SEMI-HERMETIC RECIPROCATING AND SCREW COMPRESSORS FOR CARBON DIOXIDE CASCADE SYSTEMS

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ABSTRACT

Due to its environmentally benign characteristics, low toxicity and favourable thermo-physical properties in sub-critical operation, carbon dioxide (CO_2) is increasingly being considered as a preferred fluid for secondary circuits and for low temperature cascade systems.

In comparison to conventional low temperature applications a particularly high volumetric refrigeration capacity allows significant cost reductions in compressors and pipe-work. Even for larger capacities this results in a potential use of compressor sizes usually found in commercial and light industrial applications. On the other hand, high operating and standstill pressures demand special criteria for compressor design and protection measures.

This presentation deals with possible solutions in system layout and in particular with the major development stages with semi-hermetic compressors and lubricants. Further subjects are related to protection measures and performance behaviour versus conventional plant designs.

1 INTRODUCTION

After CO_2 had been of little significance in refrigeration technology for many decades it was primarily for ecological reasons that its application was rediscovered. As well as development projects for trans-critical operating conditions, in recent years a series of sub-critically operated cascade systems have been carried out in large commercial and industrial low temperature cooling down to evaporating temperatures below –50°C. CO_2 offers favourable thermo-physical properties for this application range, it is also chemically inert, non-flammable and only harmful to the health in high concentrations. This means that for a number of applications it even has advantages over ammonia.

Open type reciprocating and screw compressors have hitherto been used with the systems involved. However, due to the high pressure levels, particularly demanding and therefore expensive design solutions are required. For this reason there has been increased interest lately in semi-hermetic compressors, which are based on large-scale production units and thus facilitate significant cost reductions.

In the meantime various projects have been realised with semi-hermetic prototypes. The following remarks describe the requirements, stages of development and safety measures for the relevant compressors.

2 CASCADE SYSTEM WITH CO_2

Fig. 1 shows the simplified sketch of a system in which CO_2 is liquified in a cooling unit (with refrigerants NH_3, HC or HFC) and transported by circulation pumps directly to the evaporators for medium temperature application. For the actual cascade stage an additional low-pressure receiver is foreseen; it is pumped down to the required evaporating pressure by one or several single stage compressors. The compressor discharge gas is fed into the cascade cooler together with the suction gas from the medium temperature evaporators and is then guided into the following receiver. From there injection takes place into the low pressure receiver by means of a float device.

Circulation pumps or systems with gravity circulation are used to supply the cold spaces with refrigerant. For systems with only one or a few evaporators the plant can also be designed as an

LPR system like Pearson (1983) described. For genuine low temperature cooling the system components for the medium temperature circuit are not necessary.

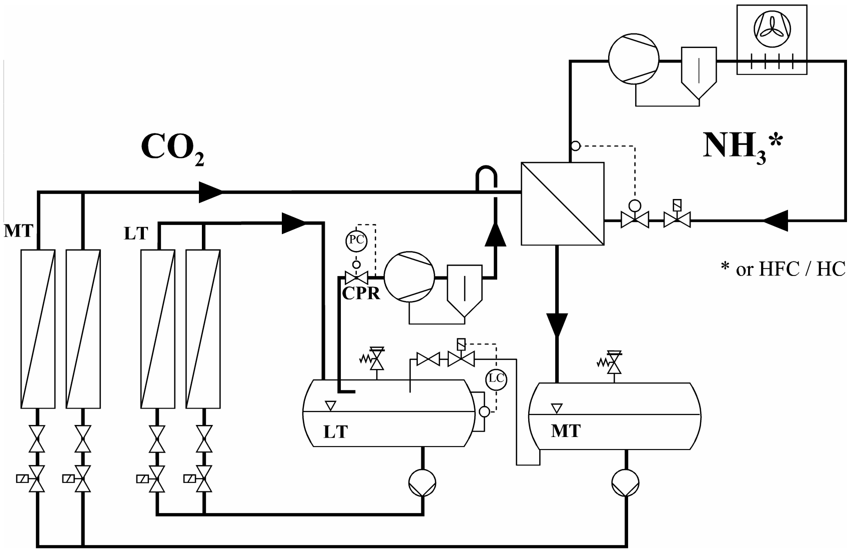

Figure 1 Cascade system with CO_2 (simplified sketch)

