carbon capture journal

Sept / Oct 2012 Issue 29

CO2 compression special features

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The Past, Present and Future of CO2 Compression

Dresser-Rand has a rich history in carbon dioxide (CO2) compression, yet there is always room for improvement. This is why Dresser-Rand joined forces with Ramgen Power Systems LLC in 2008 to develop solutions that address the future of CO2 compression.

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Dresser-Rand has supplied reciprocating and centrifugal compressors for CO2 compression for more than 80 years. The first unit, a reciprocating compressor, went into service in 1928, and the company shipped its first centrifugal compressor for CO2 service in 1948.

Dresser-Rand has shipped more than 400 reciprocating and centrifugal CO2 compressors totaling more than 900,000 BHP (671 MW) and believes it has the largest installed base of CO2 compression equipment in the world. More than 250 of these units are on CO2 injection service, totaling more than 500,000 BHP (372 MW).

The highest pressure achieved using a CO2 centrifugal compressor is more than 8,000 psia (550 bar), while the maximum inlet flow is greater than 48,000 acfm (82,000 m3/hr.). With a CO2 reciprocating compressor, the maximum discharge pressure achieved is more than 6,000 psig (425 bar) and the maximum inlet flow exceeds 4,000 acfm (7,000 m3/hr.).

The reinjection process is an enhanced oil recovery (EOR) technique that helps bring more oil to the surface by both pressurizing the well and reducing the oil's viscosity. The first CO2 re-injection project developed specifically to mitigate greenhouse gas emissions began operation in August 1996 in the North Sea. As of 2012, more than 16 million metric tonnes of CO2 have been injected at this site (approximately 1 million metric tonnes of CO2 per year). The CO2 is captured by an amine plant and stored in a saline aquifer. The objective is to reduce the CO2 content in the methane from 9 percent to 2.5 percent, so that the methane can be exported as "sales gas". Compressor availability has been reported at 98 to 99 percent.

Figure 1 - Ramgen 8 MW, 10:1 pressure ratio CO2 compressor being assembled for test on the Dresser-Rand dedicated closed-loop CO2 test facility in Olean, NY, USA

Past to Present

On May 4 2012, a successful hydrocarbon test was performed on a DATUM® Frame 6 centrifugal compressor in Olean, New York, USA. This was the highest discharge pressure CO2 compressor ever tested on hydrocarbon in Olean at more than 8,250 psig (581.4 bar), with a suction pressure of approximately 3,500 psig (241 bar). Also, this compressor is believed to be the highest density compressor ever manufactured and tested in the world, 34.7 lbm/ft3 (556.2 kg/m3), compressing gas that has a molecular weight of approximately 36 and consists mainly of carbon dioxide. This unit was purchased for a floating production, storage, and off-loading (FPSO) vessel gas reinjection project for offshore Brazil.

In order to predict the CO2 compressor performance (specifically the head and power requirement), it is critical to use the correct gas properties. Although high-pressure gas properties do exist for CO2, the addition of methane to the gas at these discharge pressures does change the gas properties and can create uncertainty in aerodynamic performance predictions. As a result, extensive gas property testing was conducted with the field simulated gas mixture to ensure accurate performance predictions. Full-load, full-pressure testing results were such that, as tested, head and power aerodynamic performance curves matched the predicted curve and head and power guarantees were achieved.

Typically, as the power, gas density and discharge pressure of a centrifugal compressor increase, there is concern that rotor vibrations will increase, particularly sub synchronous vibrations. However, through its R&D activities, Dresser-Rand developed advanced bearing and sealing technologies that actually improve rotordynamic stability as power, gas density and discharge pressure increase.

This was demonstrated during a rotordynamic stability test at full-load and full-pressure using a magnetic bearing exciter to impart asynchronous forcing functions into the rotor while operating at full speed and load. The purpose of the testing is to evaluate the robustness of the design by "exciting" the compressor to extract a stability parameter known as logarithmic decrement. During testing of the 8,250 PSIA (581.4 bar) compressor, the logarithmic decrement was measured as the compressor discharge pressure was increased. Again, the testing results matched the predictions, confirming that the rotor became more stable as power, gas density and discharge pressure increased. The testing validated both mechanical and aerodynamic robustness and successfully mitigated risk prior to field operation.

A New Era in CO2 Compression

CO2 compression is on the dawn of a new era. Dresser-Rand is working with Ramgen Power Systems LLC to develop the next generation of low-cost, high-efficiency CO2 compressors. The joint engineering team is developing a unique shockwave compression technology for use on high molecular weight gases like CO2. The primary goal is a low-cost, high-efficiency CO2 compressor that will significantly reduce the overall capital and operating costs of carbon capture, utilization and storage (CCUS).

