APPLICATIONS AND EXPIRIENCE WITH NATURAL REFRIGERANTS CARBON DIOXIDE / CO2 AND HYDRO CARBON R-1270

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1. Abstract

This presentation will show pictures, explain the techniques and the experience from real "full scale" installations with natural refrigerants.
It is our aim to show that refrigeration systems with natural refrigerants are reliable, energy efficient and available for most applications and sizes in the low, medium and high temperature (AC) range.
The experiences in this paper are based on our installations with CO2 installations since 2001 and Hydrocarbon HC R-1270 since 2004.

2. Introduction

The whole process of development of refrigeration systems with natural refrigerants started after the IIR conference in Aarhus 1996, where the Danish environment minister Svend Auken predicted the HFC phase in Denmark out within 10 years.
After some time considering if this political message was for real, we decided to take HFC phase out as a technical challenge and started our theoretical investigations.
Our first CO2 installation was started 10/2001. in a supermarket in Copenhagen. It was a low temperature cascade system with a capacity of 30 kW at -35°c./-10°c.
In September 2004 followed medium and high temperature systems with up to 50 bar CO2 design pressure.
Since no suitable CO2 pumps were available we had to develop other solutions to generate a pumping pressure, witch lead to our thermal pump system, described later in this paper.
The technology has since moved from the laboratories and field test phases to "real life", serial production and full scale installations.

3. Why use CO2 as refrigerant?

- Natural refrigerant.
- ODP = 0 = No effect on ozone layer.
- GWP = 1 = No effect on Global Warming Potential.
- Relative "harmless" refrigerant, not explosive, can not burn.
- Excellent energy efficiency, especially in the sub-critical phase..
- Simple and compact design of refrigeration plant, small dimensions of piping, valves, insulation etc.
- Basic design as traditional HFC refrigeration plants.
- No refrigerant taxes. Refrigerant tax in Denmark: 51 EURO pr. kg R-404A.
  This means that many CO2 applications in Denmark can have same installation costs as traditional HFC refrigeration plants.
- **HFC phase out in Denmark 01.01.2007 !!!!!!!**
  Max. 10 kg. of HFC allowed in all new installations. (HFC = R-134a, R-404A, R-407C, R-410A….)

4. Applications

A wide range of systems with natural refrigerants are manufactured and installed by Birton under the brand name "CO2OLSolutions":

The systems are suitable for most applications:

- **Low temperature: HC R-1270 / CO_2 cascade systems. (**Figure 2, 4 5)

- **Medium and high temperature: (Air Conditioning)** (Figure 1, 3)
  HC R-1270 as primary refrigerant cooling the CO_2 circuit.
  Volatile (evaporating) CO_2 as secondary refrigerant.
  Featuring the Birton patent pending thermal pump system, circulating CO_2 with "free energy" only. (figure 8, 9, 10)

- **The Birton patent pending CO_2 thermal pump system for "Add On" to existing refrigeration systems. Reducing refrigerant charges (HFC, HCFC etc.) and minimizing the risk of leaks.**

All systems are available as units for outdoor and indoor installation.

Figure 1: Outdoor unit with Birton thermal pump system, circulating CO_2 with "free energy" only.

Outdoor units featuring:

- Compact air-cooled units with compressors in closed sound insulated compartments.
- Hydro carbon HC R-1270 as primary refrigerant system in a separate closed box.
- Energy efficient direct condensation of R-1270 in the air-cooled condenser.
- Manufactured according to PED and ATEX.
- Integrated controls and electrical panel.
- Cooling capacity up to 500 kW. (Po -10°c. / Pc +40°c.) in one unit. (max length 14,5 m.)
- "Plug and play" solution.

