

Components used in carbon dioxide refrigeration systems

Carbon dioxide as a refrigerant

Among all the fluids currently used or proposed for use as refrigerants carbon dioxide (CO₂) is something of an oddity. Unlike any other substance in the refrigeration and air-conditioning world it is applicable to a range of systems from low temperature freezer plants at -50°C to hot water heating systems at 80°C in sizes from small domestic units up to huge industrial facilities. Also unlike most other refrigerant fluids CO₂ combines the twin advantages of being non-flammable and non-toxic with the environmental benefits of having no ozone depletion potential and a global warming potential of 1.

There is no single reason for this universal applicability of CO₂; rather it is the result of several system properties which mark it out from the majority of working fluids. The most obvious of these is the higher operating pressure of CO₂ systems, but to this we can add extremely low viscosity, even at the lowest operating temperatures, and the low critical temperature of CO₂.

In the 1950s and 60s CO₂ was displaced in new plants by synthetic refrigerants, touted by the chemical industry as so-called safety refrigerants. It wasn't rediscovered until the early 1990s, when researchers and practitioners realized that CO₂ can be an excellent refrigerant for today's energy and environmental situation. Now it is possible to source a wide range of components for use in refrigerating systems up to 120 bar operating pressure, as demonstrated in this paper. It is also apparent that the high pressure of the CO₂ delivers many of the inherent benefits of these systems. The compressors are relatively small and so is the pipework. The gas is very dense, and as a result gives good transport and heat transfer performance. The system efficiency is relatively unaffected by pressure drop, because the saturation temperature profile is so flat. It is fair to say that the high operating pressure of CO₂ offers opportunities to create significantly more efficient systems than the current best practice, provided the whole system is designed to capitalise on these advantages.

The viscosity of liquid CO₂ is about one-tenth of that of water at 5°C. Unlike brine and glycol solutions this figure remains almost constant at lower temperatures, even down to -50°C. This gives CO₂ a significant advantage as a low temperature heat transfer fluid, and if the liquid is allowed to boil in the cooling heat exchanger the benefit in performance is even

greater. This property has been exploited in a wide range of applications including food processing equipment, cold storage and IT cooling systems.

The critical temperature of 31 °C is also often said to be a disadvantage, but like operating pressure it offers opportunities to do things differently, and in many cases to generate significant advantage over conventional technology. High grade heat recovery is the most common advantage. This is available whether the operator chooses to exploit it or not, and the range of domestic, commercial and light industrial heat pumps already on the market show that this advantage is sufficiently large to justify system installation in its own right, rather than as a supplement to a cooling system. The benefits of this property are even greater when the cooling and heating systems are integrated.

Although CO₂ was first used as a refrigerant nearly one hundred and fifty years ago, it has only been intensively studied in the last fifteen years. There is still significant scope for further product and system development. With increased attention paid to the environmental implications of refrigeration system efficiency the possible advantages to be gained from the use of CO₂ are as important today as they have ever been.

Components for carbon dioxide refrigeration systems

Components	Page
Compressors (open type reciprocating and screw compressors)	3
Compressors (semi-hermetic reciprocating compressors)	4
Condensers/gas coolers (air-cooled)	4
Condensers/gas coolers (liquid-cooled), inner heat exchangers	5
Evaporators	5
Heat exchangers	5
High side float regulator	6
NH ₃ /CO ₂ cascade systems	6
Pressure vessels	6
Pumping stations	7
Refrigeration pumps suitable for NH ₃ and CO ₂	7
Temper-40 heat transfer fluid (used as defrost media in low temperature CO ₂ refrigeration installations)	8
Valves (shut off refrigeration valves, filters, check valves, hand regulating valves and stop check valves)	8
Ball valves	9
Refrigeration purge/drain/gauge valves	10

Compressors (open type reciprocating and screw compressors)

Sub-critical applications

Grasso 5 HP (50 bar design pressure) reciprocating range, 4 different models, 100 to 200 m³/h swept volume, 152 up to 303 kW at -40°C/-5°C

Grasso screw compressors in 22 different types in their HP version (52 bar design pressure), 231 to 8,570 m³/h, 328 up to > 10,000 kW at -40°C/-5°C, all screw compressors are suitable for hot gas defrost in due to its unique design pressure of 52 bar.

Trans-critical applications

Grasso developed an open type screw compressor particularly for the use on higher pressures which occur in trans-critical CO₂ applications and NH₃ heat pumps.

