

EXPERIMENTAL PERFORMANCE OF VCR SYSTEM USING R134A AND R152A

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Abstract

There is increasing concern in India and other countries that global warming is growing in its effect. The global warming impact of a refrigerant relative to CO₂ can be measured by its GWP. R134a was initially assessed as having a GWP of 1300 (IPCC 2001) and later assessed to have a GWP of 1430 (IPCC 2007). This is thought to be disconcertingly high and has prompted a search for alternatives. The European Union (EU) is one body that has taken the course of proceeding down the legislative path to try to address possible future consequences of global warming. Under the legislation, the replacement refrigerants must have a GWP of less than 150. Industry has begun searching for alternatives with a lower global warming potential (GWP). So, there is urgent need of alternative refrigerants to R134a. R-152a is a more environmentally benign refrigerant compared to R-134a with a GWP of 120. Both refrigerants are hydro-fluorocarbons – HFCs - (contain no chlorine) and hence, have zero ozone depletion potential. R152a have some flammability issues but have no ozone depletion potential and have a significantly lower GWP. R152 is energy efficient than R134a. Project work deals with testing a Vapor Compression Refrigeration System using the two likely drop-in candidate refrigerants R134a and R152a in representative environments under controlled conditions. Performance Parameters such as COP, Cooling capacity, condenser capacity, energy efficiency etc. has been analysed for same condensation temperature of 44°C and evaporation temperature ranging from -5°C to 10°C.

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1. Introduction

The environmental impacts of the fluids are characterized by their Ozone Depleting Potential (ODP) relative to R11, Global Warming Potential (GWP) relative to carbon dioxide, Total Equivalent Warming Impact (TEWI), Life Cycle Climate Performance (LCCP), and atmospheric lifetimes. While the decision to phase out R22 is based on its potential to deplete stratospheric ozone, consideration of alternatives also must consider additional environmental data.

1.1 Environmental Criteria

- The Ozone Depleting Potential (ODP) is a normalized indicator of the ability of refrigerants (and other chemicals) to destroy stratospheric ozone molecules
- The Global Warming Potential (GWP) is a normalized indicator of the potency to warm the planet by action as greenhouse gas (GHG). These days, greenhouse warming has become one of the most important issues and Kyoto protocol was proposed to resolve this issue, and classified HFCs as greenhouse gases. R134a (GWP = 1300) will be banned in mobile air conditioners of new vehicles from 2011 (HFC who's GWP is more than 150 will be banned).
- Total Equivalent Warming Impact (TEWI) is besides GWP measure used to express contributions to global warming. It is defined as the sum of the direct (chemical emissions) and indirect (energy use) emissions of greenhouse gases:

TEWI = GWP (direct effects due to refrigerant leaks) + GWP (indirect effects due to A/C operation)

- (1) The direct and indirect impacts are determined by: Direct effects = Refrigerant charge \times (Annual loss rate \times lifetime + End of- Life loss) \times GWP
- (2) Indirect effects = Annual power consumption \times Lifetime \times Country-specific
- (3) TEWI results have indicated that the direct GWP of the refrigerant is less important than 10% of the total TEWI for these products depending on what assumptions are used for the analysis, and that the direct GWP of the refrigerant is less important than the overall efficiency of the unitary system. This indicates that any refrigerant blend proposed as an alternative for R22 must provide good cycle efficiency in addition to a low or moderate GWP.

Life Cycle Climate Performance (LCCP): The use of Life Cycle Climate Performance (LCCP) assessment is becoming a preferred alternative to the Total Equivalent Warming Impact (TEWI) calculation because it includes consideration of the equivalent warming impact of the refrigerant during production as well associated with the manufacture of any fluorocarbons must be accounted for. Two basic categories of manufacturing related warming impact have been identified:

