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Performance Evaluation of Eco- Friendly Alternate Refrigerants for VCRS

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Abstract: **The Montreal Protocol has sealed the use of Halogenated Hydrocarbons; keeping in view they affect the environment in the form of Ozone layer depletion and Global warming. Thus one of the major thrust areas is to identify substitute of Halogenated Hydrocarbons, especially CFCs. The substitute refrigerant should be eco-friendly, chemically stable and compatible with existing refrigeration systems with transport and thermal properties similar to or better than CFCs. According to the recent studies carried by U.S. energy development society, approximately 75 million new refrigerators are manufactured would wide every year and year and the total number of refrigerators will cross 100 million mark by the year 2010. Since the refrigeration system use CFC-12 as refrigerant universally, the search for a suitable alternative for CFC-12 is inevitable. HFC-134a is currently the leading alternative to CFC-12. Other promising substitutes are R-407c a ternary mixture of HFC-32 & HFC-125 & HFC-134a. R-507 Binary mixture of HFC-143a & HFC-125 and R-404a is a ternary mixture of HFC-125, HFC-143a, HFC-134a. The present work aims to analysis suitability of three newly discovered mixtures R-407c R-507 & R-404A for replacement of CFC-12 in existing refrigeration units. A cycle analysis has been carried out to predict the performance of system under various operation conditions. In this paper, performance evaluation of eco-friendly alternate refrigerant 407c, R-507 & R-404a for replacing CFC12 has been done and a suitable alternative refrigerant for retrofitting has been identified.**

The Montreal Protocol has sealed the use of Halogenated Hydrocarbons; keeping in view they affect the environment in the form of Ozone layer depletion and Global warming. Thus one of the major thrust areas is to identify substitute of Halogenated Hydrocarbons, especially CFCs. The substitute refrigerant should be eco-friendly, chemically stable and compatible with existing refrigeration systems with transport and thermal properties similar to or better than CFCs. Since the refrigeration system use CFC- 12 as refrigerant universally, the search for a suitable alternative for CFC-12 is inevitable.HFC-134a is currently the leading alternative to CFC-12. Other promising substitutes are R-507 as a binary mixture of R-143a & R-125, R-407c ternary mixture of R-134a, R-32 & R-125 and R-404a ternary mixture Of R-134a, R-143a & R-125 In this paper, performance evaluation of eco-friendly alternate refrigerant R-134a, R-507a, R-407c & R-404a for replacing CFC12 has been done and a suitable alternative refrigerant for retrofitting has been identified.

Keywords: **Ozone depletion, Montreal protocol, eco-friendly refrigerant, hydrocarbon refrigerant, retrofits.**

I. INTRODUCTION

Recent studies have established that CFCs are depleting the Ozone layer and also contributed towards global warming. As due to favourable thermo dynamical and transport properties CFCs are used in the refrigeration system so there must be some alternative refrigerant, which is eco-friendly and having properties which are suited for refrigeration purpose In 1987, several countries across the world signed an international treaty, the Montreal protocol, to control substances that deplete the ozone layer. According to this protocol, countries would phase out CFCs and other ODS as per a given schedule, with a complete halt by 2010. 190 countries are signatories to the Montreal protocol. Under this agreement, the use of CFCs as refrigerants in all commercial and industrial refrigeration and air-conditioning equipments has been banned in 1999 in all developed countries. Countries like India which have ODS consumption below the threshold annual value of 0.3 kg per capita are required to freeze the consumption of CFC by 1999, then reduce the use by 50% by 2005 and complete phase out by 2010 (Agrawal, 2001). It is believed that if the international agreement is adhered to the ozone layer is expected to recover by 2050.

