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IMPACT OF THE MIGRATION FROM R410A TO R454C IN THE COMPRESSOR PERFORMANCE

Rubén Ossorio*, Javier Marchante-Avellaneda and Emilio Navarro-Peris

Instituto Universitario de Investigación en Ingeniería Energética, Universitat Politècnica de València.
Camí de Vera s/n 46022, Valencia, Spain.
e-mail: r.ossorio@iie.upv.es

Abstract: *The quasi-azeotropic mixture of refrigerants R410A replaced R-22 as the preferred refrigerant for use in residential and commercial air conditioners. However, newer regulations have mandated the phase-down of refrigerants with a high GWP as R410A, and thus, new substituting refrigerants and mixtures must be selected. Among the different possibilities, some manufacturers have been interested in mixtures such as R454C, composed of R32 and R1234yf (21.5/78.5), which has a GWP lower than the limit imposed by the new F-Gas regulation.*

In this study a variable-speed scroll compressor was tested working with both R410A and R454C at different operating conditions. From these tests, the compressor behavior with these refrigerant mixtures has systematically been analyzed in terms of compressor efficiency, volumetric efficiency, and working range.

Keywords: R454C, drop-in, compressor efficiency, EER, Low-GWP mixture

1. INTRODUCTION

In the evolving landscape of refrigerant technologies, the search for more efficient and environmentally sustainable options is critical in order to achieve the more restrictive environmental policies fixed by the European Union. This study focuses on the comparative performance of a compressor operating with R410A as reference refrigerant and R454C as lower Global Warming Potential (GWP) alternative.

The selection of R454C has been motivated by the current trend toward new mixtures based on R32 for split and multi-split systems, as they offer lower values of GWP.

Guilherme et al., 2022 underscore that no other refrigerant has been proven to improve the efficiency of R410A, except for R32 [1]. This assertion is based on a series of drop-in tests where R32 was employed in systems originally designed for R410A, including a wide range of applications from heat pump to rooftop air conditioning units.

The results show that R32 has a higher critical temperature, which is advantageous from a thermodynamic point of view, and it also has lower densities in both liquid and vapor phases, leading to less refrigerant charge requirement and reduced pressure drop. Furthermore, R32's enhanced thermal conductivity increasing the heat transfer coefficient, coupled with the benefit of lower production costs.

However, the transition from high-GWP Hydrofluorocarbons (HFCs) like R410A to medium-GWP alternatives such as R32 is still under discussion. Critics argue that it may be more economically viable to skip directly to low-GWP refrigerants (lower than 150) rather than undergo a gradual and costly change through intermediate levels of GWP.

In order to further decrease the GWP of R32, it tends to be mixed with Hydro-Fluoro-Olefins (HFOs) as R1234yf in new mixtures defined with the identification of R454X, being the mixture R454B (R32/R-1234yf [68.9/31.1]%mass) the proposed direct drop-in alternative for refrigeration applications.

However, this mixture still manifests a high GWP close to 500, and thus, some manufacturers have shown interest in adding extra HFOs to obtain a GWP lower than 150. The mixture R454C satisfies the abovementioned requirements.

The summary of the specifications of the mentioned refrigerants are shown in Table 1.

Table 1. Summary of the main properties of mentioned refrigerants.

ASHRAE Name	Safety Class	GWP (AR5)	Composition % mass	Normal Bubble Point ºC	Critical Temp ºC	Critical Pressure bar
R410A	A1	**1924**	R32/R-125 [50/50]	-51.44	71.34	49.01
R32	A2L	**675**	R32	-51.65	78.11	57.82
R454B	A2L	466	R32/R-1234yf [68.9/31.1]	-50.49	78.10	52.67
R454C	A2L	146	R32/R-1234yf [21.5/78.5]	-45.89	88.50	44.74

R454C, although it has a low GWP, includes higher condensing and evaporating temperatures at the same working pressures which would prevent from direct drop-in solutions in some applications.

In Figure 1, a compressor envelope limited by working pressures is defined for the different mentioned refrigerants, and a typical working point for air conditioning application is highlighted (Tevap=0 ºC and Tcond = 50ºC).