- (1) The indirect warming impact associated with the energy consumed (electric energy and various fuels burned on site) to manufacture both the fluorocarbon and the raw materials used to make the

fluorocarbon (the so-called “embodied energy” or “embedded energy”) and

(2) The direct warming impact of any byproduct greenhouse gases that are emitted by the manufacturing process (the so-called “fugitive” emissions). $LCCP = TEWI + \text{embedded energy (Indirect)} [(chemical\ production\ of\ refrigerant\ \&\ transport) + (manufacturing\ A/C\ components\ \&\ their\ assembly) + (end-of-life)] + \text{fugitive emissions (direct)} [(atmospheric\ reaction\ products\ of\ refrigerant) + (end-of-life) + (manufacturing\ leakage)]$

(3) It is an indicator that includes the direct contribution of greenhouse gases used as refrigerants in the systems and the indirect contribution of the carbon dioxide emissions resulting both from the energy required to run the systems over their lifetime and producing the refrigerant.

(4) The atmospheric lifetime is defined as the time after which the concentration of an emitted chemical substance has decreased approximately by 64%. It is an indication of the average persistence of refrigerant released into the atmosphere until it decomposes, reacts with other chemicals, or is otherwise removed. Long atmospheric lifetime implies the potential for slow recovery from environmental problems, both those already known and additional concerns that may be identified in the future. Hence, short atmospheric lifetime is desirable. The atmospheric lifetime impacts both the ODP and GWP.

1.2 Technical Criteria

- The Thermal stability of the molecule: The molecule of refrigerant (or the molecules of the components of a refrigerant mixture) must be able to support, without decomposing, the action of the temperature.
- Electrical conductivity: The electric conductivity of the refrigerant, in particular its liquid phase, plays an evident role in the technique of the hermetic groups, it also has its importance in the problems of corrosion.
- The efficiency of the thermal exchanges of the condenser and the evaporator: The efficiency of the thermal exchanges depends on various thermophysical properties of the refrigerant such as the thermal conductivity, the density, the viscosity, the specific heat capacity, the surface tension, and the latent heat.
- Leaks: Openings of very small sizes are filled with corks of oil maintained in place by capillary strengths. The durability of these corks depends directly on the surface tension of the oil in the presence of the refrigerant. When the oil absorbs the refrigerant, its superficial tension decreases and corks of oil are chased and leaks appear.
- Detection and localization of the leaks: To improve the waterproofs of a refrigerating plant, it is better to confine the refrigerant. If there are leaks, it is necessary to detect their presence.

1.3 Economic Criteria

Prices of the refrigerant and the associated lubricants: It is a considerably fluctuating criterion. For

a long time, its impact on the choice of the fluid was considered as minor. However, today it is considered as an important criterion. It is usual to report the price of the refrigerant in the unit of mass while the price referred to the unit volume is much more significant. The rise of the price of refrigerants incites to the research, on one hand, for a reduced load of refrigerant in machines and, on the other hand, for a better seclusion. The prize of lubricants associated to refrigerants also is to be considered. Polyoester oils (POE), imposed using HFC refrigerants and their mixtures are more expensive than mineral oils used with former refrigerants. Besides, the choice of the refrigerant influences directly those of the compressor and heat exchangers. To give refrigeration power and pressure drop, the nominal diameter of the liquid and vapor lines, thus their prices, as well as those of the accessories (stop valves, regulating valves, filters, etc.) depend directly on the choice of the refrigerant. Availability of the refrigerant: It must be sufficient to cover immediately the needs. Indeed, the refrigerated service cannot be interrupted for a long time. The refrigerant thus must be a widely produced fluid and internationally distributed. The follow-up of the manufacturing and the distribution of the classic refrigerants have never raised serious problems. Users were assured to find the refrigerant during the life of the installations.

1.4 Refrigerant Comparison

The basic properties of R152a and R134a are shown in Table 1. The data shown in this table are taken from a paper published by R. Cabello et al. (2015), where different aspects of these two refrigerants are discussed. Thermodynamic properties are calculated using the software application REFPROP v9.1 [Lemmon et al. (2013)], the Safety Group is in accordance with ASHRAE Std-34 [ASHRAE (2013)], HOC and RCL values are extracted from [Calm (2012)], and GWP values are taken from [IPCC (2013)].

