Eco Cities (2023) Volume 4 Issue 1
doi: 10.54517/ec.v4i1.2283

ORIGINAL RESEARCH ARTICLE

The utilizability of non-flammable R471A with low-GWP in air-conditioning systems

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ABSTRACT

The utilizability of non-flammable refrigerant R471A with low-GWP is theoretically investigated in an air-conditioning system. In this context, R410A, R32, and R471A are compared for the evaporation temperatures of 4, 8, and 12 °C with the condenser temperatures of 40 and 50 °C. The results indicate that both the mass flow rate and power consumption of R471A are higher compared to R410A and R32. Although COP of R471A is determined to be smaller than R410A and R32 by about 19% and 22%, R471A can satisfy the restrictions for air-conditioning systems due to its considerable low-GWP compared to R410A and R32 (GWP of R471A is lower by 78% and 93% in comparison with R32 and R410A, respectively). Hence, it should be possible to suppress global warming through the reduction of carbon emissions as a result of using R471A in these systems. Additionally, since R471A is non-flammable, it can be safely used for systems requiring a high amount of refrigerant charge without violating the restrictions.

***Keywords**:* R471A; carbon reduction; air-conditioning system; low-GWP refrigerant; non-flammable refrigerant

1. Introduction

The effects of global warming and climate change have become more noticeable in the last few years. One of the reasons for the global temperature increase is due to refrigerants. Although the effect of refrigerants on global warming is not substantial, the prevention or reduction of this effect is important[1]. In this context, hydrofluorocarbons (HFCs) were planned to be phased out gradually in the market by 2045, according to the Kyoto Protocol[2]. However, early implementation of this protocol could only be achieved by developed countries. Economy, flammability, low-global warming potential (GWP), stability, critical temperature, and toxicity criteria are considered for determining suitable refrigerants[3]. Hydrofluoroolefins (HFOs) can be proposed as promising low-GWP refrigerants that may be used in pure or mixture form[4].

According to the ASHRAE safety classification, A2L class HFOs are mildly flammable refrigerants. Therefore, it may be appropriate to mix HFC/HFO blends while conducting an optimization between flammability and GWP. In this context, the refrigerant R471A may be a suitable choice since it has not only a GWP value of 148 but also a safety class of A1. R471A is a non-flammable, HFO-based refrigerant that does not deplete the ozone layer. It is a blend of the HFOs of R1234ze(E) and R1336mzz(E), and the fire

ARTICLE INFO
Received: 11 February 2023 | Accepted: 30 March 2023 | Available online: 16 April 2023

CITATION
Devecioğlu AG, Oruç V, Taneli T. The utilizability of non-flammable R471A with low-GWP in air-conditioning systems. *Eco Cities* 2023; 4(1): 2283. doi: 10.54517/ec.v4i1.2283

extinguishing agent (HFC-227ea) with amounts of 78.7%, 17%, and 4.3%, respectively. It contributes to reducing carbon footprints through its low GWP value. It can be used as a replacement refrigerant for medium-temperature applications. According to EU F-Gas regulations, it is forbidden to use a refrigerant with GWP > 150 in new commercial refrigerators and freezers since 1 January 2022[5].

In the available literature, the alternatives to R410A—R32, R452B, R454B, and R466A—were compared in terms of energy and exergy for two-speed heat pump models[6]. The use of L41b in an air source heat pump working with R410A has been investigated. COP reductions were found to be 2.3%–10.1% compared to R410A[7]. R134a and its three low-GWP alternatives, R513A, R516A, and R1234yf, were compared in refrigerating and heating systems[8]. The highest heating capacity was seen to occur for the R513A case, while the lowest amount was determined for the R516A case in heating mode. 22 different R32-based mixtures were investigated as alternatives to R410A[9]. The cooling capacity of all 22 alternative mixtures was slightly higher than R410A, while their COP value was found to be about 10% lower than R410A. Both the cooling capacity and COP of R32 are higher than R410A; however, it is flammable. Also, its GWP value is not too low, which can be considered a disadvantage. R410A was compared with R32, R446A, DR5, and L41a in a heat pump[10]. It was expressed in the study that the energy efficiency ratio (EER) values of R32 and DR5 were better than R410A. The best substitutes for commonly used refrigerants and their mixtures for air conditioning systems were investigated. R152a/R1234ze(E) mixture (70%/30%) has been suggested as the best refrigerant for air-conditioning systems due to its high COP value and economic cost[11]. Further, previous studies dealing with low-GWP alternatives to R410A can be found in the available literature[12–14].

In this study, it is aimed to theoretically compare the energy performances of non-flammable R471A (GWP = 148) with R410A and R32 for air-conditioning systems at different condenser and evaporator temperatures. The use of non-flammable refrigerant with low-GWP will contribute to reducing greenhouse gas formation and carbon emissions.

