the ENERGY lab

PROJECT FACTS

Existing Plants, Emissions & Capture

Novel Concepts for the Compression of Large Volumes of Carbon Dioxide

Background

The mission of the U.S. Department of Energy/National Energy Technology Laboratory (DOE/NETL) Existing Plants, Emissions & Capture (EPEC) Research & Development (R&D) Program is to develop innovative environmental control technologies to enable full use of the nation's vast coal reserves, while at the same time allowing the current fleet of coal-fired power plants to comply with existing and emerging environmental regulations. The EPEC R&D Program portfolio of post- and oxy-combustion carbon dioxide (CO_2) emissions control technologies and CO_2 compression is focused on advancing technological options for the existing fleet of coal-fired power plants in the event of carbon constraints.

Studies conducted by DOE have revealed the high cost and energy requirements that exist for CO_2 compression. The CO_2 captured from a power plant will need to be compressed to 1,500 to 2,200 pounds per square inch absolute (psia) to be effectively transported via pipeline and injected into an underground sequestration site. This compression requires significant power and the penalty can be as high as 8 to 12 percent on a typical integrated gasification combined cycle (IGCC) plant, and even higher on oxy-combustion and pulverized coal (PC) plants. Reduction of the compression cost and energy requirements will be beneficial to the overall efficiency of carbon capture and sequestration for utility applications.

Description

Southwest Research Institute (SwRI), partnered with Dresser-Rand, is developing improved methods to compress CO_2 to pipeline pressures while minimizing the energy expended. This project will design and evaluate an efficient and cost-effective compressor for sequestering IGCC plant CO_2. Various concepts will be investigated using fundamental thermodynamics and economics to determine if achieving the pressure rise is best accomplished through a liquid or gaseous CO_2 state. Novel methods to compress gaseous CO_2 while removing the heat of compression internal to the compressor will be investigated. The high pressure ratio required to compress CO_2 from near atmospheric pressure to pipeline levels results in significant heat of compression. Less energy is required to boost the pressure of a cool gas; therefore, both upstream and interstage cooling is desirable. Researchers will determine the optimum compressor configuration and develop technologies for internal heat removal. Process streams within the IGCC environment, such as nitrogen, steam, and synthesis gas (syngas), will be utilized to provide a total system solution by fully integrating with the air separation units, combined cycle, and gas cleanup system. Alternate compression options using liquefied CO_2 and cryogenic pumping will be explored as well.

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PARTNERS

Dresser-Rand

PERFORMANCE PERIOD

Start Date	End Date
10/01/2005	12/31/2013

COST

Total Project Value
$11,648,503

DOE/Non-DOE Share
$8,179,355 / $3,469,148

AWARD NUMBER

DE-FC26-05NT42650

U.S. DEPARTMENT OF ENERGY

This project was initiated with two phases and included plans for a potential third phase of pilot-scale testing. Phase I, Scoping and Modeling, planned to focus on CO_2 compressor technologies and determine performance characteristics; and Phase II, Bench-scale Testing and Evaluation, to evaluate and test the optimal CO_2 compressor technologies. Phase I work has identified two optimal compression concepts: isothermal compression and liquid CO_2 pumping. The first concept uses interstage cooling to achieve near-isothermal compression. The second concept, liquid CO_2 pumping, initially compresses CO_2 to 250 psia and then uses refrigeration to condense the CO_2 to a liquid. The liquid CO_2, which requires significantly less power to compress than gaseous CO_2, is then pressurized to 2,200 psia with a considerable cost savings. Preliminary analysis indicates up to a 35 percent reduction in compression power is possible with the new concepts being considered. Phase II investigated the two concepts further through the development of experimental test rigs. As both test programs successfully met their objectives, Phase III pilot-scale testing has been authorized to focus on the scale-up and testing of a fully integrated system, which includes the CO_2 compressor with intercooling, a refrigerant based liquefaction system, and a liquid CO_2 pumping system.

Project Goal

The project goal is to examine methods to pressurize CO_2 to pipeline pressures while significantly decreasing parasitic energy consumption, assisting central power plants to capture and store CO_2 economically.

Objectives

The project objectives are to advance CO_2 compression and pumping technology to increase composite energy efficiency of a compression system to 85 percent. These efforts are aimed at advancing and evaluating two distinct cycle concepts: (1) a two-stage advanced centrifugal compressor and (2) a liquid CO_2 test loop with a custom developed multi-stage pump.

Liquid CO_2 pump test loop

Planned Activities

Phase I:

- Conduct a thermodynamic and economic analysis to determine the preferred CO_2 state for compression.
- Identify and evaluate intercooling concepts, develop preliminary intercooling designs, and calculate total potential energy savings.
- Complete a comprehensive thermodynamic and cost analysis of an IGCC plant incorporating the new compression technology.

