Evaluate R600a and R1234yf as Low Global Warming Substitute of HFC134a in Domestic Refrigerator

Nimesh M Gajjar[1), Nilesh M Bhatt[2)

[1)*Research scholar, Kadi Sarva Vishwavidyalaya, Gandhinagar, 382015 Gujarat, India*
[2)*Professor, L.D. College of Engineering, Ahmedabad, 380015 Gujarat, India*

Abstract

Domestic refrigerator and freezers are among the primary appliances targeted as environmental aspects being taken into consideration. Earlier, R12 (Chlorofluorocarbon -CFC) was used as a refrigerant in domestic refrigerator and freezer. However, R12 was phased out because of a harmful impact on ozone layer. R134a was the refrigerant choice to replace R12 in domestic refrigerators because it is chlorine-free, no-flammable, no/less toxic, has zero ODP and comparable cycle efficiency. R134a has no ozone depletion potential, but do act as a greenhouse gas and very global warming potential, it is strongly recommended phasing out in near future. Now a days R600a (Hydrocarbons – HC) is considered as a domestic refrigerant due to its low global warming potential. Similarly, R1234yf (Hydrofluoroolefins – HFO) possess similar thermal properties and good environmental properties compare to R134a. This paper comparatively assesses the feasibility of R600a and R1234yf as a substitute of R134a in a domestic refrigerator.

Keywords: *Retrofit, Substitute, Phase-out, CFC, HCFC, HFC, HC, HFO, Ozone depletion, Global warming, Energy efficiency, R12, R134a, R1234yf, R600a*

Abbreviation

GWP	Global Warming Potential
HCFCs	Hydro chlorofluorocarbons
HCs	Hydrocarbons
HFOs	Hydrofluro-olefins
MO	Mineral Oil
ODP	Ozone Depleting Potential
POE	Polyol Ester
PAO	Poly Alpha Oelfin
PAG	Polyalkylene Glycol
VCR	Vapour Compression Refrigeration
GWP_{100}	Global Warming Potential in time frame of 100 years

Subscripts

atm	atmosphere
c	condenser
e	evaporator
sat	saturation

A. Introduction

Domestic refrigerator is a daily-necessity domestic appliance and operates practically all the year. It becomes essential part of the life to make our life comfortable. In India demand of domestic refrigerator is likely accelerate due to rising incomes, easy access to credit, increasing electrification of rural areas and wide usability of online sales. In domestic refrigerator, refrigerant is used as a non-corrosive medium to transfer heat from closed space to its external environment. Refrigerant development took place due to different reasons, such as safety, stability, durability, economic or environmental issues throughout the history. The screening criteria for refrigerant selection for domestic refrigerator are: stability, non-toxicity, non-flammability, miscible with lubricating oil and capable of operating in domestic refrigerator positive pressure. Initially CFCs refrigerants like R12 was used in domestic refrigerator because of its safety and durability compare to other refrigerants used that times. But major issue with CFC refrigerants leakage was depletion of protective ozone molecules and layer [1]. For stratospheric ozone protection, Montreal protocol was initiated in 1987 by an international group of scientist and government officials to control the production and use of CFCs and HCFCs refrigerants, including commonly used refrigerants like R12. After the ban on use of R12 and many years of investigation and testing, R134a was most likely chosen refrigerant for domestic refrigerator due to its zero Ozone Depletion Potential (ODP), no-flammability, acceptable toxicity level and it also has physical-chemical properties very similar to R12. Global warming potential (GWP) is considered as an important screening criteria after ODP. GWP value which is used to measure greenhouse effect of a gas based on its radiative properties relative to CO_2 in a given time frame [2]. The ODP of R134a is zero, but it has a relatively high global warming potential (1430) in time period of 100 years. In 2015, the European Commission approved a new release of the F-Gas regulation (517/2014, 2014), stating that from January 2015, refrigerants with GWP > 150 cannot be anymore used in new domestic refrigerators. To mitigate the impact of domestic refrigerator on climate change, it is necessary to rediscovering the use of environment friendly refrigerant as an alternative of R134a.

