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Review of Current Automobile Refrigeration System on Basis of Refrigerants Used & Their Impact on Global Warming Potential.

Tejas Mahajani[1] Prof. Pravin Lokhande[2]
Department of Mechanical Engineering,MMCOE,Pune
Corresponding Author: Tejas Mahajani1

Abstract: *This review focuses on theoretical aspects of automobile air conditioning system using R-134a as a refrigerant. Further we focus on the limitations of R134a in terms of environmental impact and then suggest some alternatives for it. We have compared refrigerants like R152a,R-1234yf,R404a,R410a,R-290,R-600,R-407 with R-134a and suggested which of the mentioned refrigerants is the best suited replacement for R-134a.We have also covered the performance of engine study with respect to refrigerants. Finally we suggest the best alternative with minimum modifications to the existing system.*
Keywords: *Global warming potential,refrigerants,R-134a,R-1234yf*

I. Introduction

Global warming potential (GWP) is a relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide. Higher the value of GWP higher is the potential of the substance to have an impact on the ozone layer. Ozone layer depletion can intern can have harmful effects on living things as the harmful UV rays penetrate the ozone layer . This ozone layer depletion occurs due to emissions of freons (gases having chlorine and fluorine atoms) from refrigerants like R-134a. R134a refrigerant, which is widely used in current automobile air conditioning systems, is one of the controlled substances in the kyoto protocol (1997). In United Nations, the current air conditioning system was banned for refrigerants that have a Global Warming Potential (GWP) of over 150 by 2011. In India, Higher GWP refrigerants are also going to be banned in near future. The first response to the kyoto protocol by the automobile manufacturers was thus to improve R134a systems by reducing leakage. However, efforts are being made to find an -alternative refrigerants to replace R134a due to its high GWP of 1430 [1]. Hence this study involves finding of suitable alternative refrigerants of R134a AAC system so that kyoto protocol requirements are fulfilled. The refrigerant currently being used is R-134a,which has a GWP of 1430. Whilst that of R-152a is 140 and that of R-1234yf is just 4.

II. Existing Automobile Air Conditioning System

The current automobile air conditioning system using R134a as refrigerant is as follows.

A typical automotive AC system consists of a compressor, an expansion device, a condenser and an evaporator, as illustrated in Figure 1. In many applications, a dryer or a receiver is installed to increase the reliability of the system. The compressor circulates and compresses the working fluid (refrigerant) to the required pressure and temperature. It is coupled to the engine shaft in an ICE car or driven by an electric motor in an electric car. It takes up most of an. AC system's total energy consumption. From the compressor, refrigerant enters the condenser, which is typically installed near the car radiator & heat is rejected from the fluid to the ambient. The refrigerant changes phase from superheated gas to gas-liquid mixture or even to sub-cooled liquid. The fluid then enters the expansion device, where its pressure and temperature drop. This low-temperature fluid then flows into the evaporator, where heat load from the cabin is absorbed. The most common working refrigerant (fluid) is currently R134a. Unfortunately, it has a high global warming potential (GWP) and is being phased out as directed by the

Kyoto Protocol. R1234yf has been proposed as the substitute due to its low GWP and ease of retrofitting with existing systems.[2]

