Sustainability of Automobile Air- Conditioning System Using Refrigerant R1234yf Instead of R134a

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Abstract

Air conditioning refrigerant R134a has value of global warming potential (GWP) 1300, which is much higher than MAC Directive (GWP below 150) passed in July 2006. This prompted a search for alternative refrigerant with GWP value less than 150. R1234yf is a new refrigerant which has lower GWP value of 4. Effect of blower speed has been compared and flammability issue of R1234yf has been addressed. Cooling time and relative humidity of car air -conditioning system using refrigerant R134a and R1234yf has also been discussed. The paper discusses various aspects for the replacement of R134a and provides a long term sustainable substitute of presently used refrigerant R134a in automobile air-conditioning.

Keywords: *Global Warming Potential, Alternate Refrigerant, Flammability, Energy.*

1. Introduction

Lots of research work has been done for replacing “old” refrigerants with “new” refrigerants with the aim of reducing GWP and maintaining energy efficiency. Maintaining high COP was not as important at the time, because energy prices were relatively low. Today, high COP is much more important for two reasons. Overall energy prices are considerably higher than during the last refrigerant change and COP is affecting indirect GWP. COP is the ratio of refrigeration effect to the net work input given to the system. The COP of vapour compression refrigeration system can be improved either by increasing refrigeration effect or by reducing work input given to the system. Ullrich Hesse [1] found that almost all the vehicles equipped with an air-conditioning system uses R134a as a refrigerant. Due to the European Communities motor vehicle directive (EU 2006) refrigerants with a GWP higher than 150 are not allowed from January 1st 2017 in new passenger cars. Thus, a replacement for R134a is needed. Proposed has been the HFO R1234yf which has similar thermodynamic properties and a reasonable retrofit replacement for R134a with modification in expansion valve. Lars Sjoholm et al. [2] demonstrated that a traditional vehicular air conditioning system using vapor compression increases fuel consumption by at least 15%, while provoking a reduction in engine power. Whereas an internal combustion engine converts about 30% of the energy into mechanical energy, about 35% is released in the form of exhaust gas and 25% is dissipated through the cooling system, and approximately 50% of the available fuel energy is released as heat to the environment. . An energy and exergy analysis, applying the first and second law of thermodynamics to the systems involved, is developed in a simulator to evaluate the technical feasibility of using this system to weatherize large vehicles. Esbr J. N. et al. [3] suggested that search for better alternatives which have zero ozone depletion potential (ODP) and zero or lower global warming potential (GWP) is still on. R1234yf is a new refrigerant which has lower global warming potential than R134a. R1234yf has global warming potential (GWP) of 4, so it satisfy MAC Directive (GWP below 150) passed in July 2006. R1234yf has nearly similar value of molecular weight and normal boiling point, making R1234yf a good replacement of R134a. Minxia Li, Chaobin et al. [4] have investigated that R 1234yf has been proposed for mobile air-conditioners due to its low GWP and performance comparable to that of R134a. However, its performance is inferior to that of R410a. This makes it difficult to be applied to residential air-conditioners. Alison Subiantoro et al. [6] stated that air conditioning is integral for modern cars, particularly in high-temperature regions like the tropics. Automotive AC regulates air as per condition in the cabin, particularly the temperature and humidity. This is not only to provide comfort, but also for health and safety reasons because a driver’s concentration level changes with the air condition in the cabin. With the urgent need to make cars more energy efficient due to ever increasing fuel prices and the harmful effects of greenhouse gases, it is important to reduce the energy consumption of automotive ACs. Santanu P. Datta et al. [7] suggested that the optimum operating condition with compressor and blower speed along with refrigerant charge level has also been identified for car air-conditioning system. The steady state performance of the system has been investigated for three independent variables, namely the refrigerant charge level, the compressor speed and the speed of the evaporator fan as they are the only variable parameters for a running car. A. Kilicarslan et al. [8] presented energy and exergy analysis of the air conditioning systems employing the mixture of outdoor and return air. The effects of the incoming air dry bulb temperature to the coil and relative humidity, and leaving air dry bulb temperature from the coil on the heat transfer and exergy destruction are investigated by means of a computer code developed.

Through a lot of work had been done on energy and exergy analysis of automobile air-conditioning and to find substitute of R134a which has GWP value of 1300 but its alternate refrigerant with low GWP finds limited practical applications. Present work is a systematic analysis of its alternate refrigerant R1234yf for actual car practical applications. In air-conditioning of car, the refrigerant must be safe even during accidents and therefore, safety aspects have been addressed in this paper. This paper mainly deals with the various aspects of replacement of R134a of GWP value 1300 with R1234yf of GWP value of 4 in air-conditioning of car to meet MAC Directive (GWP below 150) passed in July 2006.