Figure 2: Indoor low temperature cascade unit:

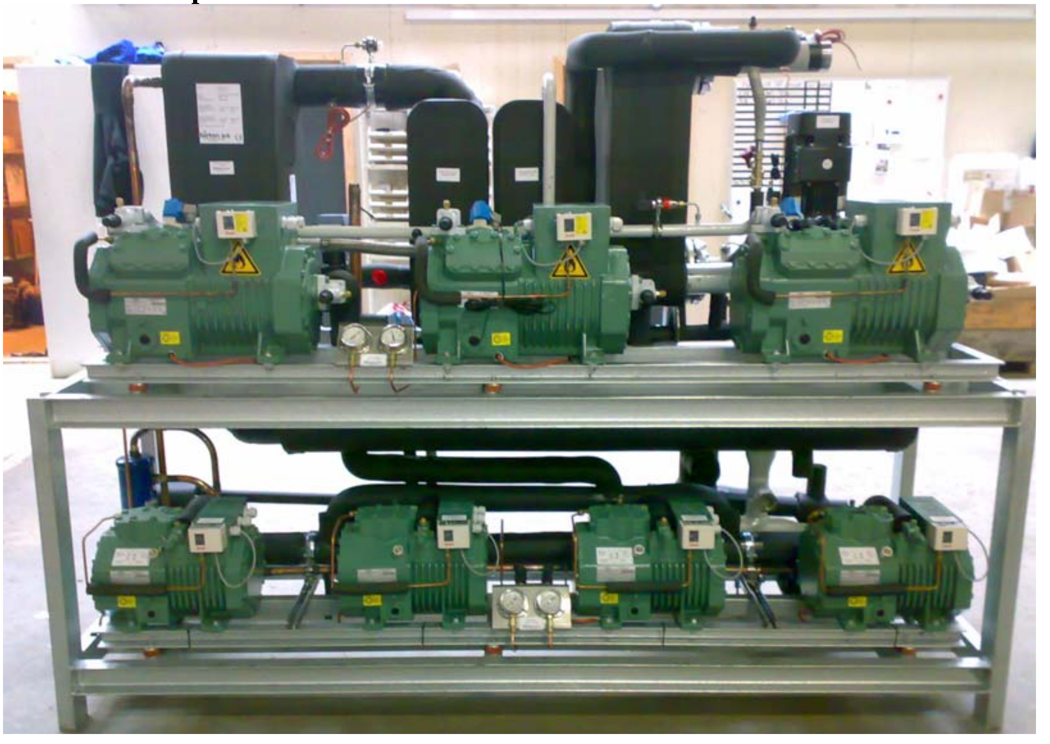
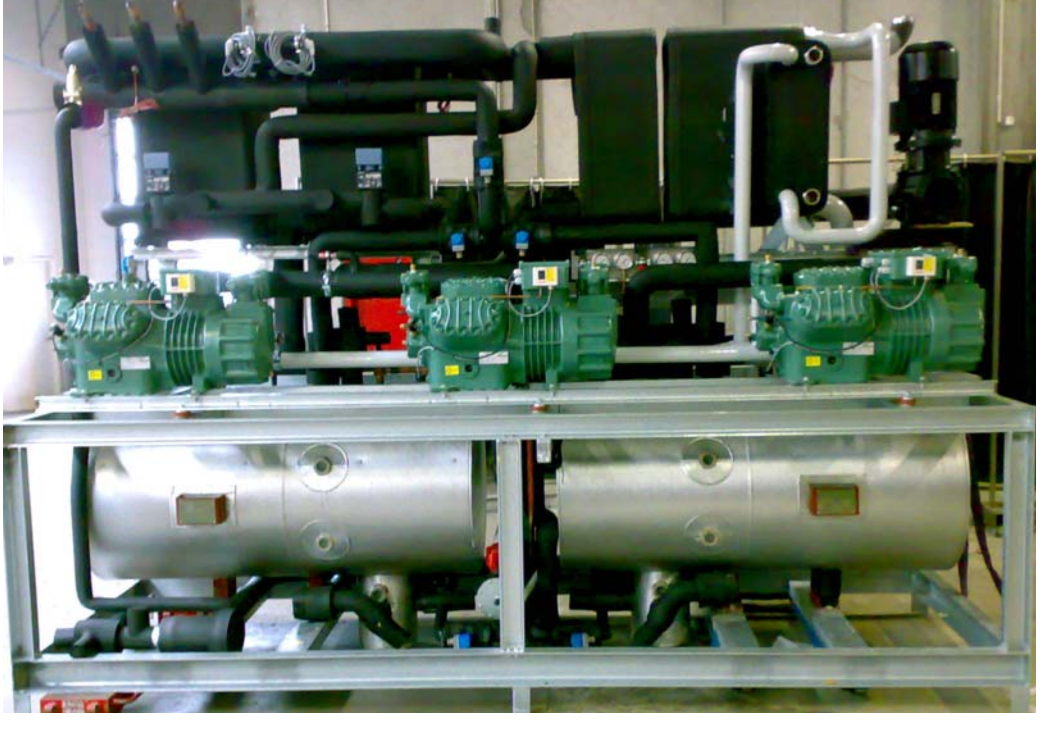


Figure 3: Indoor unit with Birton thermal pump system, circulating CO2 with ”free energy” only.

