Opportunities for CO_2 in supermarket refrigeration.

AUTHOR.

P.J. Verhoef, Adviesburo Verhoef b.v.
Vlijtseweg 47, 7317 AD Apeldoorn, The Netherlands
Phone +31 (0) 555 222 477
Fax +31 (0) 555 211 549
E-mail p.verhoef@verhoef.net

ABSTRACT.

The Dutch Government (Ministry of Housing, Spatial Planning and the Environment) has initiated the Reduction Program non-CO_2 Greenhouse Gases (ROB). Program implementation and support have been outsourced to SenterNovem, The Netherlands agency for Energy and the environment. SenterNovem took the initiative to do this feasibility study.

This article describes the results of a feasibility study for CO_2 applications in supermarket refrigeration:

- ✓ State of the art in Europe.
- ✓ The availability of equipment for CO_2 has been investigated.
- ✓ For three categories of supermarkets, small, average and mega the feasibility of CO_2 has been analysed.

The study indicates that the necessary equipment is available, however there is less choice compared to the traditional refrigerants. Especially for the small supermarkets one compressor often has enough capacity, while two compressors, one for back up, would be preferable to achieve better reliability.

It can be concluded that the average contractor does not have the necessary knowledge of CO_2. Therefore education will be vital for the future of CO_2 technology. Also a lot has to be done to further develop CO_2 systems and components, which will enable contractors to install these systems more frequently.

Most of the supermarkets that use CO_2 have Ammonia or Propane for the high temperature stage. Some have all CO_2, such as Costan, Italy. At this moment there is not enough experience yet to promote all CO_2, trans critical, systems. Systems with Ammonia or Propane will be favourite in the near future. However Ammonia and Propane are more and more banned because of safety reasons. Especially in residential areas this will become problematic in the future.

For the three categories of supermarkets the cost of ownership and investments have been studied. It appears that the investments, when using CO_2 are 9 to 17% higher, compared to HFC systems. The cost of ownership are 2 to 8% higher compared to HFC systems.

The chances for CO_2 will increase when it is stimulated by subsidiaries that stimulate the reduction of greenhouse gasses based upon TEWI calculations. Also governmental regulations that discourage the use of traditional refrigerants will encourage the use of CO_2. This has been the situation in the Scandinavian countries.

1. INTRODUCTION.

CO_2 is not poisonous and not explosive. This makes CO_2 safe to work with, as also can be obtained from the specifications given by the manufacturers.
Special attention should be paid to the ventilation of the rooms, as CO_2 reduces the oxygen content of the air. Rooms should be well vented when working with CO_2. In the Netherlands special guidelines have been produced for this reason, such as the IOR/R744.
Also special attention should be paid to the high pressure in the equipment and piping. Therefore the guidelines PED, CPR 13-2 and NPR 7600 apply.

CO_2 is suitable to serve as a refrigerant. For the determination of the applications the following properties are important:

- Critical point 30,98 °C / 73,77 bar
- Triple point –56,60 °C / 5,18 bar

In supermarkets in The Netherlands CO_2 had not been used until 2004. In other sectors, like the food industry and cold stores CO_2 has been introduced widely. Many applications have been build so far. As the Dutch government wants to introduce CO_2 in the supermarket sector also, it was decided to investigate the results with CO_2 obtained so far in other countries. Investigations have been done to determine the state of the art of CO_2 applications in supermarket refrigeration. Also interviews with equipment suppliers has been done.
Three types of systems have been found to be working in practice:

- Cascade systems using NH_3 in the high temperature stage and CO_2 as an indirect media for cooling purposes and as active refrigerant for freezing purposes.
- Cascade systems using HFC in the high temperature stage and CO_2 as an indirect media for cooling purposes and as active refrigerant for freezing purposes.
- One stage CO_2, trans critical systems, separate systems for freezing and cooling.

2. STATE OF THE ART; LITERATURE SURVEY.

2.1 Experiences with CO_2 in refrigeration systems.

In countries, other then The Netherlands experience is available with the following CO_2 systems:

- Cascade systems, with Propane as active refrigerant in the high temperature stage [lit. 9,12,13,16]
- Cascade systems with NH_3 as active refrigerant in the high temperature stage [lit. 16]
- Trans critical CO_2 systems, separate systems for freezing and cooling. [lit. 8,19]

The next part of this chapter describes the experiences, as found in the literature.