2. Compressor Performance in Car Air-conditioning System

2.1 Compressor

In a car, the environment to be cooled would be the cabin and the heat would be transferred to the outside air through condenser. Air conditioning is also used to maintain required humidity in the cabin. R-134a is the mostly used refrigerant in motor vehicle air-conditioning system at present. The refrigeration cycle consists of four stages, evaporation, compression, condensation and expansion. Car uses swash plate type five cylinder reciprocating compressor. Swash plate compressor (Fig.1) is widely used in automotive air conditioning systems and its parts are the swash plate and the piston cylinder arrangement.

2.2 Smaller temperature lift

A certain temperature difference is required between the refrigerant in the heat exchanger and the surrounding air to allow for heat exchange to occur. In the benchmark system, this difference is 5°C between the evaporating and the dew point temperatures at the evaporator; and 20°C between the condensing and the outdoor temperature at the condenser. This results in a temperature lift of around 40°C between the evaporating and the condensing temperatures, which corresponds to about 9 bar of pressure difference that the compressor has to provide in both the R134a and R1234yf systems.

The temperature difference between the condensing and the outdoor temperature is reduced to only 100C-15°C which reduces the corresponding temperature lift is by 100C-15°C. This is because the reduction of the temperature lift to 30°C from 400C across the evaporator and condenser reduces the pressure difference to only about 6-7 bar, as compared to 9 bar in the benchmark system. However, the size of condenser is to be increased because temperature difference is lesser. S. Sanaye and M. Dehghandokht [9] showed that the mini-channel heat transfer rate was higher than that of the laminated evaporator in all operating conditions in automotive vehicles. The mini-channel evaporators have further advantages of 33% more compactness, lower power consumption of compressor and 20% lighter weight than that of currently used laminated evaporator. Similarly, advance design of mini-channel heat exchangers on condenser side can be used to have compactness, lower power consumption of compressor and for the purpose of weight reduction.

2.3 Cabin Set Temperature

Indoor set temperature may be increased from 20°C to 24°C; the compressor power requirement can be reduced. It may be noted that the savings are achieved without any major modification to the system. The energy saving is obtained because with a higher indoor temperature, the corresponding dew point temperature is higher. The condensing temperature, on the other hand, remains unaffected and so, the pressure difference that the compressor has to provide is lesser. These results in lesser compressor power requirements and higher COP.

2.4 Effect on Compressor Power and COP

When the temperature difference between the condensing and the outdoor temperature is reduced to only 10°C, and cabin set temperature is 24°C instead of 20°C, the compressor power requirement reduces while the COP increases. Increasing indoor set temperature from 20°C to 24°C and smaller air lift is advantageous in reducing flammability of R1234yf because of decrease in compression ratio, reduction in load on the compressor and temperature in the system. It will also reduce the leakage of refrigerant and oil from the system to the environment, thereby, reducing the flammability risk.

3. Effect of Blower Speed

A stationary test has been performed for the investigation of steady state and dynamic performance of a car air conditioning system. The car body effective area was 2.5 m2. Compressor displacement is 117 cc. Air conditioner compressors run by direct connection with the engine crank shaft by a groove type pulley and belt. In general, automobile air-conditioner consumes power as per ambient temperature, cabin cooling load, and type of refrigerant, air volume and heat absorbed by various parts of cabin in a car.

The experiments are carried out with varying blower speed. Blower speed was changed by knob.Its speed was measured by non-contact type tachometer.The swash plate compressor runs at different speeds as it is driven by the engine in the car but in the present analysis, the car was parked in a garage and it was not exposed to sunlight. The engine was running at constant speed and supplying constant power to the compressor through pulley and belt arrangement. The temperature of surrounding and cabin was recorded to 320C.There was only one person in the vehicle to note down temperature reading by Sling psychomotor, time taken for cooling by stop watch and velocity of air by anemometer. The one set of reading was taken with R134a (Table1) and another set of reading was taken with R1234yf (Table2). Same quantity of both refrigerants (by volume) was charged in turn.

It may be observed that cooling time decreases with increase in blower speed for both the refrigerants. Similarly, the increased air flow rate at higher blower speed reduces the RH when the cabin temperature changes from 320C to 240C. Cooling time was found to be lesser in case of refrigerant R1234yf as compared to R134a and decreases in the range between 4% to 6%. There is negligible change for the effect of blower speed on relative humidity (RH) of R1234yf over R134a.

It was revealed that for the same compressor work, the cooling time of R1234yf decreases up to 7% because R1234yf has about 25% more mass than R134a. However this 25% more mass indicated by the R1234yf did not produces an equivalent increase in cooling capacity because the latent heat of vaporization of R1234yf is about 18% lower than that of the R134a, as shown in (Table 3).