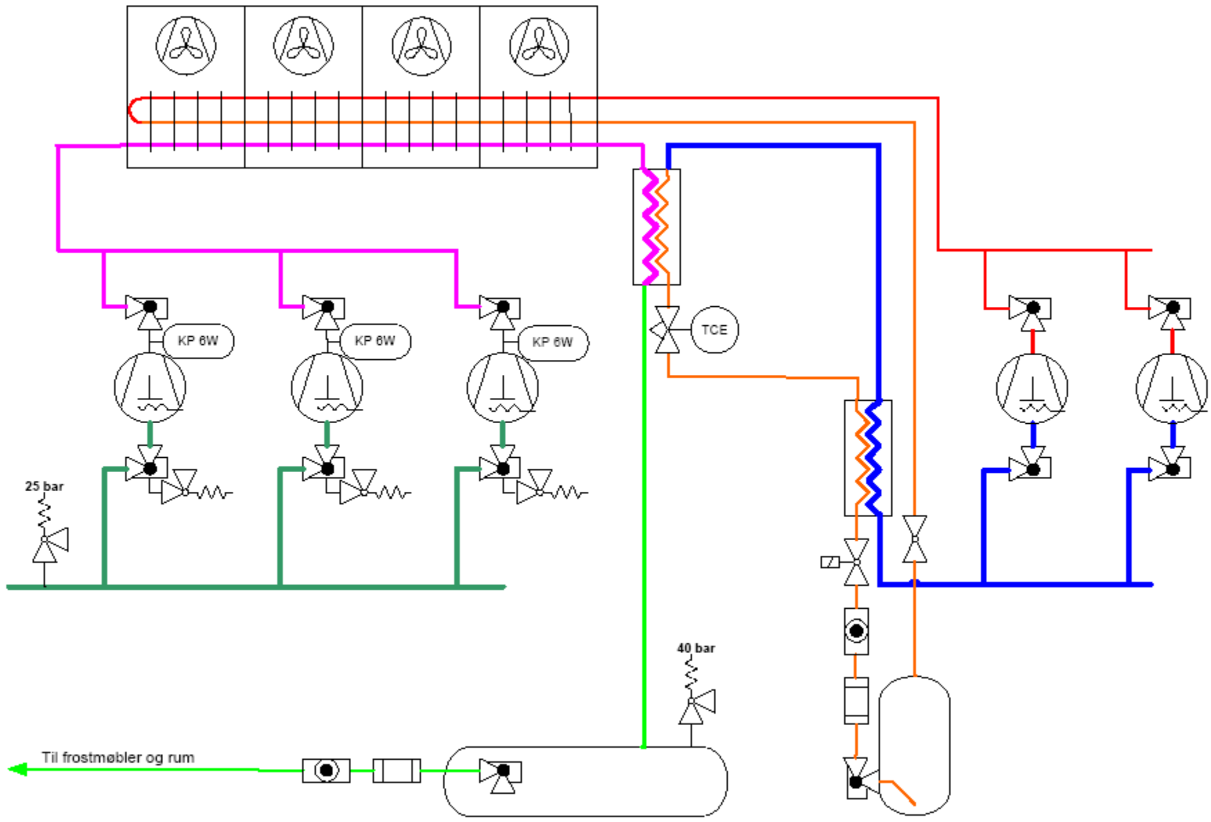


Indoor units featuring:

- Compact water-cooled units with compressors in a rigid steel frame.
- Plate heat exchangers and very compact pipe system minimizing the HC R-1270 charge.
- Plate condenser and pump for separate dry-cooler system.
- Manufactured according to PED and ATEX.
- Separate compressor room must be provided.
- Controls and electrical panel for installation in a separate room..
- Cooling capacity up to 250 kW. (Po -10°c. / Pc +40°c.) in one unit.

