EXPERIMENTAL DROP-IN COMPARISON OF R516A AND R134A FOR WATER-TO-WATER REFRIGERATION APPLICATIONS

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Abstract: *R134a is still one of the most used hydrofluorocarbons (HFCs) in refrigeration and air conditioning applications. However, it should be phased out in the coming years because of its high global warming potential (GWP). The refrigeration sector needs to find as soon as possible technically suitable alternative refrigerants. R516A is a promising azeotropic mixture at medium-low temperatures. The operational and energetic performance of the lower GWP refrigerant R516A is analysed as a drop-in replacement to R134a. Experimental measurements are taken from in vapour compression test rig at several steady-state refrigeration conditions. The evaporating temperature is -5 ºC, -10 ºC and -15 ºC, and is combined with 32.5 ºC condensing temperature, considering the effect of the internal heat exchanger (IHX) effectiveness. R516A presents a good performance in terms of refrigerating effect and cooling capacity. R516A coefficient of performance (COP) is higher than R134a at the evaporating temperature of -15 ºC.*

Keywords: cooling, vapour compression system, low global warming potential (GWP), R516A.

1. INTRODUCTION

In October 2016, the parties of the Montreal Protocol decided to concrete their schedule to phase down HFCs. Developed countries that ratified the Kigali Amendment to the Montreal Protocol must reduce by 2045 their HFCs consumption to 80 % [1]. On the 27th of December 2020, the American Innovation and Manufacturing Act was enacted, which directs EPA to regulate and phase down production and consumption of HFCs to 15% of their baseline levels in a stepwise manner by 2036 [2].

One of the most commonly used HFC refrigerants is R134a, widely used in refrigeration applications [3]. It is a greenhouse gas, approximately 1400 times more potent than carbon dioxide. Phase-down and transition to working fluids with a GWP below 150 would mitigate the climate impact significantly caused by these widespread Refrigeration, heating ventilation, and air conditioning systems [4].

Hydrofluoroolefin (HFO) refrigerants are included in the fourth generation of fluorine-based refrigerants, potentially offering many of the benefits shown by HFCs but with a lower GWP. Owing to the olefinic structure, they have very short atmospheric lifetimes and have emerged as the best option for replacing high GWP HFCs. The first HFO, developed by DuPont and Honeywell, is R1234yf [5]. It presents comparable thermodynamic properties to R134a. Therefore, some authors consider it a straightforward replacement for R134a, with the only concern of its mild flammability.

De Paula et al. [6] simulated heat pumps using R290, R1234yf, and R600a as alternative refrigerants to R134a. The system with R290 showed higher system performance.

HFC/HFO mixtures have also been investigated as R134a drop-in replacements, offering a trade-off between flammability and GWP in such a way that the risk of the mixture would be lower than that of the single HFO refrigerant. However, based on the GWP, such blends would be considered intermediate solutions [7]. Many studies have already investigated these new refrigerant mixtures. Meng et al. [8] experimentally studied automobile air conditioning units using a mixture of R1234yf/R134a (89/11 by mass percentage). The blend reduced R134a COP in cooling and heating mode between 4 % and 9 % and 4 % and 16 %, respectively. For a small refrigeration system. Mota-Babiloni et al. [9] determined the influence of IHX effectiveness variation on system performance at different evaporating temperatures. R513A presented a noticeable reduction in discharge temperature compared to R134a and a cooling capacity and COP benefit when the IHX was used.

Due to the GWP value of 631, its use can be limited in specific applications as directed by the (F-Gas) Regulation (EU) 517/2014 phase out for refrigerants with GWP above 150 in 2025 [10]. Therefore, the research of low-GWP mixture refrigerant R516A with GWP below 150 is necessary and meaningful. Al-Sayyab et al. [11] performed a numerical performance comparison for a compound ejector-heat pump system using twelve low global warming refrigerants, including R516A. The study concluded that R516A and R1234yf have comparable system performance.

The thermodynamic properties of R516A can make it a close match to R134a, so it is proposed as a future-proof alternative. There are limited experimental data of R516A to promote its market introduction and deployment and replace R134a.

From an operational and energetic point of view, this work uses experimental data to comprehensively analyse the benefits and limitations of the refrigerant R516A as a compatible replacement for R134a in refrigeration systems. Operational parameters such as compressor consumption power, cooling and heating capacity, and discharge temperatures were measured to compare this working fluid in the vapour compression system. Additionally, the impact of IHX actuation was studied at different evaporating temperature levels.

2. EXPERIMENTAL METHODOLOGY

2.1. Experimental setup

The schematic diagram is shown in Figure 1. The system is composed of a fully monitored single-stage system with an IHX vapour compression circuit and two closed-loop with glycol brine and water. The main components of the vapour compression circuit are shown in Figure 1.a. Full system components descriptions were mentioned in [12].