3 DEMANDS ON CO_2 CASCADE COMPRESSORS

The fluid properties of CO_2 result in comparatively high pressure levels even at low evaporating and condensing temperatures, which in some cases are well above the operating limits of typical standard compressors (Fig. 2). In comparison to R22, -35°C evaporating temperature (SST) and -10°C condensing temperature (SCT) for CO_2 are equivalent to "+30°C / +64°C", that are, conditions which do not usually occur in real systems. Despite the low vapour density of CO_2 compared with halogenated refrigerants (Fig. 3), this results in a higher mechanical load and a definite rise in the torque requirement. Whereby even more extreme load conditions have to be taken into consideration during the pull down process.

Another criterion relates to lubrication – because of the relatively high suction pressure, with a number of oils, there is significant CO_2 solubility and thus a definite reduction in the mixture viscosity.

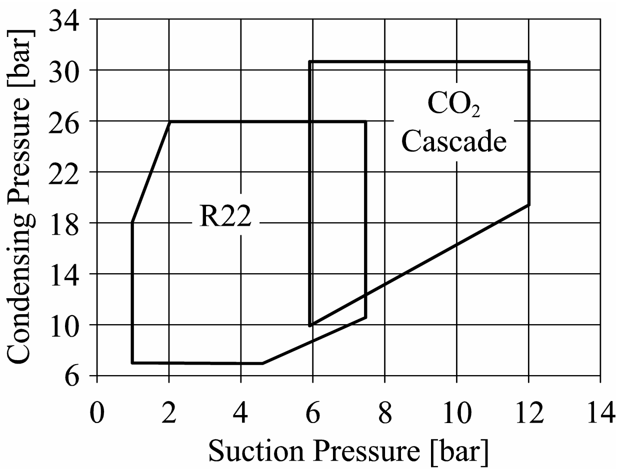

Figure 2 CO_2/R22 – Comparison of evaporating and condensing pressures within standard application range

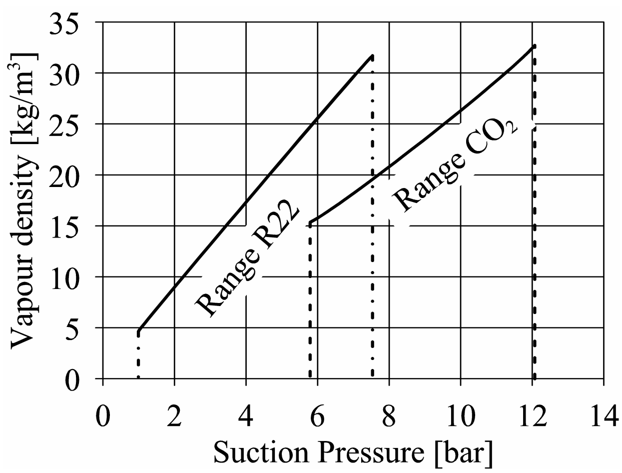

Figure 3 CO_2/R22 Comparison of vapour density across the standard suction pressure range

With semi-hermetics the material compatibility (with CO_2 and lubricant) of the winding insulation must also be considered. Another aspect is motor cooling, which is particularly challenging because of the high torque requirement and the very compact motor size.

In view of the properties explained before it becomes obvious that standard semi-hermetics can only be used with important limitations. Nevertheless, our investigations show that by combining components properly within a family of compressors, and by making appropriate design modifications aa well as using suitable lubricants, all important requirements can be met.

4 DEVELOPMENT STAGES / DESIGN FEATURES

4.1 Pressure load

Modern semi-hermetic compressors have a design pressure based on a five times safety factor which has to be demonstrated by carrying out regular type tests. In connection with an integrated relief valve, type tested safety valves and an individual pressure test according to relevant standards the usual application limits (HP 28 bar / LP 19 bar) can be lifted even higher. If necessary, gaskets with metal backing or support elements can also be applied.

The use of globular spheroidal cast iron instead of grey cast iron with a laminate structure for housing parts offers additional potential for raising pressure levels with the same wall thicknesses.

4.2 Mechanical load / Torque requirement

Related to the maximum operating conditions defined in Fig. 2, the evaporating and condensing pressures are approx. 60 % and 20 % above the usual maximum values for R22 compressors respectively.

