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Applications of refrigerant R1234yf in heating, air conditioning and refrigeration systems: A decade of researches

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Abstract

HFC refrigerants as R134a, R404A, R407C and R410A are commonly used in heating, air conditioning and refrigeration (HACR) systems since Kyoto protocol. However, they are phased-out due to their high global warming potential (GWP). There are various options to replace high GWP refrigerants, among all hydrofluorolefin (HFO) fluids, such as R1234yf, represents an excellent alternative. With GWP <1, R1234yf is a promising substitute for R134a. This paper presents the most relevant researches concerning the application of R1234yf in the last decade. This review paper regroups experimental and theoretical studies which assess the performance of pure R1234yf as working fluid of the compression systems such as mobile and residential air conditioning, air and water heat pump, domestic refrigerator and freezer. Studies depict that R1234yf can be recommended for small-scale systems instead of R134a, but an optimization process is necessary to achieve the optimum operating conditions.

Keywords: R1234yf; HFO; Low GWP refrigerant; HACR systems; Review paper.

1. Introduction

During the last thirty years, R134a refrigerant has been employed as working fluid in many thermal and refrigerating systems such as space heating and cooling, food refrigeration, and hot water production. Investigations have depicted that R134a is more common in medium temperature refrigeration systems (with cool temperatures of 0°C to 15°C). Although this fluid has ozone depletion potential (ODP) equal to zero, it has a global warming potential (GWP) of 1430 contributing to the greenhouse effect. In 2006, the legislation No 842/2006 in the European Union has been approved and agreed on the use of refrigerants with a low GWP. Therefore, the R134a refrigerant (and other fluids with high GWP as R410A and
R407C) should be eliminated in Europe. This was announced in the European Union with the Regulation No. 517/2014 (F-gas Regulation) and in the level of international with Kigali’s amendment on Montreal Protocol in 2016 (Mota-Babiloni et al., 2017). Some options to replace R134a are (i) natural refrigerants such as ammonia and carbon dioxide (ii) hydrocarbons (HC) (iii) hydrofluorocarbons (HFC) with low GWP, like R32 and R152a and (iv) hydrofluoroolefins (HFO), specifically R1234yf and R1234ze(E) developed by Honeywell and DuPont (Minor and Spatz, 2008). Among all these alternatives, R1234yf has been proposed as the primary replacement for R134a automotive air conditioning systems because the thermophysical properties of R1234yf are similar to those of R134a (Koban, 2009).

R1234yf or 2,3,3,3-tetrafluoroprop-1-ene is a HFO (hydrofluorocarbon derived from alkenes), which has zero ODP and GWP (100 years) < 1 (Hodnebrog et al., 2013). In terms of security, Schuster et al. (2008) concluded that R1234yf exhibited low toxicity. R1234yf has a relatively high lower flammability limit that is 6.2 vol% in air, high minimum ignition energy from 5,000 to 10,000 mJ which indicates there may be very few potential ignition sources in a vehicle (Takizawa et al., 2009). Furthermore, it has a very low burning velocity at 1.5 cm/sec indicating a low potential for damage by which ignition occurs. In addition, it possesses a high ignition temperature (678.15 K) (Minor et al., 2010). Therefore, R1234yf is classified as A2L (lower flammability) of ASHRAE classification.

About the compatibility of R1234yf with compressor oils in the market, Fujitaka et al. (2010) reported that the stability of PAG (polyalkylene glycol) and POE (polyolester) which are predominantly used with R134a and R410A was low for R1234yf due to the formation of higher amount of breakdown acid products. In POE lubricant, this chemical instability for R1234yf is more critical than PAG lubricant (Fujitaka et al., 2010). Another issue is the miscibility/solubility of the refrigerant in the oil. Bobbo et al. (2014) indicated a rather different behavior of R1234yf in comparison with R134a in PAG lubricants originally developed for R134a. In general, R1234yf shows lower solubility than R134a in the same lubricant, that can increase the oil retention in condenser and evaporator, thus reducing the heat transfer efficiency (Zilio et al., 2011a). All works indicated that the lubricants developed for R134a or R410A are not suitable for the use with R1234yf. Akram et al. (2014) studied on the tribological performance of gray cast iron of R1234yf with PAG, POE and Mineral oil. PAG/R1234yf exhibited better tribological performance compared to the other systems. Due
to the above-mentioned facts, new PAG lubricants were developed for R1234yf, for example ZEROL® HD-46-R1234yf (Dixon and Seeton, 2017).