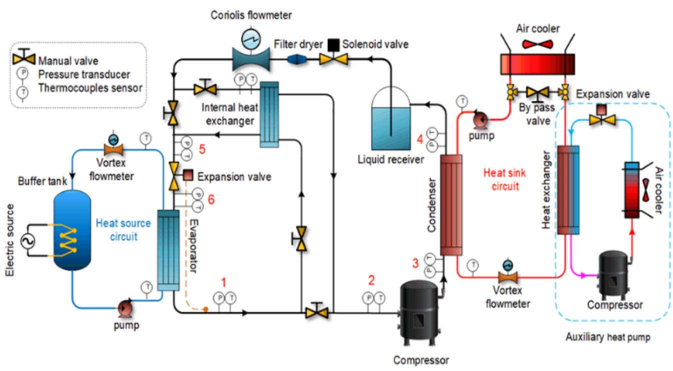

Figure 1. Experimental setup schematic diagram

2.2. Operating conditions

To evaluate the suitability of the low GWP R516A as an alternative drop-in replacement to R134a in refrigeration applications (Table 1), experiments were carried out at three different evaporating temperatures, -15 ºC, -10 ºC and -5 °C, with 5 °C glycol temperature difference across the evaporator. Meanwhile, the condensing temperature was set at 32.5 ºC, and 6 °C condenser's cooling water temperature difference, with the assessment of the IHX impact on the overall system performance.

Table 1. Thermophysical properties of the tested refrigerants [13,14]

Refrigerant	Molecularweight (g mol^{-1})	T_{crit}(°C)	P_{crit} (MPa)	ρ_{vapor} [a] kg m^{-3}	ρ_{liquid} [a] kg m^{-3}	h_{fg} [a] kJ kg^{-1}	NBP(°C)	ODP	GWP100	Safety class ASHRAE
R134a	102.03	101.0	40.59	5.258	1377	217.0	-26.09	0	1430	A1
R516A	102.58	97.30	36.45	5.929	1321	188.5	-29.40	0	142	A2L

[a] At a pressure of 1.01325 bar

2.3. Equations

The refrigerating effect can be obtained from Eq. (1) with the refrigerant specific enthalpy difference across the evaporator.

$$q_e = \left(h_{e,out} - h_{e,in}\right) \tag{1}$$

In the same context, the cooling capacity can be evaluated from Eq. (2), multiplying the refrigerating effect by the refrigerant mass flow rate.

$$\dot{Q}_e = \dot{m}\, q_e \tag{2}$$

The system coefficient of performance (COP) results from Eq. (3), being the compressor power consumption directly measured.

$$COP = \frac{\dot{Q}_e}{\dot{W}_c} \tag{3}$$

3. RESULTS AND DISCUSSION

The experimental results were carried out at different evaporating temperatures (-15 ºC, -10 ºC and -5 ºC) and 32.5 ºC condensing temperature.

Figure 2 shows that the evaporating temperature increase positively influences refrigerant mass flow rate. The IHX reduces the refrigerant mass flow rate delivered due to a higher total superheating degree and a lower compressor suction density. R516A has a higher mass flow rate by 5 % to 53 %.

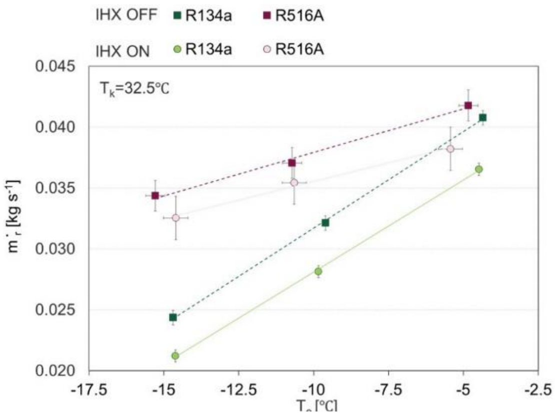

Figure 2. Refrigerant mass flow rate at different evaporating temperatures.

From Figure 3, at a given evaporating temperature, the IHX actuation significantly increases the refrigerating effect due to refrigerant mass flowrate reduction (Figure 2) with constant glycol heat source capacity. On the other hand, for the OFF case, the higher the evaporation temperature, the higher the refrigerating effect because of the slope of the saturated vapour line. Then, it should be considered that the evaporator superheating degree and the total subcooling degree are comparable. When the IHX is actuated, this difference is compensated by the additional subcooling degree introduced by the IHX, which is higher at lower evaporating temperatures. This is reflected in the evaporator refrigerating effect. R516A displays a lower refrigerating effect compared with R134a.

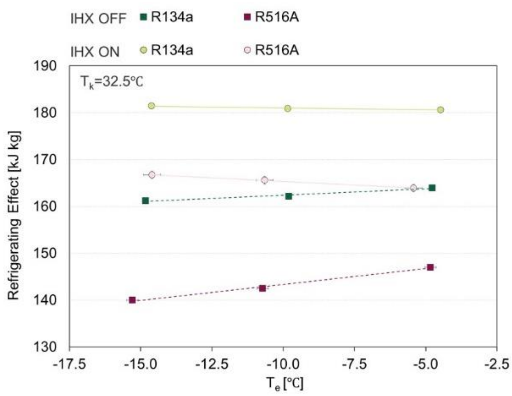

Figure 3. The refrigerant effect at different evaporatingtemperatures.

