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A Review on Domestic Refrigerator Using Hydrocarbons as Alternative Refrigerants to R134a

Safvan Khansaheb¹, Dr. R.G Kapadia²

P.G. Student, Department of Mechanical Engineering, SVMIT Engineering College, Bharuch, Gujarat, India¹

Principal, SVMIT Engineering College, Bharuch, Gujarat, India²

ABSTRACT: In India, about 80% of the domestic refrigerators use R134a as refrigerant due to its excellent thermodynamic and thermo physical properties. But R134a has high GWP of 1300. The higher GWP due to R134a emissions from domestic refrigerators leads to identifying a long term alternative to meet the requirements of system performance, refrigerant-lubricant interaction, energy efficiency, environmental impacts, safety and service. The Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) calls for reductions in emissions of six categories of greenhouse gases, including hydro fluorocarbons (HFCs) used as refrigerants. From the environmental, ecological and health point of view, it is urgent to find some better substitute for HFC refrigerants. After reviewing the various literature the hydrocarbons (R290 and R600a) refrigerants and their mixture gives good performance in small capacity domestic refrigerator compare to R134a.

KEYWORDS: Refrigerant selection, Alternative refrigerants, Propane (R290), Isobutene (R600a), Hydrocarbon mixtures, R134a

I. INTRODUCTION

Many investigators have reported that GWP of HFC refrigerants is more significant even though it has less than that of chlorofluorocarbons (CFC) refrigerants [1]. HCFCs (hydro chlorofluorocarbons) and CFCs (chlorofluorocarbons) have been applied extensively as refrigerants in air conditioning and refrigeration systems from 1930s as a result of their outstanding safety properties. However, due to harmful impact on ozone layer, by the year 1987 at Montreal Protocol it was decided to establish requirements that initiated the worldwide phase out of CFCs. By the year 1992, the Montreal Protocol was improved to found a schedule in order to phase out the HCFCs. Moreover in 1997 at Kyoto Protocol it was expressed that concentration of greenhouse gases in the atmosphere should be established in a level which is not intensifying global warming ozone layer. Subsequently it was decided to decrease global warming by reduction of greenhouse gases emissions [2].

Refrigerant selection:

Selection of refrigerant for a particular application is based on the following requirements:

1. Thermodynamic and thermo-physical properties
2. Environmental and safety properties, and
3. Economics

1. Thermodynamic and thermo-physical properties:

Generally, thermodynamic and transport properties of refrigerants are the key factors in refrigerant's selection as they determine the performance of the system. The desirable thermodynamic properties are a normal boiling point slightly less than target temperature and, thereby, an evaporating pressure higher than atmospheric pressure. The other favorable characteristics are, low liquid viscosity, high heat of vaporization, modest liquid density and slightly high gas density. It is worthwhile to mention that high heat of vaporization and gas density lead to higher capacity with a specific compressor in a refrigeration system. High liquid thermal conductivity intensifies heat transfer and results in

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 4, Special Issue 6, May 2015

smaller required heat exchangers. Low viscosity also causes low pressure drop in the heat exchangers. Smaller pressure ratio leads lower compression work and improve COP of the system [3].

2. Environmental and safety properties:

Environmental effects are the main problems of common refrigerants so that non environmental friendly impacts of CFCs and later on HCFCs brought about them to be phased out despite of being stable, non-flammable and non-toxic (comparing to Sulfur Dioxide and other refrigerants used before the introduction of CFCs). Ozone depletion potential (ODP) and global warming potential (GWP) are the significant factors demonstrate the direct impact of refrigerants in case of any leakage or releasing to the surroundings. However, using low GWP refrigerants are not the only efficient way to reduce greenhouse gas emissions. In fact it is probable to choose a low GWP refrigerant but still raise total greenhouse gas emissions. When the low GWP refrigerant causes more energy use and fuel consumption actually there are larger indirect emissions. Therefore in developing the low GWP refrigerants always energy efficiency of the system must be studied and its indirect climate impacts should be considered besides its direct emissions [4]. Life cycle climate performance (LCCP) helps to consider overall potential of greenhouse gas emission of the system including materials, transportation, and operation, production, recycling, servicing and end-of-life. Furthermore, toxicity and flammability are the determining factors to select suitable refrigerant for any application. Low toxicity and flammability are the most desirable aspects in safety and health studies [5].

