A New Generation of Compact Screw Compressors Optimised for R134a

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1. Introduction

In the past, most liquid chillers and heat pumps with positive displacement compressors were operated with refrigerant R22. The safety relevant and thermodynamic properties of this refrigerant provide especially favourable conditions for a high degree of efficiency and operational reliability.

Due to the early phase-out of R22 in Europe, most new product developments favorised R407C. Since this refrigerant's volumetric cooling capacity, pressure level and mass flow are very similar to those of R22, compressors which had originally been developed for R22, could easily be adapted. Therefore, less attention was paid to R134a, for instance, although screw manufacturers had pointed out the advantages of this alternative at an early stage. Increased compressor costs were used as major arguments against the R134a technology.

2. Refrigerant properties – assessment with focus on the compressor

In order to evaluate a refrigerant's suitability for a certain compressor design, the comparison of their particular thermodynamic properties is very helpful. Besides the expected performance characteristics, the best application range may be determined, and the volumetric and isentropic efficiency development can be evaluated.

According to different analyses and research programs [1] R134a, R407C and R410A have shown to be particularly suitable for liquid chillers in air conditioning systems, heat pumps and other high temperature applications. The thermodynamic properties of these substances, however, show considerable deviations which can have various effects on performance and efficiency characteristics depending on compressor technology.

2.1 Relative comparison of cooling capacity

The comparison of the volumetric cooling capacity given in Fig. 1 shows significant differences between the refrigerants which derive from the substance's specific thermodynamic data.

R134a is found at the bottom of the scale, whereas when operating screw compressors with economiser a considerable increase can be noticed. The relatively low cooling capacity of R134a requires a higher displacement which, in case of screw compressors, can be achieved by a larger set of rotors.

As mentioned above, R407C is closely related to the reference refrigerant R22. Therefore the basic design and construction of the compressor may be retained.

R410A shows by far the highest performance data, resulting in a reduced displacement and smaller physical dimensions respectively. What seems to be an advantage at first sight causes a lower rotor tip speed with negative effects on the volumetric efficiency and COP for screw compressors – see also sections 2.2 and 3.

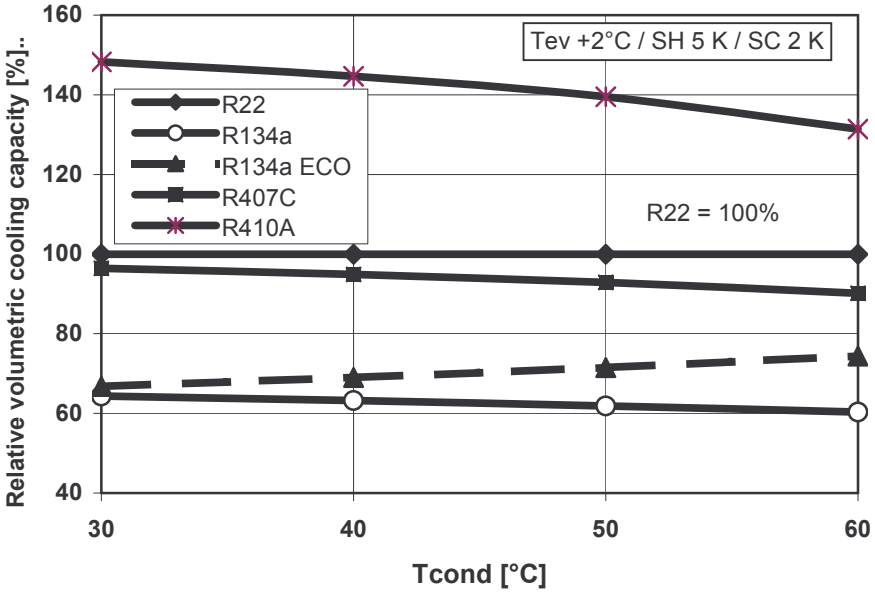

Fig. 1 Relative comparison of the volumetric cooling capacity

2.2 Relative comparison of the theoretical compressor COP

Contrary to the cooling capacity, the theoretical COPs of the considered refrigerants vary rather slightly (Fig. 2).