This paper comparatively assesses the feasibility of R600a and R1234yf as a substitute of R134a with respect to different parameters like environmental impact, thermos-physical properties, etc.

B. Literature review

Giulia Righetti et al. [3] examined low GWP refrigerants R1234yf, R1234ze(E) and R600a as a substitute of R134a inside a commercial roll-bond evaporator of domestic refrigerator. Two different evaporation temperatures (-15°C and -20°C) and different refrigerant mass flow rates were considered inside roll-bond evaporator for experimental investigation. After experimental work they concluded that the air-side coefficient was almost constant for all the collected data points, refrigerants R1234yf, R1234ze(E) and R600a exhibited vaporization performance similar to R134a, therefore each of them can be surely considered an environmentally friendly substitute for R134a. Finally, they suggested that refrigerant R1234yf exhibited vaporization performance similar to R134a at similar mass flow rate, therefore it can be considered a direct drop-in alternative for HFC134a in domestic refrigeration. Sanchez D. et al [4] experimentally tested five low GWP refrigerants R290 and R600a (HCs); R134a and R152a (HFCs) and R1234yf and R1234ze (HFOs) in refrigerating facility designed for R134a. In experiment investigation different parameters like refrigerant mass flow rate, compressor power consumption, descharge temperature and coefficient of performance (CoP) were analysed. Finally, they concluded that hydrocarbon R290 (propane) was not suitable for use as a direct drop-in alternative of R134a due to increment in power consumption (up to 44.8%)., In case of R600a a strong reduction in cooling capacity and electrical power consumption was observed mainly due to its low specific volume. This behaviour means that the R600a compressor needs a larger displacement to produce the same cooling capacity as with R134a. In that case, R600a is not appropriate for use as a direct drop-in alternative to R134a. The cooling cpacity was decreased by 4.5% to 8.6%, power consumption was increased by 1.6% to 6.7% and COP was reduced by about 10% in case of R1234yf. Therefore, R1234yf can be considered a direct drop-in alternative to R134a with an appreciable COP reduction. Padilla M et al. [5] experimentally investigated flow visualization and pressure drop of R1234yf and R134a in a 6.7 mm diameter horizontal glass return bend of compact refrigeration system.During testing they observed different flow regimes were slug, intermittent and annular flows and found that flow pattern map was able to satisfactorily predict the R1234yf flow regimes at the return bend inlet. They also concluded that there was no significant difference in the return bend pressure drop when it was measured from a pressure tap located a least 10D upstream and 20D downstream of the return bend and for lower mass velocities of less than 570 $kgm^{-2}s^{-1}$ in 7.90 mm diameter tube. Padilla M et al. [6] investigated flow visualization and pressure drop of two phase flow of R134a, R1234yf and R410a in sudden concentration. They used 10 mm glass tube with a cross-section area ratio of 0.49 for qualitative two-phase flow visualizations and flow pattern across sudden concentration observed by top and side views with a high speed high resolution camera. The tube diameter (D) varied from 5.3 to 10.85 mm and the cross-section area ratio from 0.45 to 0.53 and sudden contraction pressure drop was determined by subtracting the inlet and outlet regular pressure drop in straight tube from the total pressure drop. After investigation the results shown that there was no significant difference for the sudden contraction pressure drop for R134a and 41234yf. Chao-Chieh Yu and Tun-Ping Teng [7] employed HC refrigerants as alternatives for R134a refrigerator. He evaluated the refrigeration performance and feasibility of using these alternative refrigerants HC1 (65% R290 + 35% R600a), HC2 (50% R290 + 50% R600a) and HC3 (00% R290 + 100% R600a) by conducting the no-load pull-down test and 24-hour on-load cycling test. The charged ratios were 30%, 40%, 50%, and 60% based on the charged mass of R134a for HC refrigerants. The results of the no-load pull-down test revealed that the optimal charged mass for all the HC refrigerants was 40% of that of R134a and efficiency factor (EF) of HC1, HC2, and HC3 were 9.1%, 12.2%, and 42.3% higher than that of R134a. Navarro E et al. [8] experimentally investigated compressor behaviour in terms of compressor efficiency, volumetric efficiency, losses to the ambient and oil-refrigerant properties using R1234yf, R290 and R134a. The operating parameter comprised two compressor speeds, evaporation temperatures from -15°C to 15°C and condensation temperatures from 40°C to 65°C. After investigation they concluded that R-290 has shown a significant improvement in compressor and volumetric efficiencies and the heat losses were considerably lower than for the other two refrigerants and R-1234yf improves its efficiencies compared to R-134a for pressure ratios higher than 8. Karber K. M. et al [9] performed experiment for R-1234yf and R-1234ze as drop-in replacements for R134a in two household refrigerators with one baseline and one advanced technology. An experiment was conducted to evaluate and compare the performance of R134a to R-1234yf and R-1234ze, using AHAM standard HRF-1 to evaluate energy consumption. These refrigerants were tested as drop-in replacements, with no performance enhancing modifications to the refrigerators. In Refrigerator 1 and 2, R-1234yf had 2.7% and 1.3% higher energy consumption than R134a, respectively. This indicates that R-1234yf is a suitable drop-in replacement for R134a in domestic refrigeration applications. In Refrigerator 1 and 2, R-1234ze had 16% and 5.4% lower energy consumption than R134a, respectively. In order to replace R134a with R-1234ze in domestic refrigerators the lower capacity would need to be addressed, thus R-1234ze might not be suitable for drop-in replacement