Minor and Spatz (2008) in collaboration with Honeywell/DuPont published the first article regarding the performance of R1234yf in automotive air conditioning. Results show that with no system changes, the cooling capacity and energy efficiency of R1234yf has a difference within 4-8% compared to R134a. Life Cycle Climate Performance (LCCP) calculations also indicate a significant environmental benefit of R1234yf versus R134a, R152a and CO2. Finally, R1234yf presented similar behavior with plastics, elastomers and metals compared to R134a, indicating that many materials in use air conditioning systems may be compatible with R1234yf.

In 2010 the number of works concerning R1234yf increased significantly with the majority of the studies focusing on the thermodynamic properties (Akasaka et al., 2010; Brown et al., 2010; Di Nicola et al., 2010; Tanaka and Higashi, 2010; Ziegler, 2010) and two-phase flow characteristics (Del Col et al., 2010; Park and Jung, 2010). After that, during one decade several works were conducted to investigate the performance and the design of refrigeration systems using R1234yf. In this paper, a review of the pertinent researches on R1234yf published in scientific journals in heating, air conditioning and refrigeration (HACR) is carried out. The objective is to summarize the current knowledge of the refrigerant R1234yf to understand the physical principles behind the replacement of the R1234yf with conventional refrigerants. Since R1234yf is an R134a alternative, special attention is given to compare both refrigerants in all the sections.

2. Bibliometric search

The articles used in this paper were collected from the Elsevier, World Scientific, and Taylor & Francis Online databases for the period 2009-2019. This time range was chosen because 2009 was the period when the literature on R1234yf began to grow. The keywords searched in titles and abstracts were R1234yf, HFO-1234yf, low GWP. The results were restricted to articles written in English (the principal scientific language) and to articles published in indexed journals in the thermal engineering area. Moreover, books, book chapters, and conference proceedings were excluded of search. In this stage, we identified near of 300 articles, including the determination of thermodynamic properties, two-phase flow, application in organic Ranking cycles, R1234yf as part of blend refrigerants, etc. The next
step was the revision of the relevant articles and definition of exact criteria of selection. The review criteria was the performance of cooling and heating systems using pure R1234yf. A total of 63 papers remained after this filtering. It is important to note that studies on the performance of devices such as heat exchanger or compressor were not included because only the overall performance of the systems are the objectives of this review.

Figure 1 presents the number of articles published in each year of the studied time range. The activity began after 2009 and the interest to study the performance of R1234yf in HACR systems was growing until 2015. In the time range of 2015-2017, almost 50% of articles were published and are included in this review. Recently the number of publications decreased because the new trend is the research on R1234yf in HFC/HFO mixtures (Heredia-Aricapa et al., 2020).

![Figure 1 Number of articles published on R1234yf in heating, air conditioning and refrigeration systems](image)

3. Mobile air conditioners (MAC)

The F-gas Regulation in Europe restricted the refrigerant used in the MAC (Mobile Air Conditioners) systems to GWP<150. This is a critical limit because there are not a lot of substances with GWP<150, only the natural refrigerants, HC and HFOs are in this range. R134a (GWP=1430) is the most used in MAC systems nowadays, which should be phased-out. The similarity in the thermophysical properties between R134a and R1234yf had fundamental role in the rapid growing of use of R1234yf in the mobile air conditioners.
(Chemours, 2020). However, from an environmental point of view, low GPW is inadequate to guarantee the reduction of global warming. Papasavva and Moomaw (2014) implemented a Life Cycle Analysis (LCA) that evaluates the full cycle of Greenhouse Gas (GHG) emissions of R134a as an alternative refrigerant in MAC systems. The results indicate that R1234yf has the potential to reduce GHG emissions in all world regions compared with R134a and R744 (CO₂). Thus, the environmental benefits can also accrue with the R1234yf. In the following, the energy and exergy efficiencies of the R1234yf in MAC systems are summarized.