5. Low temperature HC R-1270 / CO2 cascade systems

Figure 4: PI diagram.



Cascade system where the CO2 low temperature condenser is cooled by a primary R-1270 system featuring:

- “Pack” design with more compressors, due to capacity control, energy efficiency and reliability.
- Intermediate CO2 discharge desuperheater improves efficiency and saves energy.
- R-1270 liquid sub cooler / suction gas heat exchanger due to required min. suction gas / oil temperature of the R-1270 compressors.
- Design pressure of CO2 system 25 / 40 bar.
- Energy efficiency COP similar or better than “traditional” HFC R-404A 1 stage systems.
- System price can be similar to HFC R-404A 1 stage systems. (higher price for unit, but major savings on CO2 pipes, insulation, refrigerant, tax etc.)

Figure 5: Outdoor low temperature cascade unit:

6. CO2 for medium and high temperature: (Refrigeration and Air Conditioning)

The challenge of CO2 system design:

Trans-critical CO2 systems?

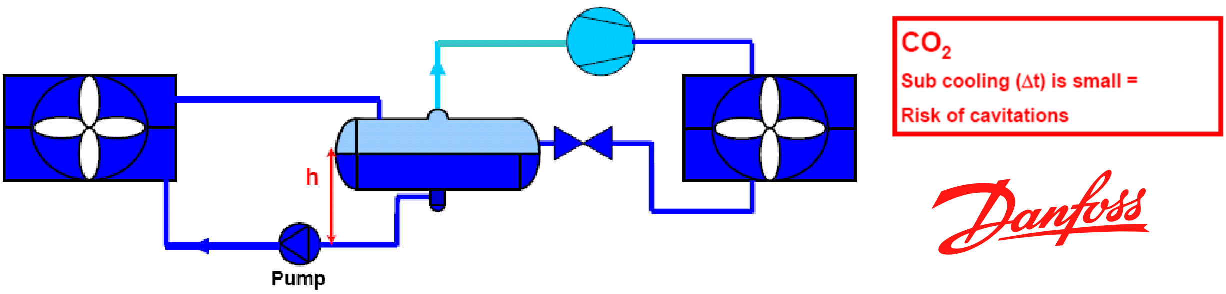
- In general the CO2 trans-critical cycle is not very efficient and systems still need a lot of improvement before the energy efficiency can be acceptable.
- Only a few components were available in 2004 and still today only a few suppliers can provide components and knowledge for trans-critical CO2 systems.
- A big difference of cooling capacity in sub- and trans-critical mode requires pack design and / or a good capacity control to match the cooling load.
- Design pressure up to 120 bar on the gas-cooler / condenser side.

Sub-critical CO2 systems:

- The thermodynamic properties and efficiency of CO2 as a volatile (evaporating) secondary refrigerant in the sub-critical phase below +31°c. are excellent.
- CO2 as secondary refrigerant requires a primary refrigerant circuit to be cooled to the selected temperature. (-15 - +10°c.)
- Pumping CO2 is a challenge. (figure 6)

Figure 6: The challenge of CO2 pumping:

Refrigerant		R134a	R717	CO2
High "h"	[m]	3	3	3
Pump inlet pressure - Dp	[bar]	0,418	0,203	0,329
Pump inlet pressure - Dt	[°C]	14,91	5,21	0,88



- The sketch and table above shows that the height of liquid before the pump (NPSH) provides much less sub-cooling than traditional pumped refrigerants.
- Pressure drop before or in the pump can easily cause flash gas and cavitations of the pump.
- Energy consumption of the pump must be added to the system efficiency.
- Heat rejection from the liquid cooled pumps must be added to the cooling load.
- Capacity control of the pump and / or overflow device must be installed.
- Minimum 2,0 bar pumping pressure required for CO2 direct expansion operation.

7. The solution: “CO2OLSolutions”

HC R-1270 as primary refrigerant cooling the CO2 circuit.
Volatile (evaporating) CO2 as secondary refrigerant.
Featuring the Birton patent pending thermal pump system, circulating CO2 with ”free energy” only.

