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Small Oil Free Piston Type Compressor For CO2

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SMALL OIL FREE PISTON TYPE COMPRESSOR FOR CO_2

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ABSTRACT

One remaining issue of CO_2 processes are problems in connection with the lubrication oil. The objective of this project is to prove the feasibility of a small oil free semi hermetic piston type CO_2-compressor for supercritical heat pump applications with large temperature spans. These processes involve high pressures like 35 bar suction pressure and 80 to 150 bar delivery pressure.

A functional compressor model was designed and manufactured, and performance tested over the full range of speed and pressure.

Two kinds of cylinder heads from stainless steel and from plastic were tested in order to find out the influence of heat conduction in the cylinders.

The tests confirmed the feasibility of the technology for the use in small oil free CO_2-compressors.

INTRODUCTION

Carbon Dioxide is a Natural Working Fluid and substitute for the synthetic refrigerants. It is particularly interesting for applications like

Automotive air conditioning (heating and cooling)
Domestic water heating and
Drink and food refrigeration

because it is neutral to the environment, is odourless, non-toxic, non-flammable and is not limited in nature, and furthermore has interesting thermodynamic properties. These applications require supercritical processes with high pressures. The compression in oil-lubricated compressors often creates problems caused by the mutual solubility of oil and Carbon Dioxide. The use of oil free compressors is proposed in order to overcome these problems.

The objective of this project is to proof the feasibility of a small oil free semi hermetic piston type CO_2-compressor for supercritical heat pump applications with large temperature spans.

A Functional Model was designed and manufactured, with the use of two serial proven key elements which are

- high pressure clearance seal piston/cylinder combination and
- PEEK-plate valves with flat valve springs

The Functional Model was tested and its performance characteristics evaluated over a wide range of speed and pressure.

COMPRESSOR-DESIGN

The compressor (see cross-section figure 1) was designed as a heat pump for domestic water heating applications. In order to use all the available heat for the heat pump process the CO_2 gas was used to cool the motor. The CO_2 gas enters at the bottom end of the motor and flows through the motor and crankcase into the cylinder heads. A high efficiency motor should guarantee a high overall efficiency of the compressor and keep the preheating of the suction gas as low as possible.

Data of the compressor:

-Number of stages	1
-Number of cylinders	4
-Cylinder diameter	10 mm
-Stroke	16 mm
-Suction pressure	35 bar
-Delivery pressure	80–150 bar
-Speed variable	500–3000 RPM
-Power cons.@1500 RPM	500 W
-Cylinder volume	1.25 cm^3
-Dead volume	18 %

Design features:

-Semihermetic design, motor integrated
-4 cylinders in cross arrangement
-Scotch yoke drive with complete mass balance
-Simple shaft with one crank pin and two counter weights
-Piston/cylinder: Clearance seal
-Valves: Plastic-plate valves with flat spring
-Driven by Permanent Magnet Synchron Motor
-Cooling effected by working media CO_2