2.1.1 *Cascade systems using HFC, Propane or NH_3 as refrigerant in the high temperature stage.*

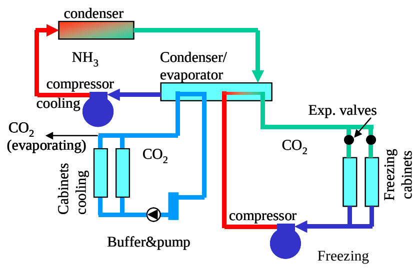

Figure 1 Typical system design cascade system and CO2

Cascade systems are used in many forms. For the high temperature stage HFC, NH_3 and Propane are used. The best energetic efficiency can be obtained when using NH_3 and Propane. Because of safety reasons the cooling part of the systems are indirect, in case of NH_3 and Propane. In those cases Glycol, Ice slurries and liquid CO_2 serve as secondary refrigerant.
As far as energetic efficiency is concerned Propane and NH_3 do not differ much. For both refrigerants about the same safety precautions are to be taken.

Due to good heat transfer properties the evaporation temperatures can be kept high for good energy efficiency. In general, evaporating CO_2 as a secondary refrigerant has the following advantages, compared to traditional indirect systems:

- Lower temperature inside the coolers in the cabinets.
- Smaller circulating pumps.
- Smaller heat exchangers.

The following experiences have been obtained from literature, when using CO_2 in the freezing part of the cascade system:

- Liquid flow 2,5 times bigger, compared to NH_3
- Gas flow 5,5 times smaller, compared to NH_3
- Suction lines 3 to 4 NEN sizes smaller, compared to R404A
- Liquid lines 1 to 2 NEN sizes smaller, compared to R404A
- Swept volume 8 times smaller compared to NH_3
- COP compressor is 4.90 at –35 °C/-5 °C
- Lower maintenance costs, due to smaller equipment
- As lubricant polyester oil is used.
- An oil rectifier system is needed.
- The extra energy input, due to the cascade application, is compensated by two factors:
    - A 2K higher evaporation temperature, due to better heat transfer
    - A 1K lower pressure loss in the suction line
- Special precautions should be made to avoid excessive high pressures, when the system is switched off.
- Leakage between NH_3 and CO_2 will give serious problems and blocks the system.

2.1.2 *Trans critical CO_2 systems.*

Despite the low critical point, CO_2 has been used also for –10 °C by Costan e.o. [lit. 7,8]. The prospects for trans critical systems are good. Developments take place.

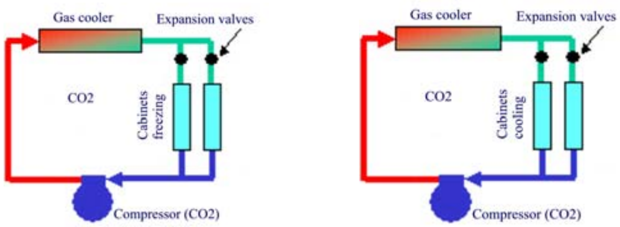

Figure 2 Separate trans critical system for freezing and cooling

Both Costan [lit. 8] and Gebhardt [lit.7] found an energy consumption much higher then expected. The main reasons for that were given by them:

- Oil return problems, causing bad heat transfer
- Internal leakages, due to the high pressures
- Lack of available components, which forced the designer to use components out of range.

The trans critical systems however will be developed further and have good perspectives for the future. They also offer good possibilities to apply heat recovery.

2.2 Available knowledge.

Dutch contractors for supermarkets do not have much experience with CO_2, NH_3 and Propane. It can be concluded that introducing these refrigerants should be done step by step. It will be important to provide education for these new technologies. Also import of new technology from other countries is an option.

As the study has to serve the Dutch contractors, only systems that can be build today without any risk or extra experiments have been selected to stimulate the application of CO_2 in Dutch supermarkets:

- The trans critical CO_2 systems will not be considered as proven technology at this moment and have therefore not been evaluated in this report.
- Propane will not be selected as a refrigerant. Propane is new for the Netherlands and will introduce too much new elements, when installing CO_2 systems for the first time and have therefore not been evaluated in this report.

2.3 Available equipment.

For the application of CO_2 enough equipment seems to be available for the average applications. However the range is small, which results in problems when selecting the right size. Especially for smaller capacities the choice is limited. For small supermarkets this means for instance that only one compressor has sufficient capacity. For reliability reasons two compressors would be better, however not available yet.