2. Literature Review

D. Sanchez A et al [1] in their work five low-GWP R134a possible choices have been tested and compared in an identical refrigerating facility equipped with a hermetic compressor, under the same operating conditions. The refrigerants used in this analysis are: R290 and R600a (HCs); R134a and R152a (HFCs), and finally, R1234yf and R1234ze(E) (HFOs). All of them have been assayed without changes in the facility, that is, as direct drop-ins. The results obtained from the experimental tests are presented and commented in this work from the energetic point of view. The hydrocarbon R290 (propane) obtains the best results in terms of cooling capacity and COP, achieving an increase between 40.5% - 67.4% and 22.4% – 2.8%, respectively. R. Cabello et al [2], an experimental comparison has been performed of a cascade refrigeration facility working with the refrigerant pairs R134a/R744 and R152a/R744. R134a/R744 cascade refrigeration system designed to operate at the low evaporating temperature level of commercial refrigeration (-40 to -30 °C). The plant is driven by two single-stage reciprocating compressors. The replacement of R134a with R152a was performed as a drop-in, and no changes were made in the facility or the

lubricant. For a proper regulation of the electronic expansion valves, the R152a saturation curve was programmed in the expansion valve controller. R. Cabello et al [3], the presented work shows the results of using R152a in a vapour compression plant equipped with a hermetic compressor and an IHX designed for R134a. The refrigerant was replaced by a conventional “drop-in” process in order to carry out an energy comparison. The results have revealed an improvement in the COP with R152a up to 13% despite a reduction in the cooling capacity of about 10% a reduction up to 16% in electrical power. During the test campaign, R134a hermetic compressors have been shown to be capable of operating with R152a. B.O. Bolaji, a refrigerator designed and developed to work with R134a was tested, and its performance using R152a and R32 was evaluated and compared with its performance when R134a was used. The results obtained showed that the design temperature and pull-down time set by International Standard Organization (ISO) for small refrigerator were achieved earlier using refrigerant R152a and R134a than using R32. The average coefficient of performance (COP) obtained using R152a is 4.7% higher than that of R134a while average COP of R32 is 8.5% lower than that of R134a [4]. A.S. Dalkilic et al [5], a theoretical performance study on a traditional vapor-compression refrigeration system with refrigerant mixtures based on HFC134a, HFC152a, HFC32, HC290, HC1270, HC600, and HC600a was done for various ratios and their results are compared with CFC12, CFC22, and HFC134a as possible alternative replacements. Mark O. Mclinden et al [6], explored the possibilities for refrigerants having low global warming potential (GWP). A set of about 1200 candidate fluids is identified from more than 56 000 small molecules examined by applying screening criteria to estimates for GWP, flammability, stability, toxicity, and critical temperature. Lixiang Yang et al [7], (vapor + liquid) equilibrium (VLE) for the {1,1-difluoroethane (R152a) + 1,1,1,3,3- pentafluoropropane (R245fa)} system was determined by a static-analytical method at $T = (323.150 \text{ to } 353.150) \text{ K}$. Yin Hai Zhu et al [8], a refrigeration system was developed which combines a basic vapor compression refrigeration cycle with an ejector cooling cycle. The ejector cooling cycle is driven by the waste heat from the condenser in the vapor compression refrigeration cycle. Alberto Cavallini [9], did a review of working fluids for mechanical refrigeration. The main issues associated with the use of the new generation refrigerants are discussed, such as behaviour with oil; flammability; efficient use of temperature glides, fractionation, and heat-transfer degradation with zeotropic mixtures. Eric Johnso [10], using a variety of public sources, a computer model of hydrofluorocarbon (HFC) refrigerant emissions in the UK has been developed. Gaurav et al [11], studied and presented a comparison of energy and exergy analysis for R134a, R152a, R290, R600 and R600a in refrigerator. Also analyzed the domestic refrigerator with alternative refrigerants for computing coefficient of performance, exergy destruction ratio, exergy efficiency, and efficiency defect. A.C. Tiwari et al [12], in this paper, the performances of four ozone-friendly Hydrofluorocarbon (HFC) refrigerants (R125, R134a, R143a and R152a) selected to replace R12 in a vapor compression refrigeration system were investigated experimentally and compared. The performance in term of coefficient of performance (COP), refrigerating capacity (RC), and compressor work (W_c) were evaluated for the investigated refrigerants at various evaporating and condensing temperatures. Bukola O. Bolaji [13], studied, the exergetic performance of a domestic