Speed range: 2,500 to 6,000 rpm

Swept volume: 60 to 154 m³/h

Capacity: 300 to 770 kW

at t₀/t_{GC-out} = 5°C / 45°C / 120 bar

Shaft power: 110 to 360 kW

Fields of application:	CO ₂ in normal and deep-freeze refrigeration as booster or cascade system, deep-freeze cascade systems, normal refrigeration systems, hot water heat pumps and industrial applications
Particulars of specification:	Compressors for sub- and trans-critical applications are adapted to the high, specific requirements regarding material strength, bearing load and oil supply. In CO ₂ applications generally attention must be paid to the thermodynamic properties of the substance and special care given to keeping the systems clean and dry. Grasso delivers the components both as units and as industrial prefabricated complete systems (eg cascade system).

Compressors (semi-hermetic reciprocating compressors)

Sub-critical applications

With the introduction of the further developed Bitzer Octagon® CO₂ compressor, there are now 17 models available in the range from 2.7 to 81 kW refrigerating capacity (-35 °C/-5 °C) for sub-critical CO₂ cascade and booster applications. This new series of compressors replaces the K-series which has been used successfully all over the world in CO₂ projects already since the 1990s. A particularly robust drive version and valve plate design adapted specially to the demands of CO₂ permit further increases in efficiency and operating reliability. As well as expanding the product range with closer graduations in capacity, the operating limitations of the compressors have been broadened and harmonized.

Trans-critical applications

Based on the Octagon® compressor series, an extra series has been developed for the specific requirements of trans-critical CO₂ applications. This means that a series is now available for such systems with the attributes of the proven Octagon® compressors. The wide operating range of the compressors permits their use in a large number of system variants. This particular series addresses interested companies involved in corresponding developments with trans-critical CO₂ systems. The warranty for such machines is subject to a special agreement, because of the specific requirements applying to the installation and operation of these systems.

Fields of application:	Supermarket applications with CO ₂ in normal and deep-freeze refrigeration as booster or cascade system, deep-freeze cascade systems, normal refrigeration systems, hot water heat pumps, industrial applications
Particulars of specification:	Compressors for sub- and trans-critical applications are adapted to the high, specific requirements regarding material strength, bearing load and oil supply. In CO ₂ applications, generally attention must be paid to the thermodynamic properties of the substance and special care given to keeping the systems clean and dry.
Technical data:	See technical documentation KP-120 and KP-130 at www.bitzer.com
Advantages:	The compressors stand out with efficient, quiet, low-vibration operation. The products are also ideal for operation with frequency converters to enhance and control output. In addition, all CO ₂ compressors are equipped with wear-resistant drives, compression-proof housings and overflow valves.
Disadvantages:	CO ₂ applications cannot yet be considered state of the art, particularly in the case of trans-critical applications. Complicated system equipment is required for cascade or booster systems. In normal refrigeration and air-conditioning systems, the cumulative frequency of the ambient temperatures is a major criterion for energy efficiency, which restricts the global use of CO ₂ .
Stage of development:	CO ₂ compressors by Bitzer have reached a leading development status. Both series are being expanded with further models.
Limitations on CO ₂ use:	The low efficiency of CO ₂ applications at high gas cooler outlet temperatures influences applicability in hot climatic zones, similarly to the sublimation point which prohibits deep-freeze applications below $t_0 = -56 \text{ °C}$.

Condensers/gas coolers (air-cooled)

Tube and fin condenser, made of stainless steel tubes and aluminium fins, that is used as condenser in subcritical operation mode and as gas cooler in trans-critical operating mode

Fields of application:	Commercial refrigeration
------------------------	--------------------------

Particulars of specification:	For high ambient temperature applications water spray system can be delivered, optimal with cathodic dip coating; any kind of special design is possible
Technical data:	$Q_{c \max} = 500 \text{ kW}$ Max. operating pressure 120 bar, max. temperature 150 °C
Advantages:	Excellent durability (long service life) due to stainless steel tubes, proven successful floating coil system
Disadvantages:	Delivery time for special designs
Stage of development:	Almost serial product
Comments:	Tested with 170 bar water pressure

Condensers/gas coolers (liquid-cooled), inner heat exchangers

Plate heat exchanger made of stainless steel, copper soldered in vacuum. For use as condenser in sub-critical operating mode, as gas cooler, suction gas heater, economizer and oil cooler in trans-critical operating mode.

