Total equivalent warming impact calculation for air conditioning technological application

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Abstract. This paper shows an aggregated compact cooling liquids (refrigeration system) used in air conditioning technological process who works in present with R407C refrigerant. The paper has focused on theoretical study case. Regarding F-Gas Regulation the optimum alternative for this application is R134a refrigerant with Total Equivalent Warming Impact (TEWI) calculation.

1. Introduction

In terms of global warming potential (GWP), at international level regarding the refrigerants, according with the new legislative Regulations ecological alternatives must be founded. Romania has implemented cleaner alternative technologies, that led to the reduction of national annual consumption at well below the limits imposed by the Protocol of Montreal (1987), on substances that deplete the ozone layer. The result is due to the effort of adjusting the national systems in order to reach the requirements of the Protocol for developed countries, given the accession process to the Europeans.

The paper shows also a possible retrofit solution for R407C, actually used in aggregated compact cooling liquids refrigeration systems replace with R134a refrigerant with GWP low in according with EU Regulations.

In table 1 are presented some properties thermodynamic of R407C and R134a refrigerant alternative have been determined by RefProp software [2]. One can observe that in Table 1 critical temperature and pressure for alternative refrigerant R134a are increasing in comparison with refrigerant R407C.

| Refrigerant | R407C | R134a |
|-------------|-------|-------|
| Critical temperature [ºC] | 86,02 | 101,06 |
| Critical pressure [bar] | 46,29 | 40,59 |
| Critical density [kg/m³] | 484,2 | 511,9 |
To implement the international Legislation [1], in the future it is necessary to replace HFC refrigerant with an ecological refrigerant (with zero ODP and low GWP).

2. Study Case
The theoretical comparative study was done for a technological application for cooling liquids[6]. From the technical specification of the producer one can see the COP of refrigerant R407C for operating conditions such as suction superheat (10K), subcooling(0K), condensing temperature $t_c$ (+45°C) and evaporating temperature $t_e$ (+10°C) is 4.55 and for refrigerant R134a is 4.38.[7]. The apparatus consists essentially of a cooling circuit, a heat exchanger for liquids and a control unit and are connected mechanically CAREL in the base of the unit. As an option, the aggregated can be equipped with a recirculating pump. The refrigerant flows inside the pipes of the heat exchanger and process liquid flows out of the pipe. The evaporator must always go on the process liquid processing a sufficient flow of liquid because otherwise it freezes and damage (breaks) [2]. The refrigerant (AF) is transported from the compressor, in a closed cooling circuit between the evaporator and the condenser. In the evaporator, it removes heat from the liquid to be cooled, changed and state of aggregation from liquid to gaseous state. The condenser gives up the heat taken from the evaporator to the environment. Aggregate state changes from gaseous to liquid. In order to obtain a pressure drop between the condenser and the evaporator is expansion valve which controls depending on the refrigerant injection the suction temperature of the before scroll compressor with technical data (nominal motor power [HP]: 2,75, displacement [m³/h]: 8, sound pressure level: 57, oil charge [dm³]: 1,1). The liquid of refrigerant tank is used to capture necessary for safe operation of the machine. A moisture sight glass circuit serves to verify the refrigerant in case of malfunctions. Solenoid valve refrigerant locking feature blocking refrigerant circuit when power is off. This prevents the penetration of liquid refrigerant in the evaporator. The pressure switch for high pressure / low serves as a safety device in the refrigerant circuit. He stops the machine if pressure too high or too low.

In figure 1 it is presented Air Conditioning (AC) technological process:
Figure 1. The cooling liquids equipment of technological process [6]
The legend of equipment are: 1) Compressor, 2) Condenser, 3) refrigerant tank, 4) Drier filter, 5) Solenoid valve, 6) liquid and moisture Viewfinder, 7) Expansion valve, 8) Evaporator, 9) High-pressure pressure switch / low, 10) Recirculation pump (optional).

The COP for the refrigeration systems was calculated in Table 3 for condensing temperature tc [+30 ÷ +65] and evaporating temperature te [-20 ÷ +15] of refrigerant R407C and in Table 4 for refrigerant R134a. The TEWI factor was calculated in accordance with UE legislation. The total global warming potential method calculation (GWP) of Ecological Alternative was done in accordance with REGULATION (EC) No 842/2006 (from 1 January 2015 REGULATION (EC) No 517/2014). The TEWI (Total Equivalent Warming Impact) factor was determinate taking account of the Standard SR EN 378-1 [3,4].

To calculate TEWI factor were following assumptions: mass of refrigerants made seen in Table 3. 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 0.28985 kg / kWh for Romania country.