- The lubricating oil has a tougher job compared to systems with HFC’s. Especially the bigger forces in the compressor and the higher temperatures are causing this. The right types of oil are available.
- Compressors, if not too small, are widely available up to condensing temperatures of 0 °C. For higher temperatures special designed compressors are needed, so less available. (semi) hermetic

compressors are favourite, because of less leakage. CO_2 compressors run at 1.450 rpm and make as much noise as in traditional systems.

- Special cascade condensers are available. It is recommended that separate condensers are used to:
  - Serve as emergency cooler
  - Serve as condenser for the freezing system
  - Serve as liquid cooler for the cooling cabinets

  A combination of all three causes problems due to oil recirculation.
- The CO_2 circulation pump needs special attention:
  - The use of a (semi) hermetic type is preferred, preventing leakages.
  - The MPSH value should be high; at least 2,5 m.
  - Both suction and discharge lines have to be insulated in order to enable a restart.
  - Frequency controllers are recommended.
- The coolers in the cabinets should be able to resist high pressures, up to 45 to 50 bar, during defrost with CO_2. This normally means an increase of the costs by 9%. Electrical defrost is an alternative, which probably will be adopted in the Netherlands.
- Control equipment and –valves are widely available.

2.4 Safety and law related aspects.

Like all other refrigeration facilities, a NH_3/ CO_2 system will have to obey the safety regulations like PED. For the Dutch area also the rules as presented in EN378 and CPR 13-2 have to be respected, which are normal rules for the design of refrigeration systems.
In The Netherlands the maximum content of NH_3 should be less then 200 kg. In that case no extra licences have to be given by local authorities. As the bigger supermarket needs less then 150 kg of NH_3 there are no special licenses needed for the application of a NH_3/ CO_2 system.
However Propane and NH_3 are not easy to introduce in residential areas.

2.5 Inquiry supermarket owners.

An inquiry has been set up to find out how supermarket owners think about CO_2. Twelve supermarket chains have been asked, of which 4 responded, representing 145 supermarkets. From the inquiry the following can be concluded:

- Supermarkets know about CO_2. They get their information from the contactors and the government publications.
- Supermarket owners believe that CO_2 is expensive, less safe and have higher cost of ownership.
- If CO_2 would reduce their indirect CO_2 emission then they are interested. This however is not the case.
- If CO_2 does not influence the reliability, then it will be accepted.
- If the costs of ownership does not increase, then supermarkets are willing to use it.

It can be concluded that the supermarkets in the Netherlands are not very interested. They think that CO_2 systems are expensive. However they appreciate environmental friendly systems, preferably without HFC’s.

3. PROSPECTS FOR CO_2 IN THE DUTCH SUPERMARKETS.

For 3 categories of Dutch supermarkets it has been calculated what consequences the introduction of CO_2 will have. The following table gives specifications of each category.

		Supermarket category		
		Small	Average	Big
Shop floor area	m^2	300	760	1.500
Cooling load cooling cabinets	kW	42,6	74,1	110,4
Cooling load freezing cabinets	kW	6,9	8,9	16,8

For each category it has been calculated what consequences can be expected, compared to a traditional HFC system, when using an NH_3/ CO_2 system and a HFC/ CO_2 system.
The following components in the calculations have been used:

- Investment for cooling system and cabinets, based upon offers.
- Cost of ownership, which is:
  - Writing-off in 5 years, which equals the life span between two renovations.
  - Rest value after 5 year 30%
  - All in service contract, according to quotation contractor:
    - 3,5% per year for HFC DX system (traditional system), reference
    - 2,8% per year for NH_3/ CO_2 cascade system
    - 3,5% per year for HFC/ CO_2 cascade system
  - Energy costs; € 0,07 per kWh
  - Refrigerant costs:
    - HFC € 10,- per kg
    - NH_3 € 3,- per kg
    - CO_2 € 0,50 per kg
  - Interest rate 5,5%
- Environmental impact, according to the TEWI calculation method. The refrigerant leakage is assumed to be 5% [lit. 4]
- Reference system, single stage compression, cooling R404A, -10/+42 ºC; Freezing R404A, -35/+42 ºC. This is the average system in The Netherlands.
- NH_3/CO_2 system, Cascade, Cooling –14/+42 ºC; Freezing –10/-35 ºC
- R404A/CO_2 system. Cascade, Cooling –13/+42 ºC; Freezing –10/-35 ºC

The reference system is a DX system with electronic expansion valves and R404A as refrigerant, which is the average in The Netherlands.
In the next part of this report the results of the comparison are given.

