Theoretical study for an air -water heat pump with low gwp refrigerant

Studiu teoretic privind agenti frigorifici cu gwp scazut utilizati la pompa de caldura aer-apa

Gratiela Tarlea [1], Mioara Vinceriuc [2], Viorel Constantin[1]

[1] Technical University of Civil Engineering of Bucharest
Pache Protopopescu Boulevard, no.66 Bucharest Romania
E-mail: gratiela.tarlea@gmail.com

[2] Romanian General Association of Refrigeration
Pache Protopopescu Boulevard, no.66 Bucharest Romania
E-mail: vinceriuc@gmail.com

DOI: 10.37789/rjce.2024.15.1.7

Abstract. *The paper shows alternative refrigerant mixtures for R134a that can be used in heat pump air-water systems with ecological alternatives R1234yf, R452A and R513A. In the article it is shown the calculation of COP with Chemours Refrigerant Expert software for single stage heat pump cycle. As a result of the new legislative strategy at international level regarding the refrigerants, in the following years must be find ecological alternatives in terms of global warming potential (GWP) in according with F-gas Regulation.*

Key words: heat pump, refrigerant, GWP, COP, TEWI factor

1. Introduction

The ecological refrigerants (AF) proposed in this scientific article are chemicals obtained by mixing in different proportions various current ecological refrigerants with one or more natural or synthetic substances that have zero values of ozone depletion potential (ODP) and low global warming potential (GWP).

At the international level in the last 10 years from the point of view of AF study [1], a lot of research has been done in the field, taking into account the severe restrictions stipulated by law: Kyoto Protocol, Regulation (EU) 517/2014, Paris Agreement / 2015, Kigali Amendment / 2016 / Montreal Protocol [2,3,4,5].

In 1987 a comprehensive agreement was developed to phase out production and

use of CFC's. Montreal Protocol was considered one of the most successful international implemented agreements. Climate change was attributed directly or indirectly to human activity which alters the composition of global atmosphere.
In Figure 1 it is shown the Ozone on October 1 for various years between 1979 and 2021 the view being made by NASA TOMS [6,7].
Global warming and ozone depletion are two separate environmental problems, but finally are in connection.

In the early 1970's that the Earth's ozone layer had become thinner so that it could cause damage due to emissions of chemicals known as halocarbons, containing chlorides, fluorides, bromine, carbon and hydrogen.

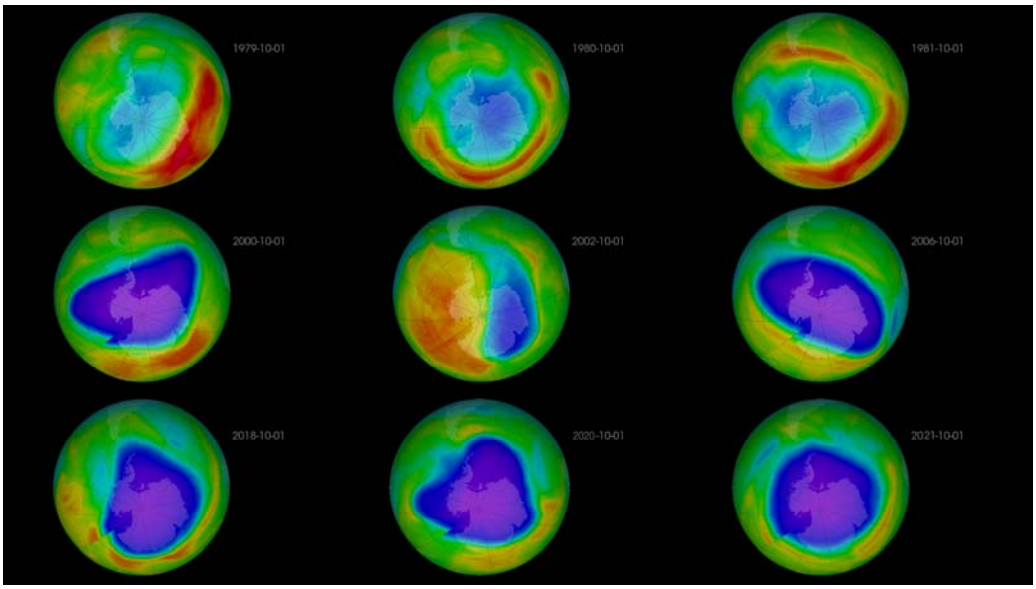

Fig.1. The ozone on October 1 for various years between 1979 and 2021 [6,7]