The easiest way of adapting a compressor consists of combining the smallest displacement within a compressor series with the largest motor. With **reciprocating compressors** this also means that the smallest piston diameter is used, which results in reduced bearing load and shaft bending. The same is also true of the piston pin bearing, on which there are relatively high stresses. With smaller compressors the pin is usually sliding directly in the connecting rod material, depending on the specific load, additional bearing bushings can also be fitted.

Due to the high mass flow the working valves may have to be modified as well.

With **screw compressors** a short rotor design can be used and therefore also large bearing diameters in comparison to displacement. Because of the low pressure ratios with usual operating conditions in cascade systems this design concept causes no disadvantages in terms of efficiency.

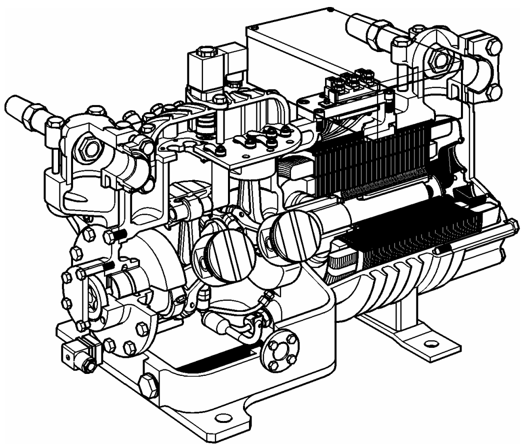

Figure 4
Cross-section of a
semi-hermetic reciprocating compressor

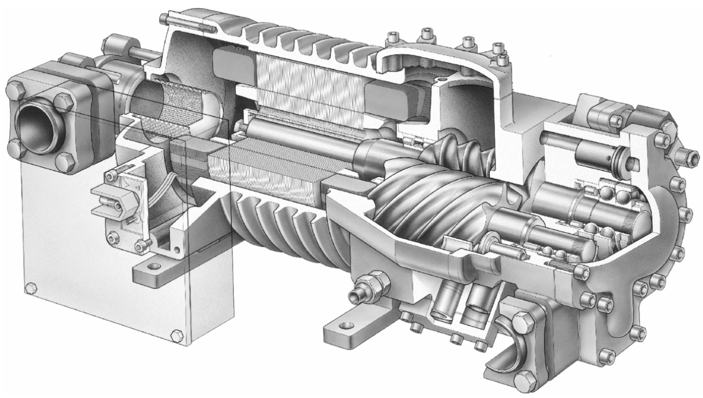

Figure 5
Cross-section
of a semi-hermetic screw compressor
(without oil separator)

In order to protect the compressor against mechanical and motor overload during pull down conditions it is essential to include a crankcase pressure regulator in the suction line, immediately at the compressor inlet. The setting is chosen so that shortly after starting the suction pressure stabilises below the permitted maximum.

4.3 Motor cooling

Because of high specific motor load combined with small volume, air cooling in many cases is not feasible due to the insufficient external surface area of the compressor motor end. This type of cooling would require a special design of compressor thus severely reducing the advantage of using standard parts from series production.

Suction gas cooling, which is widely used with semi-hermetics, offers far better potential in this respect, although with low temperature cooling and with refrigerants that have low superheat enthalpy there are also disadvantages. The result is additional superheat from the flow through the motor, therefore a change in volume and a reduction in mass flow.

On closer consideration it can be seen that the losses from suction gas cooling in the relevant application range are low. The reasons for this are the high mass flow with CO_2 and the low suction superheat with flooded evaporators. This yields particularly intensive motor cooling and the low winding temperature guarantees minimum copper losses and optimal motor efficiency.

The windings are also fitted with PTC resistors in each coil, which in combination with an electronic control module offer good protection against thermal overload. With sufficient cooling the motor can thus also be operated in very high torque levels.