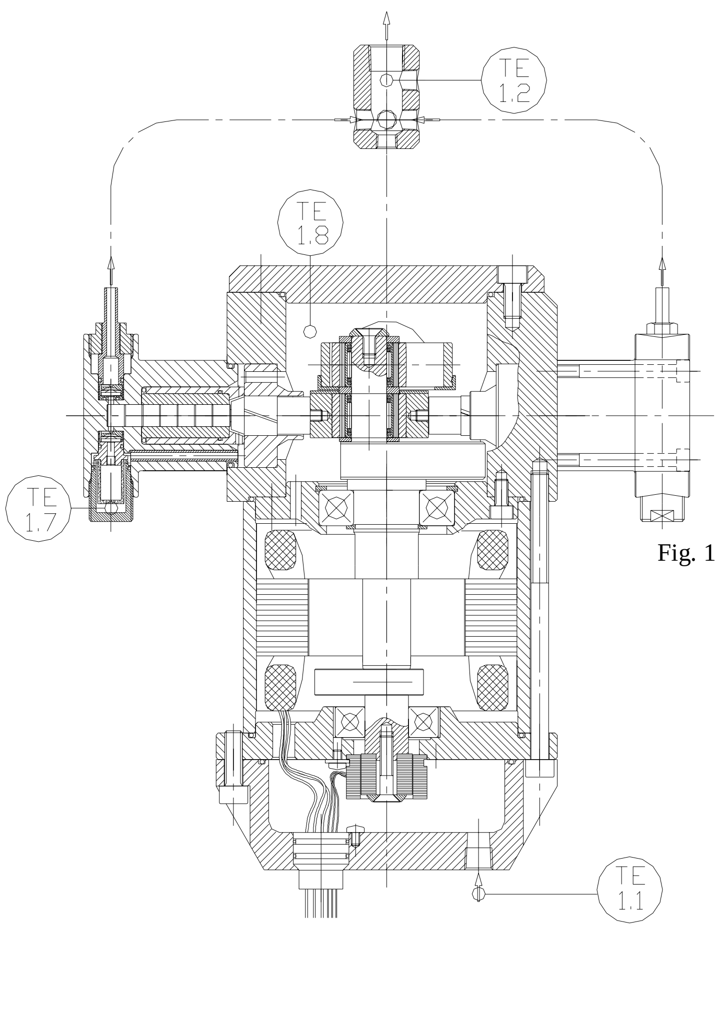
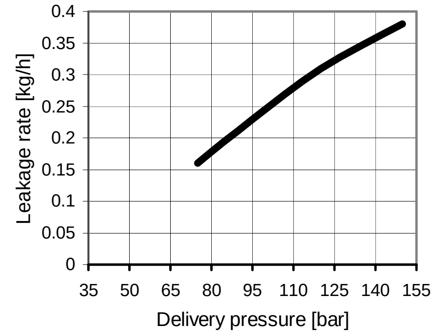


Fig. 1 : CO_2-Compressor, Functional Model with Temperature measuring points

The following components are serial proven in small oil free gas-compressors:

- ***High pressure piston/cylinder clearance seal***
  The clearance seal is a smooth piston running in a smooth cylinder, sealing with a minimal gap of 4÷6 µm in diameter between piston and cylinder. The leakage flow through the gap is laminar and according to pressure a few percent of the flow rate (see diagram 1). The piston moves practically frictionless back and forth and does not wear.



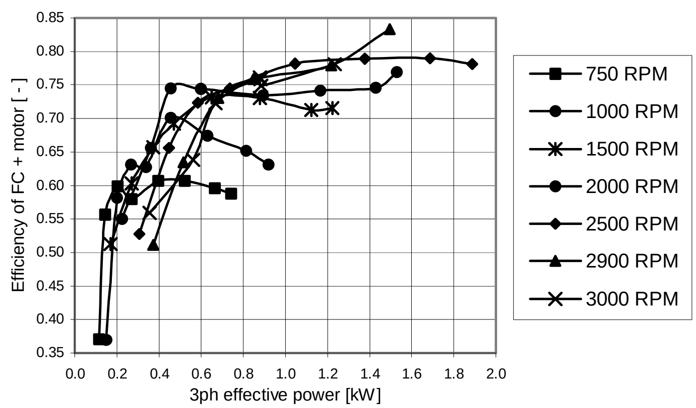
Diagr. 1: Estimated clearance seal losses

- ***Valves***
  The compressor valves are flat sealing plates from PEEK, pushed against the metallic seat by a flat spring. The sealing plates have good sealing qualities, are light and operate quietly without any wear.

Cylinder heads
For best heat pump performance the suction gas should flow into the cylinder as cold as possible and leave the compressor without heat losses. As the heat transfer coefficient of Carbon Dioxide is very high, it is important to keep the heat conduction coefficient of the cylinder material as small as possible in order to prevent heat flows from the delivery side to the suction side of the cylinder and from the cylinder to the crankcase. To investigate the influence of heat conduction we made tests with two kinds of cylinder-head materials: first **stainless steel** and second a temperature resistant **plastic**.
The compressor and motor housing parts were all manufactured in aluminium.

Motor
A Permanent Magnet Synchron Motor was chosen for highest efficiency over a wide range of speed and torque. The speed could be varied by a frequency converter between 500 and 3000 RPM. The resolver on the motor side shaft end served the control of speed.

For a detailed analysis of the compressor efficiency the performance of the drive train <frequency converter – motor – shaft> was measured on a motor test-stand at the respective operating conditions (see efficiency-curves in diagram 2).
The compressor test runs covered the power range between 160 and 950 Watt.
The efficiency of the motor was not as good as expected.