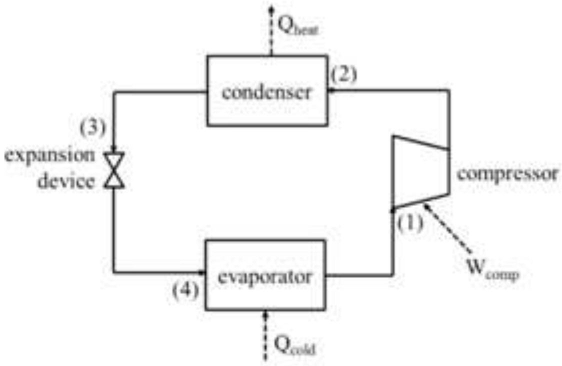


Fig 1 Schematic of AC system

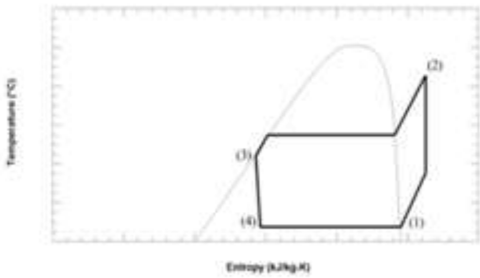


Fig 2 Temperature (°C) vs Entropy (KJ/Kg)

1.Brief explanation of refrigerants:

1.1 R-134a

1,1,1,2-Tetrafluoroethane (also known as norflurane (INN), R-134a, Freon 134a, Forane 134a, Genetron 134a, Florasol 134a, Suva 134a, or HFC-134a) is a haloalkane refrigerant. Mixtures with air of the gas 1,1,1,2-tetrafluoroethane are not flammable at atmospheric pressure and temperatures up to 100°C (212 °F). However, mixtures with high concentrations of air at elevated pressure and/or temperature can be ignited. Contact of 1,1,1,2-tetrafluoroethane with flames or hot surfaces in excess of 250 °C (482 °F) may cause vapor decomposition and the emission of toxic gases including hydrogen fluoride and carbonyl fluoride.

1.2 R-152a

1,1-Difluoroethane, or DFE, is an organofluorine compound with the chemical formula C2H4F2. As an alternative to chlorofluorocarbons, it has an ozone depletion potential of zero, a lower global warming potential (124) and a shorter atmospheric lifetime (1.4 years). It has recently been approved for use in automobile applications as an alternative to R-134a. Though not extremely flammable in gaseous form, 1,1-difluoroethane can burn under some conditions.

1.3 R-1234yf

2,3,3,3-Tetrafluoropropene, or HFO-1234yf, is a hydrofluoroolefin (HFO) with the formula CH2=CFCF3. This colorless gas has been proposed as a replacement for R-134a as a refrigerant in automobile air conditioners. Although the product is classified slightly flammable by ASHRAE, several years of testing by SAE proved that the product could not be ignited under conditions normally experienced by a vehicle. In addition several independent authorities evaluated the safety of the product in vehicles and some of them concluded that it was as safe to use as R-134a, the product in use in cars today. [5]

1.4 R410a

R-410A, sold under the trademarked names Suva 410A, Forane 410A, Puron, EcoFluor R410, Genetron R410A, and AZ-20, is a zeotropic, but near-azeotropic mixture of difluoromethane (CH2F2, called R-32) and pentafluoroethane (CHF2CF3, called R-125), which is used as a refrigerant in air conditioning applications. R-410A cylinders are colored pink. It is flammable so it has to be handled with care.[flamability]

1.5 R-404a

R-404A is a blend refrigerant developed as a substitute for R-134a (HCFC/CFC blend refrigerant) which has been widely used for commercial-use refrigeration equipment. It is a mixture of HFC-125, HFC-143a, and HFC-134a, and is a pseudo-azeotropic refrigerant.

1.6 R-407

R-407c is a mixture of hydrofluorocarbons used as a refrigerant. It is a zeotropic blend of difluoromethane (R-32), pentafluoroethane(R-125), and 1,1,1,2-tetrafluoroethane(R-134a). Difluoromethane serves to provide the heat capacity, pentafluoroethane decreases flammability, tetrafluoroethane reduces pressure. R-407c cylinders are colored burnt orange.