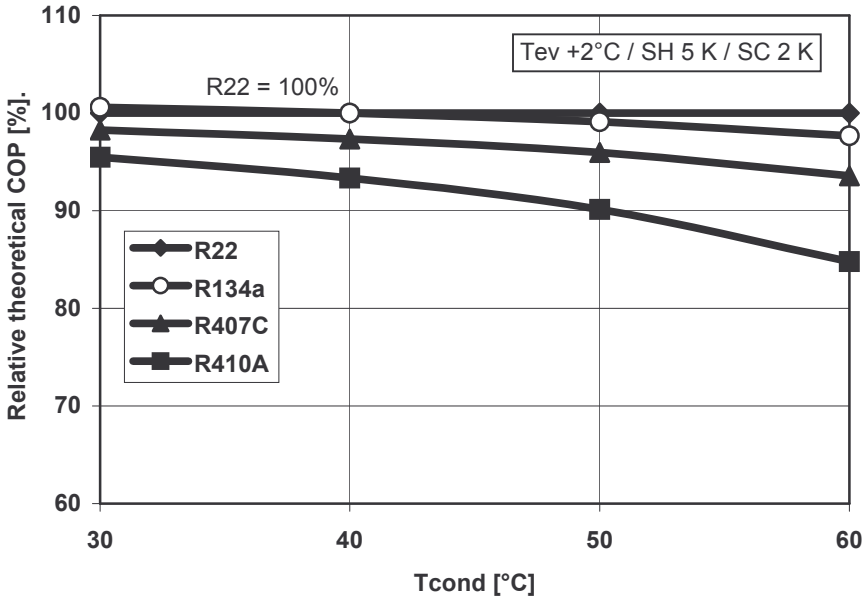

Fig. 2 Relative comparison of the theoretical compressor COP

The noticeable drop of R410A at higher condensing temperatures is caused by the low critical temperature (73°C) among others. This disadvantage, however, can partly be compensated by the relatively high heat transfer coefficients and low pressure drops in evaporators and condensers.

R134a shows most advantageous conditions over the entire application range. Considering the required extension of the displacement even better results can be achieved using larger rotors with screw compressors.

With consideration of the displacement, larger rotors lead to reduced sealing lengths with less flow-back losses during compression. Furthermore, the small pressure differential of R134a (approx. 67% compared to R407C / 45% to R410A) results in additional advantages. These conditions are crucial for the extremely high isentropic efficiencies and COP values of optimised R134a screw compressors.

2.3 Refrigerant mass flow / vapour density

In spite of significant differences in the volumetric cooling capacity, the mass flow for a defined cooling capacity varies within 10% according to R22 for all three alternatives. This can be attributed to the almost proportional relations of vapour density and volume flow rate for these substances.

According to these facts and with respect to the relatively small total mass flows and vapour densities, the pressure drops in compressors, heat exchangers and pipe lines can be kept at low levels.