2. The investigated refrigerants

The GWP values and safety classification of the refrigerants used for refrigeration and air conditioning systems are given in **Table 1**. The GWP of R471A is lower by 93% and 78% compared to R410A and R32, respectively. Note that R471A and R410 are non-flammable, but R32 is classified as mildly flammable by ASHRAE Standard 34.

Table 1. Composition, GWP and safety classification of the studied refrigerants.

Refrigerants	Composition	Mass fraction (%)	Safety classification	GWP
R471A	R1234ze(E)/R1336mzzE/R227ea	78.7/17/4.3	A1	148
R410A	R32/R125	50/50	A1	2088
R32	R32	100	A2L	675

The pressure-enthalpy (*P-h*) diagram of the refrigerants can be seen in **Figure 1**. The critical temperatures of both R410A and R32 are higher than R471A. Obviously, for a given pressure, the latent heat of vaporization, or, in other words, the cooling capacity, which is the enthalpy difference between the outlet and inlet of the evaporator, is the highest for R32, followed by R410A and R471A.

The critical temperature and pressure values of the refrigerants are given in **Table 2**. Since the vapor pressure will be low when the critical temperature is high, the volumetric cooling capacity will be smaller for the refrigerants with a high critical temperature.

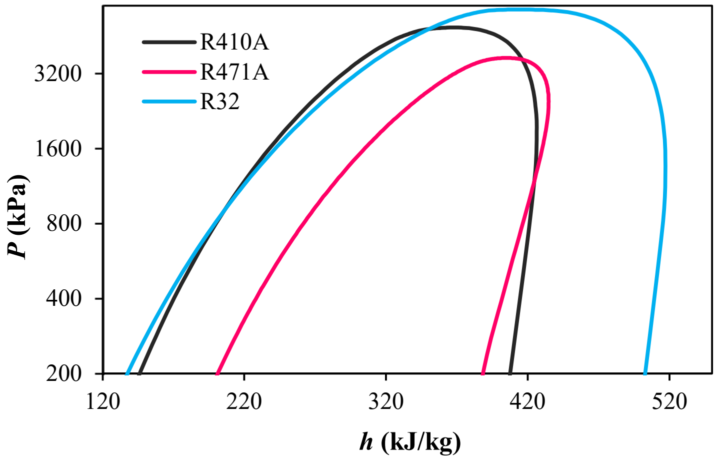

Figure 1. Pressure-enthalpy diagram of the investigated refrigerants.

Table 2. Some thermodynamic properties of the investigated refrigerants[15].

Property	R471A	R410A	R32
Normal boiling point (°C)	–16.6	–51.6	–51.7
Critical temperature (°C)	118.7	72.1	78.1
Critical pressure (kPa)	3699	4926	5782
Liquid density (kg m^{-3})	1199.4	1058.6	961
Vapor density (kg m^{-3})	17.85	66.0	47.3
c_p likit (kJ kg^{-1} K^{-1})	1.3	1.7	1.9
c_p vapor (kJ kg^{-1} K^{-1})	0.9	1.4	0.8
k liquid (mW m^{-1} K^{-1})	73.4	89.2	125
k vapor (mW m^{-1} K^{-1})	13.5	15.7	13
Viscosity likit (µPa s)	207.7	118.0	116
Viscosity vapor (µPa s)	11.8	13.7	12.6
Latent heat (kJ kg^{-1})	197.3	272.9	382

3. Theoretical method

The theoretical study has been conducted for a basic refrigeration cycle. The system with the basic components and its pressure-enthalpy diagram are demonstrated schematically in **Figure 2**.

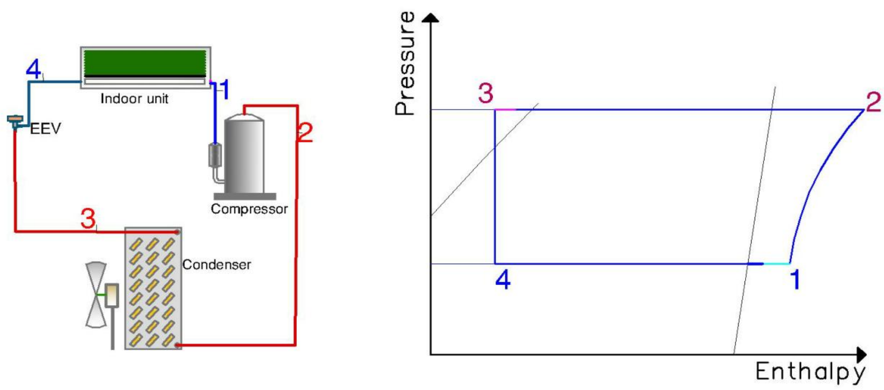

Figure 2. A schematic demonstration for the vapor-compression refrigeration cycle.