II. ANALYSIS & EVALUATION

1.1 India's commitment to the Montreal protocol:

India became party to the Montreal protocol on Sept 17, 1992. India mainly produced and used seven of the 20 substances controlled under the Montreal protocol. These are CFC-11, CFC12, CFC113, Halon1211, Halon-1301, CTC, methyl chloroform and methyl bromide. India had prepared a detailed country programme (CP) in 1993 to phase out ODS in accordance with its national industrial development strategy (INFRAS, 2000). The objectives of the CP were to phase out ODS without undue economic burden to both consumers and industry manufacturing equipments using ODSs and provided India with an opportunity to access the protocol's financial mechanism. The other objectives of the CP also include minimization of economic dislocation as a result of conversion to non-ODS technology, maximization of indigenous production, preference to one time replacement, emphasis is on decentralized management and minimization of obsolescence. In 1991, the total ODS consumption in the refrigeration and air-conditioning sector in India was 1,990 MT. This constituted about 39% of India's total consumption of CFCs. About two-thirds of this consumption was estimated to be used in servicing of existing equipment. The growth rate in this sector was forecast at 10-20% annually until 2010. The refrigeration and air-conditioning sector was therefore identified as a priority sector in India for initiating phase-out activities (Kapil, 2008).

1.2 Retrofitting:

Imminent CFC shortages would threaten the useful life of the appliance of CFC equipment. As the CFC shortages increase, the cost of CFCs will rise, along with the operating costs of the equipment. "Retrofitting" is the only long term and the most effective solution for discontinuing and reducing the CFC emissions from existing appliances. Retrofitting is the process by which the equipment currently using an ODS refrigerant is made to operate on a non ODS refrigerant, without major effects on the performance of the equipment and without significant modifications or changes for the equipment, ensuring that existing equipment operates until the end of its economic life. It has been proved by various case studied that retrofitting is economically viable in small scale refrigeration equipment (Othmar & Adrian, 1998) than in large capacity systems.

2. Vapour compression refrigeration systems:

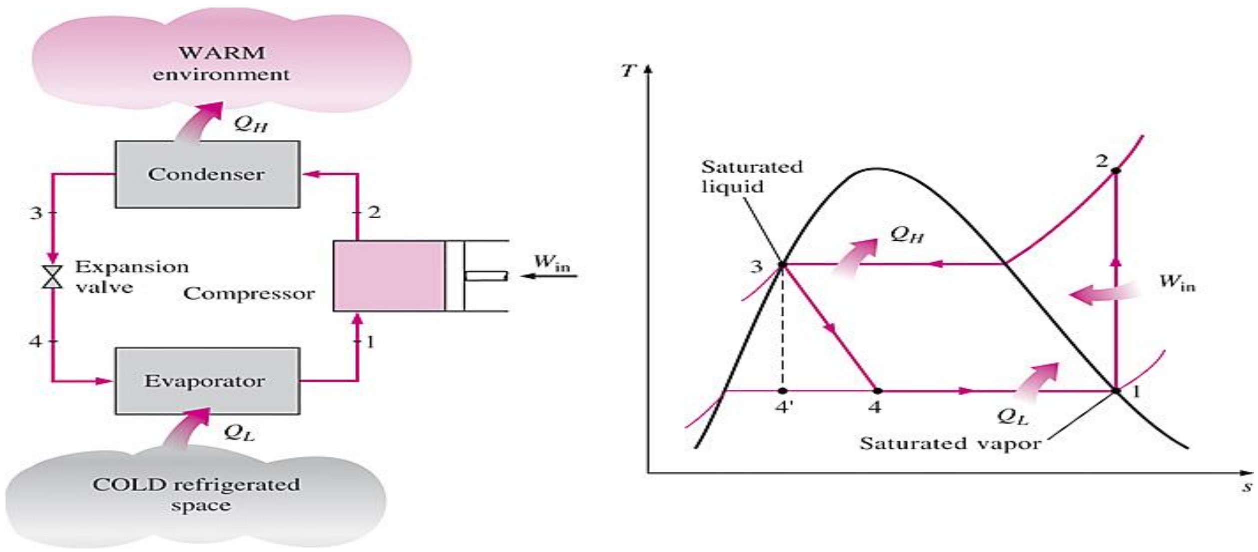

Fig. 1

The simple Vapour Compression Refrigeration cycle is shown in Fig.1. It consists of following four essential parts1.Compressor, 2.Condenser, 3.Expansion Valve, and 4.Evaporator.