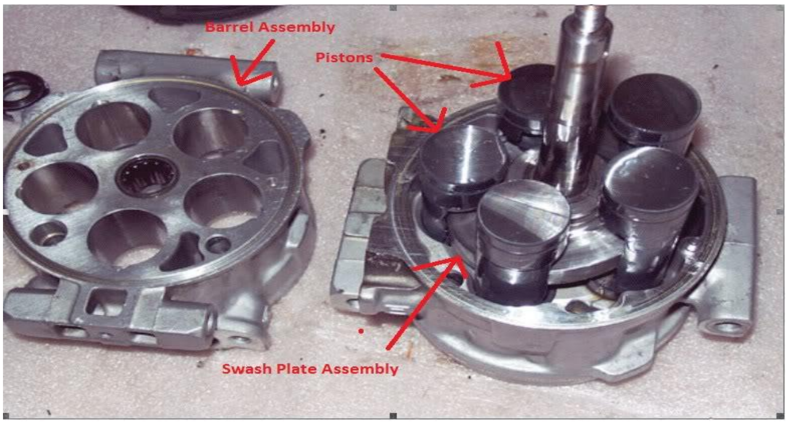

Fig.1: Five cylinder swash plate reciprocating compressor

Table 1.Effect of blower speed on refrigerating effect of R134a

S.N.	Blower speed(rpm)	Time taken for cooling the cabin from 32^{0}C to 24^{0}C, seconds	RH (%)
1	1400	525	57.98
2	1740	411	56.01
3	2250	319	54.70
4	2656	293	52.13

Table 2: Effect of blower speed on refrigerating effect of R1234yf

S.N.	Blower speed (rpm)	Time taken for cooling the cabin from 32^{0}C to 24^{0}C, seconds	Relative decrease in time taken for cooling (%) [(R1234yf – R134a)/ (R134a)]* 100	RH (%)
1	1400	503	4.19	57.91
2	1740	387	5.83	55.98
3	2250	303	5.01	54.30
4	2656	280	4.4	52.07

Property	R134a	R1234yf	[R134a-R1234yf]/[R134a]*100
Sat. vapour density(kg/m^3) at -10.60C	9.816	12.296	-25.26%
Latent heat of vaporization (kJ/kg) at -10.60C	206.4	169.81	17.73%
Saturated pressure @-10.6°C (kPa)	195.9	216.92	-10.73%
Saturated pressure @54.4^{0}C (kPa)	1469.8	1444.5	1.72%
Boiling point at 1 atm pressure	-26.1	-29.2	11.80%
Ctitical Temperature(^{0}C)	101.06	94.8	6.10%

4. Safety Aspect of 1234yf

As per ANSI/ASHRAE standard [5] refrigerants regarding Safety and collecting values of ODP and GWP from published paper as follows (Table 4):

Since R152a has higher flammability concern than R1234yf, so it has not been discussed in the present paper.

The same refrigeration system is adapted with limited modification of the expansion valve while replacing R134a by R1234yf. While heat exchanger process and design development appears less critical, the main concern of flammability is with the compressor. Even so R1234yf is announced to be a mildly flammable refrigerant with the ASHRAE classification of A2L but still in an accident simulation with rupture of the refrigerant line, leaking of refrigerant, its contact with engines and hot exhaust gas lines, ignition takes place and fire occurs . A key question to be clarified is that if the flammability of the refrigerants can be suppressed by R744. It is known, that R744 (CO_2) is a good flame suppressant. Explosion limits have been investigated. Adding R744 as an inert gas can suppress the explosion. One pressurized gas container with R744 may be fitted in vehicle near compressor which will automatically explode in case of accidents or any rupture to supply R744.

There can also be possibility to develop, an indirect system based on R744 as secondary refrigerant to use with R1234yf primary refrigerant for confining the refrigerant (R1234yf) in limited space. But, it may take time to develop such a system and COP of system is expected to be reduced because of heat exchange process. In such a process only R744 will be allowed to enter the cabin cooling coils and system will be safer but costly.

5. Conclusions

The paper concludes that R1234yf is substitute of R134a in a car application due to following points:

1. Increasing indoor set temperature from 20°C to 24°C and smaller air lift is advantageous in reducing flammability of R1234yf because of decrease in compression ratio, reduction in load and temperature in the system. It will also reduce the leakage of refrigerant and oil from the system to the environment, thereby, reducing the flammability risk.

2. It may be observed that cooling time decreases with increase in blower speed for both the refrigerants. Similarly, the increased air flow rate at higher blower speed reduces the RH when the cabin temperature changes from 320C to 240C. Cooling time was found to be lesser in case of refrigerant R1234yf as compared to R134a and decreases in the range between 4% to 6%. There is no relative change for the effect of blower speed on relative humidity (RH) of R1234yf over R134a.

3. It is known, that R744 (CO_2) is a good flame suppressant. Adding R744 as an inert gas can suppress the explosion. One pressurized gas container with R744 may be fitted in vehicle near compressor which will automatically explode in case of accidents or any rupture to supply R744.

4. There can also be possibility to develop, an indirect system based on R744 as secondary refrigerant to use with R1234yf primary refrigerant for confining the refrigerant in limited space. In such a process only R744 will be allowed to enter the cabin cooling coils and system will be safer but costly.

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