.68
	-20	7.21	7.19	7.05	7.27	7.25
	-30	4.99	4.99	4.89	5.03	5.04
	-40	3.66	3.67	3.1	3.7	3.72
	-10	7.41	7.4	7.2	7.46	7.48
	-20	5.17	5.14	5.01	5.17	5.21
	-30	3.77	3.79	3.7	3.81	3.86
20	-40	2.87	2.9	2.83	2.91	2.96
	-10	5.24	5.27	5.08	5.28	5.35
	-20	3.85	3.89	3.76	3.89	3.97
	-30	2.93	2.98	2.89	2.97	3.05
30	-40	2.29	2.33	2.27	2.32	2.4
	-10	3.9	3.95	3.77	3.93	4.06
	-20	2.97	3.03	3.9	3	3.13
	-30	2.31	2.38	2.28	2.34	2.47
40	-40	1.83	1.89	1.82	1.86	1.98

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Table 2 shows the COP values for various evaporator temperatures (T_e) ranging from -10°C to -40°C at various condenser temperatures (T_c) ranging from 10°C to 40°C in single stage vapour compression cycle with R22 substitutes.

It is observed that up to condenser temperature of 30°C R454c offers highest COP and after condenser temperature of 30°C, R407 offers highest COP.

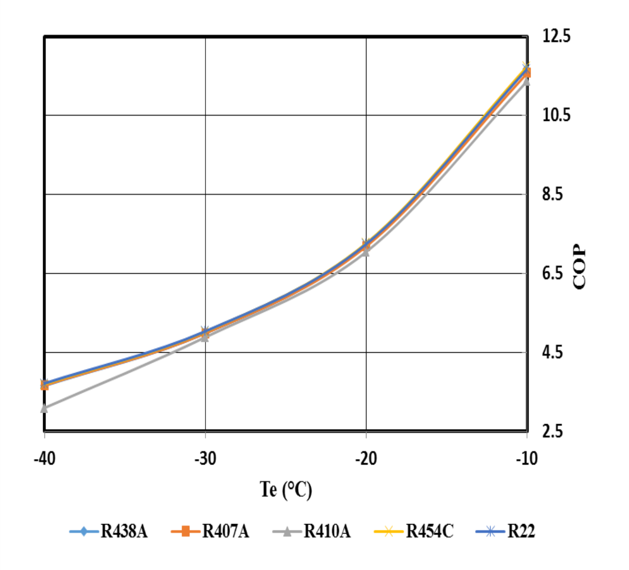

Figure 4: COP vs evaporator temperature (Te) at condenser temperature of 10°C

Figure 4 shows the graph with COP at vertical axis and evaporator temperature (T_e) at horizontal axis for constant condenser temperature of 10°C for R438a (Freon M099), R407C (Freon 407C), R410A (Freon 410c) and R454C (Opteon XL20) and R22 refrigerants for single stage vapour compression cycle.

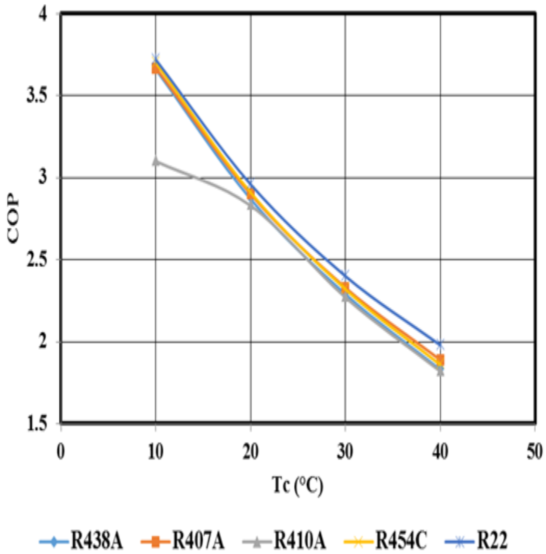

Figure 5: COP vs condenser temperature at evaporator temperature of -40°C

Figure 5 shows the graph with COP at vertical axis and condenser temperature (T_c) at horizontal axis for constant condenser temperature of -40°C for R438a (Freon M099), R407C (Freon 407C), R410A (Freon 410c) and R454C (Opteon XL20) and R22 refrigerants for single stage compression cycle.