Minor and Spatz (2008) measured the cooling capacity and coefficient of performance (COP) in a bench-scale apparatus using MAC components from a small car. The results showed that with no system changes, the performance difference between R1234yf and R134a is 4-8%, depending on automotive vehicle operation. Moreover, significant improvements can be expected with minor system optimization, such as thermostatic expansion valve adjustment and larger diameter suction line tube. A similar conclusion was found experimentally for drop-in of R1234yf in a R134a MAC system by Zilio et al. (2011b) through numerical simulations; they also indicated major modifications in the R1234yf system, such as the enhancing face area of the condenser by 20% and evaporator by 10%, to obtain the same cooling capacity as R134a system. Qi (2013) studied two types of evaporators widely used in MAC systems (laminated plate and microchannel parallel flow) using R1234yf and R134a. The experimental results showed that the cooling capacity of the laminated plate evaporator working with R1234yf is reduced by 8.0%. But in microchannel evaporator, cooling capacity is comparable and/or larger than that of R134a up to 6.5%.

Zhao et al., (2012) conducted drop-in tests of R1234yf in the R134a MAC system under low-, middle- and high-load conditions. The results illustrated that the optimum refrigerant charge of R1234yf was approximately 90% of R134a charge. Other drop-in tests were carried out under summer and winter conditions with R1234yf and R134a for MAC system with open type compressor by Lee and Jung (2012). The results showed that the COP and cooling capacity of R1234yf are 2.7% and 4.0% lower than those of R134a, respectively. Also, the compressor discharge temperature and amount of charge of R1234yf are 6.5 °C and 10% lower than those of R134a.

Searching for new ways to improve the performance of R1234yf, Cho et al. (2013) installed an internal heat exchanger (IHX) in the MAC system. They concluded that cooling capacity
and COP of the R1234yf system compared with R134a without the IHX decreased by 7% and 4.5%, respectively, but those with the IHX decreased by 1.8% and 2.9%, respectively. In continuation of their work, Cho and Park (2016) showed the influence of the compressor speed of the MAC system with IHX. The COP of the R1234yf system with the IHX was lower than that of the R134a system by 0.3–2.9% for a compressor speed of 800–1800 rpm. The second law efficiency of the R1234yf system was 3.4–4.6% lower than that of the R134a system at all compressor speeds without IHX. The second law efficiency of R1234yf with the IHX was improved by 1.5–4.6% compared to the R1234yf system without the IHX. Qi (2015) also concluded that adding an IHX and improving compressor efficiencies would be good options for the future R1234yf MAC system enhancement.

Lee et al. (2015) proposed changing the conventional vapor compression cycle for a new saturation cycle concept to enhancement MAC systems using R134a alternatives as R1234yf, R152a, R444A and R445. In the conventional refrigeration cycle, the R1234yf shows the lowest COP and the R445A shows the highest one. However, when the saturation cycle is applied, R1234yf shows the highest COP improvement and the COP for this new cycle is almost the same for all refrigerant tested as presented in Fig. 2.

![Fig. 2 Variation of the COP in MAC systems for some R134a alternatives (Lee et al., 2015).](image)

Concerning MAC system optimization, Di Battista and Cipollone (2016) presented a model of cabin and MAC system with condenser cooled by air or liquid considering R1234yf as working fluid. In the traditional systems with air-cooled condensers, they showed that a 20% bigger condenser could achieve a 7% higher COP, but it has higher costs and frontal area
requirements. Orifice diameter, instead, could be sized in order to improve COP of 20% for
different cabin cooling requests. In addition, the use of a liquid-cooled condenser presented a
reduction of about 22% of the compressor work, with respect to the air-cooled condenser
case, which represents about 8% of the propulsion power of medium-class cars.