1.7 R-290

It is a hydrocarbon based nonsynthetic substance. It's GWP is 3. But it is not suitable to use in mobile system as it is extremely flammable.[10]

1.8 R-600

Isobutane, also known as i-butane or methylpropane, is a chemical compound with molecular formula C_4H_{10}. Isobutane is used as a refrigerant. The use in refrigerators started in 1993 when Greenpeace presented the Greenfreeze project with the German company Foron. In this regard, blends of pure, dry "isobutane" (R-600a) (ie. isobutane mixtures) have negligible ozone depletion potential and very low global warming potential (having a value of 3.3 times the GWP of carbon dioxide) and can serve as a functional replacement for R-12, R-22, R-134a, and other chlorofluorocarbon or hydrofluorocarbon refrigerants in conventional stationary refrigeration and air conditioning systems.[7]

2. Comparison of refrigerants

The summary of the derived thermodynamic data for all mentioned alternative refrigerants is presented in Table. 1. The data have been derived by taking R134a as a basic refrigerant on following conditions. Evaporating temperature=7.2°c, Condenser temperature= 55°c, compressor inlet temperature=35 C

REFRIGERANT	COP	REFRIGERANTION EFFECT(KJ/Kg)	PRESSURE RATIO	COMPRESSOR WORK(KW)	DISCHARGE TEMP. ( )
R290	-2.459	88.152	-17.931	2.562	-2.176℃
R600a	3.044	77.292	-4.224	-2.947	-12.053
R407c	-7.884	7.616	-2.782	8.584	13.340
R410A	-11.944	7.828	-12.999	13.518	16.178
R404A	-14.715	-26.516	-13.733	17.279	-4.730
R134A	0.00	0.00	0.00	0.00	0.00
R152A	4.137	64.880	-0.784	-3.972	13.245
R1234yf	-6.323	-56.530	-7.486	6.791	-16.083

Table no 1: Summary of Thermodynamic cycle analysis[1]

2.1 R290 and R600a (Hydrocarbons):

R290 has about 2.4% lower COP but has 17.9% lower pressure ratio compared to R134a. Hence compressor efficiency is higher. Discharge temperature is about 2.1% lower. Main advantage of R290 is having low GWP i.e. Main disadvantage is that it falls in A3 safety class. Flammability of R290 is very high but it can be used if safety aspects are addressed and diminished. R600a has about 3% higher COP and has 4.2% lower pressure ratio compared to R134a. Hence compressor efficiency is higher. Discharge temperature is about 12% lower. Main advantage of R600a is having low GWP i.e. 3 only. Main disadvantages are that it falls in A3 safety class and requires higher SCD hence larger capacity of compressor is required. It is also highly flammable but can be used if safety aspects of using R600a are addressed and diminished.

2.2 R407C, R410A and R404A (Zeotropic mixtures):

R407C, R410A and R404A have about 7.8%, 11.9% and 14.7% lower COP compared to R134a respectively. They have about 2.7%, 12.9% and 13.7% lower pressure ratio compared to R134a respectively. Hence compressor efficiency is higher. Discharge temperature is about 13.3% and 16.1% higher in case of R407C and R410A while it is 4% lower in case of R404A. Main advantage of zeotropic mixtures are that they fall in A1 safety class. It is non-flammable refrigerants. Main disadvantages are that they are high discharge pressure refrigerants and hence pipelines connecting main components of AAC must be very reliable that can sustain high pressure. They have high GWP also.

2.3 R152a (Hydro Fluorocarbon):

R152a (1, 1-difluoroethane) can be possible substitute of R134a if safety measures are provided. Refrigerating effect is 64.8% higher while compressor work is 3.9% lower compared to R134a. Discharge temperature is 13.2% is-higher but COP is 4.1% higher compared to R134a. Pressure ratio is almost similar to that of R134a. Main advantages of R152a refrigerant are that it has low GWP and higher COP compared to R134a. Main disadvantage are that it is flammable refrigerant and discharge temperature is higher than R134a.