Table 3: Mass flow rate (kg/s) for various evaporator temperatures (Te) at various condenser temperatures (Tc)

T_c (°C)	T_e (°C)	Mass Flow (kg/s)				
		R438A	*R407A*	*R410A*	*R454C*	*R22*
10	-10	0.5414	0.47	0.4585	0.5168	0.4944
	-20	0.5599	0.4783	0.4628	0.5342	0.5056
	-30	0.5803	0.4924	0.4735	0.5533	0.5178
	-40	0.6026	0.5077	0.4855	0.5742	0.531
	-10	0.5865	0.4997	0.4881	0.5584	0.5257
	-20	0.6083	0.5145	0.4991	0.5788	0.5383
	-30	0.6323	0.5309	0.5116	0.6013	0.5521
20	-40	0.6589	0.5488	0.5256	0.6261	0.5672
30	-10	0.6416	0.5408	0.5305	0.6096	0.5622
	-20	0.6678	0.5582	0.5435	0.6339	0.5766
	-30	0.6969	0.5775	0.5583	0.661	0.5925
	-40	0.7293	0.5987	0.575	0.6911	0.6099
	-10	0.7111	0.5913	0.5837	0.6742	0.6056
	-20	0.7434	0.6121	0.5995	0.7041	0.6224
	-30	0.7797	0.6354	0.6176	0.7377	0.641
40	-40	0.8204	0.6612	0.6381	0.7754	0.6614

Table 3 shows mass flow rate (kg/s) for various evaporator temperatures (Te) ranging from -10°C to -40°C at various condenser temperatures(Tc) ranging from 10°C to 40°C for single stage compression cycle .

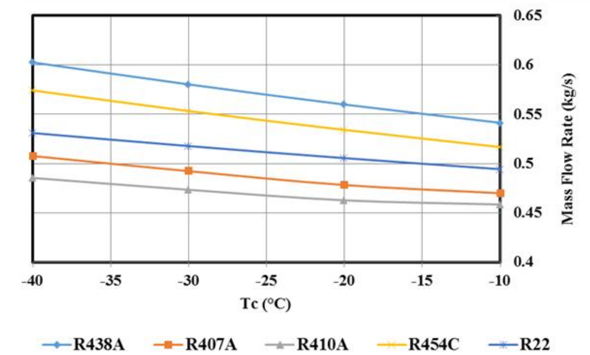

Figure 6: Mass flow (kg/s) vs evaporator temperature at condenser temperature of 10°C for single stage compression cycle

Figure 6 shows the graph with COP at vertical axis and evaporator temperature (Te) at horizontal axis for constant condenser temperature of 10°C for R438a (Freon M099), R407C (Freon 407C), R410A (Freon 410c) and R454C (Opteon XL20) and R22 refrigerants for single stage compression cycle.

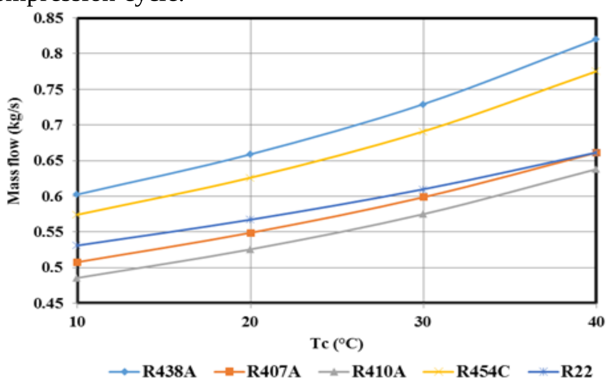

Figure 7: Mass flow (kg/s) vs condenser temperature at evaporator temperature of -40°C for single stage compression cycle

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Figure 7 shows the graph with COP at vertical axis and condenser temperature (Tc) at horizontal axis for constant evaporator temperature of -40°C for R438a (Freon M099), R407C (Freon 407C), R410A (Freon 410c) and R454C (Opteon XL20) and R22 refrigerants for single stage compression cycle.