Diagr.2 : Motor measurements;
Efficiency of Frequency Converter + Motor

COMPRESSOR TESTLOOP

The test loop was planned and operated as a so called Hot Gas Loop (see fig.2), which was more practical for performance measurements on the compressor than a complete heat pump process with condensation and evaporation.

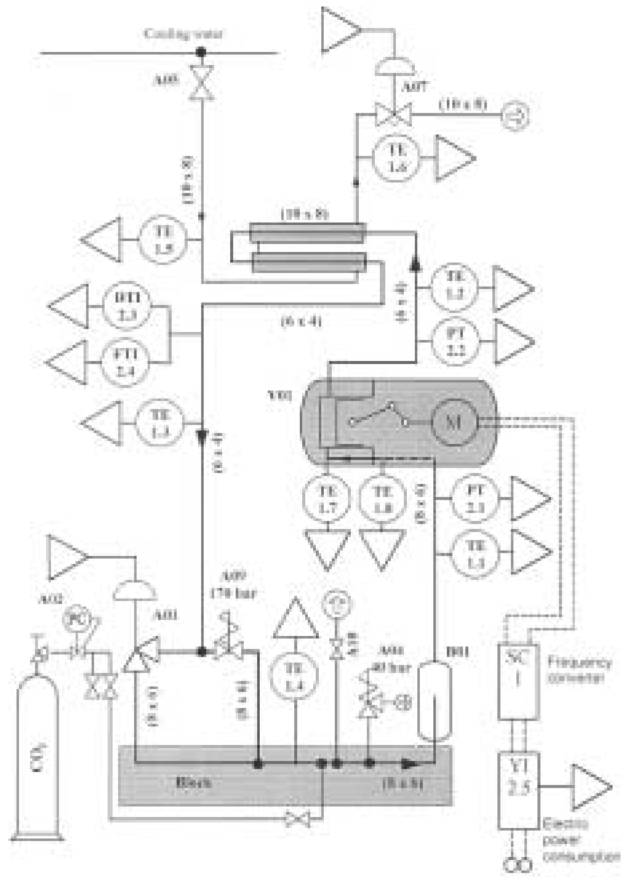


Fig. 2: (P+I) – diagram of the Hot Gas test loop

Equipment list:

Desig-nation	Description
A01	Expansion valve
A07	Cooling water metering valve
A02	Gas cylinder pressure control valve
A04	Low-pressure relief valve 40 bar
A05	Cooling water shut-off valve
A09	High-pressure relief valve 170 bar
B01	Vessel 300 cm^3
WT01	Double-pipe heat exchanger
V01	Compressor
TE	Thermo couple
PT	Pressure transducer
DTI	Density transmitter
FTI	Flow transmitter

COMPRESSOR TEST RESULTS

Functionality

The key components piston/cylinder and the valves showed no sign of wear or fatigue after several hundred hours of operation. These components are excellent for the use in oil free CO_2-compressors at high pressures.

Measurements, Test results

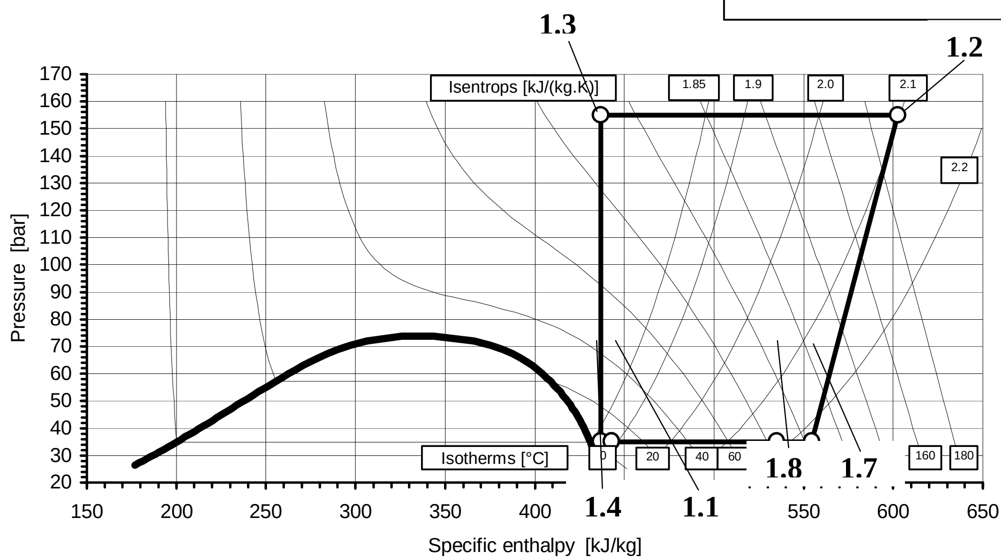
The compressor measurements were carried out both with cylinder heads from stainless steel and with cylinder heads from plastic.