3. Economics:

The refrigerant used should preferably be inexpensive and easily available.

II. ALTERNATIVE REFRIGERANTS TO R134A

1. Characteristics of R134a and new proposed refrigerants:

The properties of the refrigerants (such as saturation pressure and liquid density) for wide range of temperatures (between -60 and 60 °C) are compared in Figs. 1. Using Refprop 7 all properties can be evaluate and their comparison as shown in graphs. Fig. 1(a) depicts the variation of saturation pressure of R134a, R290, R600a, and blends of R290/R600a % by wt. (45.2/54.8 HCM 1, 50/50 HCM 2, 54/46 HCM 3, 56/44 HCM 4, 60/40 HCM 5 and 68/32 HCM 6) against temperature. It was observed that all of the HCM has approximately the same vapor pressure as R134a in the evaporator temperature ranging between -60 and 10^0 C. Hence the compressors can operate relatively at lower pressures with HCM than R134a. R290 has higher vapor pressure than R134a hence the compressor operate at higher pressure and R600a has very low vapor pressure (below atmospheric pressure) than R134a, thus increasing the possibility of drawing contamination in to the system in the event of a leak so that R600a is less suitable for low temperature applications. Hence with pure HCs (R290 and R600a) HC type compressor is needed.

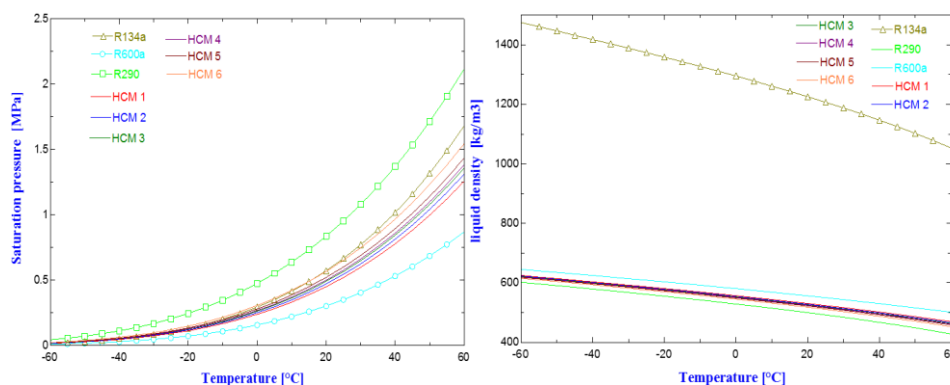


Fig. 1. Effect of temperature on (a) saturation pressure and (b) liquid density

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

In Fig. 1. (b) Depicts the variation of liquid densities against temperature. It was observed that the liquid densities of all of the HCM and Pure HCs (R290 and R600a) refrigerants were found to be lower than that of R134a, as the liquid density is low it will significantly reduce the refrigerant charge requirement. Thus we can expect that if we will proceed with R290, R600a, and HCM it requires less charging amount as compare to that of the R134a. The other properties such as critical temperature, critical pressure, boiling point, molecular weight, ODP and GWP of R134a, R290, R600a and all of the HCM are compared in Table 1.1.

Table 1.1 Alternative low GWP refrigerants to R134a.

