EXECUTIVE SUMMARY

FINAL REPORT ARTI-21CR/611-10070-01
MEASUREMENT OF PERFORMANCE OF CARBON DIOXIDE COMPRESSORS

The subject of this project was to measure the performance of two carbon dioxide prototype compressors using a compressor load stand and to develop compressor performance maps based on the experimental data. A compressor load stand was specifically designed and constructed for this purpose, which is based on a hot-gas bypass design and uses an oil-separator in the discharge line. The measured compressors were a semi-hermetic, two-piston, single-stage, reciprocating compressor with an estimated cooling capacity of 10.6 kW (3 tons of refrigeration) and a hermetic, two-stage, rotary compressor with an estimated cooling capacity of 2.8 kW (0.8 tons of refrigeration).

A test matrix of 48 operating conditions was established. The first series of compressor tests were conducted for varying evaporation temperatures of –23.3, -12.2, -3.9, 7.2, and 12.8 °C and varying discharge pressures between 6.90 and 13.79 MPa at a constant superheat of 10.7 K. The second series of compressor tests were conducted at constant evaporation temperature of 7.2 °C (4.20 MPa) for varying superheats from 5.6 to 22.2 K and varying discharge pressures between 6.90 and 13.79 MPa. In addition, seven compressor reliability tests were evenly distributed over the test period at standard test conditions of an evaporation pressure of 3.14 MPa, a discharge pressure of 8.27 MPa, and a suction temperature of 7.2 °C.

For each test, the compressors mass flow rate, power consumption, and temperatures and pressures at each state point were recorded. Based on these measurements, the compressor performance indices, such as the volumetric and overall isentropic efficiencies were determined. The results show volumetric efficiencies between 0.8 and 0.5 and overall isentropic efficiencies of up to 0.55 for pressure ratios between 1.5 and 6.5 for the single-stage, semi-hermetic compressor. The two-stage, hermetic compressor showed calculated volumetric efficiencies of 0.9 to 0.78 and calculated overall isentropic efficiencies up to 0.7, for pressure ratios between 1.5 and 5, based on measurements performed with an oil separator. The efficiencies are only slightly affected by different superheats.

In addition, the oil flow rates of the compressors were measured as well. While the reciprocating compressor discharges oil flow rates of less than 1% relative to the refrigerant mass flow rate, the rotary compressor discharges oil flow rates of up to 14%.

Furthermore, compressor performance maps were established for all important compressor parameters by fitting 3-degree-polynomial equations as shown in equation (6-1), which considers the case for constant superheats with varied suction pressures $p1$, and varied discharge pressures $p2$.

$$X = C_1 + C_2 \cdot p1 + C_3 \cdot p1^2 + C_4 \cdot p1^3 + C_5 \cdot p2 + C_6 \cdot p2^2 + C_7 \cdot p2^3 + C_8 \cdot p1 \cdot p2 + C_9 \cdot p1 \cdot p2^2 + C_{10} \cdot p1^2 \cdot p2 \quad (6\text{-}1)$$

Based on the collected performance data, the coefficients were determined and are summarized in Table 1 for the singe-stage, semi-hermetic compressor and Table 2 for the two-stage, hermetic compressor. These tables contain the coefficients, which are associated with equation (6-1). In addition, the investigation also obtained coefficients for the case of varied superheat, varied discharge pressures, and a constant suction pressure. Equation (6-2) governs this case and Table 17 and Table 18 contain the obtained coefficients.

These performance maps are the main deliverables of this project and are useful tools for future carbon dioxide system modeling.

TABLE 1: Summary of the coefficients C_1 to C_{10} that are used for the curve fits of the single-stage, semi-hermetic compressor parameters based on the data series with a constant superheat of 10.7 K.

	η_{vol}	$\eta_{is,o}$	$\dot{m}_R$	P_{comp}	T_2
Units	[-]	[-]	[kg/s]	[W]	[°C]
C_1	5.2807E-01	6.1204E-02	1.0197E-02	-2.8231E+02	-3.2401E+00
C_2	2.6320E-01	9.6912E-02	1.6581E-02	1.3768E+03	-2.0840E+01
C_3	-5.6760E-02	-6.4322E-02	3.8442E-03	-5.4535E+02	8.6652E-02
C_4	3.9228E-03	3.2301E-03	-2.4400E-04	3.5750E+01	3.6438E-01
C_5	-5.2443E-02	7.0467E-02	-3.1644E-03	5.6778E+02	3.3079E+01
C_6	1.3105E-03	-9.0925E-03	1.8127E-04	-5.4891E+01	-1.8009E+00
C_7	-2.3563E-05	3.6392E-04	-2.5207E-06	1.0020E+00	3.6067E-02
C_8	8.9699E-03	2.7073E-02	-2.3642E-04	1.9127E+02	-1.3174E+00
C_9	-1.2911E-04	-1.5241E-03	-1.5528E-05	2.0385E+00	8.6746E-02
C_{10}	-4.3007E-04	1.7638E-03	1.6048E-05	-1.0217E+01	-7.3485E-02
R^2	99.93 %	99.41 %	100.00 %	99.96 %	99.92 %
Equation validity: Suction pressures p1 between 1.86 and 4.83 MPa, discharge pressures p2 between 6.90 and 13.79 MPa, and a constant superheat sh of 10.7 K					

TABLE 2: Summary of the coefficients C_1 to C_{10} that are used for the curve fits of the two-stage, hermetic compressor parameters based on the data series with a constant superheat of 14.6 K.

	η_{vol}	$\eta_{is,o}$	$\dot{m}_R$	P_{comp}	T_2
Units	[-]	[-]	[kg/s]	[W]	[°C]
C_1	7.7367E-01	-2.7826E-01	2.6572E-03	5.4656E+02	9.3205E+01
C_2	2.7004E-01	8.9548E-03	4.4274E-03	2.5060E+02	-8.3652E+01
C_3	-6.2977E-02	-2.6971E-02	6.4495E-04	-1.4927E+02	1.6954E+01
C_4	6.8482E-03	9.7697E-04	3.3585E-05	8.7985E+00	-1.5621E+00
C_5	-9.4109E-02	2.5574E-01	-1.0755E-03	-8.1487E+01	2.6068E+01
C_6	8.5564E-03	-2.8353E-02	1.0814E-04	9.9727E+00	-1.3483E+00
C_7	-3.9895E-04	9.8640E-04	-7.8622E-06	-2.2334E-01	4.9352E-02
C_8	4.6579E-03	2.5839E-02	-9.8060E-06	5.2913E+01	-3.5609E-01
C_9	8.6916E-04	-9.8481E-04	3.6160E-05	-1.9199E+00	-1.1471E-01
C_{10}	-2.9343E-03	-1.7059E-04	-1.0243E-04	1.8116E+00	3.3808E-01
R^2	99.15 %	96.96 %	99.99 %	99.91 %	99.95 %
Equation validity: Suction pressures p1 between 1.76 and 4.81 MPa, discharge pressures p2 between 6.90 and 12.41 MPa or 8.27 MPa for suction pressures of 1.76 MPa, respectively, and a constant superheat sh of 14.7 K. **Remarks:** The specific volume and the enthalpies that were used to calculate the volumetric and overall isentropic efficiencies were obtained for pure carbon dioxide even though the oil-concentration in the refrigerant at state point 1 and 2 was around 10%.					