Energy Efficient Refrigeration Solutions

Eng. **Adrian MIHAI[1],** Assoc. Prof. PhD. Eng. **Adriana TOKAR[2,*],**
Assoc. Prof. PhD. Eng. **Mihai CINCA[2],** R. A. PhD. student Eng. **Daniel MUNTEAN[2]**

[1] Sildor Prod S.R.L., Romania

[2] University Politehnica Timisoara, Romania

* adriana.tokar@upt.ro

Abstract: *The current situation of Fluorinated Greenhouse Gases (F-Gas) Regulation and discussion regarding per- and polyfluoroalkyl substances (PFAS) gases problems with actual refrigerants from refrigeration installations with global warming potential (GWP) higher than 150 units will damage even more the environment. On top of the environment crises, caused by global warming and the Russia-Ukraine war, the prices of the energy increase more than 50%. So, this study shows that actual refrigerants like R404A, R448A, R449A and other refrigerants with GWP higher than 150 can be replaced for long term solution with* CO_2*.*

Keywords: *CO_2, GWP, climate change, environment*

1. Introduction

For the refrigeration field, refrigerants represented a revolutionary discovery, but their contribution to the destruction of the ozone layer and the retention of rising thermal radiation in the earth's atmosphere brings them back to the attention of specialists in the field of environmental protection.
So, in the current context of climate change and in accordance with the new Fluorinated Greenhouse Gases (F-Gas) Regulation that comes to accelerate the reduction of greenhouse gas emissions and to lower the Global Warming Potential (GWP) level from 2,500 units to 150 units starting from January 2024 in new installations, the refrigeration equipment industry must adapt to the new provisions [1].
The impact of the Montreal Protocol, finalized in 1987, which is a global agreement to protect the stratospheric ozone layer by phasing out the production and consumption of ozone-depleting substances (ODS) such as refrigerants, is shown in Fig. 1 [2].

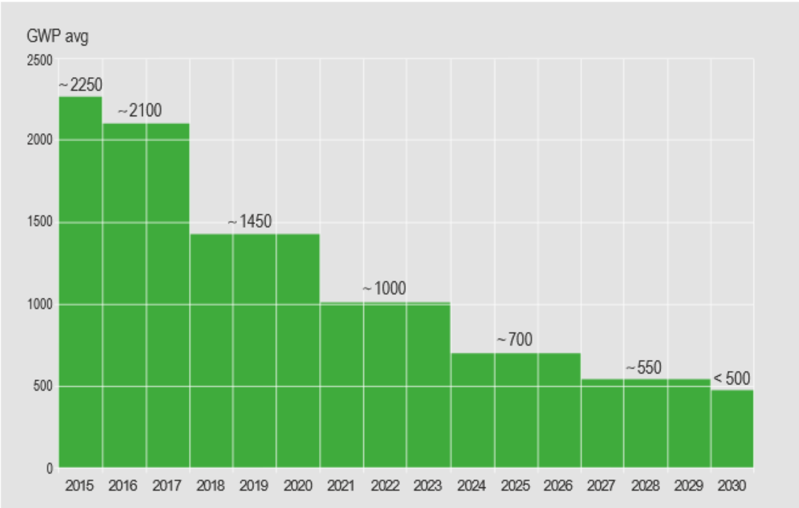


Fig. 1. Average of Global Warming Potential (GWP) [2]

In Fig. 1, the stages of reducing the refrigerant quota were considered as follows:

- 2015 – represents the reference year: 100%;
- 2016-2017 first reduction, to 93%;

- 2018-2020 second reduction, to 63%;
- 2021-2023 third reduction, to 45%;
- 2024-2026 fourth reduction, to 31%;
- 2027-2029 fifth reduction, to 24%;
- 2030 - reduction to 21%.

Also, the cost of electricity has grown considerably, comparatively with the year 2018 (Banat Enel Energie - 0.4785 lei/kWh in 2018, for consumption over 300 kWh, price 1.09 lei/kWh in 2023). In this context, refrigerants with a GWP greater than 150 units will be gradually replaced with those which are under this limit, but all of them are mildly flammable, as one can see in Fig. 2 [3].