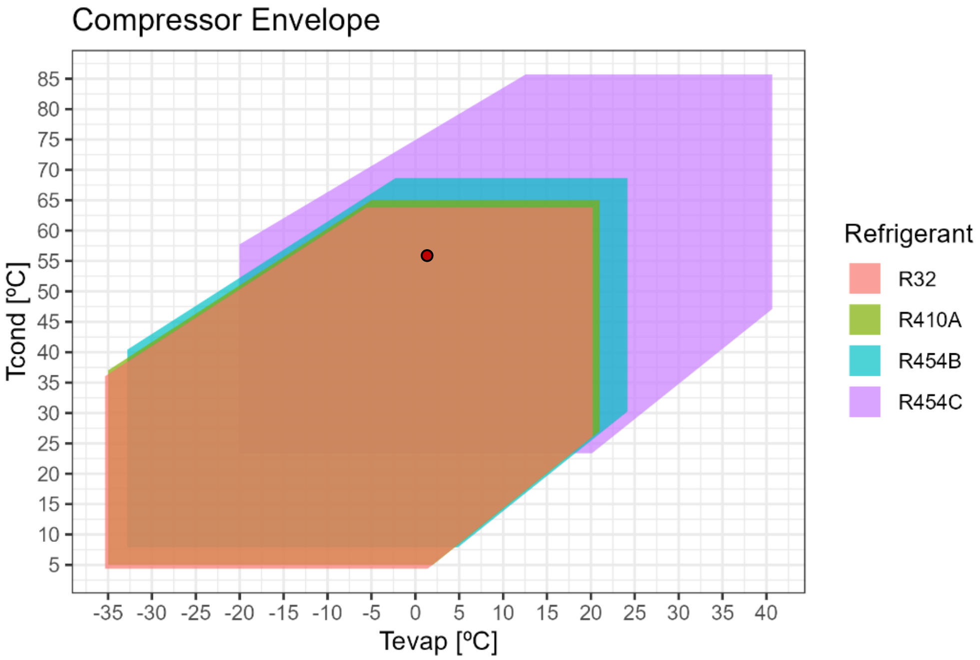

Figure 1. Operation temperatures for different refrigerants working on a compressor's pressure range

R32, R410A, and R454B show very similar operational temperature ranges, but the working temperatures of R454C would be higher. However, the operation range of R454C would be still in typical working temperatures for commercial air conditioning.
In this study, a commercial compressor for air conditioning originally designed for R410A was both tested at different working conditions and speeds with R410A and R454C. The results are compared in terms of performance.

2. METHODOLOGY

The tested scroll compressor has a displacement of 44cm3, and its envelope, which is defined in operating pressures for the different speeds, is displayed in Figure 2. The envelope was defined in pressures instead of in temperatures, so the compressor would work at the same pressure ratios with both refrigerants and wouldn't exceed the maximum allowable condensing pressure at which it was designed.

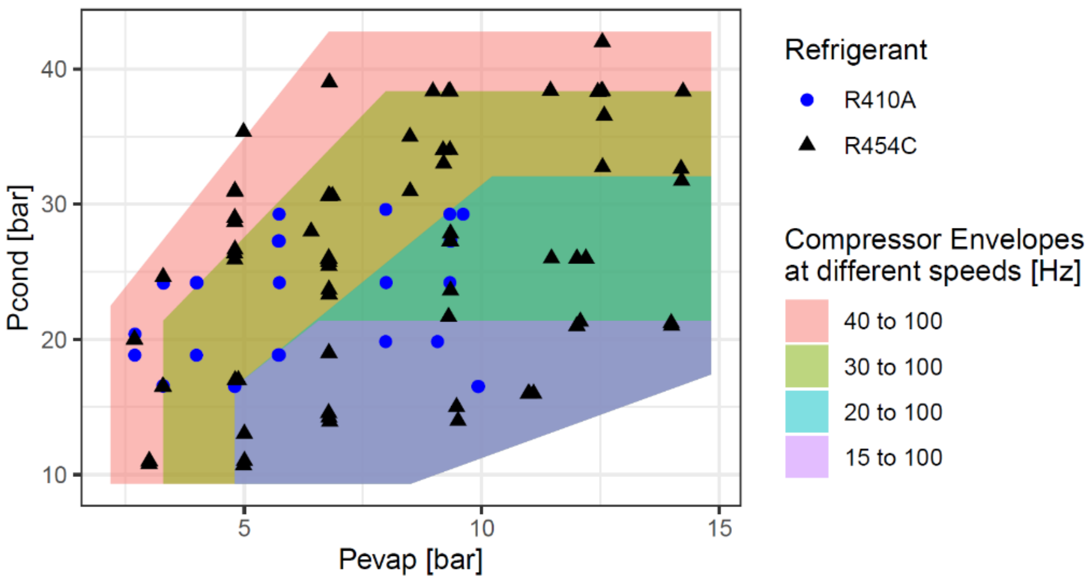

Figure 1. Compressor envelope as a function of working speeds and tested conditions for R410A and R454C

