Refrigeration theoretical comparison between European condensing units

A Anastase and G M Tarlea
Technical University of Civil Engineering, Bd. Pache Protopopescu nr. 66, Bucharest, 021414, Romania, Fax: +40 (0) 21 2523964
e-mail: adrian.anastase@phd.utcb.ro; gratiela.tarlea@utcb.ro

Abstract. Considering the current EU regulations, the GWP limit for commercial refrigeration systems is 150 starting with 1st of January 2022. This study uses a selection software for condensing units to evaluate the options available on the UE market which can fulfill the GWP limit. For this purpose a theoretical comparison between R404A (past), R449A (present) and R744 (future) condensing units with a cooling power of 10kW is made. The COP in the range of ambient temperature from 0°C to +40°C is the main criterion evaluation. Size and weight are also evaluated as secondary criteria. The results of COP evaluation are similar with conclusions from other studies and confirm that R449A unit has better COP than R744 and R404A. Also the size of the unit in case of R744 is three times bigger than R449A unit. The main conclusion is that even if R744 has low GWP and fulfill the legislation requirement it has not good efficiency. Further studies should be made in order to find a good solution for small cooling capacities.

1. Introduction
According to EU Regulation No 517/2014 [1] refrigeration systems from Europe will have to fulfill a new GWP limit from 1st January 2022. In case of medium temperature (MT) refrigeration systems the limit of GWP is 150.

This article wants to evaluate one of the available options on the market for MT applications with cooling power of aprox. 10 kW. This option is considering R744 as refrigerant.

In order to have a better view, the R744 condensing unit is compared with other condensing unit which is using R404A and R449A.
Figure 1 presents the selection software for condensing units, Select 8 [2], that was used to evaluate the parameters for an evaporation temperature of -10°C, with 10K superheating of suction vapours and ambient temperature in the range of 0°C to +40°C.

The main criterion of comparison is the COP for the same cooling power. Based on COP, the electrical consumption over an entire year is calculated. The annual variation of cooling load is neglected.

Other facts that are considered as a secondary criteria are: the size, the weight and the sound pressure. The condensing temperature is also analysed to have a better overview on the operating point.

2. Technical description of equipment
In this comparison is considered the same equipment for R449A and R404A. Different equipment is considered for R744 due to different components that are needed for high pressures.

Some refrigerant properties, important for this comparison article (as safety classification, GWP, critical temperature and pressure) are presented in table 1, according to values mentioned in the study of Makhnatch [3] for R404A and R449A and the study of Sobieraj [4].
Table 1. Refrigerants properties [3] [4]

|                          | R404A | R449A | R744 |
|--------------------------|-------|-------|------|
| Molecular mass (g mol\(^{-1}\)) | 97.6  | 87.2  | 44.01|
| EU/ASHRAE safety classification | A1    | A1    | A1   |
| AR5 GWP\(_{100\text{-year}}\)    | 3943  | 1282  | 1    |
| Critical temperature (°C)       | 345.2 | 357.0 | 31   |
| Critical pressure (kPa)         | 3729  | 4662  | 7380 |

The equipment, for each refrigerant, is presented below, with technical information relevant for this study.

2.1. R744 condensing unit

Figure 2. Technical drawing of R744 unit [2]

Figure 2 presents the drawing of the R744 unit, where can be seen that dimensions of the unit are 1574x920x1135 mm. According to technical data sheet [5] the unit has 450 kg in empty state and the sound pressure (at 10m) is 44 dBA.

The condensing unit is equipped with a semi hermetic reciprocating piston compressor 4MTL-07, suitable for transcritical and subcritical operating mode and is driven by a frequency inverter. The condenser has one EC fan and uses stepper valves type as HPV and BPV.
1 – compressor
2 – discharge muffler
3 – gas cooler/condenser
4 – flash tank
5 – filter dryer
6 – sight glass
7 – ball valve
8 – oil sensor
9 – pressure relief valve
B1-B10 – informative parameter measurement points
HPV – high pressure valve
BPV – bypass valve
HP – high pressure limiter
INV – frequency inverter

Figure 3. P&I diagram of R744 unit [5]

Figure 3 shows the P&I diagram of the R744 unit and the level of accessories. For safety purposes there are high pressure switch and pressure relief valves on: compressor discharge, gas cooler outlet and liquid receiver.

2.2. R449A and R404A condensing unit

Figure 4. Technical drawing of R449A and R404A unit [6]
Figure 4 shows the dimensions of the unit, which are 950x447x1244 mm. According to the technical data sheet [6] the weight of the unit is 118kg in empty state and the sound pressure (at 10m) is 42 dBA.

The condensing unit is equipped with one on/off scroll compressor ZX51KCE and has two fans for condenser, with horizontal airflow.

![Diagram of the condensing unit](image)

**Figure 5.** P&I diagram of R449A and R404A unit [6]

Figure 5 shows the P&I diagram of the R744 unit and the level of accessories. For safety purposes there are high pressure switch and pressure relief valves on: compressor discharge, gas cooler outlet and liquid receiver.

3. Results and discussions

![COP comparison](image)

**Figure 6.** COP comparison (R744, R449A, R404A) for MT refrigeration condensing unit.
Figure 6 shows how COP varies due to the ambient temperature from 5.5 to 1 for R744. Comparing with the measurements from Sharma [7], for bigger booster system, which presents a range from 3.3 to 1.4 for ambient temperature range from +10°C to +35°C, figure 6 shows a COP in the range of 3.7 to 1.35 for the same ambient range. The difference may be because in this study is considered only the condensing unit, without any evaporator or other auxiliary equipment. Another reason for the difference may be the selection of the gas cooler/condenser.