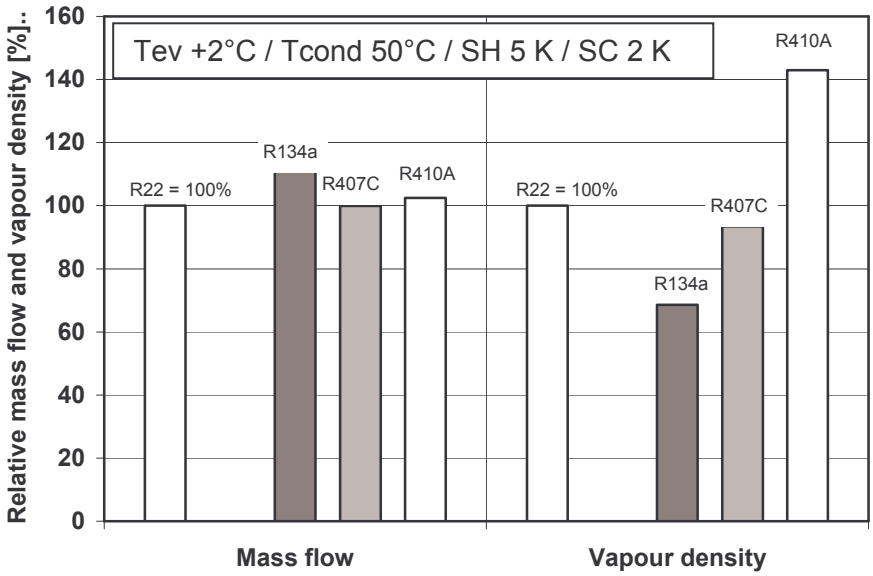

Fig. 3 Relative comparison of refrigerant mass flows and vapour density (LP)

3Development steps for highly efficient R134a screw compressors

As mentioned earlier, the general opinion is that all compressor types designed for R134a are efficient, but comparably too expensive. This is true in many cases because medium and larger size compressors are usually designed for universal operations with R134a, R22, and R407C (R404A, R507A). The higher displacement required for R134a widens the entire compressor dimensions. The potential for a cost reduction is in a smaller motor and is therefore relatively low. This "rule" can hardly be bypassed with reciprocating and scroll compressors since their overall size is mainly determined by displacement and drive gear or spiral diameter.

3.1 Constructional design of CSH compact screw compressors

CSH screw compressors are already characterised by a very compact design, which in regard to the mechanical compressor part cannot be achieved by any of the other two technologies.

The compressors contain an integrated 3-stage oil separator with a relevant oil management system. This design is very favourable for the application in liquid chillers.

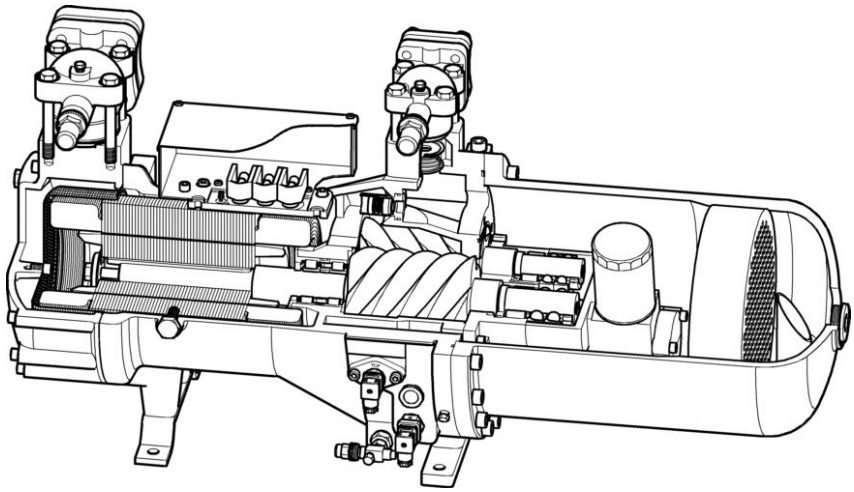

Fig. 4 Semi-hermetic compact screw compressor – Constructional design

3.2 Basic design features

–Screw profile: twin rotor design (lobe ratio of 5:6)

–Semi-hermetic design, suction gas cooled

–Basic construction (displacement, motor allocation, mechanical strength, bearing dimensions) designed for R407C and R22 (R404A, R507A)

–Double wall, pressure compensated rotor housing

–Lifetime roller contact bearings with pressure unloading

–Integrated oil separator

3.3 Slider capacity control with integrated economiser connection (ECO)

The request for an infinite capacity control led to the development of a control slider, which matches the profile contour and is located directly between male and female rotors.

For capacity control the slider is hydraulically moved in axial direction (Fig. 5). A special constructional feature ensures that for capacity reduction pre-compressed gas is not blown back to the suction side but rather compression begins when the suction gas volume has already been reduced. By energising the valves CR1 .. CR4 accordingly the capacity control can be operated in either infinite or staged mode (100-75-50-25%).