As shown also in Figure 2, a total of 35 different conditions and speeds were tested with R410A and PVE32 oil, and 87 conditions were tested with R454C and POE46 oil. All the tests were carried out at a constant superheat level of 10K. The used test bench was described in a previous study [2].
As the tests were not carried out on exactly the same conditions and speeds for both analyzed refrigerants, to compare the results side by side, predictions from pre-fitted models will be used for better interpretability. The used models are data-driven correlations which were presented and justified in a previous study [3]. These models were used instead of the most widely known AHRI 10 and 20 polynomial models as the latter were proven to have limited extrapolation capabilities and tended to over-adjust the experimental error [4].

3. RESULTS

When characterizing the performance of a refrigerating compressor, the main two variables to be analyzed are the electrical power consumption and the pumped refrigerant mass flow rate. However, as the studied compressor was tested under different speeds, in order to normalize the speed effect in both variables, $\dot{W}_c/f_c$ and $\dot{m}_{ref}/f_c$ were analyzed instead [3]. In Figure 3, the obtained results in both experimental campaigns (R410A and R454C) are displayed, showing the evolution of $\dot{W}_c/f_c$ with the working conditions.

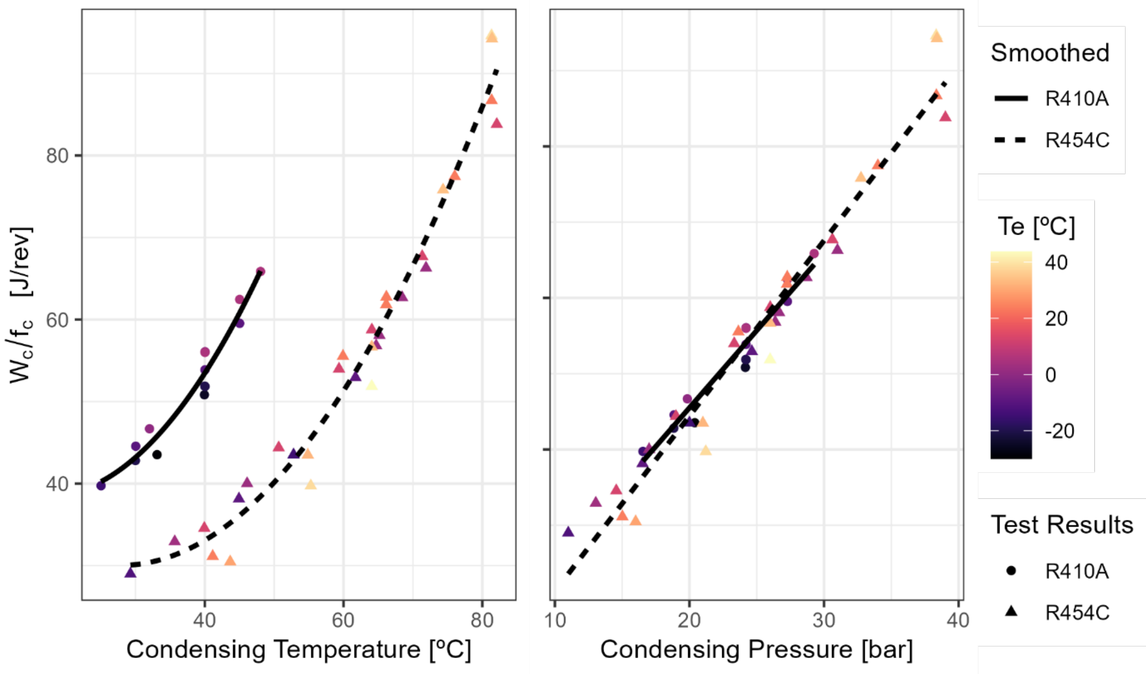

Figure 3. Evolution of experimental results of $\dot{W}_c/f_c$ with condensing conditions