- No energy consumption for pumps, compressors or other mechanical devices.
- Direct expansion assures circulation of a minimum amount of refrigerant.
- Maximal volumetric refrigeration capacity since all the latent heat of vaporization is used.
- Small pipe dimensions compared to flooded CO2 systems.
- Oil free operation assures optimal heat transfer in heat exchangers.
- No risk of cavitations in pump. (no pumps)
- No need for capacity control of pump or overflow device.
- The system is made of vessels, heat exchangers, pipes and only a few moving parts witch leads to limited maintenance required.
- Installations costs can be similar to traditional systems.
  Savings in pipes, insulation, refrigerant and tax *) might pay back the additional costs of the circulation system.
- Environmental savings due to reduced primary refrigerant.
- Primary refrigerant is limited to the compressor room or outside in a package air-cooled unit.
- Any primary refrigerant is suitable: Ammonia/ Hydro Carbon´s/ CO2 etc. (and HCFC / HFC’s where they are still allowed)
- The ”free energy” circulation system is suitable as alternative or replacement for central refrigeration and air-condition systems using direct expansion of synthetic HFC refrigerants or Chillers with water or brine systems.
- The new system is suitable for industrial, supermarkets and similar applications.

Figure 7: 2 prototype units installed 2004 at the roof of a shopping Centre in Copenhagen.
Cooling: 100 kW. CO2 circulating temperature -10°c. / design pressure 40 bar.
Air conditioning: 100 kW. CO2 circulating temperature +5°c. / design pressure 50 bar.

8. Birton patent pending thermal pump system, circulating CO2 with ”free energy” only.

No pumps !!!! Thermal circulation system where pumping pressure is generated by heating CO2 trapped in the pumping vessels. The CO2 is heated by the primary refrigerant liquid line.
Heating energy = sub-cooling = ”free energy”

- The system comprises a CO2 condenser cooled by the primary refrigeration system.
- The liquid CO2 is lead by gravity to one of the two pumping vessels, where the pressure is equalized with the condenser through solenoid valves.
- Liquid from the primary system is heating the CO2 trapped in one of the vessels, generating pressure and supplying liquid CO2 through a non-return valve to the evaporators.
- When the pumping vessel is empty, the system alternates.
- A liquid level sensor in each vessel and a small PLC is monitoring and controlling the alternation.

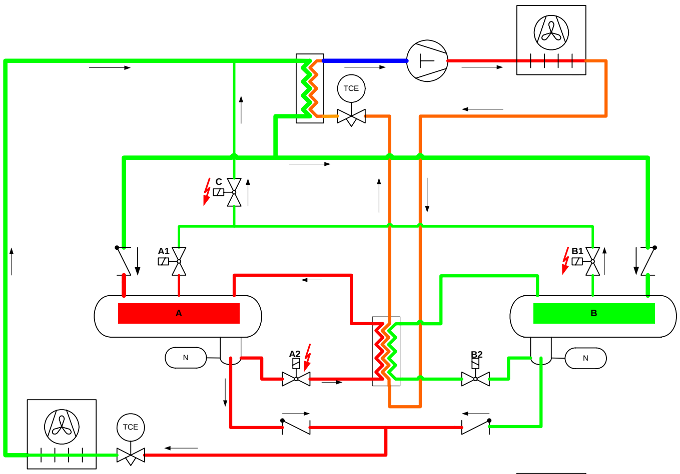


Figure 8: Sequence A:
Vessel A is pumping
Vessel B is charging

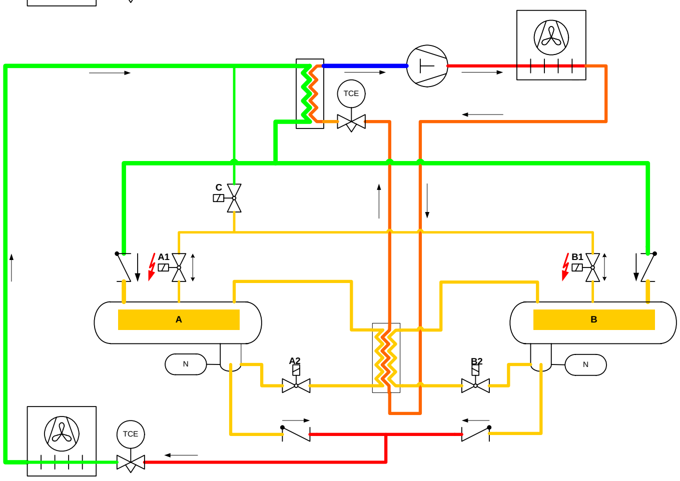


Figure 9: Alternating:
The pressure are equalizing between the vessels
Duration 5 seconds.