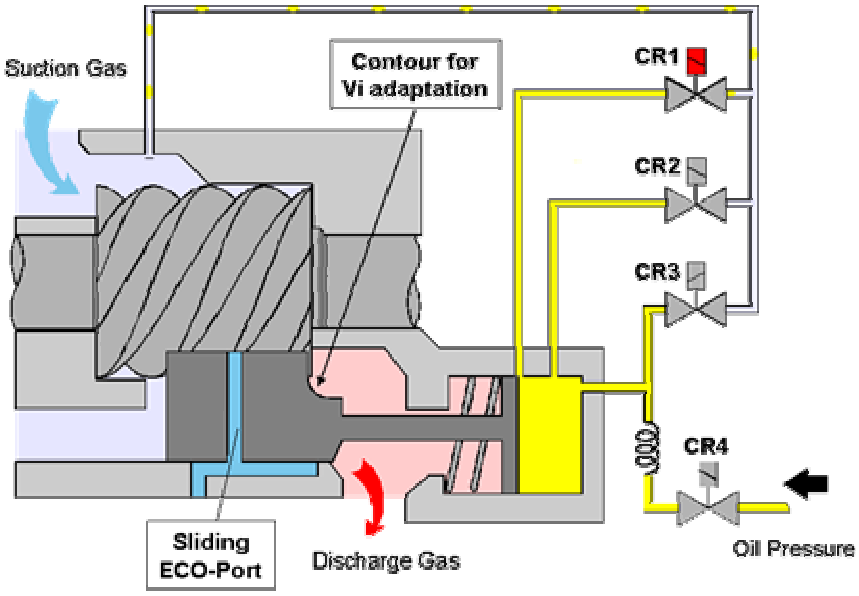

Fig. 5 Slider control with integral economiser port

With respect to a high degree of efficiency and operational reliability part of the discharge port is integrated into the control slider (Fig. 5, Pos. 4 "Contour for Vi adaptation") providing a Vi control for part-load conditions. The internal volume ratio (Vi) is kept constant to approx. 70% part-load. If the load is further reduced, it drops according to the expected smaller system pressure ratio.

The economiser port integrated into the control slider is another special feature (Fig. 5, Pos. 2); it allows the operation of a subcooling circuit independent of the compressor load.

3.4 Requirements for an optimised R134a design

As mentioned before, screw compressors can be operated very efficiently with R134a, however the required displacement must be increased proportionally to the smaller volumetric cooling capacity (Fig. 1). The challenge was to achieve an identical cooling capacity with R134a as compared to the largest versions of the existing series using R407C or R22 while keeping comparable compressor sizes and costs.

Additional requirements for an optimised R134a series:

- Same oil management, constructional features, capacity control (with sliding economiser port) like for the existing series
- Better isentropic efficiencies as comparable R407C and R22 versions
- Maximum condensing temperatures for continuous operation: 65°C for standard application / 60°C with economiser

- Bearing durability – same criteria as for existing series
- Pressure strength and safety relevant design – same criteria as for existing series (prEN12693, UL 984)
- Mounting dimensions, suction line, discharge line and ECO connections – identical positions as for existing series

3.5 Constructional realisation of the requirements

Determining factors for the basic geometry of the CSH screw compressor are motor, rotor set and oil separator.

Due to the almost constant, in tendency even lower electrical power consumption with the optimised R134a version the motor allocation is identical to equal capacity models for R407C / R22. With respect to suction gas cooling and higher volume flow rate certain modifications have been made.

All rotor profiles are proprietary BITZER developments with an extremely high stability and efficiency. On this basis the profile was modified in such a way that a higher flow rate could already be achieved by enlarging the dimensions of the rotors by approximately 10%. Thereby the necessary constructive modifications were made possible without major influence on the outer compressor contour.

The well-known solid bearing arrangements of the compressors were retained. In consequence of a better torque, less pressure differential and a low pressure level in the bearing chambers, the conditions are even better than with the basic versions for R407C and R22. Due to the dimensional changes in the rotor area modifications of the discharge port, the control slider and the bearing flange have been adapted as well.