Refrigerant	Chemical composition	N.B.P [°C]	Molecular weight [g/mol]	Critical Temp. [°C]	Critical pressure [MPa]	Liquid density [kg/m ³]	Safety class	ODP	GWP
R134a	CH ₂ FCF ₃	-26.15	102	101.1	4.059	511.9	A1	0	1300
Propane(R290)	CH ₃ -CH ₂ -CH ₃	-42.1	44.096	96.675	4.247	218.5	A3	0	3
Isobutene (R600a)	CH ₃ -CH-CH ₃ CH ₃	-11.73	58.12	134.67	3.65	224.4	A3	0	3
R290/R600a(HCM1)	45.2/54.8	-31.13	50.816	118.54	4.096	219.3	A3	0	<20
R290/R600a(HCM2)	50/50	-32.47	50.147	116.74	4.128	219.5	A3	0	<20
R290/R600a(HCM3)	54/46	-33.52	49.602	115.22	4.154	218.9	A3	0	<20
R290/R600a(HCM4)	56/44	-34.01	49.334	114.45	4.165	218.7	A3	0	<20
R290/R600a(HCM5)	60/40	-34.97	48.807	112.92	4.186	218.4	A3	0	<20
R290/R600a(HCM6)	68/32	-36.72	47.786	109.8	4.222	217.6	A3	0	<20

There are practical problems associated with the use of hydrofluorocarbon (HFC) refrigerants such as R134a:

- HFCs are not miscible with the mineral oils commonly used today. Polyol ester oils must be used instead of mineral oils. These are more dangerous to handle (contact with skin can cause problems) and more readily absorb moisture from air.
- The HFC and polyol ester oil mixture reacts in a different way, compared to R12 and mineral oils, with many seal materials. If these seals are not changed, leaks can occur.
- Polyol ester oils are more expensive.

Servicing is more difficult for HFC systems: [18]

- HFCs and polyol ester oils are not as tolerant to moisture and other contamination in systems, so failures are more likely to occur if systems are not thoroughly cleaned and dehydrated before changing.
- It is not considered feasible to repair compressors after a burn out except in closely controlled conditions.

This move away from HFCs has been further accelerated by concern caused by their potent global warming potentials. Some European countries have already decided to phase out HFCs because of this environmental problem.

2. Hydrocarbon refrigerants:

Hydrocarbons (HCs) are very good refrigerants for many reasons:

- They are compatible with copper and the standard mineral oils;
- They have a very low environmental impact in comparison with CFCs, HCFCs and HFCs;
- They perform very well, with good capacity and efficiency;
- Due to lower liquid densities, low refrigerant charge than that of HFCs;
- High heat transfer coefficients hence high latent heat of vaporization;
- Coefficient performance (COP) of the system increases and Power consumption reduced with HCs;
- Improves compressor life due to low discharge temperature compare to HFCs, HCFCs and CFCs;

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

- Service procedures can remain largely the same as for R12 and R22 refrigerants, except for safety considerations due to its flammability.

However, HCs show relatively high flammability, but the flammability of the mixture of R290 and R600a is not a problem in a small- capacity refrigeration system with the refrigerant charge below 100g based on R134a [7]. Very few changes are needed to a system and its components to be able to use HCs refrigerants. However, care is needed to ensure that flammability does not present safety problems:

- Systems using HCs must be designed so that leakage is not dangerous;
- During charging, appropriate equipment should be used to charge the systems, and the charging area has to be chosen with care;
- Service technicians must be trained to handle HCs refrigerants safely

III. LITERATURE REVIEW

In the following studies, the refrigeration system components were not adjusted:

S. Wongwises and N. Chimres [8] in 2005, Experimental study was carried out with HC refrigerants R290, R600, R600a, and R134a as baseline refrigerant. Experimental result showed that the mixture of R290 and R600 (60% and 40% according to mass, respectively) was the most appropriate alternative. Compared with using R134a, using this HC mixture reduced the refrigerator's energy consumption by 86%. The refrigerant charge of the HC mixture system was approximately 50% of that of the R134a system (120 g) adjusting the refrigeration system was not required. The flammability of the mixture of R290 and R600a is not a problem in a small-capacity refrigeration system with the refrigerant charge below 100 g based on R134a.