The system parameters assumed for the theoretical analysis are presented in **Table 3**. It has also been assumed that the system works in a steady-state regime; the pressure and heat loss through the system components and pipes are neglected; the condenser and evaporator don't consume energy; and the changes in kinetic and potential energy are neglected. The selected evaporation temperature values are widely used in real air conditioners. Similarly, the outdoor temperatures (in hot climates) range from 33 °C to 43 °C; hence, the investigated condenser temperature values in **Table 3** simulate real-world conditions.

Table 3. System parameters considered in the theoretical investigation.

Cooling capacity, Q_e (W)	3000
Evaporation temperature, T_e (°C)	4/8/12
Condensing temperature, T_c (°C)	40/50
Superheat (K)	8
Sub-cooling (K)	3
Isentropic efficiency, η_s (%)	70

The mass flow rate ($\dot{m}$) of refrigerant circulating in the system in kg/s can be expressed as

$$\dot{m} = \frac{Q_e}{(h_1 - h_4)} \tag{1}$$

where Q_e is the cooling capacity in kW, and h the enthalpy values of the refrigerant in kJ/kg. The subscript numbers define states of the cycle, as shown in **Figure 2**. The power consumption of the compressor (W_{el}) in kW is defined as

$$W_{\mathrm{el}} = \dot{m}(h_2 - h_1) \tag{2}$$

Moreover, the isentropic efficiency (η_s) of the system can be computed as

$$\eta_s = \frac{(h_2' - h_1)}{(h_2 - h_1)} \tag{3}$$

where h' corresponds to the enthalpy for the case where entropy stays constant through exit and inlet states of the compressor. The energy performance of any refrigerating or air-conditioning system is expressed by the coefficient of performance (COP), which is defined as the ratio of cooling capacity to the power consumption of compressor[16]:

$$\mathrm{COP} = \frac{Q_e}{W_{\mathrm{el}}} \tag{4}$$

4. Results and discussion

The distribution of mass flow rate ($\dot{m}$) for the covered evaporation temperature (T_e) and condenser temperature (T_c) is indicated in **Figure 3**. Obviously, $\dot{m}$ increases for increasing T_c and decreasing T_e values. Furthermore, $\dot{m}$ values of R410A and R32 are determined 15% and 45%, respectively, lower than R471A. Generally, R471A causes higher amount of $\dot{m}$ for the covered cases.

The result for power consumption of the compressor (W_{el}) is plotted in **Figure 4**. Clearly, W_{el} is seen to be reduced when T_e increases; it is increased for higher T_c value. It can be found from **Figure 4** that W_{el} of R471A is higher about by 23% and 29% compared to R410A and R32, respectively.

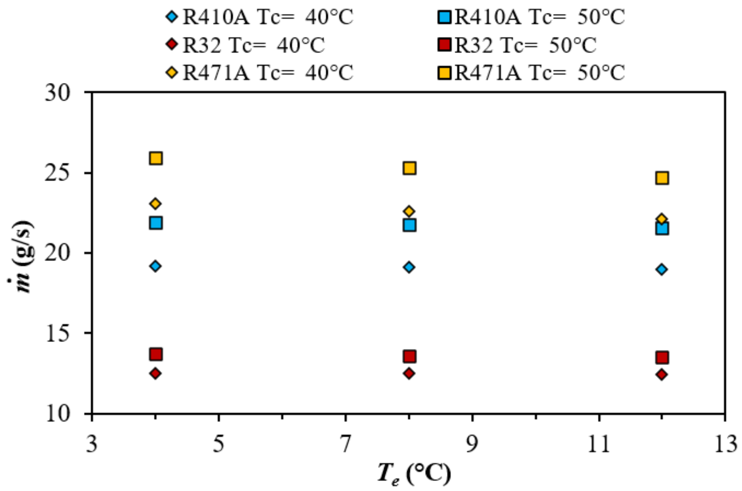

Figure 3. The variation of mass flow rate with evaporation temperature.

