ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 10, October 2016

A Review on selecting an Eco-friendly Refrigerant alternate to R134a in Domestic Refrigerators

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ABSTRACT

Time is insufficient for everyone in this express world. In the meantime, we have to concentrate on our environment for the betterment of humans and other species in the world. Ozone depletion and global warming are main disturbances for the good environmental condition. These disturbances are mainly occurring due to refrigerants which are having high GWP and ODP values. Hence, we need to find a substitute for present refrigerant in terms of low GWP and zero ODP values. In this paper, we summarized the results of researchers to find out a new refrigerant. Finally, after analyzing those results we found that the following refrigerant R1234yf having zero ODP and very low GWP will give better COP, high cooling capacity and low energy consumption.

Keywords: *Refrigerant, ODP, GWP, COP, Energy Consumption*

NOMENCLATURE

CFC	Chlorofluorocarbon
COP	Coefficient of performance
DME	Dimethyl ether
GWP	Global Warming Potential
HC	Hydrocarbon
HCFC	Hydro chlorofluorocarbon
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
LPG	Liquefied petroleum gas
NBP	Normal boiling point
ODP	Ozone depletion potential
TEWI	Total equivalent warming impact

INTRODUCTION

In the modern world, home appliances are very much essential to make over the changes in the climatic condition. Hence, refrigerator and air conditioner are essential home appliances. But when the technology and science improves, environmental impacts are also improving proportionally. Global warming is the main issue that affects the climatic conditions and species in the world [1]. One of the main reasons of increasing global warming and ozone depletion is using refrigerant as the working medium in the refrigerator and the air conditioning systems which are having high values of ODP and GWP. Those refrigerants may tend to leak into the environment during recharging or mishandling of refrigerant. Due to leakage it affects the ozone layer and causes ozone depletion and increases the global warming. Hence, R22, R12 are phased out and alternative is found as R134a for the refrigeration system because it has similar efficiency as of R12. But the GWP of R134a refrigerant is very much high. Now refrigerator, air conditioningmanufacturers are in the urge to find out a new substitute for R134a. In searching of new substitute some of them were focused on natural refrigerants like NH_3, and HC, CFC, HCFC, HFC and HFO refrigerants.

Some developed countries had already banned using refrigerants which are having high GWP [14]. Some of the developing countries are trying to phase out those refrigerants before 2030. When trying to find a new refrigerant it should be compatible with the existing system to reduce the retrofit expenses. While analyzing and selecting new refrigerants their basic properties which are related to environment, thermodynamic properties and physical properties should be considered [3].

Hydrocarbons are highly flammable but are having very low GWP. Researchers are analyzing refrigerant mixture consisting of HC, HFCs and HFOs to reduce the amount of hydrocarbons in the working fluid. To improve the performance of the system HC type compressors are used which are especially designed for hydrocarbon refrigerants.

Anothertype of refrigerant commonly used ishydrofluorocarbon (HFC) which are having zero ODP and high GWP [5]. But which give high performance in the system hence it is blended with some other refrigerants. Main drawback of HFC is its oil miscibility property, hence different types of compressors cannot be used with HFCs. To overcome this problem, HFCs are blended with HC refrigerants.

ANALYSIS OF REFRIGERANTS

Analysis of HC refrigerants

S.J. Sekhar et al. (2005) investigated a retrofitted system with HFC134a and HC blend (containing 55.2% HC600a and 44.8% HC290 by weight). The R134a/HC (9% HC blend by weight) has 10–30% and 5–15% less energy consumption (than CFC12) in medium and low temperature systems, respectively. The actual COP of the system is improved by 5–17% in low temperature systems. M09 blended refrigerant gives higher actual refrigerating effect of 7 – 26.5% for domestic refrigerator and 6 – 28.4% for deep freezer [14].

A.S. Dalkilic et al. (2010) investigated and found that the refrigerant blend R290/R600a (40/60 by wt. %) is best replacement for CFC12 and R290/R1270 (20/80 by wt. %) is found suitable alternate refrigerant for CFC22 among other alternatives [6].

A.Baskaran et al. (2012) compared low GWP refrigerants and found that RE170, R152a and R600a have slightly higher performance coefficients (COP) than R134a for the condensation temperature of 50^0C and evaporating temperature ranging between -30^0C and 10^0C. Comparing the following parameters like COP, pressure ratio, ODP and GWP of refrigerants, refrigerant RE170 was found as suitable alternative refrigerant for R134a [5].