Romania signed Kyoto (1997) and Montreal Protocol (1987) and in the same time as a new member of EU has obligations to respect environmental legislation [9]. CFC's have been replaced in many applications with HFC's (hydrofluorocarbons) and HCFC's (hydrochlorofluorocarbons). Globally, legal regulations have already been developed with great effort to reduce greenhouse gas emissions. In the EU, Regulation no. 517/2014 also known as "F-gases" [3].

2. Thermodynamic properties

In this paper there are presented some proposals as ecological alternatives (R513A, R1234yf, R452B) for the refrigerant R134a [9,10] in according with F-gas Regulations.

R134a has been an extremely useful refrigerant gas in a number of applications. In fact, it is the most common refrigerant gas in mobile air conditioning (MAC)

systems. R134a has a global warming potential (GWP) of 1430. R1234yf is a next-generation HFO refrigerant that combines environmental benefits with excellent cooling performance.

R-452B is a non azeotropic blend containing refrigerants from the hydrofluoro-olefin (HFO) family, designed to replace in new installations, particularly in heat pumps, commercial rooftop air conditioners, VRF systems and medium pressure liquid coolers (air/water chillers).

R-513A is an approved low-pressure substitute with negligible temperature glide that has been used in a wide variety of medium-temperature commercial refrigeration applications. With its A1 classification, it provides the lowest possible GWP (631) among available non-flammable refrigerant alternatives and presents no risk of ozone depletion. Compared to R-134a, R-513A provides a 56% reduction in GWP. Thermodynamic properties of these simulations were done using software RefProp.

Table 1

Thermodynamic properties and safety group comparisons alternatives for R134a [9,10,11,12]

Refrigerant	R452B	R134a	R513A	R1234yf
Safety group	A2L	A1	A1	A2
Critical temperature [°C]	79.67	101.06	97.67	94.7
Critical pressure [bar]	50.57	40.59	36.80	33.82
Critical density [kg/m^3]	438.36	511.9	490.89	475.55
Molar mass [kg/kmol]	63.52	102.03	108.43	114.04