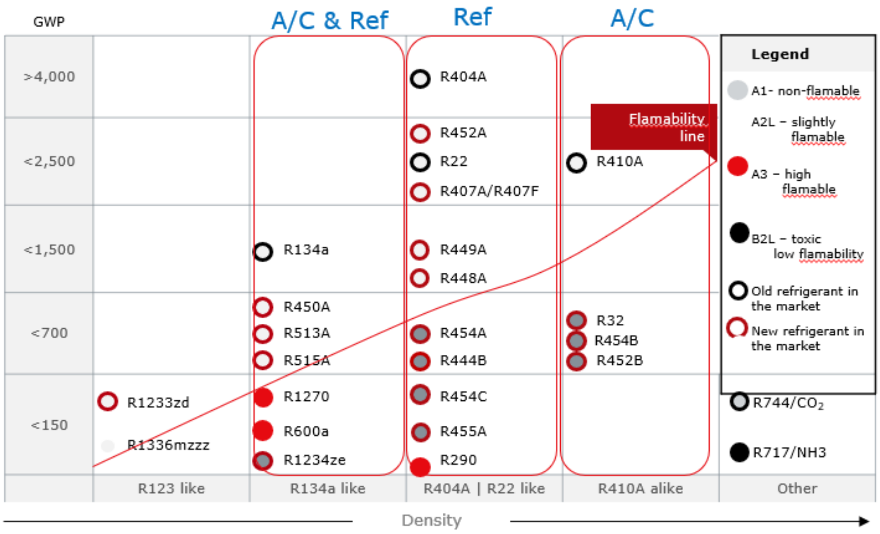


Fig. 2. Refrigerants - Present and future [3]

2. Case study

The study is made for a comparation between one installation with R404A and the new one with CO_2.

Initial conditions:

The space is the small proximity store as is shown in the Fig. 3 and was equipped with:

- vertical refrigerated display cases, 2,700mm x 3 pieces;
- 2 cold rooms, 10 m³ / room.

Fig. 3. Initial store

1 - Condensing unit, 2 - Discharge pipe, 3 - Suction pipe, 4 - Vegetable/fruit room, 4.1 - Separation valves, 4.2 - Solenoid valve, 4.3 – Evaporator, 4.4 - Control panel, 5 - Meat/sausage room, 5.1 - Isolation valves, 5.2 - Solenoid valve, 5.3 – Evaporator, 5.4 - Control panel, 6 - Refrigerated showcase, 7 - Refrigerated showcase, 8 - Refrigerated showcase

These cold consumers are driven by one condensing unit with scroll digital technology model ZXDE-050E-TFD (Fig. 4), which works with refrigerant R404A having an evaporation temperature of -10ºC and GWP = 3,922.

Fig. 4. Data sheet ZXDE-050E-TFD [3]

The performances of the ZXDE-050E-TFD unit at the point of operation are shown in Table 1, and the mechanical and physical characteristics in Table 2 [4].

Table 1: Performance at specified operating point ZXDE-050E-TFD data al 50 Hz [4]

Characteristics	Notation	Unit	Value
Cooling Capacity	Q_C	kW	7.79
Total Power Input	P	kW	4.30
Performance coefficient	COP	W/W	1.81
Current at 400 V	I	A	7.45
Mass Flow	q	g/s	78.10
Heating Capacity	Q_H	kW	11.65
Condensing Temperature	T_c	ºC	46.00
Subcooling	T_{SC}	K	0.00

Table 2: The characteristics and sound conditions for condensing unit Type ZXDE-050E-TFD [4]

Characteristics	Unit	Value
Mechanical and physical		
Condenser/Fan/Type	-	ZXM_2F/60 W
Base mounting (hole dia.)	mm	580 x 388 (12)
Number of fans	pcs	2
Air Flow	m^3/s	1.64
Total Fan Power Input	W	246
Height	mm	1,244
Depth / Width	mm	1,035/447
Suction Diameter	inch	7/8
Liquid Line	inch	½
Suction Type		Cu Type
High Side PS gauge	bar	21
Net Weight	kg	108
Sound		
Mean temperature for refrigeration applications (MT)	°C	-10-0
Sound Pressure at 10 m (MT)	dBA	41
The temperature conditions (Evap./Cond./Suction at freq./speed) for which the noise level of 41 dBA was obtained	°C	-10.0/45.0/20.0 at 50 Hz

After the remodeling the store, the upgraded space is shown in Fig. 5:

- 3 vertical 3750 mm refrigerated showcases, on CO_2;
- 2 cold rooms with CO_2 evaporators, 15 m³/room.