Mehdi Rasti et al. (2013)conducted experiments using R436A (mixture of 46% iso-butane and 54% propane) and R600a as hydrocarbon refrigerants. The investigations were done in two types of compressors one is designed for R134a and another one is designed for R600a. The optimum refrigerants charges for different compressors were varied. Compressor which is designed for R134a had given similar performance when the charge of 60 g and 55 g for R436A and R600a used respectively. At the optimum charge, the energy consumption of refrigerants R436A and R600a is reduced as 14% and 7% respectively when compared with R134a. While using another type of compressor which is designed for HC refrigerants, 50g of both alternate refrigerant charges was optimum for the better performance. Energy consumption was reduced as 14.6% and 18.7% for the refrigerant R436A and R600a respectively. When the refrigerator is retrofitted with HC type compressor, TEWI of both alternate refrigerant of R436A and R600a is reduced by 16% and 21% respectively at the optimum refrigerant charge, which is lower than existing refrigerant. In HFC type compressor total exergy destruction for R134a is 0.0389, for R600a is 0.0301 and for R436A is 0.0471. In HC type compressor the exergy destruction for R600a and R436A are 0.0292, 0.0472, respectively. To reduce the energy consumption HC type compressor is preferred instead of HFC type for hydrocarbon refrigerants [12].

Mahmood MastaniJoybari et al. (2013) analyzed exergy destruction through Taguchi parameters using 60 g of R600a, which had given similar results as R134a. 50 g of R600a charge is required at optimum condition which is 66% lower than R134a.Because of this reduction in charge flammability risk of the hydrocarbon refrigerant is significantly reduced. Compressor modification is strongly recommended to enhance the system performance [10].

Experimental results of K.Mani et al. (2008) showed that the refrigerant R290/R600a had refrigerating capacity of 19.9% to 50.1% and 28.6% to 87.2% which is higher than R12 and R134a respectively. At the lower evaporating temperature, COP of R290/R600a mixed refrigerant is increased from 3.9% to 25.1% than R12. At the higher evaporating temperatures, 11.8% to 17.6% COP is increased. The discharge temperature of R12 is higher than that of blended refrigerant R290/R600a by a very small amount. The R290/R600a mixture in the ratio of 68:32 by weight percentage can be referred as a good drop-in replacement refrigerant for R12 and R134a [11].

M.Mohanraj et al. (2009) had done an experimental investigation with a hydrocarbon refrigerant mixture of R600a and R290 in the composition of 54.8:45.2 by weight as an alternative to R134a in a domestic refrigerator. The results showed that the HC mixture has lower energy consumption. ON time ratio and pull down time as

11.1% and13.2% respectively also it has a higher from 3.25% to 3.6%. The discharge temperature of hydrocarbon mixture was found as lower than R134a from 8.5°C to 13.4°C. The overall performance has proved that the mixture of hydrocarbon refrigerant can be used as best substitute for replacing R134a [13].

Ki-Jung Park et al. (2007) analyzed refrigerant mixtures (composed of propylene, propane, R152a, and DME) and two pure hydrocarbons to replace R22. Test results show that the COP of these mixtures is higher than R22 up to 5.7%. When using propane, it results in reducing cooling capacity by about 11.5% [8].

Analysis of HFC refrigerants

Vincenzo La Rocca et al. (2011) investigated the plant working efficiency with R22 and then with three new hydrofluorocarbon refrigerants of R422D, R422A and R417A. The investigation verified the case of substitution and the usage of same mineral oil as lubricant in the compressor. The performance of the investigated refrigerants is not efficient as compared with R22. Replacing existing refrigerant of R22 with HCFCs need to do retrofit for better performance. Lubricating oils, expansion valve and other components are to be replaced with better and optimum accessories. They concluded that to achieve better performance, proper refrigerant should be used with proper accessories to reduce the environmental impact and to increase the energy efficiency [15].

Ankit Sethi et al. (2015) found that medium pressure refrigerant, R444B having low GWP of 295 is 5% more efficient than R410A [3].

Ki-Jung Park et al. (2008) showed that the coefficient of performance of R433A is higher than R22 from 4.9 to 7.6%. Cooling capacity of R433A is lower than R22 form 1.0 to 5.5%. The compressor discharge temperature of R433A is 22.6–27.9°C lower than that of R22.The COP of HCFC22 is 4.9–7.6% lower than that of R433A and therefore R433A can be considered as better replacement for HCFC22. But the capacity of R433A is 1.0–5.5% lower than that of HCFC22 and therefore it requires more mass flow rate for the same capacity [9].