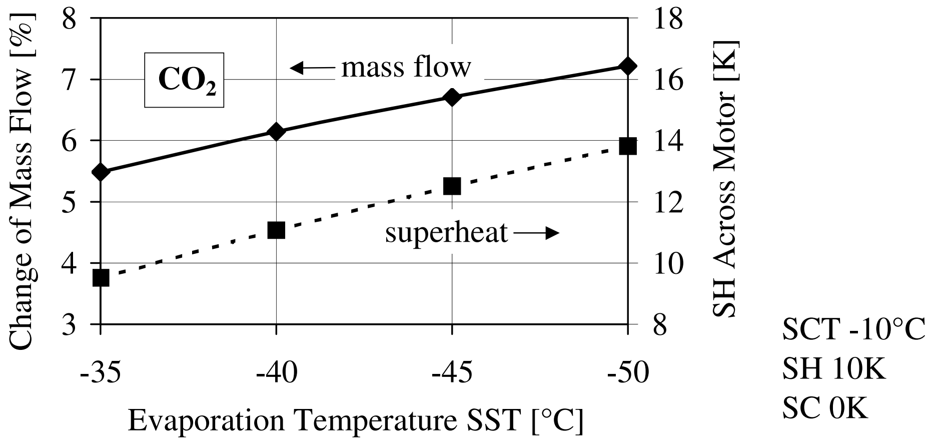

Figure 6 Suction superheat across the motor and the resulting change in mass flow

4.4 Lubrication

A relatively heavy mechanical load and the high gas solubility with conventional lubricants place very specific demands on the viscosity and tribology properties of the oil, but also on the design concept of the compressor.

With a view to simple oil return from the system, at the same time lubricants are desirable having sufficient miscibility with CO_2 also at temperatures down to -50°C and below.

Extensive investigations and practical experience have now shown that specially formulated (polar) polyol ester oils (POE) are particularly suitable for the described applications and compressor types. They have a high viscosity index, good lubrication behaviour, acceptable solubility properties and, unlike non polar mineral oils, favourable miscibility as Fahl (1997) described. However, because of their hygroscopic properties generously dimensioned molecular sieves filter dryers are essential.

Poly-alkylene glycol oils (PAG), also polar, show even less solubility under the conditions prevailing in the crankcase and oil separator of the compressor and insofar guarantee favourable viscosity behaviour. Nevertheless, their use is not recommended with semi-hermetics because of their particularly high water absorption capability and the resulting reduction in dielectric strength.

Apart from lubricating properties, it is mainly the high suction pressure which places special requirements on compressor design.

For this purpose, with **reciprocating compressors** bearings are used with very high load capacity and favourable boundary friction properties. Furthermore, the lubricating system is designed to guarantee particularly fast oil supply after starting and sufficient degassing of the bearings.

In addition to the generously dimensioned bearings already mentioned, the **screw compressors** shown in Fig. 5 also feature a particularly sophisticated oil circulating system. With this design principle the overflow of leakage gas from the profile area into the bearing housing on the high pressure side is effectively prevented by means of lip seals. The pressure in the bearing housing can thus be reduced almost to suction levels resulting in a minimum proportion of CO_2 being dissolved in the oil and at the same time maintaining highest possible viscosity. An important side effect is a significant reduction on the thrust bearing load.

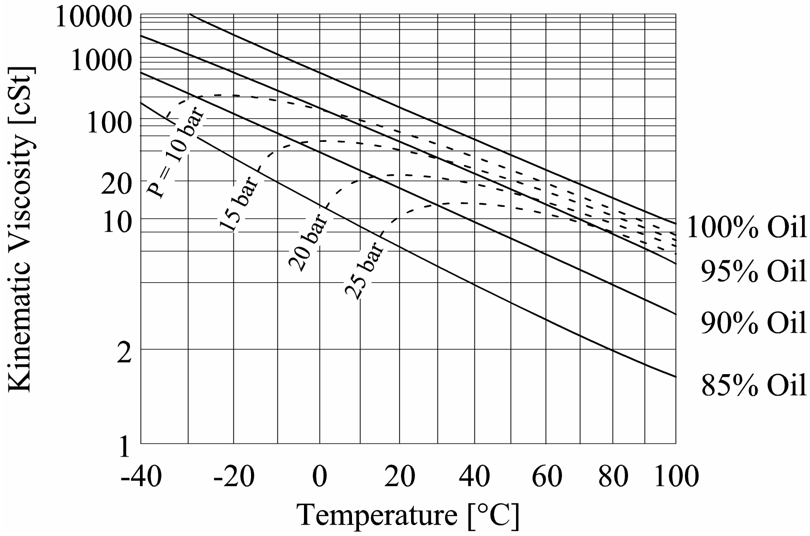

Figure 7 CO_2 solubility in POE oil and the resulting kinematic viscosity (DEA development product)