Fields of application:	Commercial refrigeration, heat pumps, transport refrigeration
Particulars of specification:	Bursting pressure over 560 bar, also suitable for high alternating pressure loads, complies with PED, ASME and KHK
Technical data:	Up to 100 kW. Operating pressure above 140 bar, max. temperature 150°C
Advantages:	Extremely compact (no frame necessary) – economic procurement costs
Stage of development:	Almost serial product

Evaporators

Tube and fin evaporators for direct expansion, made of copper or stainless steel tubes (pump systems with hot gas defrost)

Fields of application:	Commercial and industrial refrigeration
Particulars of specification:	All types of installation possible
Technical data:	$p_{\max} = 40 \text{ bar}$ Stainless steel $p_{\max} = 50 \text{ bar}$
Advantages:	Selection program for all types of CO ₂ evaporators
Stage of development:	Serial products, technical leaflets
Comments:	Tested with 44 bar (DX) and 71.5 bar (pump system) water pressure

Heat exchangers

Fields of application:	Industrial refrigeration systems
Particulars of specification:	Integrated in complete cascade units for CO ₂ /NH ₃ or heat exchanger/surge drum units with piping and insulation
Advantages:	Calculation, design and production from one source
Stage of development:	Heat exchangers are selected using own computer programs and AD regulation as well as works standards
Limitations on CO ₂ use:	According to specifications up to 65 bar

High side float regulator

Fields of application:	In industrial refrigeration systems high side float regulators are used as a mechanical expansion device behind the condenser.
Particulars of specification:	HS models were designed with regards to CO ₂ applications with a nominal standard pressure of 40 bar.
Advantages:	Witt high side float regulators offer an easy mechanical expansion of refrigerant from HP to LP side. This enables unrivalled safety (also during power outage) at a constant low pressure.
Disadvantages:	Proper venting of the refrigerant system required
Stage of development:	HS models were designed in respect to CO ₂ applications and have proven good performance in numerous CO ₂ systems.
Limitations on CO ₂ use:	The maximum permissible pressure is limited today to 40 bar.

NH₃/CO₂ cascade systems

Fields of application:	Prefabricated NH ₃ /CO ₂ cascade systems are mostly offered to contractors who work in the field of industrial refrigeration. However, Witt has also responded to the growing demand of larger commercial refrigeration systems.
Particulars of specification:	Witt offers complete heat exchanger/surge drum units, with insulation upon request. Witt engineers provide the refrigeration calculation and selection for the vessels and connections and serve as competent partner. Drawings are created to the specific needs with a 3D CAD station and send to the customer for approval prior to production.
Advantages:	Selection and design of the cascade system is provided by experienced Witt engineers. Pre-assembled complete units reduce construction time on site
Stage of development:	Special solutions were designed for NH ₃ /CO ₂ cascade systems. Cascade systems are sold for more than 5 years to the industry. Not only in Europe there have been excellent results regarding improved refrigeration performance and energy efficiency.
Limitations on CO ₂ use:	As with any other refrigerant the CO ₂ concentration needs to be monitored and an alarm system must be in place.

Pressure vessels

Fields of application:	Witt pressure vessels are mostly used from contractors who are active in the field of industrial refrigeration systems, e.g. as surge drums or receivers.
Particulars of specification:	Pressure vessels are individually selected with in house software and manufactured according to internal work standards. The Witt steel support frames can accommodate not only the pressure vessels, but also entire prefabricated piping. Witt is certified according to DIN ISO9001, GOST and PED, module H1.
Advantages:	Witt will take over part of the engineering tasks. Just provide refrigeration capacities, temperatures and specific additional requirements and Witt will select the correct pressure vessel.
Stage of development:	Special solutions were designed for CO ₂ applications. Improvements and new developments of products are tested with CO ₂ in the Witt laboratory.

Pumping stations

Witt refrigeration pumping stations comprise the combination low pressure vessel (surge drum) with refrigerant pumps interconnecting pipework and liquid level controls. All mounted on a steel base support frame.

Fields of application:	The pumping stations are used in the food and process industry where large volumes of refrigerant are required for cooling food or cold storage. Pumping stations are used to supply ring mains with refrigerant for feed blast freezers and air coolers.
Particulars of specification:	Pumping stations usually incorporate the CO ₂ systems in a cascade system for the low temperature side with NH ₃ working on the high side.
Technical data:	Refrigerant drum duties can be designed from 150 to 2,000 kW. Depending on the evaporation temperature standard 25 or 40 bar pumping stations are designed and manufactured. Higher design pressures are available upon request.
Advantages:	The Witt design of CO ₂ pumping stations incorporates a single down feed to each pump enabling gas bubbles to return to the surge drum. This ensures the pump can operate without gas locking. Witt engineers will select the correct pumping station according to the customer's requirements.
Stage of development:	The height of the liquid level above the pump centre line should not be less than 1.5 m for CO ₂ . Due to large shell size this may require a high plant room ceiling.
Limitations on CO ₂ use:	Several plants have been installed in the last 4-5 years in Europe giving excellent results and enhanced cooling performance and low energy requirements.
Comments:	As with any other refrigerant high concentrations of CO ₂ inside plant rooms are constantly monitored and fitted with alarm systems.