COP

AtillaGencerDevecioglu et al. (2015) in their study suggested some alternate refrigerants based on their performance compared with other refrigerants. R1234yf, L40, DR-5 and R444B refrigerants can be considered as good alternatives to R134a, R404A, R410A and R22, respectively [4].

Analysis of HFO refrigerants

Giulia Righetti et al. (2015) investigated HFO, HFC and HC refrigerants which are having low GWP. Refrigerants HFO1234yf, HFO1234ze(E), and HC600a exhibit vaporization performance similar to HFC134a, henceHFO1234yf, HFO1234ze(E), and HC600a can be used as substitute for HFC134a, provided that the compressor displacement should be adjusted to deliver the proper refrigerant mass flow rate [7].

Adrian Mota-Babiloni et al. (2015) also analyzed the performance of HFO refrigerant as a mixture of a non-flammable refrigerant R1234ze(E)/R134a (R450A) to drop-in replacement R134a. While R134a has high GWP value, the R450A GWP is only 547. COP of R450 is 1% higher than R134a. Hence, R450A can be considered as a good substitute to R134a. They advised to redesign and optimize the system in order to obtain better performance and low power consumption [2].

Adrian Mota-Babiloni et al. (2014) investigated HFO refrigerants with and without internal heat exchanger. Without Internal heat Exchanger the average volumetric efficiency for R1234yf and R1234ze is 4% and 5% low compared with R134a. The cooling capacity of both refrigerants is reduced, with an average difference of 9% and 30% without Internal heat Exchanger. Also, COP values are 7% lower for R1234yf and 6% lower for R1234ze than R134a. By using Internal heat Exchanger COP differences for both refrigerants were reduced. The COP difference obtained using R1234yf is between 3% and 11% and forR1234ze between 2% and 8% lower than R134a [1].

Properties of different refrigerants like GWP, ODP, NBP, critical pressure and temperature, molecular mass and their densities are illustrated in Table 1.

ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 10, October 2016

Table: 1. Properties of some basic refrigerants

Refrigerant	**Properties**							
	Critical Pressure	Critical Temperature	Gas density	GWP	Liquid density	Molecular Mass	NBP	ODP
Unit	bar	K	Kg/m^3		Kg/m^3	g/mol	K	
R12	41.36	384.97	5.22	10,900	1490	120.9	243.2	1
R1234yf	33.82	367.7	4.77	4	1100	114	243.51	0
R1234ze(E)	36.36	382.36	4.77	7	1252.9	114	254.03	0
R125	36.29	339.01	4.98	3500	1400	120.2	224.92	0
R134a	40.59	374.21	14.35	1430	1295.27	102	247.08	0
R152a	47.6	387	2.76	124	2700	66.05	248.98	0
R22	49.9	369.1	3.5	1600	1262.7	86.48	232.2	0.055
R290	42.5	369.7	4.8	3	500.1	44	231	0
R32	53.8	351.4	2.15	675	1100	52.02	221.35	0
R417A	40.3	360	2.46	1950	1230	81.6	233.9	0
R422A	37.48	344.7	5.62	3144	1136	116	224.4	0
R422D	39.03	352.6	0.811	2230	1143	109.9	229.8	0
R424A	40.4	361.8	3.82	2440	1246.9	103.5	234.3	0
R436A	41.7	389.05	2.89	10	1207	84	228.6	0
R450A	38.14	379.02	13.93	547	1253.28	75	251.2	0
R600a	36.4	407.7	8.76	10	556.9	58.1	261	0

Table: 2. Mixing composition of mixed refrigerants by mass percentage

Mixed Refrigerant	**Composition of Mixtures in mass percentage**			
	R1234ze(E)	R125	R134a	R600a
R417A	-	46.6	60	3.4
R422A	-	85.1	11.5	3.4
R422D	-	65.1	31.5	3.4
R424A	-	50.5	47	1
R450A	58	-	42	-

Some of the analyzed refrigerants having different combinations of various refrigerants by mass percentage are arranged in table 2.

Results containing charge of refrigerant, cooling capacity, COP, discharge temperature, energy consumption of different Refrigerants are summarized in table 3.