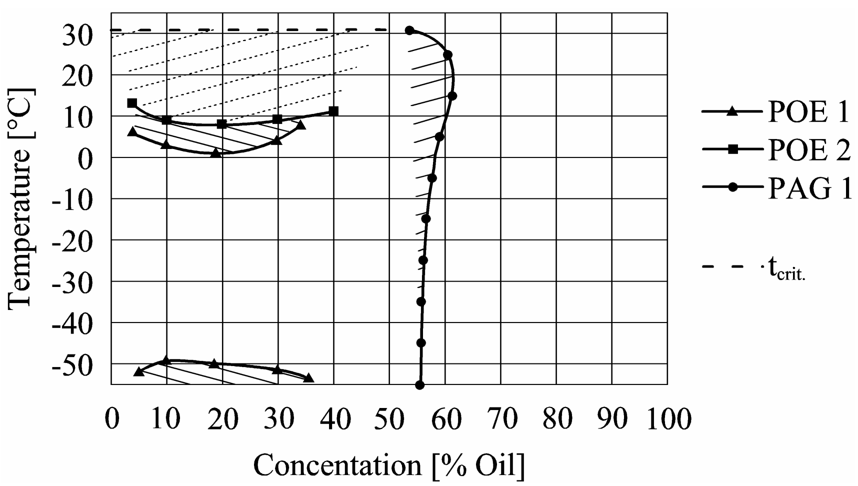

Figure 8 Miscibility limits CO_2 / POE & PAG at sub-critical temperature conditions (DEA development products)

5 PERFORMANCE BEHAVIOUR

The particularly high volumetric refrigerating capacity with CO_2 cascade applications, which shows a very flat curve over the evaporating temperature, enables the use of compressor sizes usually found in commercial and light industrial applications even with high refrigerating capacity levels.

In Fig. 9 the performance behaviour of a screw compressor with 220 m^3/h displacement is compared using CO_2, R22 and NH_3 at SST -35 to -50°C and SCT -10°C. The data for CO_2 and R22 applies to semi-hermetics, that for NH_3 to the open version. A significant difference in volumetric refrigerating capacity is apparent, but also the flatter curve with CO_2 across the evaporating temperature range (Fig. 10).

The mass flow of CO_2 (Fig. 11) is also – for equal displacement – much higher than of R22, although the vapour density (with identical pressure levels – Fig. 3) is only around 60%. These differences are the result of a pressure level which in the range described is about 7 to 10 times as high. As already mentioned, this property fits very well with the design principle of suction gas cooling.