C. Safety aspect and Environment impact

Calm J. M. and Hourahan G. C. [10] summarized the physical, safety and environmental data for different refrigerants including those widely used and the possible alternatives for the future. They developed the table regarding the data like standard designation, physical data, safety data, environmental data etc. They considered nucleate boiling point, critical temperature, critical pressure in the standard physical data, then occupational exposure limit (OEL), lower flammability limit (LFL), heat of combustion (HOC), safety classification in the safety data, and in environmental data they consider the atmospheric life of the refrigerant in year, ODP, GWP for 100 years by combining the data created by the different companies and the researcher.

Safety aspect

Table 1. ASHRAE safety classification of R134a and R1234yf [16]

Refrigerants	R134a	R1234yf	R600a
ASHRAE safety Class	A1	A2L	A3
Toxicity	Lower	Lower	Lower
Flammability	No	Mildly	Highly

As shown in Table 1 R134a, R1234yf and R600a have lower toxicity but R600a falls in 3 category of flammability i.e. it is highly flammable refrigerant compare to R134a and R1234yf. As per ANSI/ASHRAE 34, 2010 edition class 2L refrigerant should treated like 1 category in place of 2 i.e. R1234yf should be consider near no/mildly flammable in place of medium flammable. It is concluded that R1234yf is more safe as a refrigerant in domestic refrigerator compare to R600a.

Environment impact

To lessen the effect of residential refrigerator on the earth, it is important to utilize safe and environment-friendly refrigerants.

Table 2. Environmental properties of R134a and R1234yf

Refrigerants	R134a	R1234yf	R600a
ODP	0	0	0
GWP (100 year time horizon) (Co_2=1)	1300	< 1	3
Atmospheric Life (years)	13.4	0.0288	3.94

As shown in Table 2, ODP value of R134a, R1234yf and R600a is zero but when GWP compared, there is large difference in values. R600a has GWP of 3 which is more than three time higher than R134a i.e. it will absorb more infrared radiation over its lifetime in atmosphere.

D. Thermo-physical properties

Thermodynamic properties are one of the critical criteria should match to utilize the existing system with or without minor change. For legitimate substitution of current refrigerant and for best execution of domestic refrigerator, the thermodynamic properties of refrigerant ought to be appropriately assessed.
Initially refrigerants were selected based on its compatibility and performance only. Refrigerant selection is generally based on matching refrigerant vapour pressures to operating conditions, although this is not always the case. Refrigerants should also be selected so that they contribute to good environmental properties. Refrigerant properties are necessary to describe the operating characteristics of the refrigerant within a system. In particular, physical properties of refrigerants are useful for determining the applicability of a refrigerant under design operating conditions. Thermodynamic and transport properties of refrigerants are necessary for predicting system behavior and performance of components. Basic properties of various refrigerant for domestic refrigerator are provided in Table 1 [11].