Table: 3. Summary of results for various refrigerants

Refrigerant	Cooling Capacity	COP	Discharge Temperature	Energy Consumption	Evaporator Temperature
Units	**Kw**		**°C**	**W**	**°C**
R12	1.34	2.15	40	620	-2
R1234yf	1.2	3.1	35	72	-8
R1234ze(E)	1.8	3.2	41	50	-15
R125	0.7	2.6	47	90	3
R134a	1.5	3.4	75	350	-10
R152a	1.3	2.8	37	120	5
R134a/R600a	1.8	1.85	48	179	-15
R22	0.6	3.8	40	168	-2
R290	1.7	3.75	38	160	-8
R290/R600a	2.12	3.2	35	179	2
R32	1.2	2.3	33	450	12
R417A	0.6	3.1	42	170	-1
R422A	0.9	3.8	46	172	1
R422D	0.4	3.6	48	178	2
R424A	1.65	3.5	63.5	450	2
R436A	1	1.6	72	240	-8
R450A	0.6	1.53	38	65	-10
R600a	1.5	2.36	40	98	-10

RESULT AND DISCUSSION

Numerous refrigerants have been analyzed for finding out a new substitute for R134a, which are having low GWP and zero ODP. For theinvestigation purpose we analyzed some researchers result and their feedback for our selection. System performance, energy consumption and cooling capacity were analyzed. Collection of literature results is summarized here.

COP of different refrigerants are compared in Fig.1 and it shows that R22, R417A, R422A, R422D, R424A have better COP. But, there is a limitation based on ODP and GWP. On the basis of ODP and GWP R290, R600a, R1234yf,R1234ze(Z), R125 and R152a can be considered as better substitute for R134a.

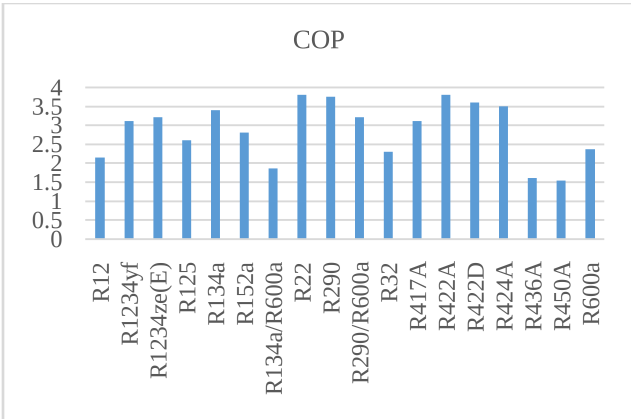

Fig.1. COP of different refrigerants

Energy consumption of the system using different refrigerants is illustrated in Fig.2. It shows that R12, R32, R424A are the refrigerants consuming more energy when compared to R134a.

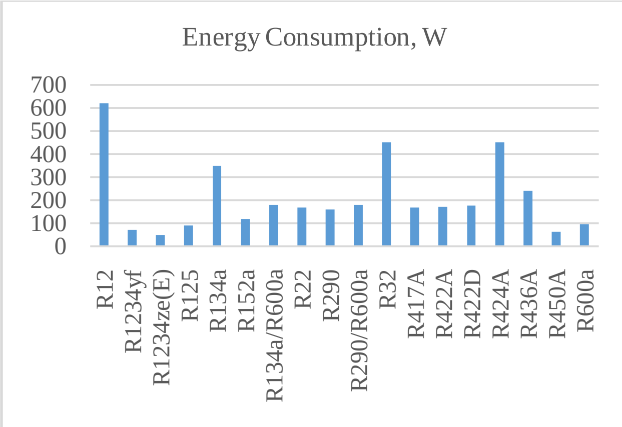

Fig.2. Energy consumption rate in W, for different Refrigerants

Evaporator temperature is the main criteria which provide good refrigerating effect. Combination of low evaporative temperature and low power consumption refrigerants can give better refrigerating effect. Evaporator temperature achieved by different refrigerants is summarized in Fig.3. HFO refrigerants and HC refrigerants will give lower evaporator temperature when compared with others.