Extensive investigations of the 3-stage oil separators, originally developed for R407C and R22, showed very high separation efficiencies in spite of the higher displacement. Among others effects this can be attributed to the lower vapour density and discharge gas temperature of R134a which enable an optimal separation. Therefore only slight modifications had to be made.

3.6 Efficiencies of the optimised R134a compressors

Even with respect to compressor efficiency all requirements were fully accomplished and thus the goal was reached.

The positive influence of enlarged rotors is confirmed by performance measurements. As generally known, standard screws used in refrigeration are oil injected compressors having small gaps between the working spaces which are sealed by an additional oil content in the swept volume. This explains that performance and efficiency characteristics depend on rotor tip speeds, gap lengths in proportion to the volume flow rate, oil viscosity and pressure differentials between the working spaces. All these parameters have positive influences on the new series and account for the good results.

The following comparison refers to the course of the isentropic efficiency dependent on the operation conditions. By calculation of efficiency times theoretical COP the actual achievable value can be determined, whereby the differences between the refrigerants (Fig. 2) have to be considered.

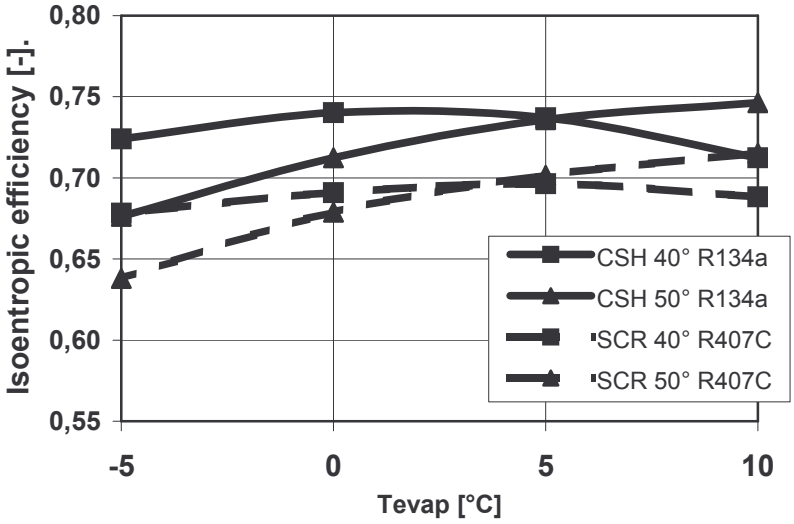

Fig. 6 Isoentropic efficiency – Coparison between a CSH8591-140Y compact screw compressor (R134a) and 25 HP scroll compressor (R407C).

Within the main application range of liquid chillers (evaporation at 0° to 5°C) the comparison shows an advantage of 5 to 7% for the screw compressor over the scroll compressor which has generally been defined as being an outstanding performer. If the 2.5 to 4.5% higher COP of R134a is also taken into account, advantages of up to 10% result in favour of the screw compressor. The often negative influence of the temperature glide of R407C in the condenser, however, has been disregarded which can cause higher condensing temperatures and consequently reduces the COP even further.

4. Performance and efficiency characteristics at full and part load operation

4.1 Capacity control and operating characteristics

CSH screw compressors are equipped with a very efficient capacity control – see [2] and section 3.3 – which can either be operated in 4 steps or stepless. It is generally known and confirmed by tests that the dynamic characteristics and the resulting efficiency of a refrigeration plant or a liquid chiller are basically determined by the control quality. In this respect the screw compressor is superior to any regulation mechanism by individual compressor ON/OFF operation, since the performance can be adjusted exactly to the actual requirements.

In a given system with two compressors per circuit the condensing temperature considerably drops if one of the compressors is switched off (to approx. 50% capacity). This results in part evaporation of liquid refrigerant (flash gas formation), while its temperature is still high. Consequences are malfunctions of the evaporator's injection control and negative effects on performance and efficiency. Moreover, if an idle compressor is started (and performance is doubled), strong fluctuations in the control circuit, often combined with insufficient suction gas superheat, lead to deviations from optimal operating conditions.