2.4 R1234yf (HydroFlouroOlefin):

R1234yf (2, 3, 3, 3-Tetrafluoropropene) is new categorical HFO refrigerant. Discharge temperature is lowest among the above all refrigerants that is 16% lower compared R134a. R1234yf has lower COP of about 6.3% compared to R134a. Pressure ratio is 7.4% lower compared to R134a. Main advantages of 1234yf refrigerant are that it has very low GWP (i.e. 4) compared to R134a (i.e. 1430 GWP) and has lowest discharge temperature. Also it can be substitute in the existing AAC system without any modification since SCD is close to R134a. Main disadvantage is that; Since R1234yf is just newly launched; its price is high in commercial market

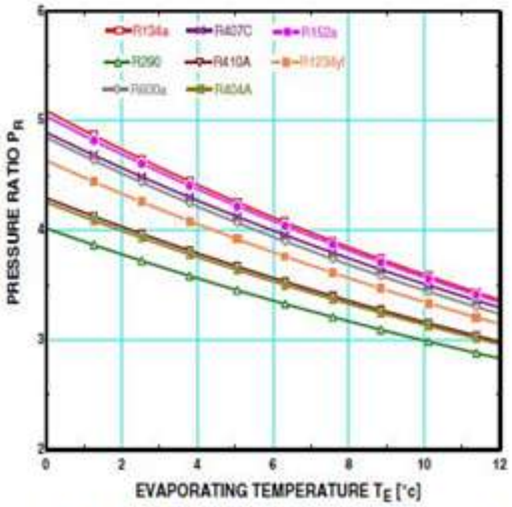


Fig 3 Pressure Ratio vs Evaporating Temperatures Temperature

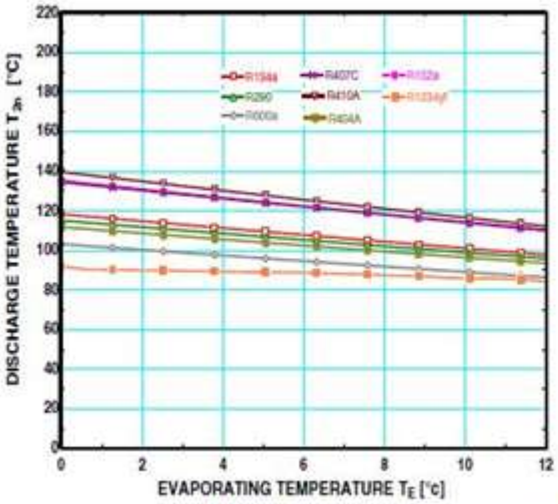
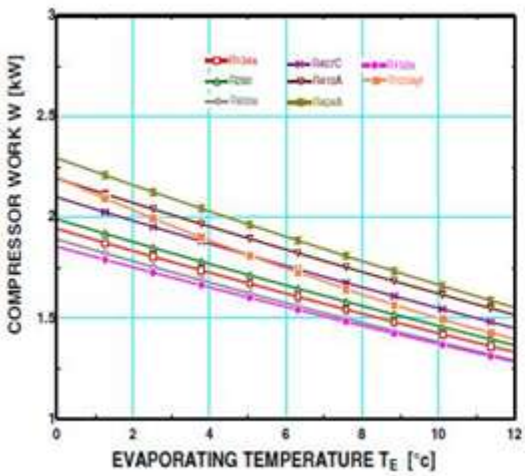


Fig 4 Discharge Temperatures vs Evaporating

The pressure ratio is highest for R134a and lowest for R290 for the entire range of T in this study. This is because of higher molecular weight and normal boiling pressure of R134a compared to R290. R152a and R1234yf have lower pressure ratio compared to R134a and hence volumetric efficiencies of R152a and R1234yf are higher. Fig. 4 shows the discharge temperature of R134a and its alternative refrigerants for various evaporating temperatures for T =55°c. As shown in fig. 4, with decrease in evaporating temperature, discharge temperature increases. For better lubricant and refrigerant stability, lower discharge temperature is beneficial. At lower discharge temperature, compressor is expected to be running at slow speed. Compressor life is higher in case of slow speed. R152a has slightly higher discharge temperature while R1234yf has lowest discharge temperature compared to R134a. Compressor life in case of R1234yf is higher.