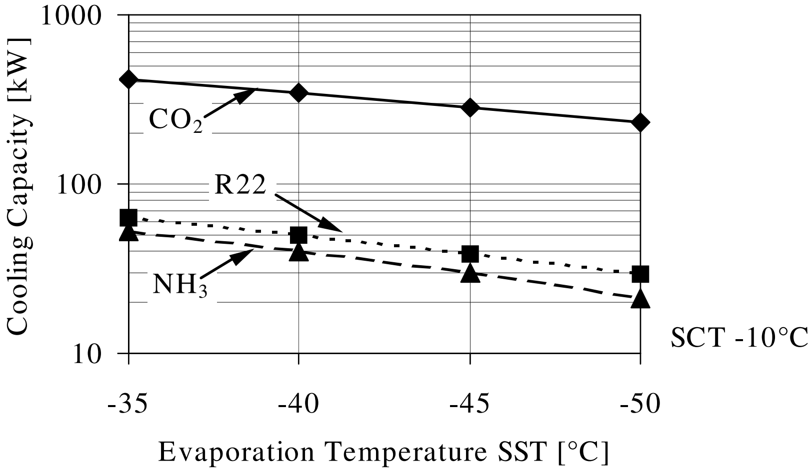

Figure 9 Performance behaviour of a screw compressor with 220 m^3/h displacement

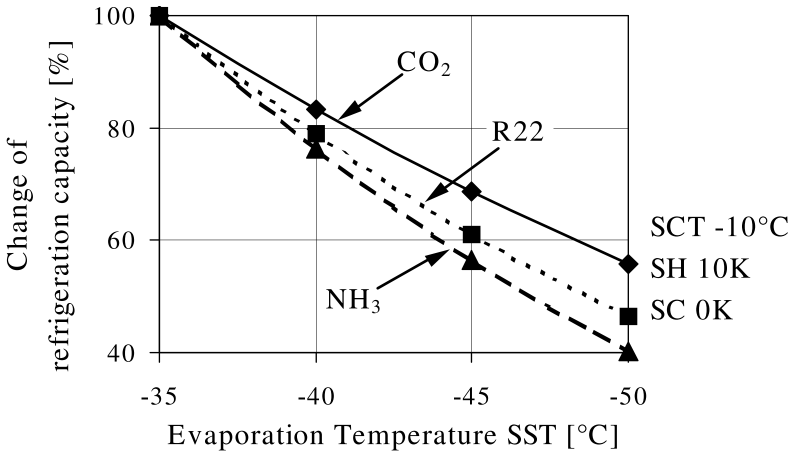

Figure 10 Relative change of Refrigeration Capacity with regard to SST - 35°C and SCT -10°C

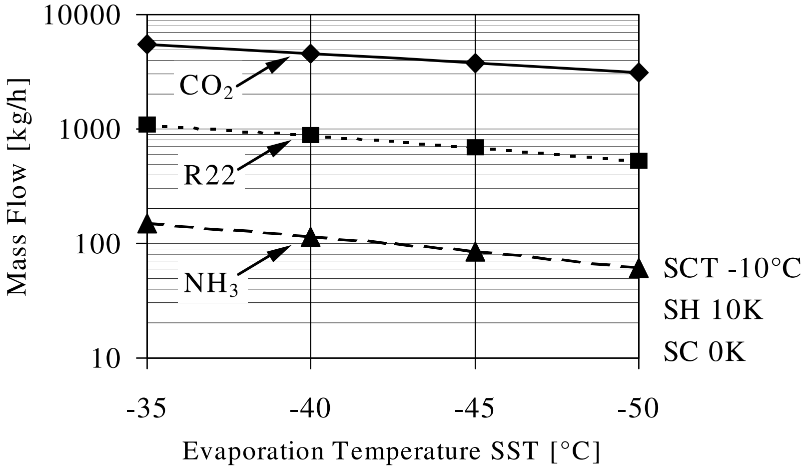

Figure 11 Comparison of mass flow (screw compressor with 220 m^3/h displacement)

6 SUMMARY

Our investigations have shown that the conditions for the further development of semi-hermetic reciprocating and screw compressors for use in CO_2 cascade systems are very favourable, also when based on existing standard products.

The modern basic design with supplementary safety measures facilitates the extension of permissible operating pressures. Moreover, with optimised adaptation of components within a family of compressors the requirements on mechanical load, motor power and cooling can be fulfilled.

Polyol ester oils have proven to be suitable candidates both for compressor lubrication and from the point of view of favourable conditions for oil circulation in the system.

Because of its high volumetric refrigerating capacity, flat performance characteristics and thus compact and inexpensive system design there will a be good future potential for the extended and economical use of CO_2 in low temperature cascade systems.

REFERENCES

1. Fahl, J., 1997, Lubricants for CO_2 – DKV Conference (Germany)
2. Pearson, F., 1983, Refrigeration Systems Using Low Pressure Receivers, BIR Paper (UK)

RESUME

Ses caractéristiques bénignes pour l'environnement, sa faible toxicité et ses propriétés thermo-physiques favorables en régime sub-critique, permettent au CO_2 d'être de plus en plus préféré pour les installations à fluide secondaire ou en cascade à basse température.

Sa puissance volumétrique élevée permet une économie au niveau des compresseurs et des tuyauteries par rapport aux installations basse température conventionnelles. De plus, les compresseurs sont comparativement plus petits même pour des puissances importantes. Par contre les pressions élevées, soit à l'arrêt soit en marche, obligent une conception et des mesures de protection spécifiques.

Cette présentation comporte des schémas réalisables, grâce au développement significatif des compresseurs hermétiques-accessibles et leur huile. D'autres sujets sont relatifs aux mesures de protection et aux performances par rapport aux installations conventionnelles.