Table 4 :COP values for various evaporator temperatures (Te) at various condenser temperatures (Tc) in single stage vapour compression cycle with heat exchanger

T_c (°C)	T_e (°C)	COP				
		R438A	*R407A*	*R410A*	*R454C*	*R22*
10	-10	11.68	11.62	11.38	11.74	11.63
	-20	7.21	7.19	7.05	7.26	7.22
	-30	4.99	4.89	4.9	5.03	5.02
	-40	3.66	3.67	3.61	3.7	3.71
	-10	7.41	7.4	7.2	7.45	7.45
	-20	5.13	5.14	5.01	5.17	5.19
	-30	3.77	3.79	3.7	3.8	3.84
20	-40	2.87	2.9	2.83	2.9	2.95
	-10	5.24	5.27	5.08	5.26	5.34
	-20	3.85	3.89	3.76	3.88	3.96
30	-30	2.93	2.98	2.98	2.96	3.05
	-40	2.28	2.33	2.27	2.31	2.4
	-10	3.9	3.95	3.77	3.91	4.05
	-20	2.97	3.03	3.9	2.99	3.13
	-30	2.31	2.38	2.28	2.33	2.47
40	-40	1.83	1.89	1.82	1.85	1.98

Table 4 shows the COP values for various evaporator temperatures (Te) ranging from -10°C to -40°C at various condenser temperatures(Tc) ranging from 10°C to 40°C in single stage vapour compression cycle with heat exchanger.

It is observed that up to condenser temperature of 20°C R454c offers highest COP and after condenser temperature of 30°C R407 offers the highest COP.

Table 5: Mass flow rate (Kg/s) for various evaporator temperatures (Te) at various condenser temperatures (Tc) in singlestage vapour compression cycle

T_c (°C)	T_e (°C)	Mass Flow (kg/s)				
		R438A	*R407C*	*R410A*	*R454C*	*R22*
10	-10	0.541	0.467	0.455	0.523	0.486
	-20	0.560	0.480	0.469	0.541	0.497
	-30	0.580	0.494	0.475	0.560	0.509
	-40	0.603	0.509	0.487	0.581	0.522
	-10	0.587	0.501	0.490	0.566	0.516
	-20	0.608	0.516	0.501	0.586	0.522
	-30	0.633	0.533	0.513	0.609	0.542
20	-40	0.659	0.551	0.527	0.634	0.557
	-10	0.642	0.543	0.533	0.619	0.551
	-20	0.668	0.560	0.546	0.643	0.565
	-30	0.697	0.580	0.561	0.671	0.581
30	-40	0.730	0.601	0.577	0.701	0.598
	-10	0.712	0.594	0.587	0.685	0.593
	-20	0.744	0.615	0.602	0.716	0.609
	-30	0.780	0.638	0.620	0.750	0.628
40	-40	0.821	0.664	0.641	0.788	0.648

Table 5 shows mass flow rate (kg/s) for various evaporator temperatures (Te) ranging from -10°C to -40°C at various condenser temperatures (Tc) ranging from 10°C to 40°C for single stage compression cycle with heat exchanger for R22 and its substitutes .

Table 6: COP values for various evaporator temperatures (Te) at various condenser temperatures (Tc) in single stage vapour compression cycle

T_c (°C)	T_e (°C)	COP				
		R513A	*R134A*	*R1234yf*	*R12*	*R409A*
10	-10	8.33	8.34	8.33	8.36	8.22
	-20	5.14	5.16	5.13	5.19	5.1
	-30	3.55	3.58	3.53	3.6	3.54
	-40	2.6	2.63	2.58	2.66	2.61
20	-10	5.29	5.32	5.27	5.36	5.28
	-20	3.65	3.69	3.63	3.73	3.68
	-30	2.68	2.72	2.65	2.76	2.72
	-40	2.04	2.08	2.01	2.11	2.08
	-10	3.74	3.79	3.71	3.84	3.8
	-20	2.75	2.8	2.71	2.84	2.81
	-30	2.09	2.14	2.05	2.18	2.16
30	-40	1.62	1.67	1.58	1.71	1.7
	-10	2.79	2.86	2.74	2.91	2.89
	-20	2.12	2.18	2.07	2.23	2.23
	-30	1.65	1.71	1.6	1.76	1.75
40	-40	1.3	1.35	1.25	1.4	1.35