Devecioğlu and Oruç (2017) compared R1234yf, R444A and R445A in numerical model of a
MAC systems. The evaporation and condensation temperatures considered in the research
were between -5 ºC to +5 ºC, and 30 ºC to 60 ºC, respectively. The simulations pointed out
that the cooling capacity of R444A and R445A were the highest, but their COP values were
smaller than the COP with R1234yf.

An important analysis about the second law of a MAC system using R1234yf was presented
by Golzari et al. (2017). Through of computational models, it was found that using R1234yf
increased the exergy efficiency compared to the R134a in the MAC system. Also, maximum
entropy generation and exergy destruction took place in the compressor with R134a. The
exergy destruction and entropy generation of the cycle components using R1234yf are less
when compared to R134a.

Daviran et al. (2017) simulated a MAC system with a multi-louvered fin and flat-plate type
evaporator, a wobble-plate type compressor, a mini-channel parallel-flow type condenser and
a thermostatic expansion valve. Two different conditions were considered for the cycle
analysis: for the first state, the cooling capacity is taken as constant, and for the second state
the refrigerant mass flow rate is considered fixed. The initial results showed that the
refrigerant-side two-phase heat transfer coefficient of R1234yf is 18-21% lower than that of
R134a, and the pressure drop is 24% and 20% smaller than that of R134a during condensing
and evaporating process, respectively. In the first case studied (constant cooling capacity) the
COP of R1234yf is lower than that of R134a by 1.3-5%; and in the second case (refrigerant
mass flow rate), the COP of R1234yf is about 18% higher than that of R134a.

The main conclusion is that R1234yf can be used as an environmentally friendly solution in
MAC systems due to its excellent environmental properties (low GPW and lower GHG
emissions) with acceptable performance. On the other hand, Bjørnåvold and Van Passel
(2017) argued that R1234yf has some economical and commercial problems due to the fact
that R1234yf is a synthetic fluid with high cost.
The majority of MAC systems are referred to as the systems used in cars. However, there are other mobile systems. Pigani et al. (2016) evaluated the use of low-GWP refrigerants in marine provision plants for cruise ships. They used ammonia (R717), R744, and R1234yf and R1234ze(E) as the most promising low GWP refrigerants for investigations. Single-stage, two-stage and cascade plant configurations were examined. The results were compared with those of the current systems with R407F. It was concluded that the examined refrigerants were not adequate to maintain or improve the level of safety, efficiency and volumetric capacity compared to the R407F system. Another different system was studied by Shin and Cho (2016), which was a truck refrigeration system. Their study predicted cooling performance by using an analytical model for refrigeration systems using R404A and R134a. Furthermore, the performances of those systems were compared with those of alternative refrigeration systems using R1234yf and R744. For various operating conditions, the COP of the R134a system was higher than that of other systems, while the R744 system showed the lowest performance.

4. Residential cooling appliances

This section includes the test of R1234yf in the small-size equipment employed in residential applications i.e. window and split air conditioners, refrigerators and freezers. Endoh et al. (2010) tested the R1234yf in a room air conditioner that worked with R410A. For cooling capacities between 2 to 4 kW, the COP decreases by almost 50% with R410 baseline. Thus, they implemented some methods to increase the COP of the system as doubling the number of paths of heat exchangers, triplicating the inner-diameter cross-sectional area of a gas-side connecting pipe, and installing an oil separator. In this case, COP using R1234yf was 90% more than the R410A original system. Barve and Cremaschi (2012) also concluded that the use of R1234yf instead of the R410A in a cooling split system for residential applications should require major modification.

Bansal and Shen (2015) presented a validated model for window air conditioners (WAC). Simulations were performed for multiple alternative refrigerants to R410A, e.g., R32, R600a, R290, R1234yf, R1234ze. In this case, R1234yf demonstrated the worst energy efficiency ratio (EER) as presented in Fig. 3, and required larger compressor displacement volumes to achieve the same cooling capacity of R32, which is the best choice since their results showed that it has a higher cooling capacity without making any system modification. Devotta et al. (2016) simulated a split air conditioner (SAC) with a nominal cooling capacity of 1.5 TR.
using an alternative to R22 as R290, R161, R1270, R32 and R1234yf. Among them, R1234yf was not recommended for these equipment types. To improve the performance of R1234yf, Pottker and Hrnjak (2015a, 2015b) showed the effect of condenser subcooling on the performance of an air conditioning system with and without internal exchanger, operating with R134a and R1234yf under the same conditions. The results indicated that the improvement in performance of a system operating with R1234yf can be higher than that with R134a, with or without internal exchanger. The use of both simultaneously still yields a more efficient air conditioning system, especially for R1234yf.