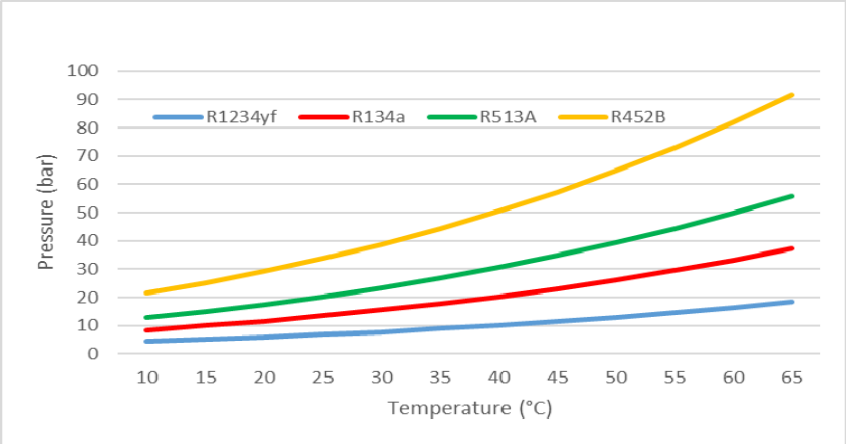

Fig.2. Pressure refrigerants vs. temperature

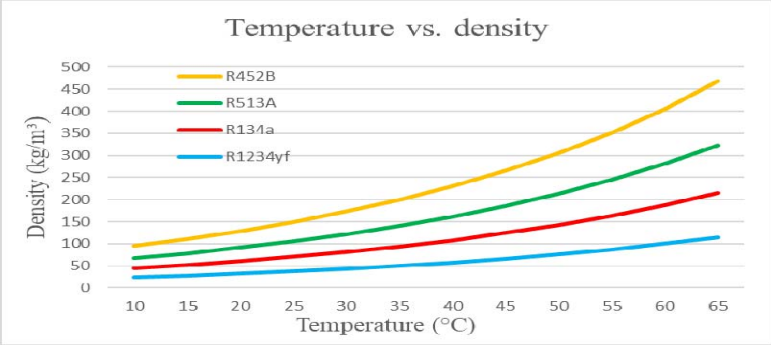

Fig.3. Vapour Density vs. temperature

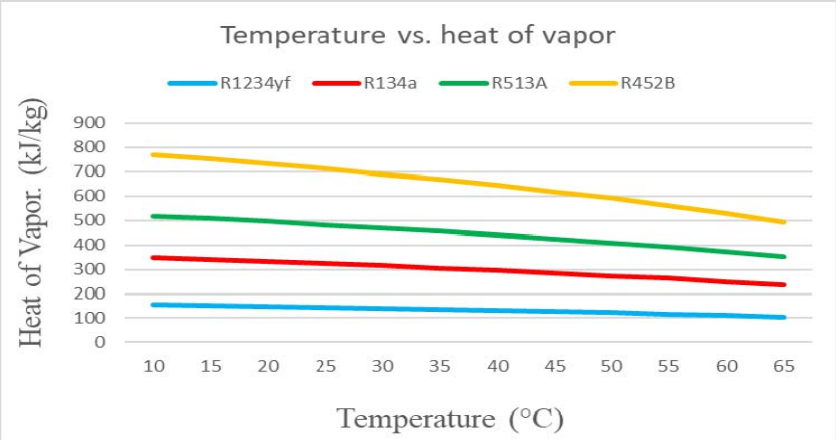

Fig.4. Heat of vaporization vs. temperature

3. Ecologycal And Energy Efficiency Analysis

The study case has a refrigeration capacity of 1,742 kW. The temperature of vaporisation for the refrigeration system is +10°C and condensation temperature is +63°C. The COP for the heat pump systems was calculated with Chemours Refrigerant Expert software [13] and TEWI factor [14] was calculated in according with UE legislation.

The total global warming potential method calculation (GWP) of Ecological Alternative was done in according with REGULATION (EC) No 842/2006 (from 1 January 2015 REGULATION (EC) No 517/2014).

The TEWI factor was determinate taking account of the Standard SR EN 378-1. The calculation relationship for TEWI is presented in detail in standard SR EN 378-1 / 2017 [14] and takes into account the amount of refrigerant in the installation, the amount of expandable refrigerant in the insulation, the amount of CO2 escaped into the atmosphere to produce the energy unit of the refrigeration system, the energy consumed for operating the refrigeration system during its operation, the efficiency

and tightness of the refrigeration system, the production mode of the electric energy of the refrigeration system, the lifetime of the refrigerant.

To calculate TEWI factor were following assumptions: mass for Alternative (R1234yf - 0,725kg, R452B – 0,668 kg, R513A - 0,748 kg) and 0,780 kg for R134a. The refrigeration system operated 24 hours per day, 365days per year [15,16,17,18,19]. The leakage of refrigerant was 8% from refrigerant charge with a recovery factor of 0.75. Operating time of the system was 15 years, and CO2 emission was 0.6 kg / kWh.