For all the test runs the suction pressure was kept at 35 bar. (35 bar is the vapour pressure of CO_2 at 0°C)

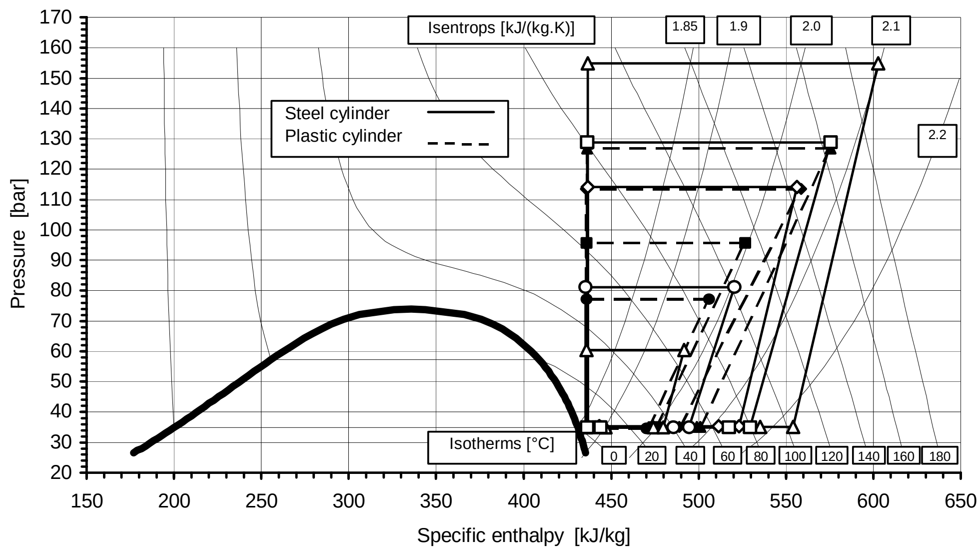
A typical course of a process is shown in diagram 3. It represents a measurement with steel cylinder heads. The suction gas is heated up in the motor and in the crankcase quite strongly by about 70°C and in the cylinder head again almost 20°C! The reason for this is the high crankcase temperature of about 85°C, which is caused by the heat conduction from the steel cylinder heads to the compressor housing. (The compressor is not cooled externally!).

Process points:

1.1	Compressor inlet
1.8	Crankcase
1.7	Compr. suction valve
1.2	Compressor outlet
1.3	Expansion valve in
1.4	Expansion valve out (fixed condition at 35 bar / 5°C)



Diagr. 3: Typical course of a test loop process in the (p-h)-diagram (with steel cylinder head)



Diagr. 4: Comparison of process-courses with steel- and with plastic-cylinder-heads in the (p-h)-diagram

Diagram 4 shows a comparison of a few process-courses with steel cylinder heads against courses with plastic cylinder heads.
The remarkable difference between the two cylinder-head executions can be recognized in the process-courses:

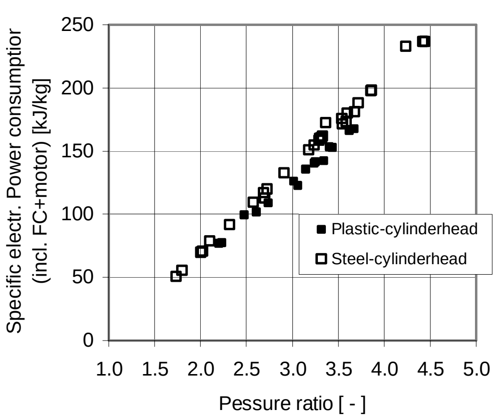
- The compressor with steel-cylinder heads shows a considerable heating up of the gas before it enters the cylinder, but compresses the gas with heat rejection.
- The plastic-cylinders prevent the heat conduction from the delivery side to the suction side and to the crankcase, which shows in lower crankcase temperatures and less heating up of the gas before the compression. The compression itself is almost isentropic which means there is less heat exchange with the cylinders.
- The compressor outlet temperatures are approximately the same, independent of cylinder-head material. All the characteristic values of compression, presented in the diagrams 5-7 show only small differences between the two executions of cylinder-head material. It seems as above effects are compensating each other.

