IMPROVED PERFORMANCE REFRIGERATION CYCLES WORKING WITH HFO (R1234ZE & R455A) & LGWP (R448A)

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In the last years many studies have been produced on the optimization of refrigeration cycle working with CO2 in transcritical conditions. Comparisons have been done with base R404A cycles.

It is certainly interesting to have the possibility to compare the transcritical CO2 cycles with cycles working with HFO or LGWP refrigerants with improved configurations using some well-known and simple technologies which are not used actually in these cycles.

For these reasons we have developed a thermodynamic study of the performances of a chiller working at the following conditions: Useful Refrigeration Power at evaporator = 38KW, Evaporation temperature = -10°C, Useful Superheating = 5°C, Passive Superheating on low pressure pipes = 5°C; Temperature of the air used at the condenser or gas cooler = 10°C, 20°C e 33°C.

The thermodynamic study has evolved by developing a software that using Refprop 9.1 of NIST, calculates the cycles performances of the chiller.

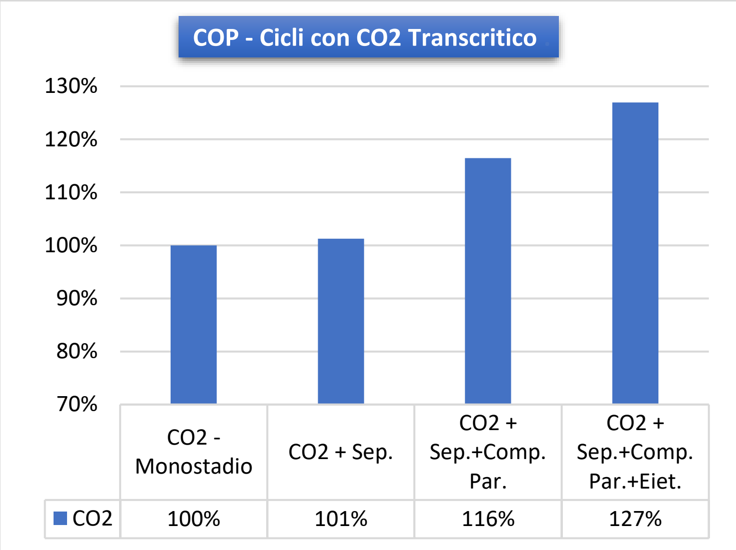
With the scope to produce a very precise study of the working point and performances of the cycles, we have used real value of the isentropic and volumetric efficiencies of the compressor produced by leader companies in the market (the most used compressors in refrigeration). These values have been calculated using the software available from the same producers.

In the first part of the study we have calculated the performances of the following cycles working with CO2 in transcritical or subcritical conditions depending on the ambient temperature. In the cases when both cycles were possible, we have taken in consideration the cycle with the best performances, best COP.

1. Single stage cycle
2. Single stage cycle with phase separator and intermediate expansion
3. Single stage cycle with phase separator and intermediate expansion with parallel compressor
4. Single stage cycle with phase separator and intermediate expansion + parallel compressor + ejector

The working conditions of the cycles are: Temperature of the air 33, 20 and 10°C; Outlet Temperature from the gas cooler = Temperature of the aria + 3°C; Gas Cooler Pressure optimized; Evaporation temperature= -10°C; Useful superheat at the evaporator = 5°C; Passive Superheat on the low pressure pipes = 5°C. In the cycles in which there is an intermediate expansion pressure, we have of course considered the optimized value to obtain the maximum value of the COP.

The results obtained with an ambient temperature equal to 33°C are shown below.



It is possible to notice in the diagram reported on the side that the COP of the cycles increase progressively using more efficient technologies as separator and parallel compressors or ejector. So we can state that the use of the technology improves the poor efficiency of the refrigerant CO_2 used in a standard cycle.

We have, then, analyzed the cycles working with R1234ze, R448A and R455A.

The cycles analyzed are the following:

5) Single Stage cycle
6) Single Stage cycle with liquid-vapor heat exchanger
7) Single Stage cycle with economizer
8) Single Stage cycle with economizer + liquid-vapor heat exchanger

The last configuration has been studied also in the “High performances” configuration; in this case the useful superheat at the evaporator is set at 1°C and the evaporation temperature has been set at -8°C using the higher evaporating heat exchange coefficient obtained decreasing the superheat at -1°C. In this way we have improved the evaporation power produced by the compressor and the COP of the cycle.

The working condition used for these cycles are: Temperature of the air = 33, 20 e 10°C; Medium Working □T at the condenser = 10°C (Medium Condensing temperature – Temperature of the air); Subcooling = 3°C ; Evaporation Temperature = -10°C; Useful superheat at the evaporator = 5°C; Passive Superheat on the low pressure pipe = 5°C. In the cycles in which an intermediate expansion pressure is used, it has been chosen a value of the intermediate pressure that produces the maximum value of the COP.