![Normalized EERs for WAC (Window air conditioners) at 35°C ambient temperature, baseline being R410A (Bansal and Shen, 2015).](image)

Other home appliances tested with R1234yf were the domestic refrigerator. Sethi et al. (2016) found out that for a small refrigerator the cooling capacity and COP for R1234yf is 2% and 3% lower than that for R134a. Aprea et al. (2016) presented an experimental investigation on a domestic refrigerator working with R134a and a drop-in with R1234yf. They concluded that R1234yf has allowed for reducing of 7.3% the pull-down time and of 23% the duty cycle in comparison with the use of R134a. It means a reduction of daily and yearly energy consumptions using R1234yf in domestic refrigerators. Belman-Flores et al. (2017b) studied three identical domestic refrigerators using R1234yf as a drop-in replacement for R134a. The optimal charge for R1234yf was 92.2 g, which is about 7.8% lower than the one for R134a, which represents a small increase of 4% in energy consumption in comparison to R134a. Belman-Flores et al. (2017a) and Rangel-Hernández (2019) presented an exergy and economical study of R1234yf as drop-in replacement for R134a in a domestic refrigeration
The results indicated that irreversibilities are mainly concentrated in the compressor, which is the case for both R1234yf and R134a. This exergy analysis showed that exergy destruction ratio is less for R134a than for R1234yf (35% less). In consequence of the unit exergy cost, the results showed that R134a performs better than R1234yf at different operating conditions. They concluded that R1234yf only could be an alternative to R134a if refrigerator could be redesigned and optimized.

In conclusion, the R1234yf is not recommended as an alternative for air conditioner systems working with R410A. In small-sized systems such as domestic refrigerator or freezer working with R134a, using R1234yf can be suitable with new design and optimization process.

5. Water and air heaters

This section presents the results of the R1234yf performance in air or water heating applications using vapor compression cycle. Endoh et al. (2010) and Barve and Cremaschi (2012) studied experimentally an R410A split residential system in air heating mode working with R1234yf and R32. As Fig. 4 shows, they found that the R1234yf provided similar COPs as those for R410A (up to 10%), however, R1234yf had lower capacities in comparison with R410A (up to -50%). In addition, R32 had similar heating capacities and COPs.

Zheng and Zhao (2015) modeled mathematically a two-stage heat pump based on the combination of vapor expander and compressor that is commonly proposed in cold regions. The refrigerants simulated were R152a, R134a, R161, R290, R227ea, R1234yf and R1234ze. Among them, R1234yf exhibits one of the worst COP and heating capacity. Botticella et al. (2017) proposed an analysis of design configurations for a 5 kW residential space heating system.
splits system comparing several low GWP refrigerants: R32, R290, R1234yf, R1234ze, XL41, XL55 as potential alternatives to the most common refrigerants actually used as R410A, R407C, R134a. Thermo-economically, R1234yf and R1234ze had the maximum cost for the same COP.

Recently, Bellos and Tzivanidis (2019) designed and optimized a solar assisted heat pump driven by hybrid PV to cogeneration of electrical power and thermal energy for air space heating in a building. The optimization is performed in steady-state conditions for seven different working fluids in the heat pumps. R32 and R1234yf were the most appropriate working fluids of the heat pump.