refrigerator using two environment-friendly refrigerants (R134a and R152a) was investigated and compared with the performance of the system when R12 (an ozone depleting refrigerant) was used. The effects of evaporator temperature on the coefficient of performance (COP), exergy flow destruction, exergetic efficiency and efficiency defect in the four major components of the cycle for R12, R134a and R152a were experimentally investigated. Ankit Tiwari et al [14], studied the performances of four ozone-friendly Hydrofluorocarbon (HFC) refrigerants (R125, R134a, R143a and R152a) selected to replace R12 in a vapour compression refrigeration system were investigated experimentally and compared. The performance in term of coefficient of performance (COP), refrigerating capacity (RC), and compressor work (W_c) were evaluated for the investigated refrigerants at various evaporating and condensing temperatures. B.O. Bolaji et al [15], studied the performances of three ozone-friendly Hydrofluorocarbon (HFC) refrigerants (R32, R134a and R152a) in a vapour compression refrigeration system were investigated experimentally and compared. The results obtained showed that R32 yielded undesirable characteristics, such as high pressure and low Coefficient of Performance (COP). The comparison of properties of R134a and R152a are mentioned in Table 1 [16-20].

Table 1. Main properties of R134a and R152a

Refrigerant	R134a	R152a
Chemical formula	CH ₂ FCF ₃	CH ₃ CHF ₂
Critical temperature (°C)	101.06	113.26
Critical pressure (MPa)	4.06	4.52
Normal boiling point (°C)	-26.07	-24.02
Specific volume (m ³ /kg)	0.190	0.296
Latent heat (kJ/kg)	216.97	329.91
Volumetric refrigerating effect (kJ/m ³)	1140.81	1113.66
Safety group	A1	A2
Atmospheric life (year)	14	2
Ozone depletion potential	0	0
Global warming potential	1300	138

3. Results and Discussion

The experiments are performed using the fabricated VCR system for both the refrigerants for different condenser and evaporator temperatures.

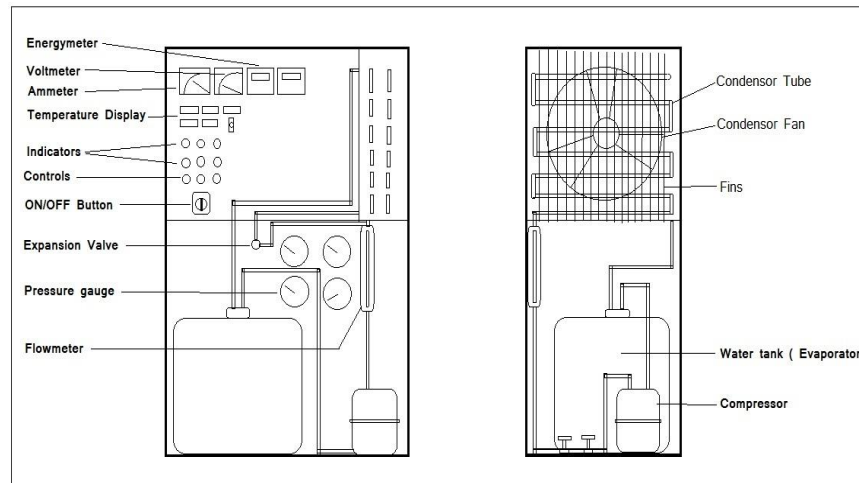


Fig. 1. Schematic diagram of fabricated VCR system

The pressure ratio for both refrigerant decreases with increase in evaporation temperature. while R134a has higher value of pressure than R152a for all the evaporation temperatures. R-152a shows 0.62% to 0.86 % deviation from R134a in pressure ratio. This is because the condensing pressure of R134a is about 12% greater than R152a.