According to a study of Makhnatch [3] the COP is similar for R404A and R449A, but a recently study of Sarwar Alam [8] concludes that the COP for R449A is better than R404A, which is similar to what shows figure 5.

|                | Yearly electrical energy consumption estimation |
|----------------|-----------------------------------------------|
|                | (kW*h/year)        | (%)               |
| R744           | 32790             | +31%              |
| R449A          | 22464             | -9.9%             |
| R404A          | 24943             | 0                 |

In table 2 are presented estimated values for electrical energy consumption over an entire year. The values are calculated using formulas (1), (2), considering 20h/day operating time and neglecting the cooling load variation during the year.

\[
COP = \frac{Q_o}{P_{abs}} 
\]

\[
P_{abs} = \frac{Q_o}{COP} 
\]

For calculation was considered that the ambient temperature has a linear variation, presented in fig. from 0°C to +40°C over the entire year and the cooling need remains at 10kW over the entire year.

The percentages are calculated considering R404A consumption as a reference.
Figure 7. Condensing temperature related to ambient temperature

Figure 7 shows the variation of the condensing temperatures for each refrigerant. The variation of R744 condensing temperature shows that when ambient temperature is below +23°C the unit operates in subcritical mode. Also, can be observed a temperature difference between ambient and condensing temperature from 10 to 7 K. These data can be taken into consideration for the future author’s research.

Figure 8. Unit size (a) and weight (b) ratio
Figure 8a is representing a visual ratio between the size of the units considering the volume. According to the dimensions mentioned on technical description, the R744 unit has dimensions of 1574x920x1135 mm and R449A unit has dimensions of 950x447x1244 mm, which means three times bigger size for the same cooling capacity needed in case of R744. Considering the weight, we know from technical description that R744 unit has 450kg and the R449A/R404A unit has 115 kg, which results also in three times bigger weight for R744 unit, which is represented in figure 8b.

4. Conclusions

In conclusion, figure 5 shows that R744 unit has, theoretically, a lower COP than R449A unit, which seems to have the best COP. Also considering the value from table 2, the yearly electrical consumption is with 40% bigger with R744 unit compared to R449A unit. It is important to mention that this difference is theoretically and considering the conclusions of Yu [9], in real operation the values can differ because of devices that are used. According to his study, using a mechanical thermal expansion valve can bring limitation in lowering the condensing pressure, which means limitation of COP. Considering this fact, the same level of devices should be used to obtain results similar to this study.

The size and weight of the R744 unit is three times bigger than R449A unit, so it can be difficult to place in some locations. This difference could also mean a difference on investment costs. Despite the size differences the sound power (at 10m) is at same level of 42-44 dBA for all the units.

Considering the GWP values of 3943 for R404A and 1282 for R449A mentioned by Mota-Babiloni [10] and comparing with GWP of 1 for R744 mentioned by Junqi [11], which are centralized in table 1, there can be concluded that R744 has a big advantage from ecological point of view.

Despite the big advantage on ecological side, R744 units are not a suitable solution for small cooling capacities. Further research should be made to find new solutions in order to meet also the efficiency requirements.

Nomenclature

- \(COP\) coefficient of performance (-)
- \(GWP\) Global Warming Potential (-)
- \(P_{abs}\) absorbed electrical power (kW)
- \(Q_o\) cooling power need (kW)

Reference

[1] 2014 EU Regulation No 517/2014..
[2] Emerson Climate Technologies Europe, Select 8 [Computer software] v. 6.0.3.2521 CUSTOMER ed., 8.70/44019
[3] Makhnatch P, Mota-Babilon A, Rogstam J and Khodabandeh R 2017 Retrofit of lower GWP alternative R449a into an existing R404a indirect supermarket refrigeration system Int. J. of Refrigeration 76 84-92
[4] Sobieraj M and Rosinki M 2019 Experimental study of the heat transfer in R744/R600a mixtures below the R744 triple point temperature Internat. J. of Refrigeration 103 243-52
[5] Emerson Climate Technologies Gmbh Application Guidelines Copeland Eazycool
CO2 Refrigeration units C6.1.11/0718-0619/E [Interactiv]. Available: https://climate.emerson.com/documents/copeland-eazycool-co2-refrigeration-unit-application-guidelines-en-gb-5400982.pdf. [Accessed 11 November 2020].

[6] Emerson Climate Technologies Gmbh Application Guidelines Copeland Eazycool Outdoor Condensing Units ZX Range C6.1.6/1017-1219/E. [Interactiv]. Available: https://climate.emerson.com/documents/copeland-eazycool-outdoor-condensing-units-zx-range-bom-304-454-application-guidelines-en-gb-3737220.pdf. [Accessed 13 November 2020].

[7] Sharma V, Fricke B and Zha S 2015 Evaluation of a transcritical CO2 supermarket refrigeration system for the USA market 6th IIR Ammonia and CO2 Refrigeration Technologies Conf Ohrid North Macedonia

[8] Sarwar Alam M and Hwan Jeong J 2020 Calculation of the thermodynamic properties of R448a and R449a in a saturation temperature range of 233.15K to 343.15K using molecular dynamics simulations Internat. Comunications in Heat and Mass Transfer 116

[9] Yu F, Chan K and Chu H 2006 Constraints of using thermostatic expansion valves to operate air-cooled chillers at lower condensing temperatures App. Therm. Engineering 26 17-18 2470-78

[10] Mota-Babiloni A, Makhnatch P and Khodabandeh R 2017 Recent investigations in HFCs substitution with lower GWP synthetic alternatives: Focus on energetic performance and environmental impact Internat. J. of Refrigeration 82 288-301

[11] Junqi D, Yibiao W, Shiwei J, Xianhui Z and Linjie H 2021 Experimental study of R744 heat pump system for electric vehicle application App. Therm. Engineering 183 1