3.1 Comparison traditional system versus CO_2 for small supermarkets.

Small supermarkets are assumed to have a shop floor space of 300 m^2.

		Reference	NH_3/CO_2	HFC/CO_2
Investment	€	158.076,-	184.863,-	166.263,-
Cost of ownership	€/year	43.312,-	46.758,-	44.836,-
Compressor efficiency % (cool / freeze)		51.1 / 41.1	54.5 / 41.8	50.4 / 41.8
COP (cool / freeze)		2.584 / 1.27	2.519/ 3.977	2.383 / 3.977
Energy consumption	kWh/year	122.878	125.025	127.582
Direct emission	kg CO_2-eq/year	26.740	8	16.087
Indirect emission	kg CO_2/year	74.956	76.265	77.825
Total emission	kg CO_2-eq/year	101.695	76.273	93.912

From the calculations it can be concluded that compared with the reference system R404A:

- The investment for a NH_3/ CO_2 system is 17% higher
- The costs of ownership for a NH_3/ CO_2 system is 8% higher and that of a HFC/ CO_2 system 4% higher
- The energy costs for a NH_3/ CO_2 system are 1,5% higher and for the HFC/ CO_2 4%
- The emission of CO_2 reduces by 25% or 25.400 kg CO_2 equivalent per year. This is mainly caused by the reduction of the direct emission.
- The main part of the costs of ownership is the writing off. If the systems could be made more flexible so that they can survive a supermarket renovation, then the costs of writing off could be lowered.

3.2 Comparison traditional system versus CO_2 for average supermarkets.

Average supermarkets are assumed to have a shop floor space of 760 m^2.

		Reference	NH_3/CO_2	HFC/CO_2
Investment	€	244.230,-	279.004,-	258.771,-
Cost of ownership	€/year	68.046,-	72.245,-	71.380,-
Compressor efficiency % (cool / freeze)		51.2 / 41.1	54.5 / 40.2	49.4 / 40.2
COP (cool / freeze)		2.587 / 1.27	2.520/ 3.823	2.334 / 3.823
Energy consumption	kWh/j	210.235	214.658	221.521
Direct emission	kg CO_2-eq/y	35.586	9	25.134
Indirect emission	kg CO_2/y	128.243	130.941	135.128
Total emission	kg CO_2-eq/y	163.829	130.950	160.262

From the calculations it can be concluded that compared with the reference system R404A:

- The investment for a NH_3/ CO_2 system is 14% higher
- The costs of ownership for a NH_3/ CO_2 are 6% higher and for a HFC/ CO_2 system is 5% higher
- The energy costs for a NH_3/ CO_2 system are 2% higher and for the HFC/ CO_2 5%
- The emission of CO_2 reduces by 15% or 24.000 kg CO_2 equivalent per year. This is mainly caused by the reduction of the direct emission.
- The main part of the costs of ownership is the writing off. If the systems could be made more flexible so that they can survive a supermarket renovation, then the costs of writing off could be lowered.

3.3 Comparison traditional system versus CO_2 for the big supermarkets

Big supermarkets are assumed to have a shop floor space of 1.500 m^2.

		Reference	NH_3/CO_2	HFC/CO_2
Investment	€	373.608,-	406.605,-	396.192,-
Costs of ownership	€/year	104.193,-	106.197,-	110.034,-
Compressor efficiency % (cool / freeze)		50.2 / 40.4	55.0 / 38.0	46.2 / 38.0
COP (cool / freeze)		2.537 / 1.248	2.542/ 3.621	2.184 / 3.621
Energy consumption	kWh/j	319.096	325.871	349.107
Direct emission	kg CO_2-eq/y	59.712	14	39.210
Indirect emission	kg CO_2/y	194.649	198.782	212.956
Total emission	kg CO_2-eq/y	254.361	198.795	252.166

From the calculations it can be concluded that compared with the reference system R404A:

- The investment for a NH_3/ CO_2 system is 9% higher
- The costs of ownership for a NH_3/ CO_2 are 2% higher and for a HFC/ CO_2 system is 6% higher
- The energy costs for a NH_3/ CO_2 system are 2% higher and for the HFC/ CO_2 9,5%
- The emission of CO_2 reduces by 22% or 55.565 kg CO_2 equivalent per year. This is mainly caused by the reduction of the direct emission.
- The main part of the costs of ownership is the writing off. If the systems could be made more flexible so that they can survive a supermarket renovation, then the costs of writing off could be lowered.
- With a lifetime of 10 years, the costs of ownership of the reference and the NH_3/CO_2 installation will be equal.