The TEWI factor was determinated taking account of the Standard SR EN 378-1:

\[
\text{TEWI} = \left[ \text{GWP} \times L \times n \right] + \left[ \text{GWP} \times m \times (1 - \alpha_{\text{rec}}) \right] + \left[ n \times E_{\text{annual}} \times \beta \right]
\]

where:

GWP – the global warming potential, CO2 related
L – leakage in kilogrammes per year
n – system operating time in years,
m – refrigerant charge in kilogrammes
\( \alpha_{\text{rec}} \) - recovery/recycling factor from 0 to 1
\( E_{\text{annual}} \) – energy consumption in kilowatt-hour per year
$\beta$ - CO$_2$ emission in kilogrammes per kilowatt-hour kg/kWh

$[\text{GWP} \times m (1-\alpha_{\text{rec}})]$ - impact of recovery losses

$[\text{GWP} \times L \times n]$ - impact of leakage losses

$[n \times E \text{ annual} \times \beta]$ - impact of energy consumption.

**Table 2.** The theoretical results of the TEWI factors of the refrigerant alternative for R407C.

|                  | R407c | R134a |
|------------------|-------|-------|
| GWP              | 1774  | 1430  |
| L                | 0.168 | 0.1776|
| n                | 15    | 15    |
| m                | 2.1   | 2.22  |
| beta             | 0.28985| 0.28985|
| GWP X L X n      | 4470.48 | 3809.52|
| GWP X m(1-\alpha_{\text{rec}}) | 931.35 | 793.65|
| n x E anual x $\beta$ | 67031.87 | 48750.45|
| TEWI [ Kg CO$_2$] | 72433.70 | 53353.62|
| TEWI [tone CO$_2$] | 724337.0 | 5335362 |

In the next Tables 3 and Tables 4 there are shown the performance coefficients (COP).

**Table 3.** The theoretical results of the COP of refrigerant R407C [7]

| $t_i/t_e$ | -20 | -15 | -10 | 5 | 0 | 5 | 10 | 15 |
|-----------|-----|-----|-----|---|---|---|----|----|
| 30        | 2.04| 2.60| 3.30| 4.13| 5.13| 6.31| 7.72| 9.43|
| 35        | 1.67| 2.14| 2.73| 3.44| 4.29| 5.30| 6.51| - |
| 40        | 1.36| 1.75| 2.25| 2.85| 3.57| 4.43| 5.46| - |
| 45        | -   | 1.43| 1.84| 2.34| 2.95| 3.67| 4.55| - |
| 50        | -   | -   | 1.49| 1.91| 2.41| 3.02| 3.75| - |
| 55        | -   | -   | -   | 1.54| 1.95| 2.46| 3.06| - |
| 60        | -   | -   | -   | -   | 1.57| 1.98| 2.47| - |
| 65        | -   | -   | -   | -   | -   | 1.57| 1.97| - |
Table 4. The theoretical results of the COP of refrigerant R134a [7]

| t/t_e | -20 | -15 | -10 | 5  | 0  | 5  | 10 | 15 |
|-------|-----|-----|-----|----|----|----|----|----|
| 30    | 1.78| 2.32| 2.99| 3.83|4.85|6.08|7.51|-   |
| 35    | 1.47| 1.93| 2.50| 3.20|4.05|5.07|6.25|-   |
| 40    | 1.21| 1.60| 2.08| 2.67|3.39|4.24|5.23|6.36|
| 45    | -   | 1.32| 1.73| 2.22|2.82|3.54|4.38|5.33|
| 50    | -   | 1.09| 1.43| 1.84|2.35|2.95|3.66|4.46|
| 55    | -   | -   | 1.17| 1.52|1.94|2.45|3.04|3.72|
| 60    | -   | -   | -   | 1.24|1.59|2.01|2.51|3.09|
| 65    | -   | -   | -   | 1.00|1.29|1.65|2.06|2.55|
| 70    | -   | -   | -   | -   |1.04|1.33|1.68|2.08|
| 75    | -   | -   | -   | -   |0.82|1.06|1.35|1.69|

Higher performance is highlighted when R134a is used - the reduced amount of refrigerant, a feature with environmental benefits reflected by the TEWI equivalent (Total Equivalent Warming Impact) in figure 2.

In the refrigeration systems, the contribution to warming the atmosphere is both direct (due to the refrigerant) and indirect (through the energy used), the latter being the most important [5,6].

Figure 2. TEWI factor

3. Conclusions

Regarding international legislation, the best alternative for this application from the point of GWP is refrigerant R134a [1,7].

The paper shows the advantages of refrigerant R134a which can replace the R407C refrigerant and could be used in equipment because critical pressure is much lower.

This paper followed the calculations of the COP and Total Equivalent Warming Impact for air conditioning technological application following refrigerants: R134a and R407C.
From the point of view of energy efficiency, the most advantageous refrigerant is R 407C with a COP of 4.55 than R134a with a COP of 4.38.

From an environmental point of view, the theoretical results of the R134a refrigerant has the best TEWI = 53,35 tons of CO2 with 26% much lower than R407C.

References
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