Table 2

The theoretical results for factor TEWI of the ecological alternatives (R454A, R452A, R449A) for R134a[14,18,19]

Refrigerant	R452B	R134a	R513A	R1234yf
GWP	676	1430	631	4
L	0.053432	0.0624	0.059832	0.057968
n	15	15	15	15
m	0.668	0.780	0.748	0.725
Recovery factor	0.75	0.75	0.75	0.75
Eannual	1221.48	1252.8	1033.56	1879.2
β	0.6	0.6	0.6	0.6
TEWI tones of CO2	48.77	44	45.62	47.31

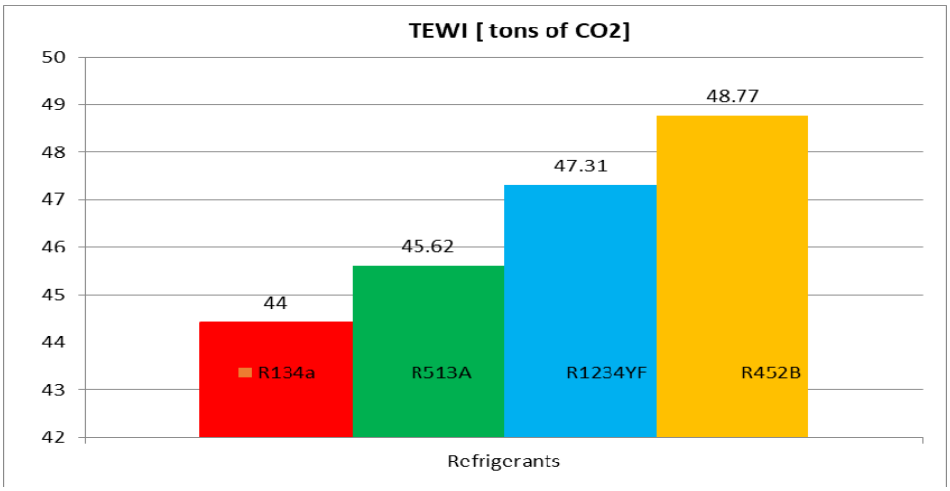

Fig.5. TEWI Factor

Calculation of COP and EER were done using Chemours Refrigerant Expert software.

Table 3

Efficiency Analysis of refrigerant retrofit [13]

Refrigerant	R452B	R134a	R513A	R1234yf
COP	2.85	3.22	3.05	2.92
EER	1.85	2.22	2.05	1.92

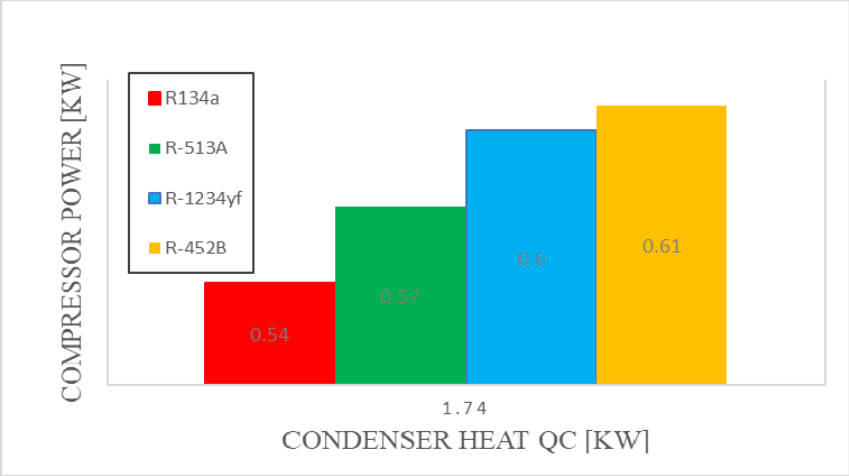

Fig.6. Condenser Heat vs. Compressor Power

4. Conclusions

In conclusion, from an ecological point of view, the refrigerant must be chosen so that according to the regulations of the current legislation, it has zero ODP and GWP low and TEWI as small as possible.