Compressor compresses the vapour refrigerant to the condenser with high pressure and temperature , in the condenser condensation takes place by rejecting heat with cooling medium either water or air as a cooling medium the phase transfer takes place from vapour refrigerant to liquid refrigerant and enters into the Expansion Valve , the function of the expansion valve is to reduce the pressure from high condenser pressure to low evaporator pressure by throttling process, finally the liquid refrigerant enters in the Evaporator where cooling effect is produced by absorbing heat from the cooling space and only pure vapour enters into the compressor.

3. Eco-friendly refrigerants R-507, R-407c & R-404A:

Recent studies have established that CFCs are depleting the Ozone layer and also contributed towards global warming. As due to favourable thermo dynamical and transport properties CFCs are used in the refrigeration system so there must be some alternative refrigerant, which is eco-friendly and having properties which are suited for refrigeration purpose.

R-507 is a blend of HFC - 143a & HFC-125 that has been developed as a zero ODP replacement for CFC-12 in existing refrigeration system. The composition or R-507a is as follows (by weight %)

	HFC- 143a	HFC-125
R- 507	52%	48%

R-407c is a blend of HFC-32, HFC-125 & HC-134a that has been developed as a zero ODP replacement for CFC-12 in existing refrigeration system. The composition or R-407c is as follows (by weight %)

	HFC - 134a	HFC-32	HFC-125
R-407c	52%	23%	25%

R-404A is a blend of HFC-125, HFC-143A & HFC-134a that has been developed as a zero ODP replacement for CFC-12 in existing refrigeration system.

	HFC-125	HFC-143A	HFC-134a
R-404A	44%	52%	4%

New refrigerants like R-407c, R-507 & R-404A have been successfully tested in The USA and seem to be major retrofits for R-12. They are also not subjected to phase -out under any amendment/Law. Also they are compatible to the existing lubricants. Analysis of vapour compression refrigeration system can be carried out using thermodynamic properties of the working fluid. Prediction of the performance of compression refrigeration system at design and off design conditions needs repeated calculations. This necessitates the development of correlation for various properties such as vapour pressure, specific volume, saturated vapour and saturated vapour enthalpy as a function of temperature and pressure.

3.1 Correlation for saturated vapour specific volume:

Correlation for liquid and vapour enthalpy for HFC-134a, R-407c, R-507 and R-404A and CFC-12 as a function of temperature are given below. The form is as follows.

$V_g= (A+B*T)/ (1+C*T+D*T^2)$

The constants A, B, C, and D are given in table 3.1a

TABLE 3.1A COEFFICIENTS FOR VAPOR PRESSURE CORRELATION

Refrigerant	**A**	**B**	**C**	**D**
R-12	308.6	10.144	0.125753	0.0006640294
R-134a	293.4	10.642	0.146852	0.0008955292
R-407c	452	14.72	2.90	-1.64
R-507	50	0.6433	0.625	-0.3375
R-404A	601.3	19.4	-.1917	.1167

3.2 Correlation for saturated liquid entropy:

Correlation for liquid enthalpy for HFC-134a, R-407c, R-507 and R-404A and CFC-12 as a function of temperature are given below. The form of equation specific Entropy saturated liquid is as flows

$S_L = A+B.T+C.T^2+D.T^3 +E.T^4$

The constants A, B, C, D, E and F are given in table 3.2a

TABLE 3.2A COEFFICIENTS FOR VAPOR SPECIFIC ENTROPY CORRELATION

Refrigerant	**A**	**B**	**C**	**D**
R-12	1.554	-0.0004	-5.080e-006	-3.755e-008
R-134a	1.727	-0.0005	6.859e-006	-6.518e-008
R-407c	1.792	-.001	-4e-05	3e-05
R-507	.192	-5e-12	2e-12	-9e-13
R-404A	1.6168	.0003	-2e-30	1e-30