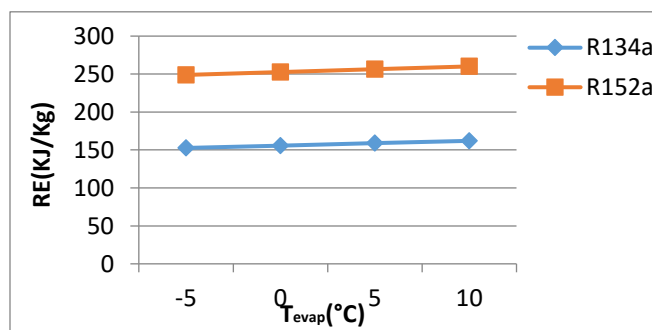


Fig.2. Refrigerating Effect Vs Evaporating Temperature

Figure 2 indicates that the refrigerating effect for both refrigerants increases with increase in evaporating temperature. While R-152a has higher value of refrigeration effect than R-134a for all the evaporating temperatures. R-152a shows 60.52% to 63.01 % deviation from R-134a in refrigerating effect. This is because, the latent heat of R152a is about 52% greater than R134a.

Hence more heat is absorbed by R152a than R134a for the given evaporating temperatures.

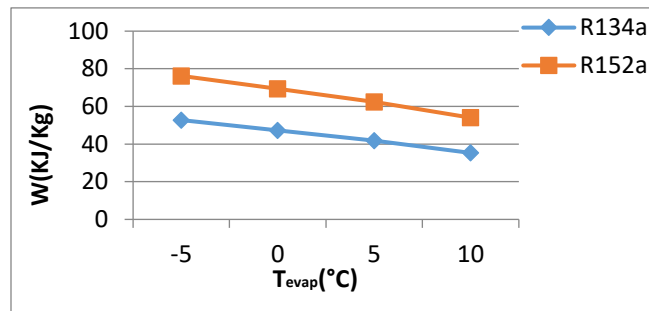


Fig. 3. Compression Work per kg of refrigerant Vs Evaporating Temperature

From Figure 3, compression work for both refrigerant decrease with increase in evaporating temperature. While R-152a has higher value of compression work than R-134a for all the values of evaporation temperature. R-152a shows 44.5% to 52.98 % deviation from R-134a in compressor work per kg of refrigerant. This is because, the discharge temperature of R152a is greater than R134a.

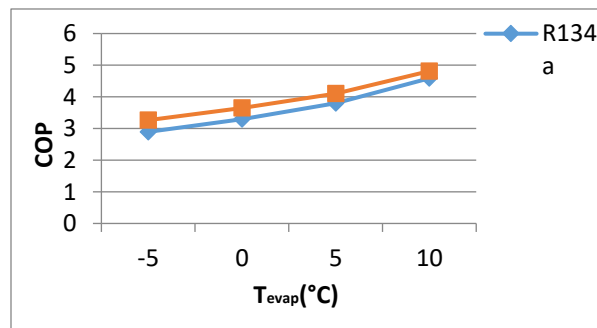


Fig.4. Coefficient of Performance Vs Evaporating Temperature

From Figure 4, it is found that COP of the system increases with increase in evaporation temperature for both refrigerants. While R-152a has higher value of COP than R-134a. R-152a shows 4.93% to 12.8 % deviation from R-134a in COP. This is because, R152a has higher value of refrigeration effect than R134a.

Conclusions

The refrigerant R-152a has higher values of COP from 4.93% to 12.8% more than R-134a. The refrigerant R-152a has mass flow rate varying from 45.95% to 46.46% less than R-134a which results in lower value of compressor power consumption. R-152a has compressor power

consumption 17.45% to 21.86% less than R-134a. Power per ton refrigeration for R-152a is 4.86% to 11.26% less than R-134a. R-152a has compressor work and refrigeration effect 44.5% to 52.98% and 60.52% to 63.01% respectively more than R-134a. Thus R-152a has shown better performance than R-134a. Hence R-152a can be used as an alternative for R-134a.

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