Refrigeration pumps suitable for NH₃ and CO₂

Witt hermetic refrigerant pumps with radial impellers are suitable for pumping liquid with entrained vapour. This is of importance for boiling liquids, such as CO₂, because during reduction of the pressure gas bubbles will form. The stator housing is designed to withstand the high nominal pressure of the pump, giving unrivalled safety. Developments of the hermetic pump include 40 bar models for CO₂, with a further development of 90 bar designs for high pressure CO₂ applications.

Fields of application:	The pump is suitable to deliver refrigerant to the evaporators (as a refrigerant or brine), e.g. for use on pumping stations for cold store and blast freezer applications, but also serve plate freezers, cascade systems and air conditioning systems for building services.
Technical data:	The Witt hermetic refrigerant pumps can supply a CO ₂ volume flow of 1 to 50 m ³ /hr with up to 60 m delivery head. All models are designed with a nominal pressure of 40 bar and there are furthermore 65 bar and 90 bar models available.
Advantages:	All HRP pumps are specifically designed for use in refrigeration systems. Liquid/gas mixtures can be pumped without interrupting the flow. The required suction head is very low. There are no further orifices or pipework required. Quiet and vibration free performance as well as outstanding efficiency characterize Witt HRP pumps.
Stage of development:	Witt manufactures HRP pumps for CO ₂ since 1999. There have been a lot of improvements for CO ₂ applications during the past years for optimum operation. All 40 bar pumps are in production and used extensively in the refrigeration industry. The 90 bar pump

	design recently developed is now being introduced into commercial and industrial installations.
Limitations on CO ₂ use:	The installation requirements in the instruction manual must be adhered to to ensure trouble free operation. A reverse flow of refrigerant through the pump is not permitted. Therefore, when two or more pumps are installed they must be fitted with non-return check valves on the delivery side.
Comments:	The Witt design HRP pump has been specially developed for use with refrigerants and is not a chemical pump. It is optimized to operate with boiling refrigerants. Witt has over 100 years experience in manufacturing and development of industrial products for refrigeration.

Temper-40 heat transfer fluid (used as defrost media in low temperature CO₂ refrigeration installations)

Fields of application:	Defrost system for CO ₂ low temperature storage/distribution centre
Particulars of specification:	Using waste heat for defrost of air coolers in low temperature storage rooms by simple and safe technology. Heat exchangers (GEA/Goedhart, Guntner, etc.) supplied with double piping.
Technical data:	Typical -28/-32 °C low temperature, by defrost cycle approx. 20/30 °C. Thermal data for Temper from www.temper.se .
Advantages:	No cost for waste heat in the refrigeration plant. Replacing electrical defrost/electrical consumption (which reduce CO ₂ emissions from power plants), also more simple than CO ₂ hot gas defrost (very high pressures). Plastic piping can be used (reduces cost, no risk of corrosion). Calculation examples on saving potential (economical/environmental) can be supplied by Temper Technology.
Disadvantages:	Extra piping needed, higher installation cost but paid back in a short time due to low electrical consumption.
Stage of development:	Already in operation in several NH ₃ /CO ₂ installations in the Netherlands, Spain and Germany. Latest reference by Lidl distribution centre in Kerpen (start of operation December 2008).
Limitations on CO ₂ use:	Not known, but small installations maybe cheaper with electrical defrost.
Comments:	This technology makes CO ₂ installations more energy efficient, saves cost by using less electricity and due to this reduce the CO ₂ emission from power plants a lot.

Valves (shut off refrigeration valves, filters, check valves, hand regulating valves and stop check valves)

The range of alternative CO₂ valves is complete from DN4 to DN450 which incorporate drop forged low temperature steel bodies up to DN65. From DN80 the valves are made from cast low temperature steel.

Fields of application:	The RFF refrigeration valves and other line equipment are used extensively in all areas of industrial and commercial refrigeration where high quality serviceable valves are required.
Particulars of specification:	Where required above line size 32 mm all valve equipment complies with the PED Regulations.
Technical data:	The refrigeration valves are designed to satisfy three design ranges, 25, 40 and 65 bar. For CO ₂ applications depending on the plant system design, either 40 or 65 bar products are available.