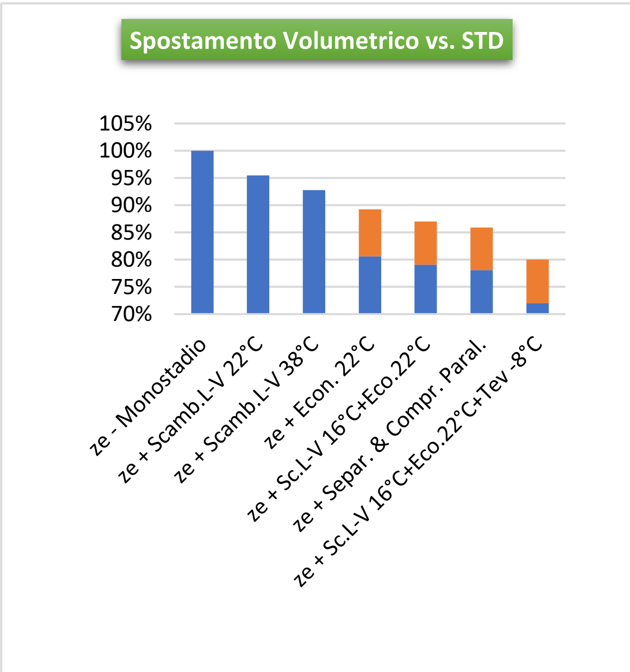
In the case in which a liquid-vapor heat exchanger is used, it has been chosen the value of the increase of the temperature of the vapor in the heat exchanger that produces the maximum value of the COP.

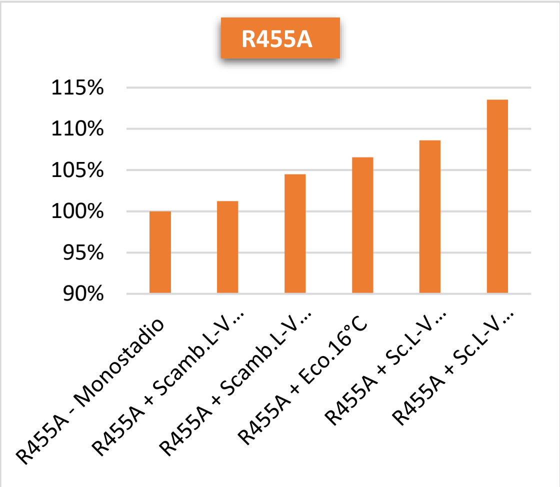
The results obtained for the R1234ze at ambient temperature equal to 33°C have been shown in the following diagram.

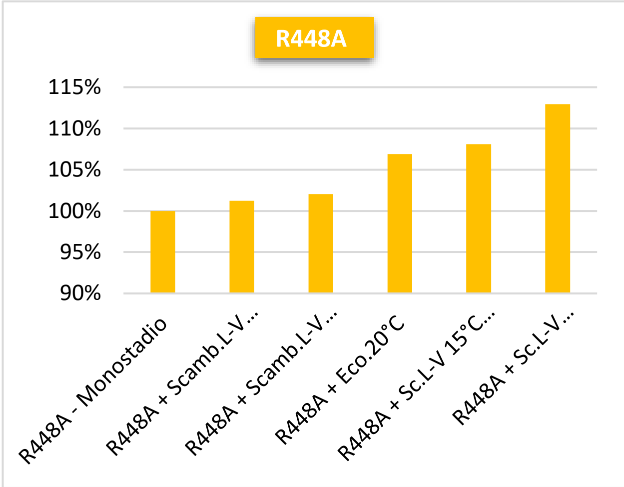
As it is possible to check in the diagram, the COP of the cycle increases up to 16% using the technologies described above. The use of the same technologies produces also a substantial decrease of the volumetric displacement of the compressor necessary to obtain the same refrigeration power, equal to 38KW.

In the diagram reported on the side, we deduce it is possible that it is possible to decrease the total volumetric displacement up to 20%. In the same diagram the volumetric displacement of the main refrigeration cycle are reported in blue and the volumetric displacement of the secondary refrigeration cycle used in some cycles in orange. It is possible to deduce that the volumetric displacement of the main cycle decreases up to 28%.

Using the other HFO refrigerant (R455A) and LGWP (R448A) it is possible to obtain similar results with the only difference that for these refrigerants it is not possible to use the separator because of the high glide of them.