3.3 Correlation for saturated vapour enthalpy:

Correlation for vapour enthalpy for HFC-134a, R-407c, R-507 and R-404A and CFC-12 as a function of temperature are given below. The form of specific enthalpy of saturated vapor is as follows

$H_g = A+B.T+C.T^2+D.T^3 +E.T^4$

The constants A, B, C, D, E, and F are given in table 3.3a

TABLE 3.3A COEFFICIENTS FOR VAPOR SPECIFIC ENTHALPY CORRELATION

Refrigerant	**A**	**B**	**C**	**D**
R-12	351.4	0.427	-0.00065	-4.161e-006
R-134a	398.7	0.584	-0.00096	-8.792e-006
R-407c	413.9	.956	-.625	.3375
R-507	87.9	0.5367	-0.3333	0.1125
R-404A	368.3	.6833	.1	.0167

3.4 Performance analysis of refrigeration system for refrigeration unit:

The refrigeration system of 1-ton cooling capacity has been chosen for the study. The system consists of the four usual components i.e. the compressor, condenser, evaporator and capillary tube (throttling device), as shown in figure 1. The operating conditions for the refrigeration unit in Indian conditions are 45 ^{0}c, 50 ^{0}c and 55 ^{0}c for condensing temperature & -10 ^{0}c, -5 ^{0}c,5 ^{0}c and 10 ^{0}c for evaporator temperature.

Performance characteristics of reciprocating compressor are-

1. Volumetric efficiency of compressor: The ratio of clearance volume v0 to the swept volume vp is called the clearance factor(c). c= v0 /vp

This factor has been taken as 0.03(3%of vp).

The expression of volume efficiency is given by-

η =1+c-c*(v suction/discharge)

2. COP of vapour compressor refrigeration system:

COP= Refrigeration Effect/Work Input

Results:

The performance analysis on the basis of volumetric efficiency of compressor and COP of vapour compressor refrigeration system has been carried out by using software & manual calculations for evaporator temperatures -100c,-50c, 00c, 50c,and 100c, and condenser temperatures 450c, 500c and 550c. The performance parameters have been calculated without considering sub-cooling & superheating.