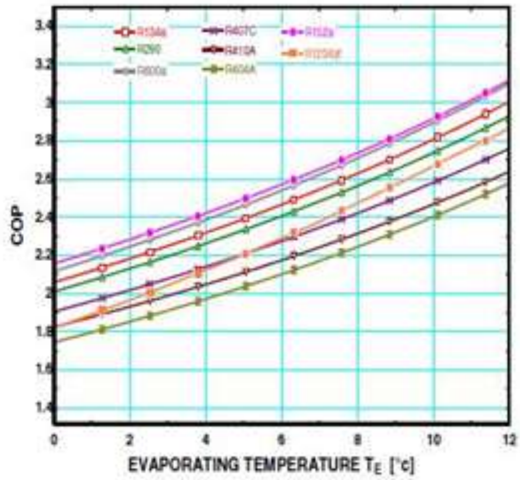


Fig 5 Compressor work vs Evaporating Temperatures Fig 6 COP vs Evaporating Temperatures [1]

Fig.5 shows the compressor work of R134a and its alternative refrigerants for various evaporating temperatures for TC=55°c. As shown in fig. 5, with decrease in evaporating temperature, compressor work increases. Lower compressor work is desirable for better overall system efficiency. The compressor work is highest for R404A and the lowest for R152a for the entire range of TE in this study. Compared to R134a, R1234yf has higher while R152a has lower compressor work respectively. Fig. 6 shows the COP of R134a and its alternative refrigerants for various evaporating temperatures for TC=55°c. As shown in fig. 6, with decrease in evaporating temperature, COP decreases. Higher COP is always desirable parameter for refrigerants. The COP is highest for R152a and the lowest for R404A for the entire range of TE in this study. Compared to R134a, R152a has higher while R1234yf has lower COP respectively.[1]

3 Result Table

Refrigerants	Chemical composition	Molecular weight(kg/kmol)	Normal Boiling Point( ) ℃	Critical Temp( ) ℃	Critical Pressure (Mpa)	Safety class	GWP
R290	C_3H_8	44.096	-42.09	134.6	4.23	A3	11
R600a	CH_3-CH-CH_3 CH_3	58.12	-11.67	134.6	3.65	A3	3
R407c	R32+R125+R134	86.2	-43.6	86.1	4.62	A1/A1	1530
R410a	R32+R125	72.56	-50.5	72.5	4.96	A1/A1	1730
R404a	R125+R134+R143	97.60	-46.5	72.04	3.72	A1/A1	3300
R134a	CH_2FCF_3	102	-26	101.1	4.056	A1	1430
R152a	CH_3-CH-F_2	66.05	-25.03	113.5	45.8	A2	140
R1234yf	CF_3-CF=CH_2	114	-29	95	3.382	A2	4

Table.2 Thermodynamic properties comparison of different refrigerants

In this table we have compared the GWP values of all the refrigerants. From this we can infer that R-1234yf is the best substitute for R-134a.As it is relatively safe and its global warming potential is 4 as compared to that of R134a which is 1430.[1][5]

III. Conclusion

From above result table we can conclude that thermodynamic properties of different alternative refrigerants i.e. R290, R600a, R407C, R410A, R404A, R152a and R1234yf are compared to R134a which is used in AAC system. R290 and R600a cannot be substituted in AAC system due to high flammability issue. From thermodynamic property analysis it is clear that R407C, R410A and R404A having very high saturation pressure so it cannot be used in current AAC system. R152a can be substituted of R134a if and only if safety mitigations are provided. From thermodynamic cycle analysis, it is derived that R1234yf has 6.3% lower COP compared to R134a; however, it is best suitable alternative refrigerants as a drop in substitute of R134a AAC system because it has very low GWP and can be substituted in the existing AAC system with minimum modification. This study is useful to design engineers of AAC system for future aspect.

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