Table 6 shows the COP values for various evaporator temperatures (Te) ranging from -10°C to -40°C at various condenser temperatures(Tc) ranging from 10°C to 40°C in single stage vapour compression cycle for R12, R409a and their substituent's. It is observed that R134A offers highest COP among the substituent's.

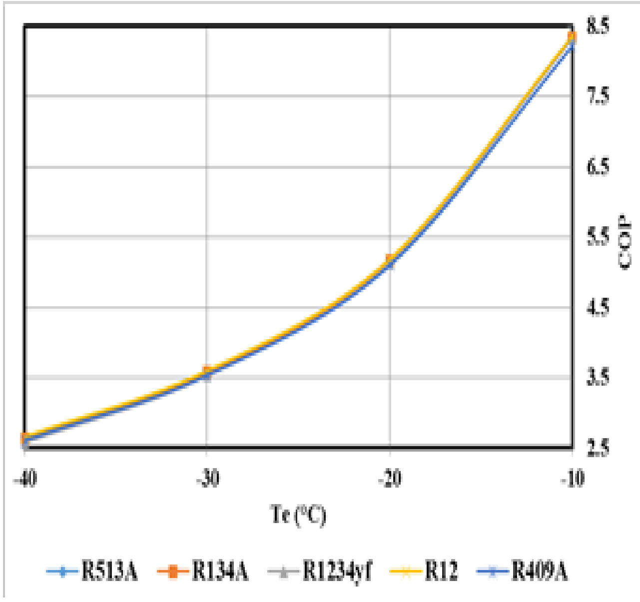

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Figure 8: COP vs evaporator temperature at condenser temperature of 10°C

Figure 8 shows the graph with COP at vertical axis and evaporator temperature (Tc) at horizontal axis for constant condenser temperature of 10°C for R513a, R134a, R1234yf, R12 and R409a.

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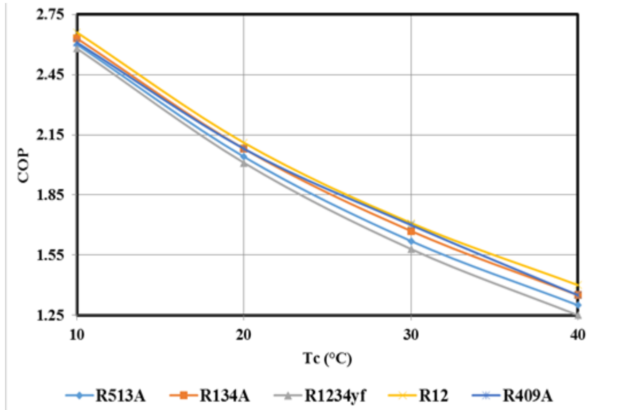

Figure 9: COP vs condenser temperature at evaporator temperature of -40°C

Figure 9 shows the graph with COP at vertical axis and condenser temperature (Tc) at horizontal axis for constant evaporator temperature of -40°C for R513a, R134a, R1234yf, R12 and R409a.