K. Mani, V. Selladurai [9] in 2008, Experimental results showed that the refrigerant R290/R600a had 19.9% to 50.1% higher refrigerating capacity than R12 and 28.6% to 87.2% than R134a. The refrigerant R134a showed slightly lower refrigerating capacity than R12. The mixture R290/R600a consumed 6.8% to 17.4% more energy than R12. The refrigerant R12 consumed slightly more energy than R134a at higher evaporating temperatures. The coefficient performance of R290/R600a mixture increases from 3.9% to 25.1% than R12 at lower evaporating temperatures and 11.8% to 17.6% at higher evaporating temperatures. The refrigerant R134a showed slightly lower coefficient of performance than R12. The discharge temperature and discharge pressure of the R290/R600a mixture was very close to R12. The R290/R600a (68/32 by wt %) mixture can be considered as a drop-in replacement refrigerant for CFC12 and HFC134a. The refrigeration efficiency of the system were also studied.

C.S Jwo, C.C. Ting [10] in 2008, The investigation aims to apply the mixture of hydrocarbon refrigerants, R-290 and R-600a with each 50% component ratio, instead of the refrigerant R-134a for home refrigerators. During test the official R-134a refrigerant was replaced by varied mass hydrocarbon refrigerant, which was mixed by R-290 and R-600a with each 50% component ratio. The results show that refrigerating effect is improved by using hydrocarbon refrigerant. Moreover, the total consumed energy is saved 4.4% and applied mass of refrigerant is reduced 40%.

M. Rasti et al. [6] in 2012, The refrigerator was charged with various masses of R436A, and in addition to the refrigerator's power consumption during operation, the temperatures in different sections of the refrigerator were measured according to the Iranian National Standard No. 4853-2. The results showed that, compared with the basic refrigerator functioning with R134a, using R436A reduced the on-time ratio and the daily energy consumption by 13% and 5.3%, respectively. The refrigerant charge of the R436A system was approximately 52% of that of the R134a system (105 g).

In the following studies, the refrigeration system components were adjusted:

D.Jung, C.B.Kim, S.B.Park [11] in 2000, The experimental results obtained with the same compressor indicated that the propane/isobutene mixture at 0.6 mass fraction of propane has a 3±4% higher energy efficiency and a somewhat faster cooling rate than CFC12. The mixture showed a shorter compressor on-time and lower compressor dome temperatures than CFC12. In conclusion, the proposed hydrocarbon mixture seems to be an appropriate long term

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

candidate to replace CFC12/HFC134a from the viewpoint of energy conservation requiring minimal changes in the existing refrigerators.

M. Fatouh and M. El Kafafy [12] in 2006, Continuous running and cycling results showed that R134a with a capillary tube length of 4 m and charge of 100 g or LPG with capillary tube lengths from 4.0 to 6.0 and charge of 50 g or more satisfy the required freezer air temperature of 12°C. The lowest electric energy consumption was achieved using LPG with combination of capillary tube length of 5 m and charge of 60 g. This combination achieved higher volumetric cooling capacity and lower freezer air temperature compared to R134a. Pull-down time, pressure ratio and power consumption of LPG refrigerator were lower than those of R134a refrigerator by about 7.6%, 5.5% and 4.3%, respectively. Also, actual COP of LPG refrigerator was higher than that of R134a by about 7.6%. Lower on-time ratio and energy consumption of LPG refrigerator by nearly 14.3% and 10.8%, respectively, compared to those of R134a refrigerator were achieved. In conclusion, the proposed LPG seems to be an appropriate long-term candidate to replace R134a in the existing refrigerator, except capillary tube length and initial charge.

M.Y. Lee, D.Y. Lee, Y. Kim [13] in 2008, The performance of a small-capacity directly cooled refrigerator was evaluated by using the mixture of R290 and R600a with mass fraction of 55:45 as an alternative to R134a. The compressor displacement volume of the alternative system with R290/R600a (55/45) was modified from that of the original system with R134a to match the refrigeration capacity. Both systems with R290/R600a (55/45) and R134a were tested, and then optimized by varying the refrigerant charge and capillary tube length under experimental conditions for both the pull-down test and the power consumption test. The refrigerant charge of the optimized R290/R600a system was approximately 50% of that of the optimized R134a system. The capillary tube lengths for each evaporator in the optimized R290/R600a system were 500mm longer than those in the optimized R134a system. The power consumption of the optimized R134a system was 12.3% higher than that of the optimized R290/R600a system. The cooling speed of the optimized R290/R600a (55/45) system at the in-case setting temperature of 15°C was improved by 28.8% over that of the optimized R134a system.