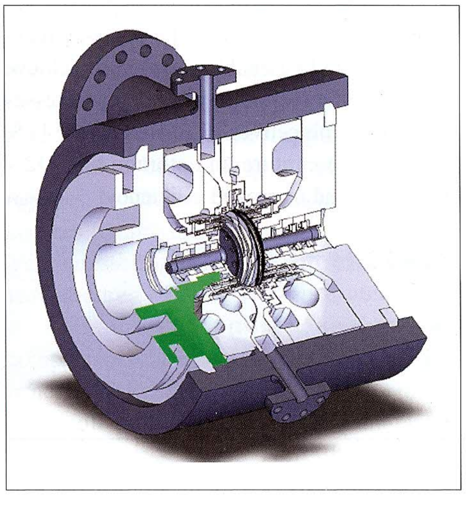

Figure 3 - Ramgen single-stage solid model – high-pressure CO2 compression stage

CO2 compressors represent approximately one-third of the capital and operating cost of a post-combustion, amine-based CCUS system. The CO2 compressor power required for a pulverized coal (PC) power plant is eight to 12 percent of the plant rating, depending largely on the suction pressure. A 1,000 MW PC plant would require 134,000 hp (100 MW) for CO2 compression at an estimated $150 million in equipment cost for the current 3 x 50% configuration, in addition to $75 - $100 million in installation costs.

Part of the reason that existing CO2 compressor designs are expensive is because the overall pressure ratio is anywhere between 100:1 and 200:1.The most significant impact on cost, however, is an aerodynamic design practice that limits the stage pressure ratio on heavier gases such as CO2. Conventional centrifugal compressors typically require eight to 12 stages of compression to meet the requirements of these applications. ["Low-Cost High-Efficiency CO2 Compressor," Carbon Capture Journal Sept-Oct 2009].

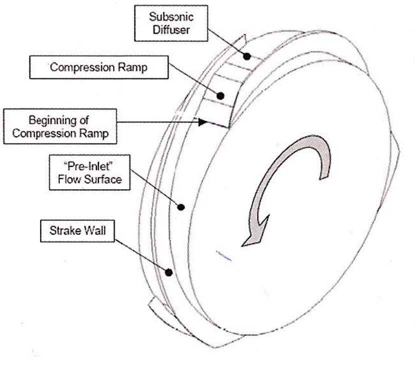

Figure 1. Supersonic compression stage rotor

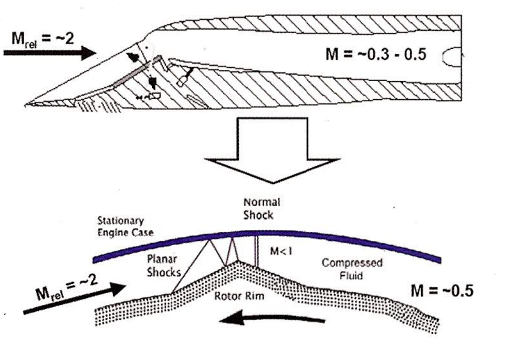

Figure 2. Shock structure & comparison to flight inlet

Figure 2 - Ramgen compression technology is based upon proven, supersonic flight inlet structures.

Ramgen Technology – Looking Toward the Future

Ramgen's shockwave compression technology is expected to represent a significant advancement for many compressor applications, and specifically for CO2 compression. The principal advantage of Ramgen's shockwave compression, based upon proven supersonic aircraft inlet design (Fig. 2), is that it can achieve high compression efficiency at very high singlestage compression ratios.

The result is a product that lowers both capital and operating costs in a smaller footprint.The Ramgen concept requires only two stages of compression, with a matched set of independent-drive, single-stage compressors instead of a conventional integral gear compressor configuration with a common bull gear drive. Each of the Ramgen stages can achieve a pressure ratio of ~10.0+:1.

An intercooler is used between the low-pressure (LP) and high-pressure (HP) stages, and an after-cooler is used after the HP stage. The high-pressure stage is shown below, along with a typical T-s diagram for the Ramgen two-stage configuration.

The stage discharge coolers can be the CCUS process itself. Cost effective heat integration, enabled by the high quality heat of compression associated with the 10:1 compression ratio, can substantially improve the economics of CCUS. The Ramgen LP and HP stages can provide 270 Btu/lb- CO2 to a variety of heat integration options.