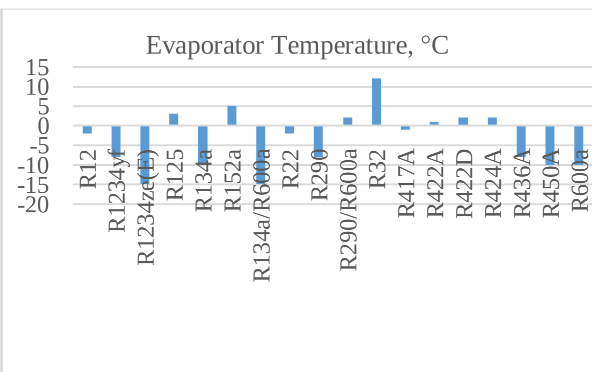

Fig.3. Different evaporative temperatures maintained for different refrigerants in °C

Discharge temperature of the refrigerant from the compressor varies the work of the compressor. It is an important parameter to be considered. Fig.4. illustrates the discharge temperature of the refrigerants. R1234yf, R152a, HC refrigerants and their mixture will give low discharge temperature. While using those refrigerants life of the compressor will be extended.

thehydrofluorocarbonrefrigerants are the best alternative for CFC and HCFC refrigerants due to their similar performance.

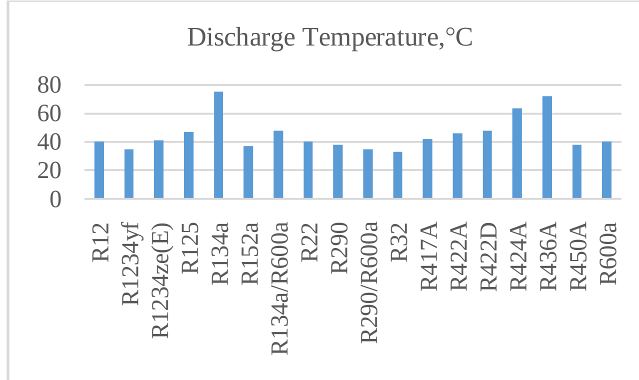

Fig.4. Discharge temperature of various refrigerant at their operating condition in °C

Cooling capacity of the refrigerator will vary for different refrigerants as shown in Fig. 5 hence, comparison of cooling capacity with other refrigerants result in consideration of suitable refrigerant. High cooling capacity refrigerants like R1234ze(E), R290/R600a mixture and HC refrigerants can be considered.

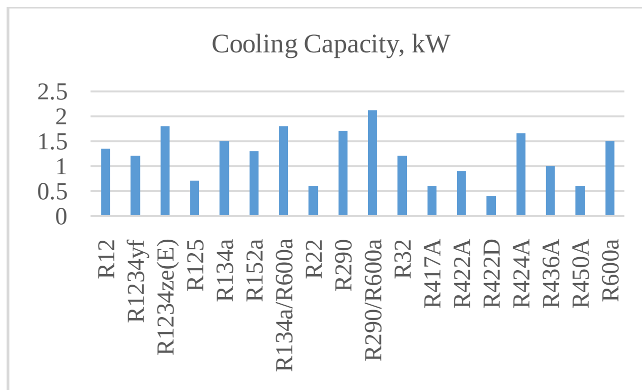

Fig.5. Cooling capacity of different refrigerants at their operating conditions in kW

CONCLUSION

After comparing coefficient of performance, pressure ratio, ODP and GWP of various refrigerants RE170 was found suitable alternative refrigerant for R134a. To achieve lower energy consumption it is advised to use HC compressor for hydrocarbon refrigerant instead of HFC compressor. The R290/R600a mixture is preferred as drop-in replacement refrigerant for R12 and R134a.

Due to high flammability and explosive property of hydrocarbon refrigerants, these are not often used as refrigerants. Most of the researchers suggested that

When compared with existing refrigerants, HFC refrigerants are energy efficient and also offering significant benefits. Replacing existing refrigerant

R22 with HCFCs needs to be retrofitted for better performance. Lubricating oils, expansion valve and other components need to be replaced with better and optimum accessories. Due to their high GWP, hydrofluorocarbons need to be phased out within 2030 as per the regulation of Kyoto protocol.

In the investigation of HFC and HFO refrigerants, R-1234yf has similar cooling capacity and energy consumption of R134a. But R-1234ze gives only better energy consumption. Because of the lower cooling capacity of R-1234ze, compressor run time increases. So it is very much essential to retrofit an R1234ze system for better performance similar to R134a due to lower cooling capacity.

From the summarization of lower GWP refrigerants with lower power consumption,low volumetric efficiency and high COP,R1234yf can be preferred as good alternative to R134a in domestic refrigeration applications.

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ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 10, October 2016

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