4.2 Evaluation of performance characteristics by "Integrated Part Load Values" (IPLV)

The dynamic characteristics of a system and its effects as described before are often underestimated or misinterpreted. Comparisons by means of (calculated) integrated part load efficiencies (IPLV) are based on quasi-static conditions in order to simulate a real operation. Therefore, this method should only be used with reservation to compare systems of different dynamic characteristics.

On the other hand, this method is more realistic than a comparison purely by means of energy requirement or efficiency at rated full load operation conditions.

The following comparison (Fig. 7) shows that CSH compact screws offer excellent conditions even without considering their advantages derived from the dynamic operating characteristics. This is made very evident at load conditions of 100 to 50% which corresponds to around 80% of total operating time (according to usual IPLV calculations).

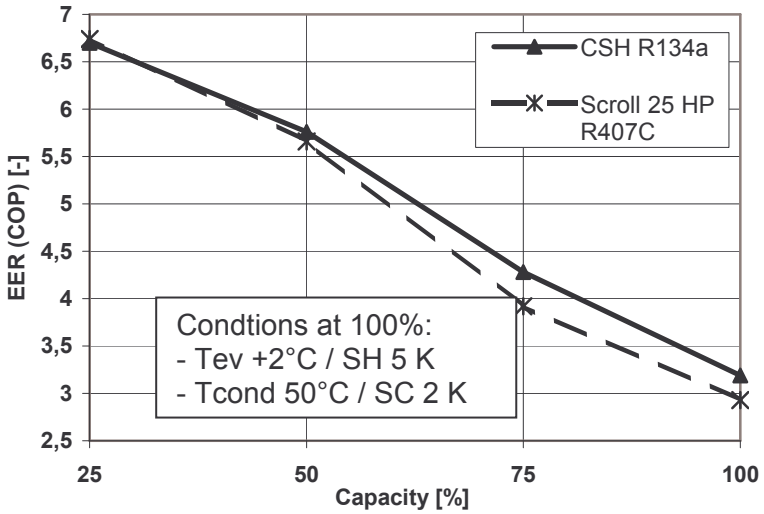

Fig. 7 Comparison of the compressor COPs at full and part load operation with typical operating condition of liquid chillers.

Reference conditions and percentage weight of the different capacity steps

(100/75/50/25%) are based on the EUROVENT [3] proposal. The proposal defines an IPLV evaluation for Europe. Hence there are differences to ARI 550/590 as usually applied in the U.S.A.
Additional comparative requirements:

⇨ Liquid chiller with CSH compact screw compressors (R134a)

2 separate cooling circuits with 1 compressor each

– Infinite or 4-step capacity control per circuit

⇨ Liquid chiller with scroll compressors (R407C)

⇨ – 4 separate cooling circuits with one compressor each

⇨ – 2-step capacity control (compressor ON/OFF) per circuit

⇨ Operating conditions at 100% cooling capacity (basis for both liquid chillers):
Evaporating temperature (to) +2°C / Suction gas superheat (Dtoh) 5 K
– Condensing temperature (tc) 50°C / Liquid subcooling (Dtcu) 2 K

5. Conclusion

Due to its thermodynamic properties, R134a offers very favourable conditions for the efficient application of screw compressors at medium and high evaporating temperatures. A drawback, however, is the small volumetric capacity, which involves relatively high cost for usual compressor constructions.

A new generation of compact screws optimised for R134a permitted a considerable increase of the displacement without changing the compressor dimensions. Thereby identical cooling capacities are achieved at similar cost as for the largest versions of the existing series for R407C or R22. Another major characteristic is an extremely high isentropic efficiency entailing a minimum energy requirement.

In combination with the very efficient capacity control
(4-step or stepless) a high performance and thus excellent system efficiency is achieved. Moreover, with regard to the IPLV evaluation extraordinary results are achieved for liquid chillers with optimised R134a compact screw compressors.

References:

[1] Bitzer Refrigerant Report A-501
[2] H. Renz
Screws with Advanced Capacity Modulation and Sliding Economiser Port
European Conference – Politecnico di Milano 6/2003
[3] EUROVENT-CECOMAF – European Committee of Air Handling and Refrigerating Equipment Manufacturers