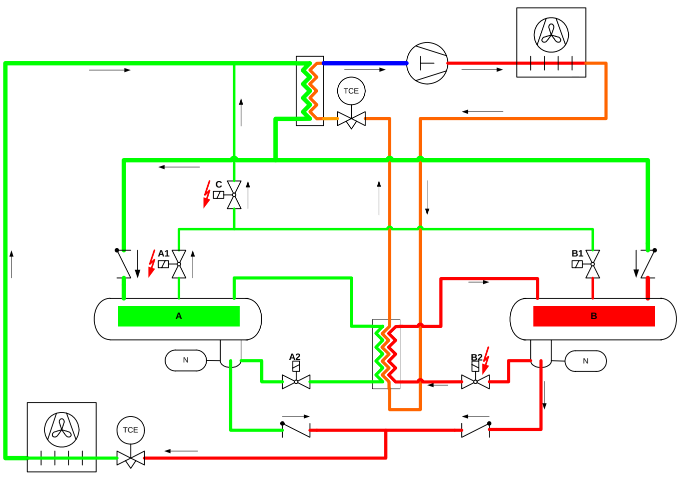


Figure 10: Sequence B:
Vessel B is pumping
Vessel A is charging

9. The Birton CO2 thermal pump system is also available as "Add On" to existing refrigeration systems.

According to the Danish Ministry of the Environment it is <u>not allowed</u> to:

- Re-build or extend an existing refrigeration system, so it requires more HCFC / HFC charge.
- Change of refrigerant, i.e. from HCFC to HFC or drop in.

With the Birton ”Add On” solution an existing compressor-pack can be re-used and connected to the CO2 thermal pump system. New CO2 pipes are installed from the thermal pump to the new cooling points. The old (HFC, HCFC etc.) refrigerant charge are then reduced and limited to the compressor-room, minimizing the risk of leaks.

10. Energy efficiency

Due to the fact that heat is exchanged between the primary HC R-1270 and the secondary CO2 there will be a loss of up to 5K evaporating temperature in the plate heat exchanger.

Nevertheless the excellent properties of CO2 and R-1270 more than catch up with losses:

- Due to the excellent heat transfer in the evaporators, the CO2 evaporating temperature can be 3-4K higher than HFC´s
- Better sensible heat ratio due to higher evaporating temperature leads to 3,5% saving of latent cooling load with the same sensible cooling capacity.
- Longer time between defrost due to higher evaporating temperature also leads to energy savings.
- Oil free CO2 also improves the heat transfer, but there is no documentation or experience available.
- Pressure drop in pipes are very low. Pipes system in a supermarket can easily be designed for a suction line pressure drop less than 0,5 K.
- Theoretical data and the selection program from Bitzer gives HC R-1270 up to 12% higher performance and 15% better COP compared with HFC R-404A. (-15 / +40°c.)

Outdoor units must be preferred due to the direct condensation of R-1270 in the air-cooled condenser. Indoor systems suffer from the losses from the dry-cooler system. (Like all other systems with dry-cooler)

No real long term measurements of the energy efficiency have yet been carried out, but values based on the logs and benchmarking towards previous HFC direct expansion systems has shown remarkable results.

11. Status 2008

- Our first CO2 installation was started 08.10.2001 and is still in operation without any modifications.
- A large number of CO2 installations is in operation and is now a standard solution for supermarkets and small industrial applications.
- A wide range of "CO2OLSolutions" units are standardized and are in serial production.
- There are reliable and well proven solutions available for most applications: Freezing, refrigeration and *even air-conditioning.*
- Service and maintenance costs are at the same or lower level as HFC systems.
- CO2 is a fantastic refrigerant with excellent thermodynamically properties.
- Our experience with natural refrigerants has exceeded our wildest expectations.