Table 7: Mass flow rate (Kg/s) for various evaporator temperatures (Te) at various condenser temperatures (Tc)

T_c (°C)	T_e (°C)	Mass flow (kg/s)				
		R513	*R134*	*R1234yf*	*R12*	*R409*
10	-10	0.576	0.514	0.628	0.494	0.493
	-20	0.600	0.532	0.659	0.505	0.507
	-30	0.652	0.551	0.689	0.517	0.522
	-40	0.653	0.572	0.725	0.531	0.538
	-10	0.635	0.553	0.685	0.525	0.524
	-20	0.652	0.574	0.720	0.538	0.540
	-30	0.68	0.596	0.759	0.552	0.556
20	-40	0.717	0.621	0.802	0.567	0.574
	-10	0.684	0.600	0.756	0.562	0.560
	-20	0.718	0.624	0.799	0.576	0.578
	-30	0.75	0.651	0.847	0.592	0.597
30	-40	0.796	0.680	0.901	0.609	0.618
	-10	0.759	0.657	0.847	0.605	0.603
	-20	0.800	0.686	0.901	0.609	0.623
	-30	0.846	0.718	.0.96	0.641	0.646
40	-40	0.898	0.754	1.032	0.661	0.674

Table 7 shows the COP values for various evaporator temperatures (Te) ranging from -10°C to -40°C at various condenser temperatures (Tc) ranging from 10°C us to 40°C in single stage vapour compression cycle for R12, R409a and their substituents.

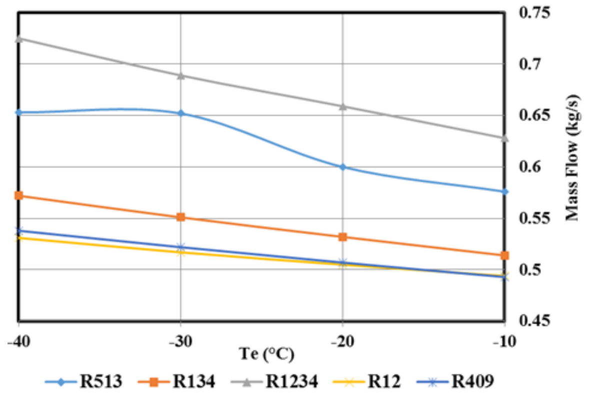

Figure 10: Mass flow (kg/s) vs evaporator temperature at condenser temperature of 10°C for single stage compression cycle

Figure 10 shows the graph with mass flow at vertical axis and evaporator temperature (T_e) at horizontal axis for constant condenser temperature of 10°C for R513a, R134a, R1234yf, R12 and R409a.

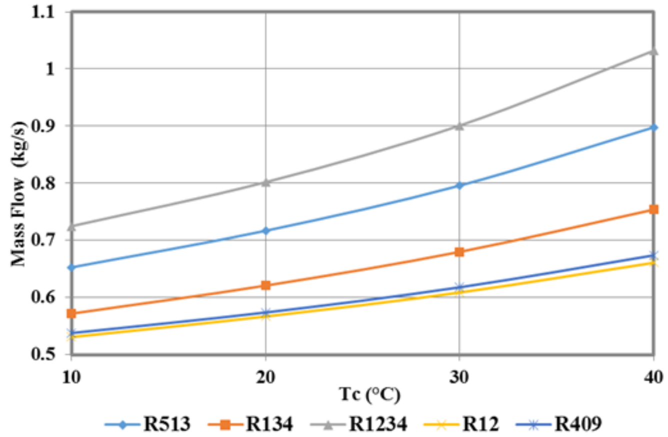

Figure 11: Mass flow (kg/s) vs condenser temperature at evaporator temperature of 10°C for single stage compression cycle

Figure 11 shows the graph with mass flow at vertical axis and condenser temperature (Tc) at horizontal axis for constant evaporator temperature of -40°C for R513a, R134a, R1234yf, R12 and R409a.

VI. CONCLUSION

In this study, performance analysis of R438a (Freon M099), R407C (Freon 407C), R410A (Freon 410c) and R454C (Opteon XL20) which are environment friendly alternatives for R22 is done. We can conclude that results indicated that among the R22 alternatives, for applications upto condensation temperature of 20°C R454c and for applications above condensation temperature of 30°C R407c are the most suitable. Among R12 and R409 replacements R134a is observed to be the best alternative. Also, these alternatives have extremely low Ozone Depletion Potential (ODP) Global Warming Potential (GWP). Hence it is proposed that the above alternatives are highly considerable from both performance as well as environmental point of view.

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