From these results, it is shown that for the same temperature applications, the compressor consumes less for the case of R454C, and the normalized electrical consumption is mainly affected by condensing temperature with a quadratic tendency. On the other hand, if the normalized power consumption is expressed as a function of condensing pressures, the results of both refrigerants converge to the same straight line. This result was demonstrated in a previous study [4] for energy consumption in fixed-speed compressors and in this study, the same conclusions can be also extended to normalized energy consumption ($\dot{W}_c/f_c$). This convergence remarks the possibility of using models based on pressures to extrapolate the compressor performance to other refrigerants.
In Figure 4, the obtained results for the normalized mass flow rate ($\dot{m}_{ref}/f_c$) for both refrigerants are represented against the evaporating pressure (left-hand plot) and the evolution of suction densities at the same working conditions (right-hand plot).

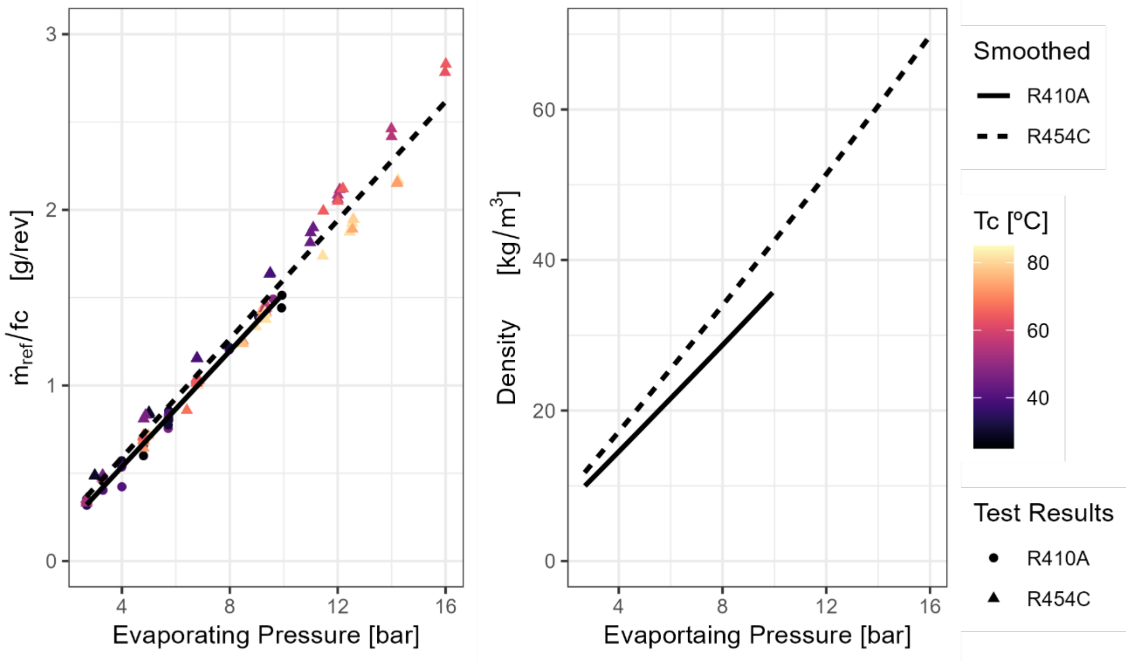

Figure 4. Evolution of experimental results of $\dot{m}_{ref}/f_c$ with evaporating conditions

The results show that $\dot{m}_{ref}/f_c$ for both refrigerants converge to the same straight line which cannot be explained by the fluid densities as they clearly differ as shown in the right plot, being the density of R454C higher in the tested pressure ranges, which would explain a higher mass flow for this refrigerant if the volumetric efficiency would remain constant.

In Figure 5, the evolution of the volumetric and compressor efficiencies is represented for both fluids, where the drawn line represents the evolution of the efficiencies at the nominal speed (60Hz) which were calculated using the correlations referenced in the methodology section.