Fig. 5. Updated store
1 - Condensing unit, 2 - Discharge pipe, 3 - Suction pipe, 4 - Vegetable/fruit room, 4.1 - Separation valves, 4.2 - Solenoid valve, 4.3 – Evaporator, 4.4 - Control panel, 5 - Meat/sausage room, 5.1 - Isolation valves, 5.2 -Solenoid valve, 5.3 – Evaporator, 5.4 - Control panel, 6 - Refrigerated showcase, 7 - Refrigerated showcase, 8 - Refrigerated showcase

The new refrigerating installation related to these cold consumers is one condensing unit with scroll inverter model technology OP-UPAC015COP04E (Fig. 6), at 5,263 rpm having a refrigerating power of 16 kW, and an hourly electricity consumption of 9.95 kW; at the evaporation temperature of -10°C, resulting in a COP=1.61 OP-UPAC015COP04E at 2,834 rpm having a refrigeration power of 8 kW, and an hourly electricity consumption of 5.43 kW; at the evaporation temperature of -10°C, resulting in a COP=1.47. The refrigerant CO_2 has GWP =1. The operating conditions for type OP-MPAM005COP04G are presented in Table 3 and selection result - in Table 4 [5].

Fig. 6. Danfoss Optyma iCO_2 P04, OP-UPAC015COP04E [5]

Table 3: Condensing unit CO_2 [5]

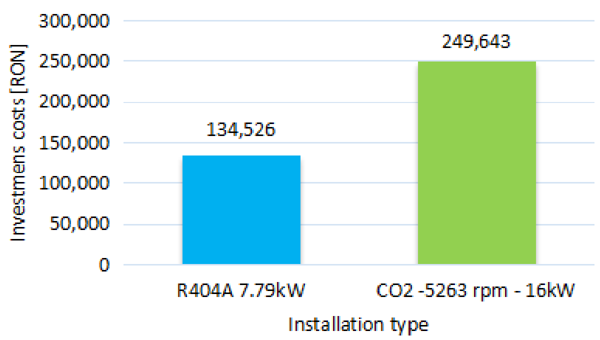
Characteristics	Unit	Value/Type
Operating conditions		
Refrigerant	-	R744
Evaporating dew point temperature	°C	-10
Evaporating pressure	bar	26.49
Useful superheat	K	10.0
Additional superheat	K	0
Return gas temperature	°C	0.0
Ambient temperature	°C	37.0
Subcooling	k	0
Additional subcooling	K	0
Altitude	m	38.4

Table 4: Selection result [5]

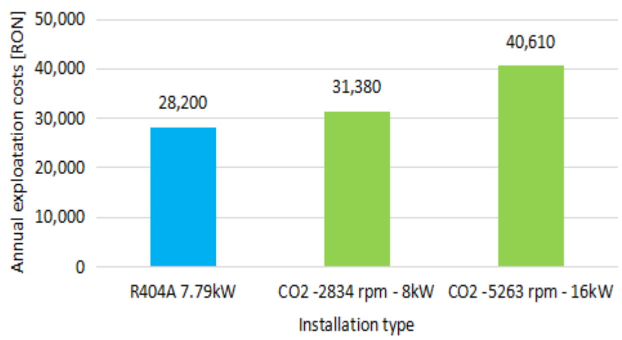
Characteristics	Unit	Value/Type
Selection : OP-UPAC015COP04E,R744-5266 rpm		
Model	-	OP-UPAC015COP04E
Code number	-	114X6003
Compressor model	-	VCO015T4E
Product range	-	Optyma™iCO2
Product version	-	P04
Refrigerant	-	R744
Cooling	kW	16.00
COP cooling	W/W	1.61
Total power	kW	9.953
Frequency	Hz	
Power supply	-	-

3. Comparative analysis

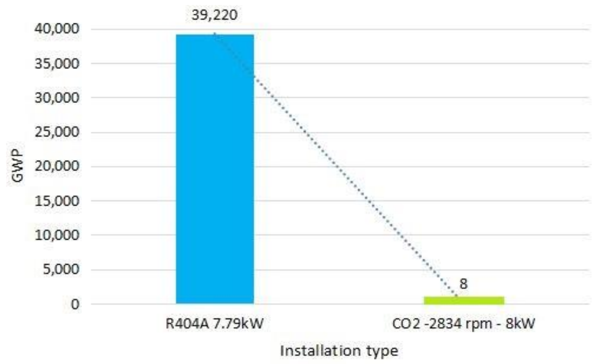
The economic evaluation of the investment, as presented in Fig. 7.a, is observed to be obviously against CO_2. This shows once again that CO_2 technology is more expensive compared to the technology related to R404A components.
When we talk about the operating cost, according to the design conditions in the most unfavorable operating point considered, we notice that the differences are no longer so high compared to that of the investment in equipment. The operating cost of the CO_2 installation becomes comparable to that of the R404A installation (Fig. 7.b).
For evaluation of investment cost, exploitation, and GWP, we take into account the graphs below that show the comparative cost of initial investments (Fig. 7.a), the cost of one year of operation (Fig. 7.b), and in Fig. 7.c, we can see a significant reduction of the GWP (Global Warming Potential) index, which proves that CO_2 has a minimal impact on the environment compared to R404A.