Table 3. Thermo-physical properties of refrigerants

Refrigerant	Molar Mass M (kg/kmol)	Normal Boiling Point at 1 atm (°C)	Critical Temperature (°C)	Critical Pressure (bar)
R12	120.91	-29.89	112	41.36
R134	102.03	-26.11	101	41
R600a	58.12	-11.67	135	36
R1234yf	114.04	29.40	95	34

As shown in Table 1 R134a is chlorine free HFC refrigerant which has zero ODP and widely used and tested comprehensively. It is also widely used for a blend with other refrigerants. The boiling point, vapor pressure characteristics and refrigeration cycle efficiency are quite similar to R12 but its volumetric capacity is less and not fully compatible with R12 lubrication system [12]. Today about 63% of newly produced domestic refrigeration system are charged with R134a and about 36% are charge with iso-butane. It is predicted that at least 75% of globally produced domestic refrigeration will use hydrocarbons in next 10 years. The iso-butane requires lesser charge than R134a and already widely accepted in Europe [13].

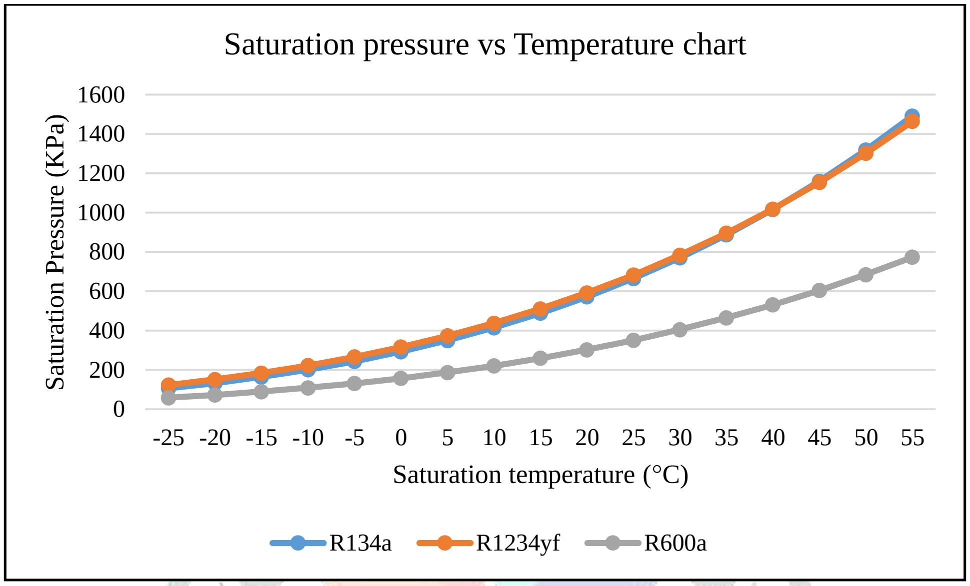

Fig.1 Saturation pressure vs saturation temperature for R134a, R1234yf and R600a

Fig. 1 shows pressure curve for R134a, R1234yf and R600a. Here R1234yf pressure curve is very close to R134a but R600a indicates low pressure for different temperature. For domestic refrigerator R600a shows suction pressure below atmosphere which results air or moisture entrance into refrigerator.