4. CONCLUSIONS AND RECOMMENDATIONS.

4.1 From a technical point of view there are no objections for using CO_2 in supermarkets. The high pressures are no basic problem.

4.2 There are sufficient components available, however the choice is restricted compared to HFC systems. This is especially the case for the small supermarkets.

4.3 From the inquiry among supermarket owners it can be concluded that they fear higher costs, when switching to CO_2.

4.4 Propane and NH_3 are not welcome in residential area's. This has more impact for the small and average supermarkets. The bigger supermarkets mostly are situated in industrial like area's.

4.5 Application of CO_2 in supermarkets leads to 9 to 17% higher investments and 2 to 8% higher costs of ownership.

4.6 Governmental support and subsidy should help to overcome the extra costs.

4.7 De total emission of CO_2 can be reduced by 15 to 25%, mainly caused by the reduction of leakages of HFC's.

4.8 The education of contractors should be initiated, to avoid problems during design and maintenance.

5. LITERATURE.

1. Adviesburo Verhoef bv; Onderzoek warmteterugwinning supermarkten; MD.865.030; 23 februari 2003.
2. Adviesburo Verhoef bv; Keuzemodel Inkoop Koeling Supermarkten; DW.920.011; 25 maart 2003.
3. Adviesburo Verhoef bv; Onderbouwing KIKS; DW.920.012; 25 maart 2003.
4. Nationaal Onderzoek Koudemiddel Stromen (NOKS), managementsamenvatting, d.d. 16 juli 2001.
5. Dr. Summerer; Güntner Symposium 2002 CO_2 evaporator Design Criteria.
6. Gebhardt, Kruse, Schiesaro; Entwicklung einer transkritischen zweistufigen Supermarktkälteanlage fur Tief- und Normalkühlung (1); Die Kälte & Klimatechnik; maart 2003.
7. Gebhardt, Kruse, Schiesaro; Entwicklung einer transkritischen zweistufigen Supermarktkälteanlage fur Tief- und Nomalkühlung (2); Die Kälte & Klimatechnik; oktober 2003.
8. Girotto, Minetto, Neska; Commercial refrigeration system with CO_2 as refrigerant experimental results; ICR 290-2003.
9. Christensen, Bertilsen; Refrigeration systems in supermarkets with propane and CO_2- energy consuption and economy; ICR 131-2003.
10. Rolfsman; Experiences from CO_2 cascade plants; ICR 081-2003.
11. Hubacher, Groll; Performance measurements of a hermetic, two-stage carbon dioxide compressor; ICR 029-2003.
12. Christensen; Use of CO_2 as primary and secondary refrigeration in supermarket applications; ICR 375-1999.
13. Kauffeld, Bertelsen, Hansen, Christensen; CO_2-Anwendungen in Dänemark; Luft- und Kältetechnik 1/2002.
14. Schiesaro, Kruse; Development of a two stage CO_2 supermarket system; IIF-IIR 2002/07.
15. Linde-Kältetechnik; Wege zum FCKW- und H-FCKW- Ausstieg in Lebensmittelhandel.
16. Haaf, Heinbokel; Supermarktkälteanlagen mit natürlichen Kältemitteln; Die Kälte & Klimatechnik; september 2002.
17. Danish Technological Institute; Demonstration af anvendelse af naturlige kolemidler i supermarkeder.
18. Linde-Kältetechnik; Propen-Kälteanlagen- umweltfreundliche Kältesysteme für kleine und mittlere Supermärkte; Technik und Wissenschaft 77/1998.
19. Jans; Fri-jado installatiegroep; Koelsystemen met CO_2 als primair koudemiddel voor de commerciële koeltechniek; 24-02-2004.

Apeldoorn; 19th July 2004