a)



b)



c)

Fig. 7. The investment and exploitation costs (in RON), and the GWP, respectively
a) Investments costs; b) Operating costs; c) GWP

In figure 7.b, one can see that when we compare the two technologies (R404 with CO_2), at the same refrigeration capacity, the operating cost is similar. This comparison is possible because the inverter technology in the unit that works with CO_2 allows the regulation of the refrigeration capacity due to changing the speed of the electric motor. At a speed of 2,834 rpm for CO_2 technology, we get the same refrigeration capacity, but with an additional annual operating cost of 3,180 RON. For doubling the cooling capacity, for CO_2 technology, it is noticed that increasing the speed to 5,263 rpm is much more advantageous compared to using two equipment items to obtain the same cooling capacity. This is highlighted in Fig. 7.b. Thus, using two units at 2,834 rpm for CO_2 technology (similar to units using R404) an operating cost of 62,760 RON (for CO_2) and 56,400 RON (for R404) is recorded, while using only one unit with CO_2 technology, at a speed of 5,263 rpm, an operating cost of 40,610 RON for CO_2 is recorded. Therefore, from a technical-economic point of view, the economy of 22,150 RON for CO_2 technology and 15,790 RON for R404 is an asset for CO_2 technology used at optimal speed. On the other hand, no matter how we look at things, from the point of view of environmental impact, CO_2 technology compared to the usual refrigerants (R404A, R448A, R449A) is more ecological. The CO_2 technology is clearly superior in terms of GWP compared to the R404A refrigerant (Fig. 7.c), which is why it is worth using even if the investment cost is higher.

4. Conclusions

The efficiency of technical solutions has a new challenge raised by environment protection. Due to the high energy prices, it is important to combine several technologies in the same technical solution such as: frequency converter, digital scroll technology, more efficient and less polluting refrigerants such as CO_2, propane or ammonia, the use of primary refrigerant and secondary refrigerant, the use of very efficient EC (Electronically Commutated) fan motors. Installations in operation that have exceeded their useful life can now be replaced with new generation refrigerant installations with almost zero impact on global warming.
Analyzing the working pressures, the current installations with R404A refrigerant have condensing pressures between 15 and 25 bar, and the CO_2 installation has a pressure in the gas cooler of almost 90 bar. These high pressures require more attention when they will be designed, installed, and serviced by personnel qualified to work with CO_2.
Analyzing from the point of view of investment and exploitation costs, it can be noticed that CO_2 becomes more and more efficient with the increase in the refrigeration capacity. From the point of view of reducing greenhouse gases, CO_2 is the solution for the present and possibly for the future. CO_2 may be the natural choice to avoid F-Gas limitations forever, but design, installation and management require vast knowledge and qualification.

References

[1] Kreider, Jan. *Handbook of Heating, Ventilation and Air Conditioning.* London, CRC Press LLC Publishing House, 2001.
[2] Bitzer Kühlmaschinenbau GmbH. ”EU F-Gases Regulation No. 517/2014 Consequences for the refrigeration, air conditioning and heat pump industry”, August 7, 2018. Accessed July 21, 2023. https://cold.world/know-how/eu-f-gases-regulation.
[3] OmniRef Ltd. “Danfoss solutions for commercial refrigeration approved for use with alternate refrigerants R448A, R449A and R452A”, July 2, 2018. Accessed July 21, 2023. http://www.omniref.gr/blog.php?title=Danfoss+solutions+for+commercial+refrigeration+approved+for+use+with+alternate+refrigerants+R448A%2C+R449A+and+R452A&article=1&lang=en.
[4] Copeland Europe GmbH. ”ZXME-050E-TFD-304 - Specifications”. Accessed July 21, 2023. https://www.copeland.com/en-gb/shop/1/copeland-eu-sku-3206669-en-gb.
[5] Danfoss A/S. ”Danfoss Climate solutions for cooling”. Accessed July 21, 2023. https://www.danfoss.com/en/about-danfoss/our-businesses/cooling/.