About water heating, Nawaz et al. (2017) conducted a model of a residential heat pump water heater using R134a as baseline, R1234yf and R1234ze(E). The impacts of condenser wrap pattern, condenser tube size, evaporator size, and heat loss factor from the storage tank were studied for the three fluids. They found out that both R1234yf and R1234ze(E) can be substituted for R134a with acceptable performance and without substantial modifications compared to the original system. Pitarch et al. (2017) studied the optimal subcooling of a water-to-water heat pump with a heating capacity up to 70 kW. The refrigerants R290, R134a, R1234yf and R32 were analyzed. In the simulations, the evaporation temperature and water temperature at the condenser outlet were fixed in the order of 0 and 70 °C, and the water temperature at the condenser inlet was varied. All refrigerants had a similar heating COP at the optimal subcooling, but the degree of improvement significantly varies depending on the refrigerant. R1234yf had the highest optimal subcooling and degree of COP improvement with comparison to the case without subcooling.

6. Vapor compression refrigeration systems

This section delineates the research works about R1234yf used in vapor compression refrigeration (VCR) systems for cooling water or air in several capacities and temperatures. Table 1 lists the articles published in the most relevant journals in this decade. The general trends of the results show that the cooling capacity and COP for R1234yf is 5–10% lower than for R134a. The IHX can reduce this difference almost to zero. Mota-Babiloni et al. (2014) monitored a VCR with water as secondary fluid in the evaporator and condenser with/without the IHX. They concluded that the employing of an IHX for R1234yf can compensate the performance difference compared to R134a without IHX. Optimization of
subcooling and surface area of the heat exchanger are other options to improve the performance of R1234yf. Yang and Yeh (2015) showed an air conditioning system with 400 kW of cooling capacity in which the maximum COP improvement with condenser subcooling was found for R1234yf in comparison with R410A, R134a and R717, due to the fact that the R1234yf has a high ratio of liquid specific heat to latent heat of vaporization.
Table 1. Studies about R1234yf in VCR systems.

<table>
<thead>
<tr>
<th>Author</th>
<th>Refrigerants</th>
<th>Cooled fluid</th>
<th>Evaporation temperature (°C)</th>
<th>Study type</th>
<th>Cooling capacity (kW)</th>
<th>Highlight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jarall (2012)</td>
<td>R1234yf, R134a</td>
<td>Water</td>
<td>-5 to 23</td>
<td>Experimental</td>
<td>1-2</td>
<td>Drop-in tests of single VCR system</td>
</tr>
<tr>
<td>Navarro-Esbi et al. (2013a, 2013b)</td>
<td>R1234yf, R134a</td>
<td>Water</td>
<td>-10 to 10</td>
<td>Experimental</td>
<td>2-12</td>
<td>Drop-in tests and addition of IHX in single VCR system</td>
</tr>
<tr>
<td>Subiantoro and Oor (2013)</td>
<td>R1234yf, R134a, R22 CO2, NH3, R32, R404A, R410A, R407C, R438A</td>
<td>Air</td>
<td>-30 to 10</td>
<td>Theoretical/Economic</td>
<td>1-10</td>
<td>Economic analysis for VCR with expanders</td>
</tr>
<tr>
<td>Molés et al. (2014) and Mota-Babiloni et al. (2014)</td>
<td>R1234yf, R234yze(E), R134a</td>
<td>Water</td>
<td>-10 to 10</td>
<td>Theoretical/Economic</td>
<td>2-12</td>
<td>Addition of IHX in single VCR system</td>
</tr>
<tr>
<td>Bell and Lemort (2015)</td>
<td>R1234yf, R1234yze(E), R134a, R152a</td>
<td>Metal</td>
<td>30 to 50</td>
<td>Theoretical</td>
<td>12</td>
<td>VCR system for satellite cooling</td>
</tr>
<tr>
<td>Yang and Yeh (2015)</td>
<td>R1234yf, R134a, R22, R134a, R410A</td>
<td>Water</td>
<td>-20</td>
<td>Theoretical</td>
<td>400</td>
<td>Optimization of subcooling of single VCR system</td>
</tr>
<tr>
<td>Nunes et al. (2015)</td>
<td>R1234yf, R134a R12</td>
<td>Air</td>
<td>-20 to 0</td>
<td>Theoretical</td>
<td>1-3</td>
<td>Simulation, optimization and dynamic state response of single VCR system</td>
</tr>
<tr>
<td>Yatahanbaba et al. (2015)</td>
<td>R1234yf, R134a R134a</td>
<td>Air</td>
<td>5</td>
<td>Theoretical</td>
<td>10-15</td>
<td>Exergy analysis of VCR system with two evaporators</td>
</tr>
<tr>
<td>Potier and Hrnjak (2015b)</td>
<td>R1234yf, R134a, R410A, R717</td>
<td>Air</td>
<td>5</td>
<td>Theoretical</td>
<td>4</td>
<td>Optimization of subcooling of single VCR system</td>
</tr>
<tr>
<td>Sánchez et al. (2017)</td>
<td>R1234yf, R134a R134a</td>
<td>Air</td>
<td>0</td>
<td>Theoretical</td>
<td>0.5-0.8</td>
<td>Energy performance evaluation of single VCR system</td>
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<tr>
<td>Yang et al. (2017)</td>
<td>R1234yf, R22, R410A</td>
<td>Water</td>
<td>-10 to 10</td>
<td>Experimental</td>
<td>2-12</td>
<td>Drop-in tests of single VCR system with variable speed compressor</td>
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<td>Mendoza-Miranda et al. (2018)</td>
<td>R1234yf, R134a</td>
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</tr>
<tr>
<td>Sierras and Santos (2018)</td>
<td>R1234yf, R134a</td>
<td>Air</td>
<td>5</td>
<td>Theoretical/Economic</td>
<td>1.5</td>
<td>Energy and energy analysis of cascade VCR system</td>
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<tr>
<td>Sent et al. (2019)</td>
<td>R1234yf, R134a, R22, R1270, R290, R711 in the high-temperature cycle</td>
<td>Air</td>
<td>-20 to 0</td>
<td>Theoretical</td>
<td>2.5</td>
<td>Drop-in of single VCR system</td>
</tr>
<tr>
<td>Illas-Gómez and García-Cascales (2019)</td>
<td>R1234yf, R134a</td>
<td>Water</td>
<td>0-5</td>
<td>Experimental</td>
<td>0.04-0.1</td>
<td>Oil-free single VCR system</td>
</tr>
</tbody>
</table>
7. Ejector refrigeration systems