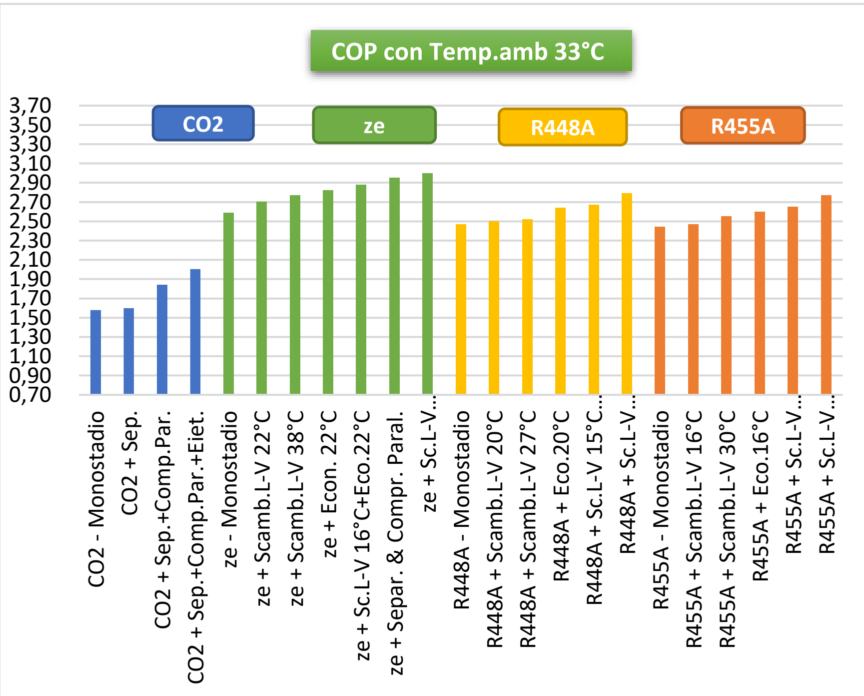




In the second part of the study we have compared the COP obtained with the different studies at the same ambient temperatures: 33°C, with the CO2 cycles and with the cycles working with R1234ze, R448A and R455A.

In the diagram shown on the side we report all the results. As it is possible to deduce, the cycles working with R1234ze, R448a and R455A show values of the COP that are better up to +50% if compared with the values obtained with the best cycles working with transcritical CO2.

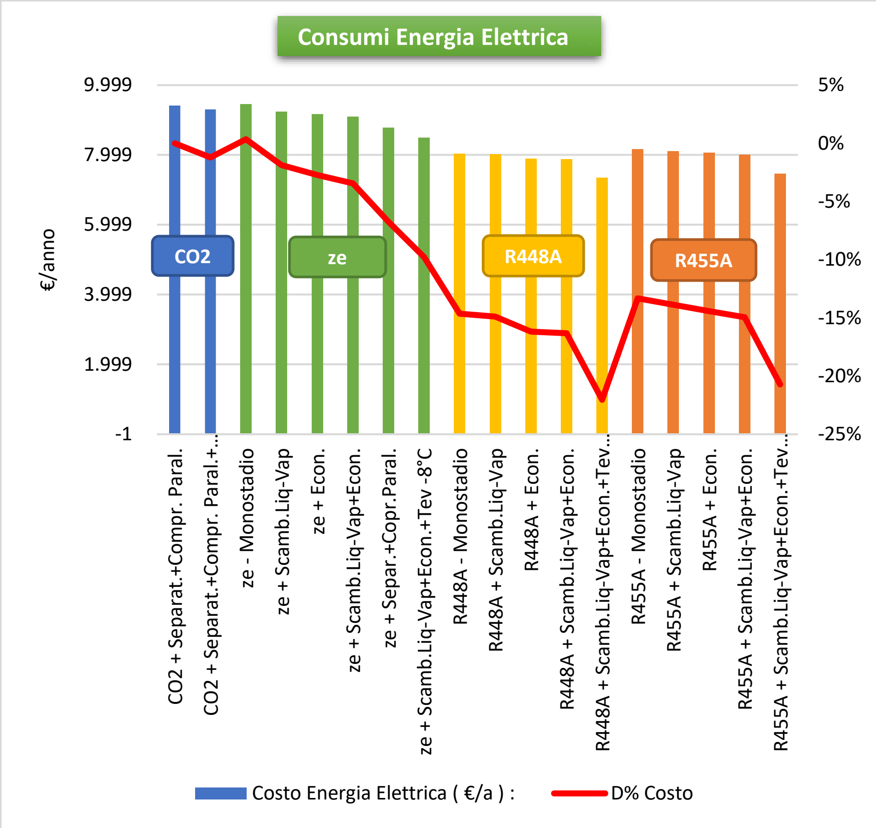
Similar improvements have been obtained calculating the COP of the same cycles working at different temperatures: 20°C (improvements between 16% and 30%) and 10°C (improvements between 12 and 22%).