Phase II:

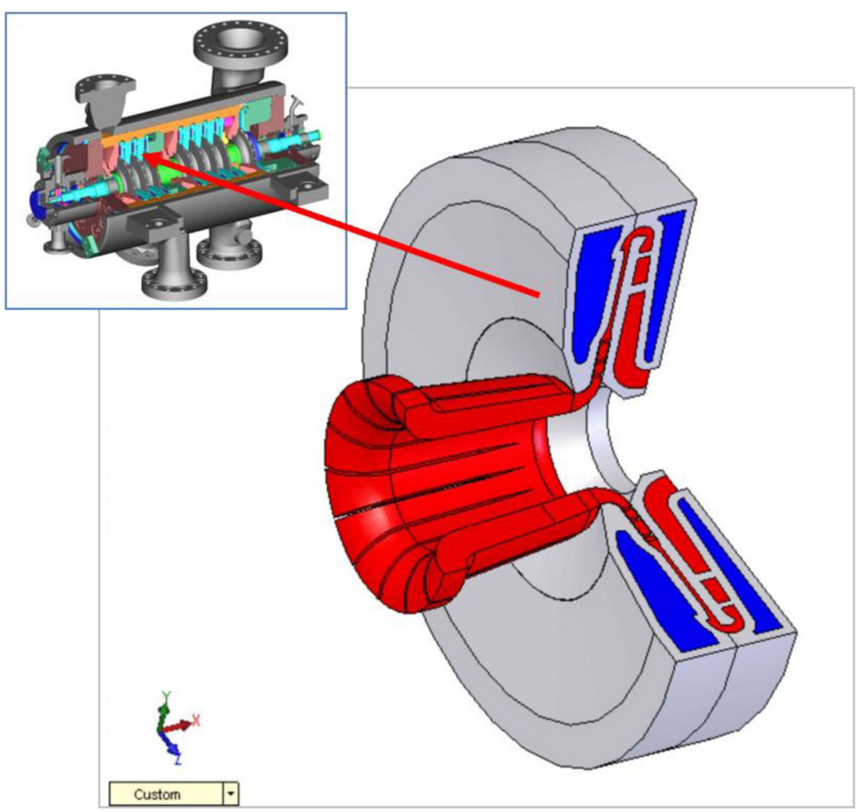
- Design and fabricate a two-stage intercooled compressor test rig based on the analyses and design studies. The flow path will be designed using state-of-the-art turbomachinery design tools and computational fluid dynamics (CFD).
- Verify and optimize performance of the intercooled compressor test rig.
- Design and fabricate a multi-stage pump test rig based on the analyses and design studies.
- Verify and optimize the multi-stage pump test rig.

Phase III:

- Design and construct a pilot-scale demonstration of the integrated compression-liquefaction pumping system.
- Extend the cooled diaphragm concept to a multi-stage design.
- Design and test the refrigeration system including an economizer, and quantify the power required for the refrigeration system.
- Establish and apply a rigorous performance testing and monitoring program to determine if overall power savings targets are achieved.

Accomplishments

- Identified two promising concepts: interstage cooling to achieve near-isothermal compression, and liquid CO_2 pumping to 2200 psia.
- Developed and tested an internally-cooled compressor diaphragm that removes the heat of compression between each impeller. A cooling jacket was designed around a state-of-the-art aerodynamic flow path that contained an optimally designed heat transfer enhancement without introducing additional pressure drop.



Internally Cooled Compressor Concept

- A compressor test rig was developed by retrofitting an existing centrifugal compressor installed in a closed loop test facility with the new cooled diaphragm concept. The diaphragms were fabricated to provide accurate aerodynamic and cooling circuit geometry. The compressor was instrumented and tested; internal instrumentation was included to permit characterization of the stage performance, heat transfer, and pressure drop. The internally-cooled compressor tests demonstrated the effectiveness of the design, which exceeded expectations.
- Conjugate heat transfer CFD models were developed and utilized for compressor design verification and optimization.
- A new pump loop facility was designed and constructed adapting an existing cryogenic turbopump for use on liquid CO_2. The pump was proven to meet all project objectives in terms of both hydrodynamic and mechanical performance.
- Phase III is currently underway to develop a new, pilot-scale, multi-stage centrifugal compressor that contains the cooled diaphragm technology and integrate it with a CO_2 liquefaction system followed by pumping.

Benefits

The compression concepts developed in this project can significantly reduce the cost of compressing CO_2 to pipeline requirements and are applicable to all types of power plants. The combination of the intercooled compression concept with the liquid CO_2 pumping concept can potentially provide up to 35 percent total power savings. Successful completion of the Phase III project effort should allow for the technology to be ready for follow-on demonstration testing.