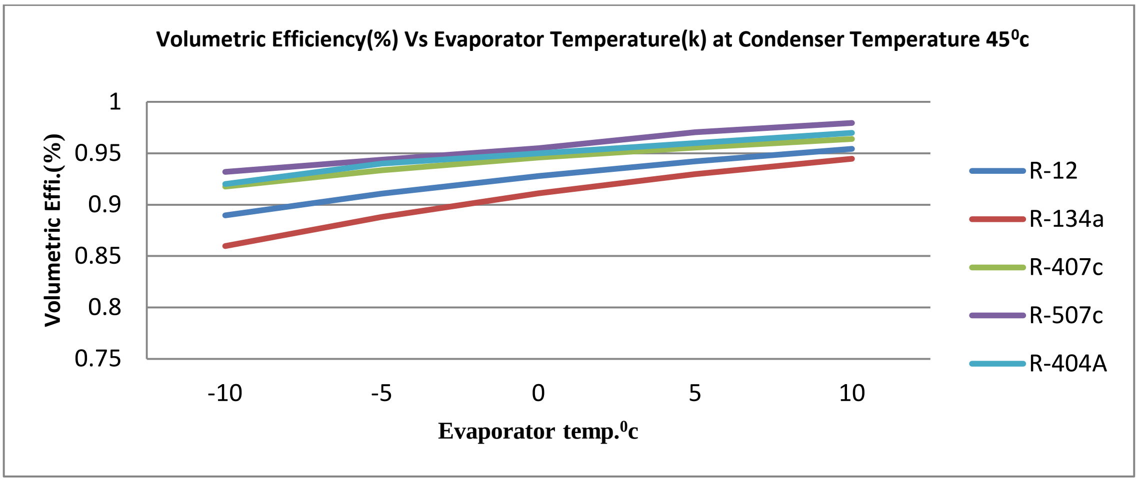

Fig. 2

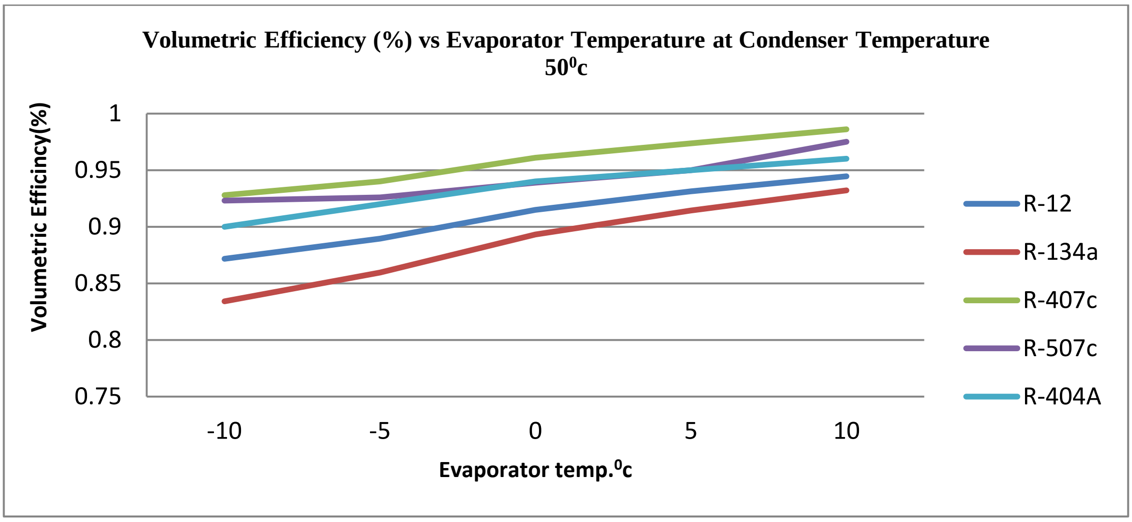

Fig. 3

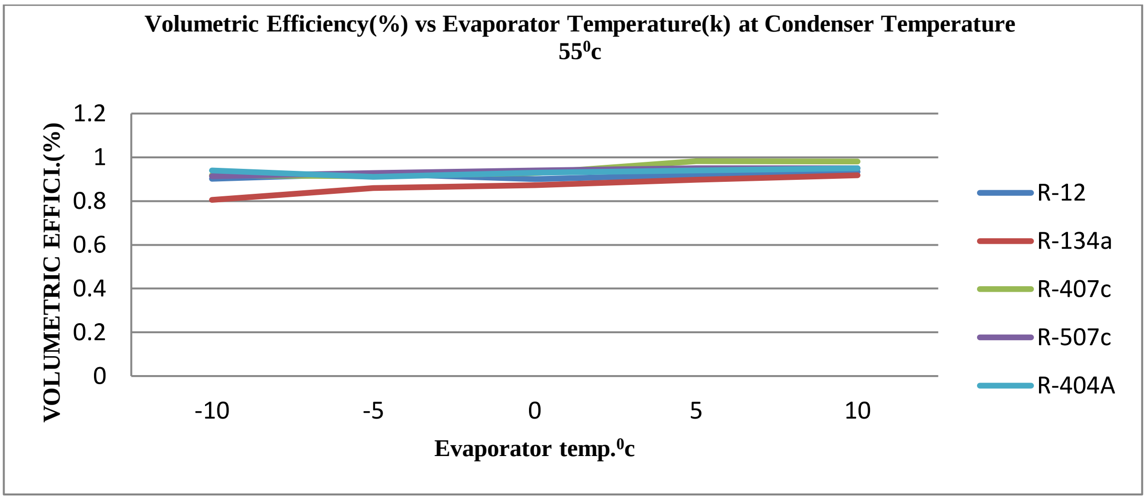

Fig. 4

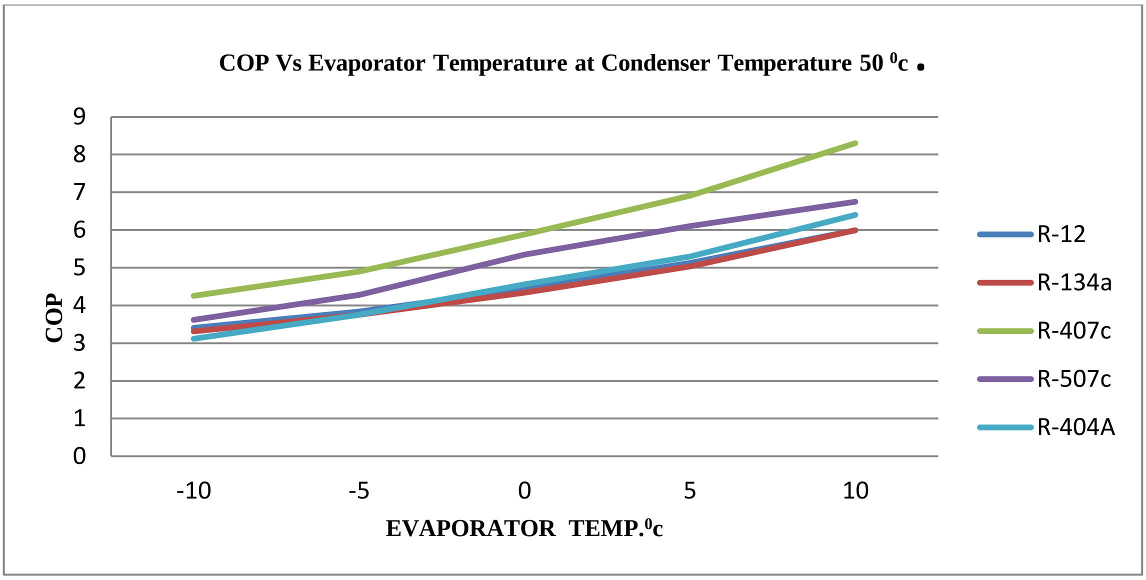

Fig. 5

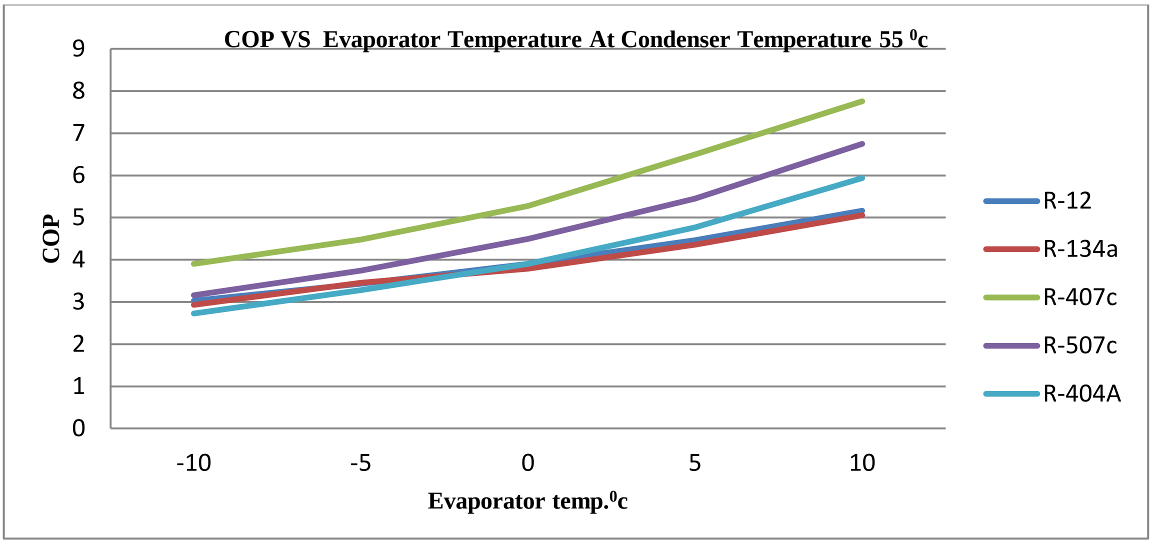

Fig. 6

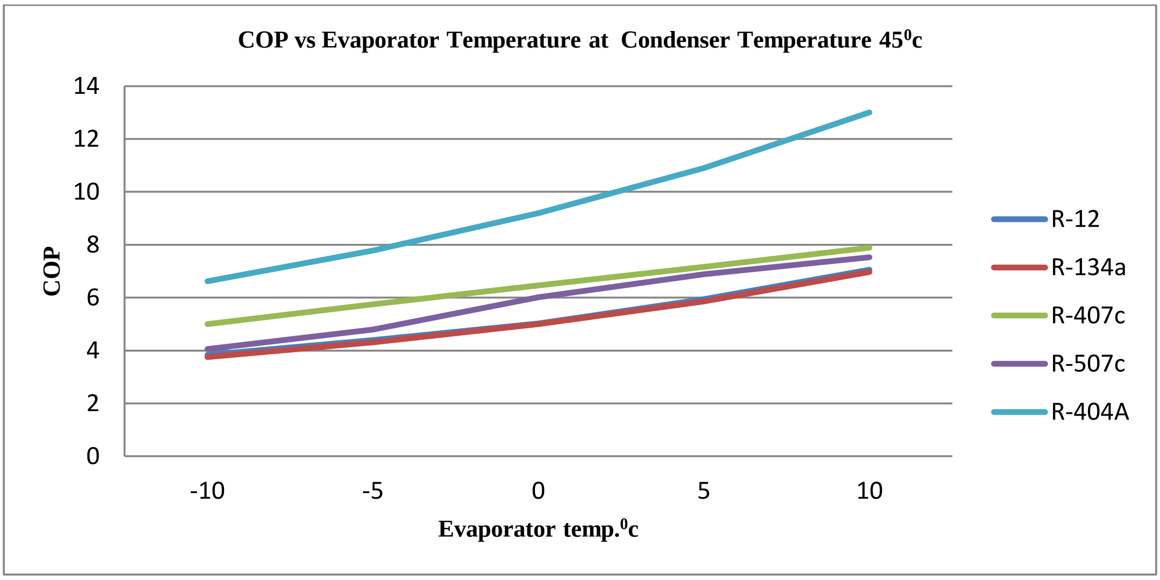

Fig. 7

In figure 2, 3 & 4 we can see that the volumetric efficiency of refrigerant R-407c, R-507c & R-404A is less compared to R-12 refrigerant. The volumetric efficiency of refrigerant R-12 is always more than that of other refrigerant. The highest efficiency is 0.9545 for R-12 at 100c for condenser temperature 450c.

In fig.5, 6, 7 we can observe that COP of the entire refrigerant are much closer or higher than R-12, COP of the refrigerant R-407c is found most promising alternatives in this regard. The highest difference in COP is 1.5695 between R-12 and proposed refrigerants.

III. CONCLUSION

COP and Volumetric efficiency of compressor of R-407c, R-507c & R-404A is nearly same & better to that of R-12. This also indicates the suitability of retrofitting of R-407c, R-507c & R-404A with an existing R-12 system. Volumetric efficiency of compressor using R-134a is slightly less than that of R-12. This is due to higher specific volume of R-134a. But this does not affect the performance of the system. Making an overall comparison, all three refrigerants R-407c, R-507c & R-404A are attractive alternatives to CFC-12. Research results are favourable, with no major drawback.

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