The heat transfer and conduction in the cylinder-heads need to be further analysed and investigated in order to be able to optimise the compressor design and keep the heat flow losses at a minimum.

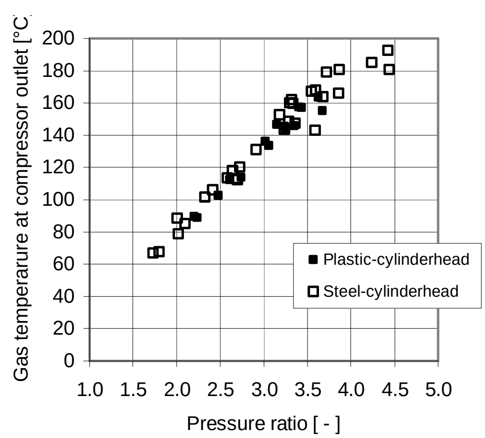
The evaluation of the numerous measurements are shown in the following diagrams 5-7.
The diagrams 4-7 apply for the whole range of speed from 750 to 2900 RPM. The speed has practically no influence on the compression specific values, i.e. the valve losses do not weight within our range of operation.

Diagram 5 shows the specific electrical power consumption measured at the input of the frequency converter, in function of the pressure ratio.

Diagram 6 shows the gas temperatures on the compressor outlet in function of the pressure ratio.



Diagr. 5: Specific electr. Power consumption inclusive frequency converter + motor



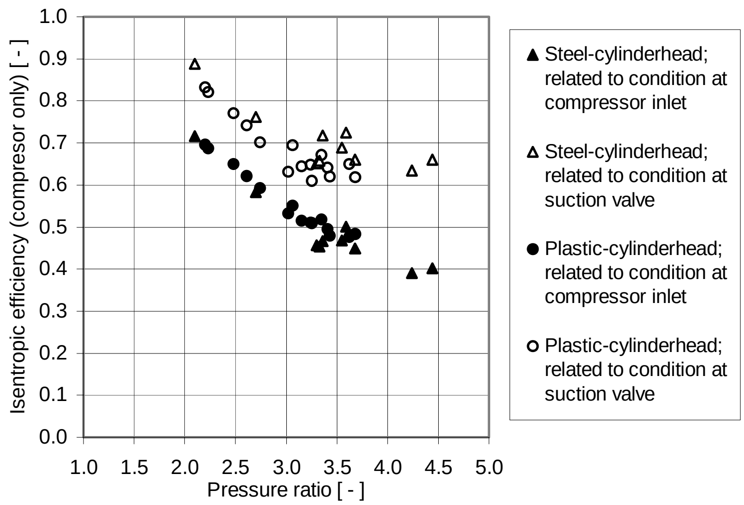
Diagr. 6: Gas temperatures at compressor outlet (TE1.2)

Efficiency

In order to be able to compare the "quality" of the compression with values of compressors on the market, the Isentropic Efficiency (see Diagram 7) was related to the condition at ***compressor inlet*** and to the condition at the ***suction valve***. With the latter the negative effect of the heating up of the suction gas in the motor and crankcase is excluded. These values compare to compressors with the suction line directly into the cylinder.

The Isentropic Efficiency of this compressor is comparable with the one of conventional oil lubricated compressors.

(The Isentropic Efficiency compares the theoretical isentropic compression power with the shaft power).



Diagr. 7: Isentropic efficiency (compressor only)

CONCLUSION

The test series proved the feasibility of the technology for small oilfree high-pressure CO_2-compressors. The Efficiency and the Functionality show the potential of this technology, which could be particularly interesting for certain applications in the food area where oilfree compression is a must.

Precondition for most of the applications however are competitive costs in comparison to oil-lubricated systems. Further development steps will be needed in order to reach this target.

A redesign should concentrate on a more compact design and lower production costs.

ACKNOWLEDGEMENT

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