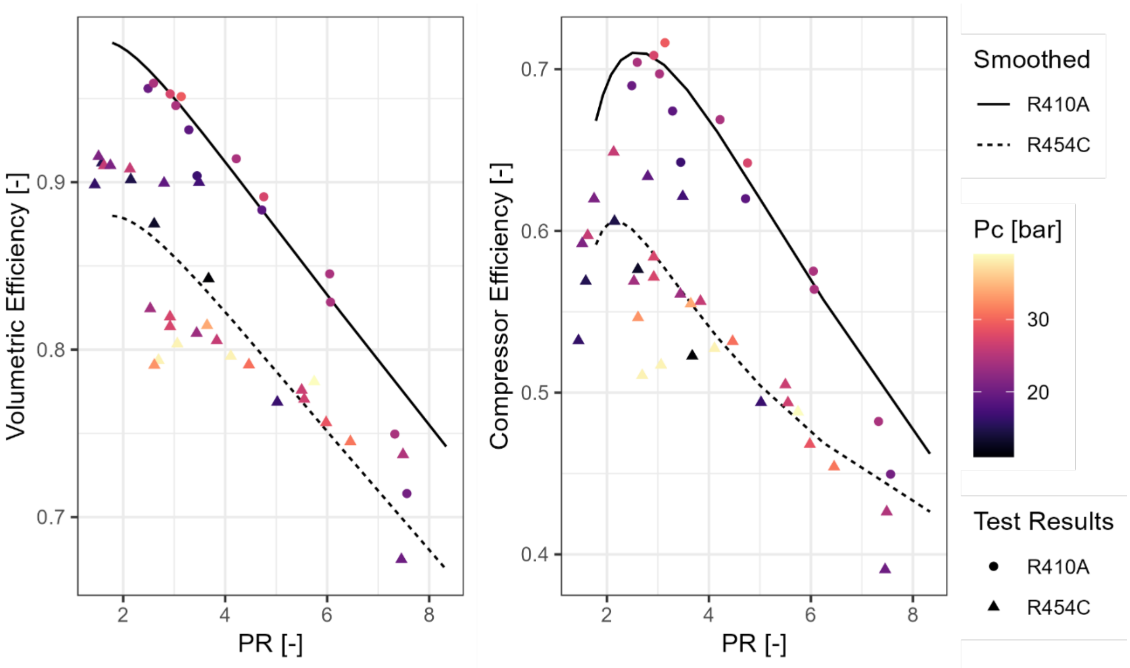

Figure 5. Evolution of compressor efficiencies with pressure ratio for both refrigerants

The volumetric efficiency drops by more than 5 percentual points for the case of R454C. This decrease in efficiency would explain why the measured refrigerant mass flow rate of R454C was lower than expected and similar to the obtained by R410A, albeit the latter having a lower density. The decrease of volumetric efficiency for the case of R454C can also explain the diminution of the compressor efficiency as the consumption based on pressures does not seem to be affected by the change of refrigerant for the same working pressures and speeds. The observed decrease in volumetric efficiency was not expected and could be explained by a poorly designed lubricant oil for the case of R454C refrigerant that could increase internal refrigerant losses during compression.

Given the obtained results, it can be studied the global effect of making a direct change in refrigerant in a variable speed heat pump when it works under certain operating temperatures and delivers a particular cooling capacity.

Table 2. Comparison of the performance of a variable-speed heat pump using the studied compressor and working with 2 different refrigerants under the same conditions of temperatures and cooling load.

Refrigerant	**Te / Tc** [ºC]	**Cooling Capacity** [kW]	**Speed** [rpm]	**Vaporization Enthalpy at 0ºC** [kJ/kg]	**Suction Density** [kg/m3]	**Electrical Power** [kW]	**EER** **[-]**
R410A	0 / 50	10	58	221	29	3.9	2.56
R454C (1)	0 / 50	10	120	189	19.7	5.7 (+44%)	1.74 (-31%)
R454C (2)	0 / 50	10	102	189	19.7	5.4 (+36%)	1.85 (-27%)

To have a fair comparison, the compressor speed should increase notably when it works with R454C to compensate for the smaller vaporization enthalpy, for a lower suction density at the same operating temperature, and for the observed decrease in volumetric efficiency. Two different results were obtained for R454C:

1. Using the experimental data and considering the decrease in volumetric efficiency.
2. Assuming that a correct lubricant oil has been selected and the volumetric efficiency at that condition can be considered analogous to the one of R410A.

4. CONCLUSIONS

A variable speed compressor for refrigeration originally designed for R410A was tested with R454C and the results show that compressor efficiencies decreased by more than 5 percentual points. A posterior analysis highlights that, to deliver the same cooling capacity at a nominal condition, the compressor speed should double to account for the worse thermodynamic properties of R454C, which would increase the required power consumption by approximately 40%, which, in turn, would decrease the EER by 30%.

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