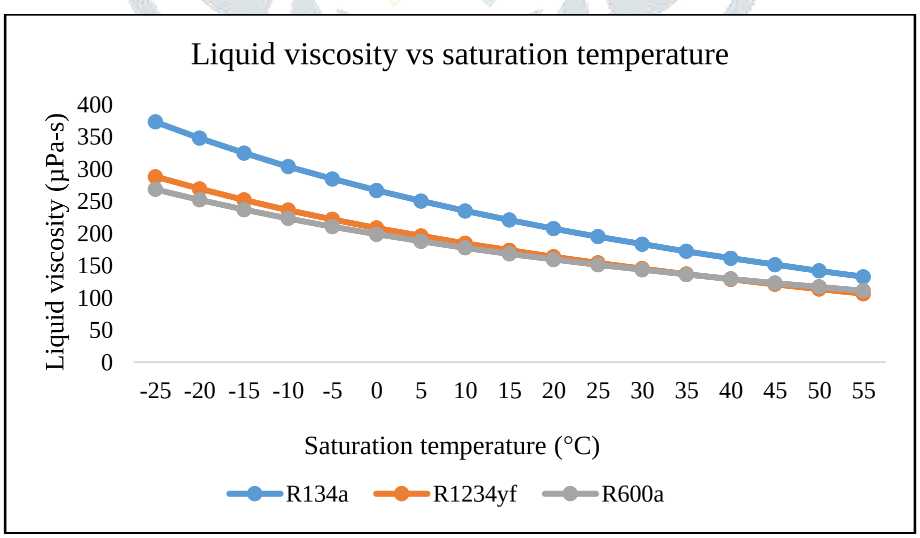

Fig.2 Liquid viscosity vs saturation temperature for R134a, R1234yf and R600a

The performance of condenser and evaporator influence by refrigerant viscosity. Fig. 2 shows liquid viscosity of R134a, R1234yf and R600a. Always low viscous refrigerant is preferable for small frictional pressure drop. Here R1234yf and R600a shows lower and comparable viscosity.

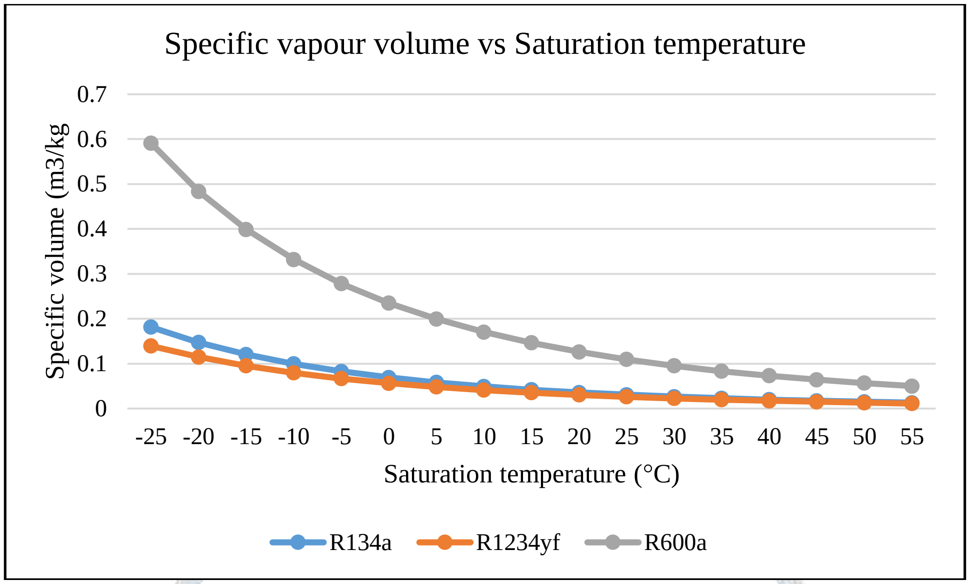

Fig.3 Specific vapour volume at different saturation temperature for R134a, R1234yf and R600a

Fig. 3 shows variation in specific volume at different saturation temperature. From figure, it is concluded that specific vapour volume of R1234yf is similar to R134a but there is large difference for R600a i.e. for R600a larger size compressor required for same cooling capacity which leads more power consumption.

Conclusion

Following observations are noted after considering various parameters like safety aspects, environment impact and thermos-physical properties of refrigerants.