The use of ejectors in the refrigeration cycles is an effort made by researchers and companies with the purpose of reducing energy consumption or making more efficient equipment. Different types of cycles can be designed using ejectors as compression/pumping device or as expansion device. Table 2 presents the studies about performance of R1234yf in Ejector refrigeration (ER) systems. The investigations show the R1234yf has greater improvement than other fluids when it is used in ER system compared with conventional VCR systems.

Table 2. Studies about R1234yf in ER systems.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Author/Highlight</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Diagram 1" /></td>
<td>Boumaraf et al. (2014) and Lawrence and Elbel (2014)</td>
</tr>
<tr>
<td>Refrigerants: R1234yf and R134a</td>
<td></td>
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<tr>
<td>In both cases, the new cycle has a remarkable improvement in COP over the conventional cycle for the same cooling capacities of the two evaporators. The ER system showed the maximum COP improvement of 12% with R1234yf and 8% with R134a.</td>
<td></td>
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<tr>
<td><img src="image2.png" alt="Diagram 2" /></td>
<td>Li et al. (2014) and Atmaca et al. (2017)</td>
</tr>
<tr>
<td>Refrigerants: R1234yf and R134a.</td>
<td></td>
</tr>
<tr>
<td>Similar COP for both fluids in ER system. The COP improve from 8.47% to 23.29% compared with VCR system.</td>
<td></td>
</tr>
<tr>
<td><img src="image3.png" alt="Diagram 3" /></td>
<td>Milazzo and Rocchetti (2015) and Fang et al. (2017)</td>
</tr>
<tr>
<td>Refrigerants: R1234yf, R134a, and eight other fluids.</td>
<td></td>
</tr>
<tr>
<td>Milazzo and Rocchetti (2015) concluded that the lowest COP values belonged to R134a, R1234ze and R1234yf, in the generator temperature range of 100 to 120°C. Fang et al. (2017) designed a new ejector and reported that R1234yf appears to be a good candidate for drop-in replacement of R134a in the ER system.</td>
<td></td>
</tr>
<tr>
<td><img src="image4.png" alt="Diagram 4" /></td>
<td>Yan et al. (2016)</td>
</tr>
<tr>
<td>Refrigerants: R1234yf and R134a.</td>
<td></td>
</tr>
<tr>
<td>The system COP, heating capacity and heating exergy output could be improved by 15.3%, 38.1% and 52.8% over the conventional heat pump system, respectively.</td>
<td></td>
</tr>
</tbody>
</table>
Expósito et al. (2017)
Refrigerants: R1234yf, R134a and R600a.
The R600a and R1234yf have increased the COP by up to 26% in these configurations.

