| **Project Title:** | |
|---|---|
| **High-Efficiency, Low-Cost $CO_2$ Compression Using Super-Sonic Shock Wave Technology** | |
| **Technology Area:**<br>Compression | **Technology Maturity:**<br>Pilot, 1680 tonnes/day $CO_2$ |

**Primary Project Goal:**

Ramgen Power Systems is designing and developing a unique compressor technology based upon aerospace shock wave compression theory for use as a land-based carbon dioxide ($CO_2$) compressor.

**Technical Goals:**

**Phase I**

- Complete testing of a high-pressure ratio (10:1) air compressor rotor for the Ram 2 program.
- Demonstrate the feasibility of high-pressure shock wave compression.
- Develop and detail a viable commercialization path.

**Phase II**

- Perform critical success factors risk reduction validation and test program to identify and reduce technical risk areas.
- Complete general assessment, preliminary, and final design of a demonstration $CO_2$ supersonic shock compressor approximately 13,000 hp in size.

**Technical Content:**

When shock waves pass through a gas they cause a localized compression. Ramgen is developing a compressor that creates and utilizes this effect to accomplish efficient $CO_2$ compression.

Figure 1 shows that the rotating rotor rim has small, shallow angles which, when rotating at high speeds, will produce supersonic shock waves both prior to and post-peak. These shock waves, modeled in the 3-D Euler Computational Fluid Dynamics (CFD) image shown, are first oblique, then normal. Additionally, strakes (ridges) are incorporated into the design of the rotor to form sidewalls. The strakes are utilized as shock compression ducts, as well as to separate high-pressure discharge from low-pressure suction. The combination of shocks and strakes result in a compressed fluid delivered from a stationary discharge duct with compression efficiencies comparable to conventional industrial turbo-compressors, but with much higher single-stage pressure ratios and therefore higher quality heat of compression that combine to deliver significant installed and operational cost savings versus existing turbo-compressors.

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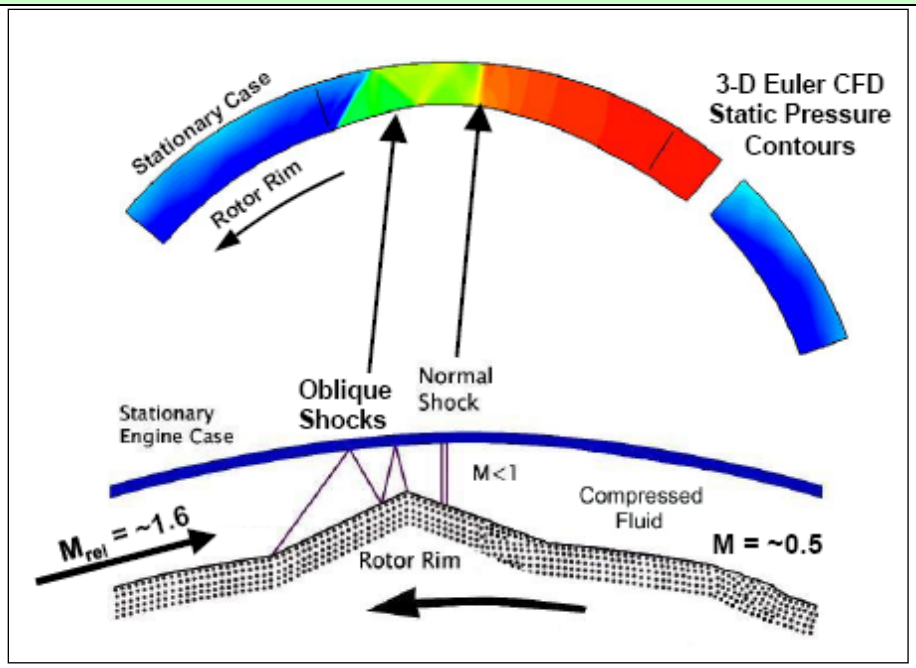


**Figure 1: Schematic of Rotor Rim and Engine Case and 3-D Euler CFD Image Depicting Shock Wave Behavior**

Two stages of compression are used with an intercooler located between the stages to optimize the efficiency of the compression process. Figure 2 shows the energy required as shaft work and the thermal energy lost to the cooling stream. The numbers found in the figure represent a stage in the process; each stage is driven independently through an external gearbox.