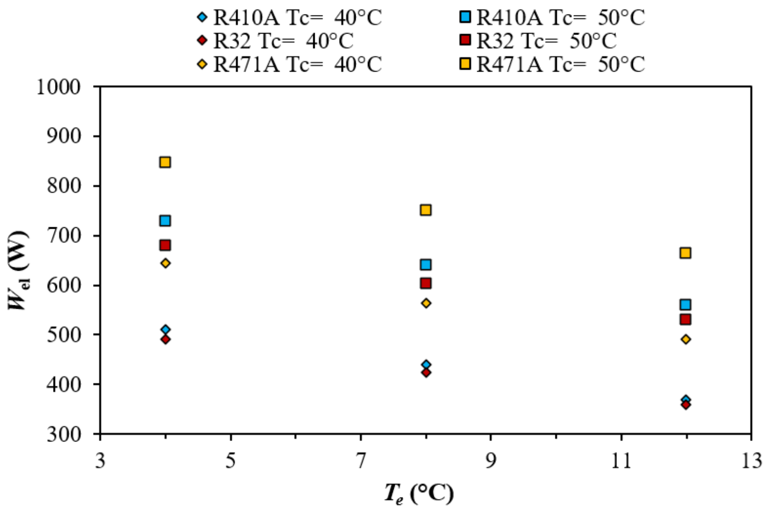

Figure 4. The variation of power consumption with evaporation temperature.

The behaviour of COP can be examined in **Figure 5** for the investigated cases. First of all, COP increases as T_e increases at a T_c value for a refrigerant. Similarly, COP is reduced as T_c increases at a T_e case for a refrigerant. Evidently, COP of R471A is smaller than both R410A and R32 and the highest COP occurs for R32 for a given case of T_c and T_e. Note that the lower power consumption of R410A and R32 (**Figure 4**) causes higher COP values in comparison with R471A. As a result, COP of R471A is computed lower about by 19% and 22% than R410A and R32, respectively. Note that the refrigerating effect (i.e., cooling capacity) decreases for the refrigerant with low latent heat of vaporization, and therefore $\dot{m}$ increases. The results are observed to develop in this manner for R471A. Then W_{el} is increased for greater $\dot{m}$ values. Hence, COP is reduced as normally expected for a constant cooling capacity value.

5. Conclusion

R410A is used for air-conditioning and heat pump systems. On the other hand, mildly flammable R32 with a lower GWP is also being widely used, especially in small-capacity air conditioners. Absolutely, there is an effect of regulations in this situation. In this study, the utilization of non-flammable R471A with low-GWP as an alternative to R410A and R32 is investigated theoretically. Although there is no inconvenience in using R471A directly as a substitute for R410A, the heat exchanger of the evaporator should be made larger,

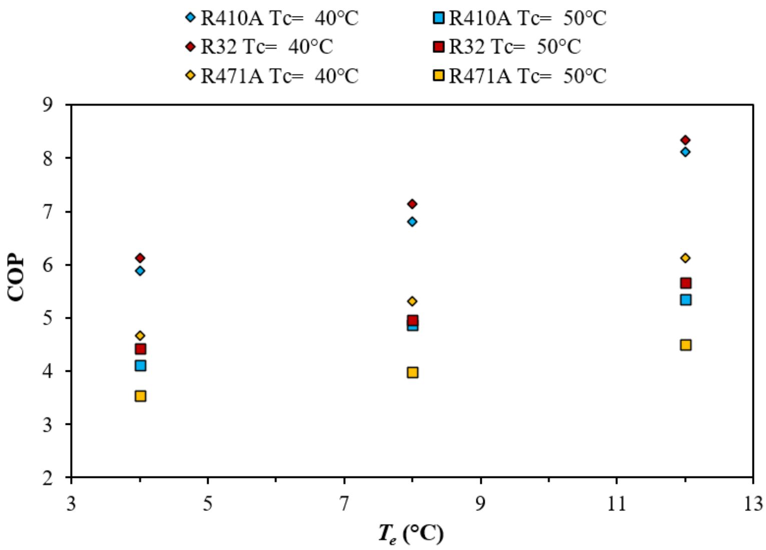

Figure 5. The distribution of COP for the studied cases.

especially to compensate for the decrease in cooling capacity. Similarly, the condenser heat exchanger should be enlarged to enhance the condenser capacity. The increase in mass flow rate may also cause you to use larger pipe diameters. Furthermore, the same compressor oil can be utilized. All these advantages and disadvantages should be evaluated together, and a recommendation should be made for the selection of the of the optimum refrigerant. In this respect, R471A reveals that it is a refrigerant that can be preferred in the short term. The basic results can be recalled as

- The mass flow rate and power consumption of R471A are higher than both R410A and R32.
- COP of R471A is lower than other two refrigerants.
- GWP of R471A is lower by 93% and 78% compared to R410A and R32, respectively.
- Since R471A is non-flammable, it can also be used for the applications requiring higher amount of refrigerant charge without violating the restrictions.

Author contributions

Methodology, VO and TT; software, AGD; investigation, AGD and TT; resources, AGD and TT; writing—original draft preparation, AGD, VO and TT; writing—review and editing, AGD and VO. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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