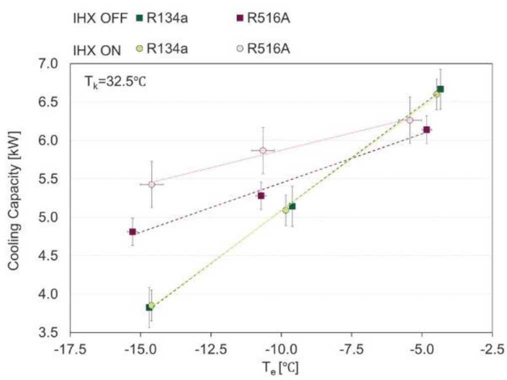

Figure 4. Refrigerant capacity at different evaporatingtemperatures.

Figure 4 shows the cooling capacity variation at different evaporating temperatures and IHX cases. The evaporating temperature increasing has a positive influence on the cooling capacity. The IHX actuation positively influences the cooling capacity, owing to a dominant refrigerating effect increase. R516A exhibits the highest cooling capacity improvement (2 % to 13 %). It also shows the highest cooling capacity at a low evaporating temperature (-15 ºC and -10 ºC), indicating that R516A is suitable for medium-low temperature applications.

Figure 5 shows that a higher evaporator temperature slightly reduces consumption power consumption. R516A shows the highest values. On the other hand, the IHX reduces compressor power consumption (Figure 5), given the reduction in refrigerant mass flow rate (Figure 2), with unremarkable influence on compressor pressure ratio (Figure 6).

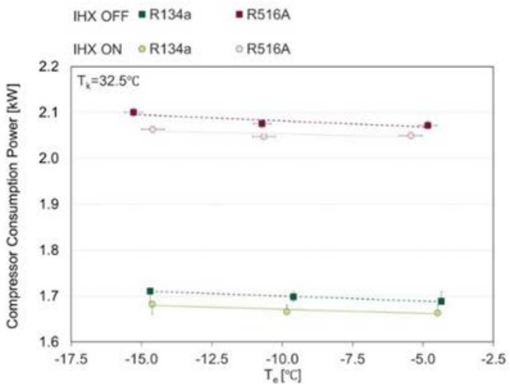

Figure 5. Compressor power at different evaporatingtemperatures

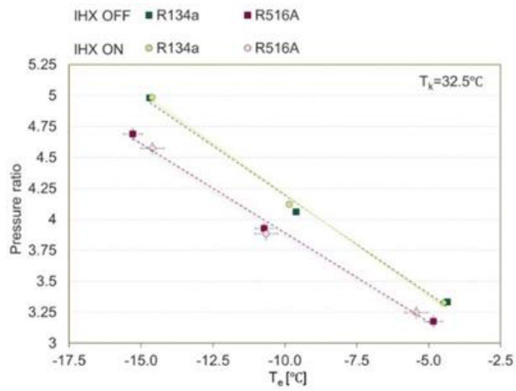

Figure 6. Compressor pressure ratio at different evaporating temperatures

In the light of the previous discussion, the evaporating temperature increase positively influences the cooling capacity (Figure 4), owing to the refrigerant mass flow rate increase and slightly reducing the consumption power (Figure 5). As a result, a higher evaporative temperature increases COP (Figure 7). On the other hand, the IHX increases COP (owing to compressor power consumption reduction and cooling capacity increase). Finally, R516A shows the highest performance at low evaporating temperatures (-15 ºC).

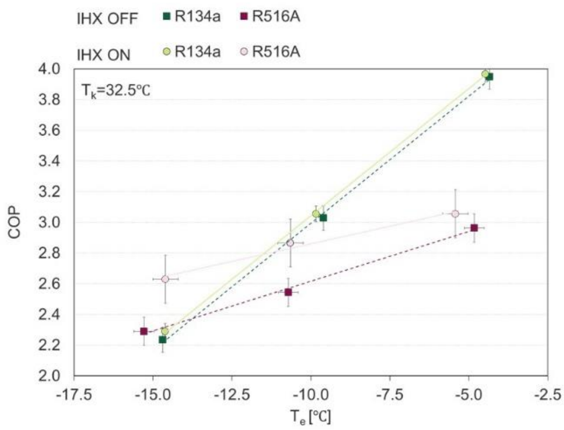

Figure 7. Coefficient of performance at different evaporating

4. CONCLUSIONS

Low GWP refrigerant R516A was compared to R134a in a test rig at the evaporating temperature of -5 ºC, -10 ºC, and -15 ºC, and the condensing temperature was 32.5 ºC, including the IHX effect. The novel mixture R516A exhibits a higher refrigerant mass flow rate than R134a. R516A presents a higher consumption power, with a lower cooling capacity at a high evaporating temperature. Meanwhile, it offers a cooling capacity augmentation at low evaporating temperatures (15 % to 40 %). R516A results in the highest COP at the lowest evaporating temperature, -15 ºC, with a COP increase ranging from 2 % to 15 %.

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