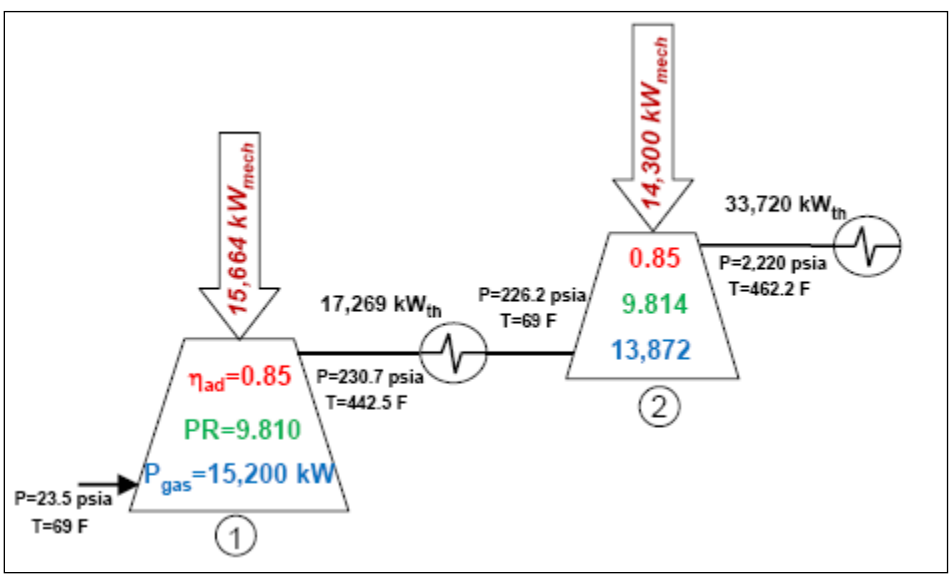


**Figure 2: Series Process Schematic**

As seen in Figure 2, the total shaft power is 29,964 $kW_{mech}$, which corresponds to a heat of compression of 50,989 kWth. Approximately 28,986 kWth of the heat of compression lost is recoverable down to 93°C (200°F).

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## High-Efficiency, Low-Cost $CO_2$ Compression Using Super-Sonic Shock Wave Technology

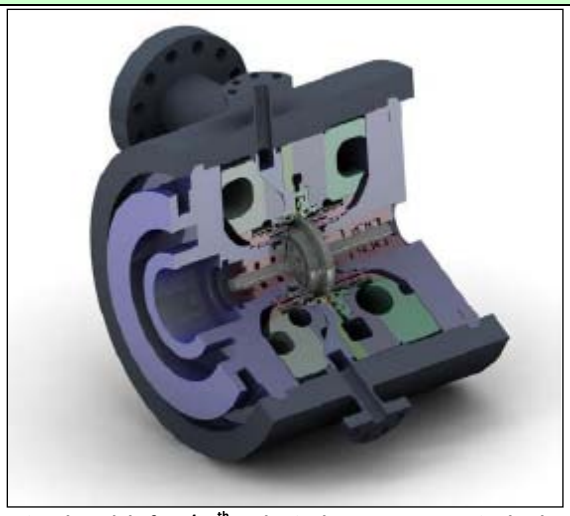

**Figure 3: Cross Sectional Model of a 1/10th Scale Single Stage Supersonic Shock Wave Compressor**

**Technology Advantages:**

- Competitive operating efficiency and reduced installed capital cost (approximately 50%) over multi-stage bladed turbo compressors.
- High stage discharge temperature enables cost-effective recovery of heat of compression.
  - Improves carbon capture and sequestration (CCS) efficiency.
  - Reduces power plant de-rate.

**R&D Challenges:**

- Complicated shock wave aerodynamics on the flow path require intensive computing capabilities and model development.
- High rotational speeds and the resulting stresses can result in expensive rotor manufacturing techniques.
- High-pressure ratio compressors yield high rotor thrust loads on bearings and structure.

**Results To Date/Accomplishments:**

- Completed flow path validation test conceptual design review.
- Completed demonstration unit feasibility study.
- Prepared a detailed systems analysis of the technology.
- Prepared a rigorous comparative economic analysis based on the systems analysis.
- Achieved breakthrough rotor pressure ratio of approximately 7.9:1 in air.
- Demonstrated tip speeds up to ~2,200 ft/s and $M_{rels}$ up to ~2.7.
- Successfully modeled full flow path 3-D viscous CFD.
- Matched performance prediction/design tools to test.
- Obtained benign surge characteristics.

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|---|---|
| • Gathered data for preliminary compressor maps.<br>• Developed and demonstrated bearing designs suitable for product application. | |
| **Next Steps:**<br>Develop high speed performance computing capability at Oak Ridge National Laboratory.<br>Final test results will not be available until the December 2010 project completion date. | |
| **Available Reports/Technical Papers/Presentations:**<br>Presentation in March 2009 at NETL $CO_2$ Capture Technology for Existing Plants R&D Meeting, http://www.netl.doe.gov/technologies/coalpower/ewr/co2/co2compression/supersonic.html (May 2009).<br>Presentation at 2008 Seventh Annual Conference on Carbon Capture and Sequestration, http://www.netl.doe.gov/technologies/coalpower/ewr/co2/co2compression/supersonic.html (May 2009). | |
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