Regarding the safety requirements that refrigerants must meet, they are provided by standards both at national and international level and refer to: flammability, danger of explosion, toxicity, danger of biological contamination and the effects they may have. have on the products to be cooled. The location of the refrigeration installation (dwellings, public places, industrial areas) as well as the amount of refrigerant contained in the installation must also be taken into account.

After determinations of the COP with Chemours Refrigerant Expert software it could be observed (Table 2) that the alternative R513A is the best alternative in comparison with R1234yf and R452B refrigerants and a best option for R134a replacement. From an environmental perspective of lower global warming potential (GWP) alternative R513A has the advantage of 56% GWP than R134a.

References

[1] Mioara Vinceriuc, „Research regarding the contribution of refrigeration, air conditioning and heat pump systems to global warming", PhD Thesis, Technical University of Civil Engineering of Bucharest, 2021

[2] Kyoto Protocol to The United Nations Framework Convention on ClimateChange , United Nations Frame Work Convention on Climate Change, 1997

[3] Regulation (EU) no 517/2014 of the European Parliament and of the council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014R0517

[4] The Montreal Protocol on Substances that Deplete the Ozone Layer (2000), Secretariat for the Vienna Convention for the Protection of the Ozone Layer & the Montreal Protocol on Substances that Deplete the Ozone Layer.

[5] Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer Kigali, 15 October 2016
[6] *** https://earthobservatory.nasa.gov/world-of-change/Ozone/show-all.
[7] *** https://svs.gsfc.nasa.gov/31201
[8] Calm, J. C., G. C. Hourahan, A. Vonsild, D. Clodic, and D. Colbourne - 2014 Report of the refrigeration, air conditioning, and heat pumps technical options committee, Ch. 2: Refrigerants. United Nations Environment Programme (UNEP) Ozone Secretariat, Nairobi, ozone.unep.org /en/assessment-panels/technology-and-economic-assessment-panel, 2015
[9] Ţârlea G. M., Vinceriuc M., Zabet I., Ţârlea A., R513A AND R1234yf ALTERNATIVE REPLACEMENT OF R134a REFRIGERANT, autori publicata la a XVII-a Conferinta nationala de Termotehnica, cu participare internationala, noiembrie 2016, Universitatea Transilvania Brasov, categoria B+.
[10] Ţârlea G. M., Vinceriuc M. Alternative ecologice ale agentului frigorific R134a, Revista de Instalatii , I.S.S.N. 2457 – 7456, AIIR 2018, Editura Matrix Rom; NR 4/2018;
[11] Ţârlea G. M., Vinceriuc M., Zabet I., Ţârlea A., Water-Air Heat Pump Ecological and Energy - Efficiency Study Case SME Cluj 2017
[12] The National Institute of Standards and Technology (NIST) - Refprop version 8.0, USA, 2007
[13] *** Chemours Refrigerant Expert software version 1
[14] EN378- Refrigerating systems and heat pumps - safety and environmental requirements, 2016, European standard
[15] Vinceriuc M., Ţârlea G , Tarlea A., Air-Water-Heat Pump with low GWP refrigerant, Paper presented at CLIMA 2019 - the REHVA HVAC World Congres and publish in Romanian Journal of Civil edited by MATRIX ROM Volumul 10 (2019), Numărul 3, ISSN 2068-3987, pp. 296-298, Proceedings of CLIMA 2019;
[16] Mioara Vinceriuc, Gratiela TARLEA- Mathematical And Experimental MV3TN Heat Pump Validation, 2nd Conference of the UTCB Doctoral School, 25th of October 2019, Hydrotechnics Faculty, https://sd.utcb.ro/dsc-2019/programme/
[17] Air-Water Heat Pump Modelling, Gratiela Tarlea, Mioara Vinceriuc, Ion Zabet- 50-International Hvac&R Congress And Exhibition (KGH), 2019, Belgrad;
[18] ASHRAE – HVAC Systems & Equipment, 2020
[19] AHRI - Specification for fluorocarbon refrigerants. Standard 700-2011. Air-Conditioning, Heating, and Refrigeration Institute, Arlington, VA, 2011