Zhang and Cheng (2017; 2017)
Refrigerants: R1234yf, R134a and three other fluids.
R1234yf had the best performance between them. With evaporation and condensation temperatures of 10 °C and 30 °C, the optimal generator temperature was 78.4 °C.

Xu et al. (2018)
Refrigerants: R1234yf and 15 other fluids.
Considering both the performance of ER and VCR systems, R134a, R1234ze, R152a, and R600a were promising, and R1234yf was not recommend.

Li et al. (2018)
Refrigerants: R1234yf, R134a and R141b in the ER sub-system
The VRC sub-system used R1234yf as a refrigerant. The best performance was for the system working with R141b/R1234yf.

Rostamnejad and Zare (2019)
Refrigerants: R1234yf and five other fluids.
R1234yf had the worst performance and this fluid was not recommended for configuration studied. The best fluid was R1234ze.
Refrigerants: R600a, R1233zd(E) and R601a for VVER cycle and R290, R152a, R1234ze(E) and R1234yf for LVER.

The best case was R600a-R152a in VVER-LVER cycle. R1234yf was the worst fluid.

8. Conclusion

One of the current problems that refrigeration systems face is using refrigerants with high GWP values. Among them, R134a stands out, which is still used in several applications. Due to the restrictions of the European F-gas, alternative refrigerants have been developed and evaluated. In the last decade, R1234yf has been studied extensively as a replacement for R134a. Thus, this paper has presented a review of the most relevant applications on the use of R1234yf as a replacement for R134a. The review showed theoretical and experimental comparisons between both refrigerants in various systems such as: mobile and residential air conditioning, air and water heat pump, domestic refrigerator and freezer.

Among the topics reviewed, it can be highlighted that R1234yf represents an environmentally viable alternative due to its low GWP. However, almost all applications require improvements in operating conditions of the vapor compression cycle (i.e. subcooling), including an internal heat exchanger (IHX), or optimization of cycle components (i.e. size of condenser, rotation speed of compressor). With these strategies, the system can have the same or a better overall efficiency with R1234yf as compared to R134a. The applications with good acceptance for R1234yf energy performance are in MAC systems and other small-sized devices that commonly use R134a. In addition, R1234yf has compatible behavior in refrigeration systems that use an ejector such as compression/pumping device or expansion device. R1234yf is not recommended to replace with R410A because the heating and cooling capacities are low compared with the other low GWP alternatives. However, R1234yf can be suitable for new design of heat pumps.
Finally, it can be said that R1234yf is not recommended for drop-in of R134a system. The R1234yf has some compatibility problems with lubricants developed only for R134a, thus new PAG oils must be used. Some security features should be implemented in new systems to take into account the low flammability of R1324yf. Within the years 2010 to 2019, the performance of R1234yf in HACR systems was comprehensively tested by researches. For this reason, nowadays the tendencies are to use the R1234yf as a part of HFO/HFC mixtures, which makes a low GWP refrigerant instead of using R134a, R404A and R410A, in systems with medium and high heating/cooling capacities where the F-Gas Regulation allows fluids with GWP<750.

References


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Tanaka, K., Higashi, Y., 2010. Thermodynamic properties of HFO-1234yf (2,3,3,3-