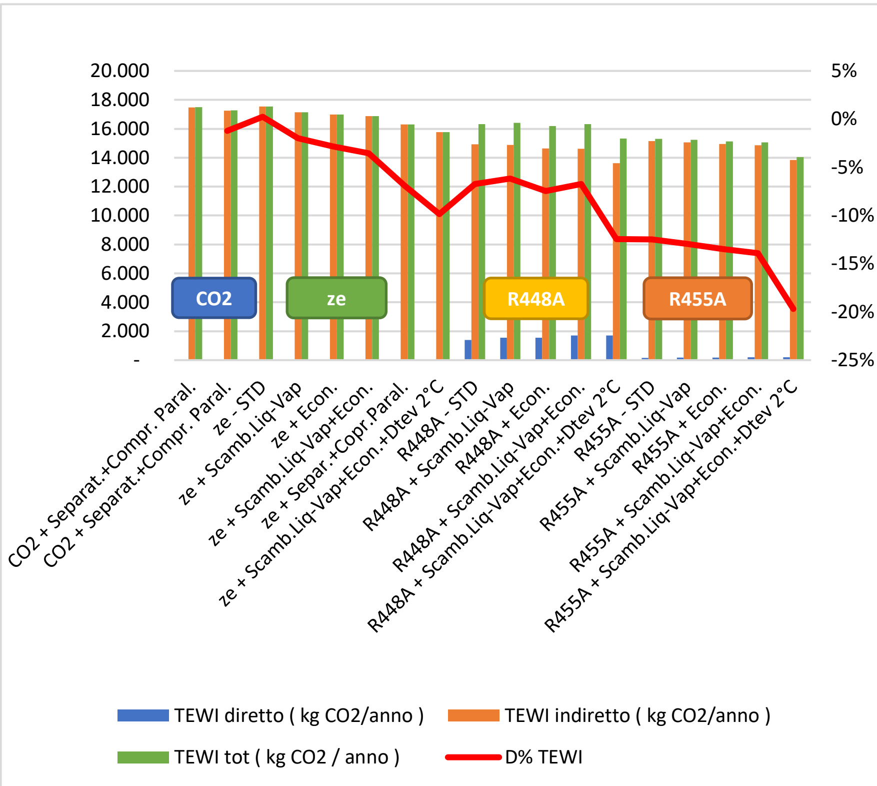
In the third part of the study we have calculated the energy consumption of the different cycles obtained to produce a refrigeration power equal to 38KW at -10°C at the ambient temperature characteristic of Milano in a standard year.

We report the results in the following diagram in which it is possible to deduce that the cycles working with HFO and LGWP produce lower consumption of electricity compared with better CO2 solutions up to -23%.

Then we have calculated the TEWI of each technology to establish which technology produces the minim quantity of CO2 considering both contribution: direct and indirect. To produce these results we have used the ratio 0,334 kg CO2 / kWhr related to Italy in the 2016.



We report the results obtained on the following diagram. In the same diagram it is possible to deduce that the direct contribution produced by the leakage of the refrigerants, weighs less than 1,5% on the total TEWI value, also in the case of R448A whose GWP is 1273 kg of CO2.



These results recommend that the technologies using R1234ze and R455A are the technologies that produce the minimum quantities of CO2 per kW of refrigeration power produced by the equipment as first choice; as second choice the technologies using R448A and only as third choice the technologies using CO2. The technologies that use CO2 are deeply penalized by the lower energy efficiency of the cycles. We obtained similar results with an ambient temperature equal to 20 and 10°C.

The differences in the energy efficiency or in the COP of the cycles working with HFO or LGWP vs. the cycles working with CO2 decrease when the ambient temperature decrease.

To summarize we cannot report the numerical results obtained at 20°C and 10°C. If you are interested in receiving these results, you can ask us sending a mail to: c.marotta@generalgas.it.

In conclusion:

In the following study we have compared different technologies chosen to increase the COP of thermodynamic cycles working with HFO refrigerant (R1234ze & R455A) and LGWP refrigerant (R448A). The results obtained demonstrate that, using some simple and well known technologies it is possible to increase the energy efficiency of these equipments at value that are much more higher compared with the value obtained using cycles working with transcritical or subcritical CO2. The improved energy efficiency obtained, improves also the value of the TEWI produced by these optimized cycles. In this way these optimized cycles working with HFO and LGWP refrigerant become the most efficient solution from the environmental point of view and not only by the energy efficiency point of view.