	Minimum operating temperatures for all the low temperature steel valves is -50°C. This is only limited by the temperature range of the 'O' rings used in the valve construction.
Advantages:	The valves are suitable for socket or butt welding, with additional range of stainless steel models from DN4 to DN25. The shut off valve seat design provides a very low CV pressure drop rating. The spindle design is a simply hydraulic seal using low temperature oil in between the two spindle 'O' rings.
Disadvantages:	Steel valves are designed for use with refrigerants and should not be used with brines or low temperature fluids containing water. Stainless steel valves can be used for all types of fluids.
Stage of development:	All the RFF refrigeration valves are mature products and comply with PED regulations having been used for several years in refrigeration plants using CO ₂ .
Limitations on CO ₂ use:	The design specification for CO ₂ valves should not be exceeded in pressure or low temperature.
Comments:	The RFF low temperature steel and stainless steel refrigeration valves have been accepted by the industry for use in a wide range of applications without any problems. The spindle seal is a simple design providing 100% efficiency sealing without any adjusting of the spindle locking nut. At all times RFF valves can be easily opened or closed and do not leak. The valves are easily serviceable and have a minimum number of parts.

Ball valves

The RFF refrigeration ball valves are constructed from low temperature or stainless steel bar material. They can be supplied with reduced bore DN20 to DN100 or full bore DN10 to DN80.

Fields of application:	The RFF refrigeration valves and other equipment are used extensively in all areas of industrial and commercial refrigeration where high quality serviceable valves are required.
Particulars of specification:	The ball valves are ideal for package units where space is a problem and a very low pressure drop is required.
Technical data:	The refrigeration valves are designed to satisfy three design ranges, 25, 40 and 65 bar. For CO ₂ applications depending on system design, either 40 or 65 bar products are available. Minimum operating temperatures for all the low temperature steel valves is -50°C. This is only limited by the temperature range of the 'O' rings used in the valve construction.
Advantages:	Can be also used as a control valve with compact design and very low pressure drop, when fitted with electric and pneumatic actuators. Simple design spindle 'O' ring seals can be serviced while on-line.
Disadvantages:	The low temperature steel valves are designed for use with refrigerants and should not be used with brines or low temperatures fluids containing water. Stainless steel ball valves can be used with all fluids.
Stage of development:	Size range is limited to DN100 reduced bore, DN80 full bore. With these sizes most CO ₂ pump applications can be satisfied. Future developments will include DN125 and DN150 models.
Limitations on CO ₂ use:	The valve is designed for applications design range -50°C to 150°C. Low temperature grease specification only to -64°C.
Comments:	The RFF ball valve was designed to meet the original requirements

	of BS4434 which specified serviceable spindle 'O' rings and remains unique in the market place as the only ball valve having this feature. The ball valve DN32 to DN100 is machined from solid steel bar and is free from all welds and long flange bolts. Suitable for use in pumping stations and industrial plants.
--	--

Refrigeration purge/drain/gauge valves

These small components are all suitable for use with CO₂ and incorporate low temperature and simple steel. A hot forged one piece design. Stainless steel spindle with serviceable 'O' ring seals. The single design pressure rating is 65 bar (PN65) for all small valves DN4 and DN8.

Fields of application:	These valves are used with purging and draining systems and for connecting small control lines and gauges.
Particulars of specification:	All valves can be supplied with hand wheels or caps.
Technical data:	The range includes DN4 and DN8 line sizes. The material used is low temperature steel or stainless steel.
Advantages:	Standard range of 30 valves with a range of 70 alternative possible inlet and outlet connections. A special advantage is the variation S5 connection which comprises 130/150 mm pipe stub for welding on to pressure vessels during fabrication.
Disadvantages:	Low temperature steel valves not to be used with brines or fluids containing water.
Stage of development:	These valves have been used in the refrigeration industry for several years and re-approved for PN65 systems.
Limitations on CO ₂ use:	Only to be used within the design specification.
Comments:	With such a wide range of alternative inlet and outlet connections, these small valves ideally satisfy the requirements of a wide range of applications. They can be mounted vertically, horizontally in any line and have a good spindle seal design incorporating two 'O' rings.

The manufacturers of the components are listed in the „Product Directory” at www.eurammon.com.

Published by eurammon
P. O. Box 71 08 64 ♦ D-60498 Frankfurt
Phone +49 69 6603 1277 ♦ Fax +49 69 6603 2276
e-mail: karin.jahn@eurammon.com
http://www.eurammon.com