It should be noted that eight- or 10-stage designs are sensitive to a two-phasing effect, because the margin between the compressor-stage discharge pressure and the two-phase region in and around the critical point (shown in red below) is small and somewhat unpredictable depending on gas impurities. The proximity of the line of a constant 100°F

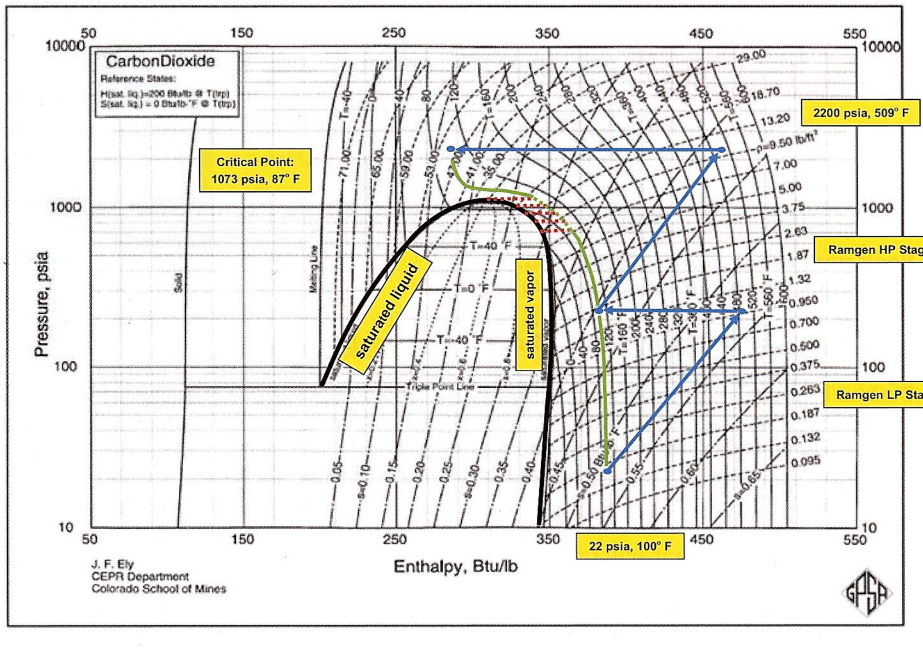

Figure 4 - Ramgen CO2 pressure-enthalpy diagram

(38°C) temperature to the CO2 vapor dome in the pressure-enthalpy diagram (show in green) illustrates the challenge of fully inter-cooling the later stages of multi-stage designs. Ramgen (shown in blue), on the other hand, operates in regions very much removed from the critical point.

Ramgen and Dresser-Rand plan to develop a series of frame sizes to support both amine-based and ammonia-based capture technologies, as well as other emerging capture technologies. The planned frame sizes would be able to support a full capacity 800 MW power plant using a single set of Rampressor units.

Ramgen's Competitive Advantage

Ramgen's technology has both capital and operating cost advantages.

- Ramgen expects to be 50-60 percent of the conventional integrally geared centrifugal compressor on an installed cost basis.

- The Ramgen two-stage configuration will require approximately the same shaft input power as the eight- or 10-stage equivalent when inter-stage temperatures and pressure drops associated with intercooler are included.

- Heat recovery can be of significant value when fully integrated at scale. The Ramgen two-stage configuration has a nominal discharge temperature of 500°F (260°C) vs. conventional integrally geared designs of 200°F (93°C).

- The Ramgen design can take advantage of colder inlet temperatures and resulting lower power consumption, if available. The Ramgen inter-stage pressures are nowhere near the critical point on the pressure enthalpy diagram and the associated two-phase concerns. Ramgen may be able to run colder inter-stage temperatures, which could further enhance its efficiencies.

- Shock compression is a near-instantaneous phenomenon. As long as the discharge pressure is above the critical point on the pressure enthalpy diagram of all the constituents in the gas mix, concerns over two-phase flow should be minimized.

- The two-stage intercooled log mean temperature difference (LMTD), a key determinant of the cooler surface area required, will be three times that of the integral gear designs resulting in coolers that require one-third of the surface area to achieve the same cooling effect.

- Ramgen's design will have a substantially smaller footprint.

- High power drives are of limited availability and expensive; Ramgen's independent drive configuration should allow for improved motor selection options.

Test Validation of Aerodynamic Performance

Ramgen and Dresser-Rand are currently preparing for a test of a 10:1 pressure ratio, 10,700 HP (8 MW) CO2 unit with a 2,215 PSIA (152 bar) discharge pressure. The unit is being assembled for testing on a dedicated 13,400 HP (10 MW) closed loop CO2 test facility at Dresser-Rand Olean Operations. The goal is to validate aerodynamic performance, as well as operating characteristics and mechanical integrity. The test facility is currently being qualified, and testing is expected to begin later this year.

Additionally, Ramgen and Dresser-Rand are currently in the process of developing a family of supersonic compressors to serve the CO2 market. Development is expected to be complete in early 2014. The high-pressure ratio-per-stage capability of the Ramgen technology is the key enabler needed to achieve this goal. The technology concept addresses the two key objectives identified by the U.S. DOE for the capture and storage of CO2 – lower cost and improved efficiency.

More information

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