M. Mohanraj et al[1] in 2009, In the present work, an experimental investigation has been made with hydrocarbon refrigerant mixture (composed of R290 and R600a in the ratio of 45.2:54.8 by weight) as an alternative to R134a in a 200 l single evaporator domestic refrigerator. Continuous running tests were performed under different ambient temperatures (24, 28, 32, 38 and 43°C), while cycling running (ON/OFF) tests were carried out only at 32 °C ambient temperature. The results showed that the hydrocarbon mixture has lower values of energy consumption; pull down time and ON time ratio by about 11.1%, 11.6% and 13.2%, respectively, with 3.25–3.6% higher coefficient of performance (COP). The discharge temperature of hydrocarbon mixture was found to be 8.5 to 13.4 K lower than that of R134a. The overall performance has proved that the above hydrocarbon refrigerant mixture could be the best long term alternative to phase out R134a.

S. Wongwises, A.S. Dalkilic [14] in 2010, Theoretical results showed that all of the alternative refrigerants investigated in the analysis have a slightly lower performance coefficient (COP) than CFC12, CFC22, and HFC134a for the condensation temperature of 50 °C and evaporating temperatures ranging between –30 °C and 10 °C. Refrigerant blends of HC290/HC600a (40/ 60 by wt. %) instead of CFC12 and HC290/HC1270 (20/80 by wt. %) instead of CFC22 are found to be replacement refrigerants among other alternatives in this paper as a result of the analysis. The effects of the main parameters of performance analysis such as refrigerant type, degree of sub cooling, and superheating on the refrigerating effect, coefficient of performance and volumetric refrigeration capacity are also investigated for various evaporating temperatures.

A. Baskaran and P. Koshy Mathews [15] in 2012, used refrigerants of HFC152a, HFC32, HC290, HC1270, HC600a and RE170 were done and their results were compared with R134a as possible alternative replacement. The results showed that the alternative refrigerants investigated in the analysis RE170, R152a and R600a have a slightly higher performance coefficient (COP) than R134a for the condensation temperature of 50°C and evaporating temperatures ranging between -30°C and 10°C. Refrigerant RE170 instead of R134a was found to be a replacement refrigerant among other alternatives.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

C.C Yu and T.P Ting [16] in 2014, 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. the capillary tube lengths of R134a, HC1, HC2, and HC3 were recalculated to be 2.77, 5.05, 5.34, and 5.60 m, respectively, and the recalculated capillary tube was used in the 24-hour on load cycling test. The results of the 24-hour on-load cycling test showed that the freezer temperatures considerably decreased when the HC refrigerants were used, and that all of the HC refrigerants could be used in the R134a refrigerator after changing the capillary tube lengths.

R.Y. Mahajan and S.A. Borikar [17] in 2014, conclude that the performance of HC-12a (mixture of R290/R600a (60/40) % by wt.) in the domestic refrigerator was constantly better than those of R134a throughout all the operating conditions, which shows that HC-12a can be used as replacement for R134a in domestic refrigerator.

IV. CONCLUSION

By reviewing all these research work and by study of various thermodynamic properties of the refrigerants as shown in table 1.1, According to Montreal and Kyoto protocols, R12 should have been phased out by 2010 and the consumption of R134a must be reduced. R600a, R290 and blends of R290 and R600a are the better option for the replacement of R134a in domestic refrigerator, due to their low global warming potential (GWP) and zero ozone depletion potential (ODP). Selecting various charge mass of R600a, R290 and hydrocarbon mixture, and their experimental analysis were carried out.

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