- R1234yf is more safe as falls in 2L category compare to R600a which is highly flammable.
- R600a and R1234yf are more environment friendly refrigerants compare to R134a.
- R1234yf has comparable normal boiling temperature, vapour pressure with R134a i.e. it has potential to used direct drop-in replacement of R134a.
- The specific vapour volume and vapour pressure of R600a are not comparable with R134a i.e. it required major changes in existing system of R134a.

References

1. Calm, J.M., 2008. The next generation of refrigerants - Historical review, considerations, and outlook. International Journal of Refrigeration 31(7), pp. 1123-1133.
2. Devecioglu, A.G., Oruc, V., 2015. Characteristics of Some New Generation Refrigerants with Low GWP. Energy Procedia 75, pp.- 1452–1457.
3. Righetti, G., Zilio, C., Longo, G.A., 2015. Comparative performance analysis of the low GWP refrigerants HFO1234yf , HFO1234ze (E) and HC600a inside a roll-bond evaporator nes a Analyse comparative de la performance des frigorig e faible GWP , HFO1234yf , HFO1234ze (E) et HC600a d. International Journal of Refrigeration 54, pp. 1–9.
4. Sanchez D., Cabello R.,, Llopis R., Arauzo I., Catalan-Gil J., Torrella E., 2017. Energy performance evaluation of R1234yf, R1234ze(E), R600a, R290 and R152a as low-GWP R134a alternatives. International Journal of Refrigeration 74, 267–280.
5. Padilla, M., Revellin, R., Bonjour, J., Mae, N., 2012. Two-phase flow visualization and pressure drop measurements of HFO-1234yf and R-134a refrigerants in horizontal return bends. Exp. Therm. Fluid Sci. 39, 98–111.
6. Padilla, M., Revellin, R., Bonjour, J., 2013. Two-phase flow of HFO-1234yf, R-134a and R-410A in sudden contractions: Visualization, pressure drop measurements and new prediction method. Exp. Therm. Fluid Sci. 47, 186–205.
7. Chao-Chieh Yu, Tun-Ping Teng, Retrofit, 2014, Assessment of refrigerator using hydrocarbon refrigerants, Applied Thermal Engineering 66 (2014), pp. 507-518
8. E. Navarro, I.O. Martınez-Galvan, J. Nohales, J. Gonza lvez-Macia, 2013, Comparative experimental study of an open piston compressor working with R-1234yf, R-134a and R-290, International Journal of Refrigeration 36, pp. 768-775

9. Kyle M. Karber, Omar Abdelaziz, Edward A. Vineyard., 2012, Experimental Performance of R1234yf as a Drop-in Replacement for R134a in Domestic Refrigerator, International Refrigeration and Air Conditioning Conference at Purdue, July 16-19
10. Calm, J.M., Hourahan, G.C., 2011. Physical, Safety, and Environmental Data for Current and Alternative Refrigerants. 23rd International Congress of Refrigeration. Calm, J.M., Hourahan, G.C., 2011. Physical, Safety, and Environmental Data for Current and Alternative Refrigerants. 23rd Int. Congr. Refrig. 22.
11. Myhre, G., Shindell, D., Breon, F. M., Collins, W., Fuglestvedt, J., Huang, J., Koch, D., Lamarque, J.-F., Lee, D., Mendoza, B., Nakajima, T., Robock, A., Stephens, G., Takemura, T., Zhang, H., 2013. Anthropogenic and Natural Radiative Forcing. Clim. Chang. 2013 Phys. Sci. Basis. Contrib. Work. Gr. I to Fifth Assess. Rep. Intergov. Panel Clim. Chang. 659–740.
12. S. W. Crown et al., 1992, A Comparison Study of the Thermal Performance of R12 and R134a, International Refrigeration and Air Conditioning Conference, paper 155.
13. Mohanraj M., Jayaraj S., Muraleedharan C., 2009, Environment friendly alternatives to halogenated refrigerants-A review, International journal of greenhouse gas control, 3, pp. 108 –119.