Novel Concepts for the Compression of Large Volumes of CO_2

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Project Funded by DOE NETL
DOE PM: Mr. Timothy Fout

Co-Funded by Dresser-Rand and BP

Project Motivation

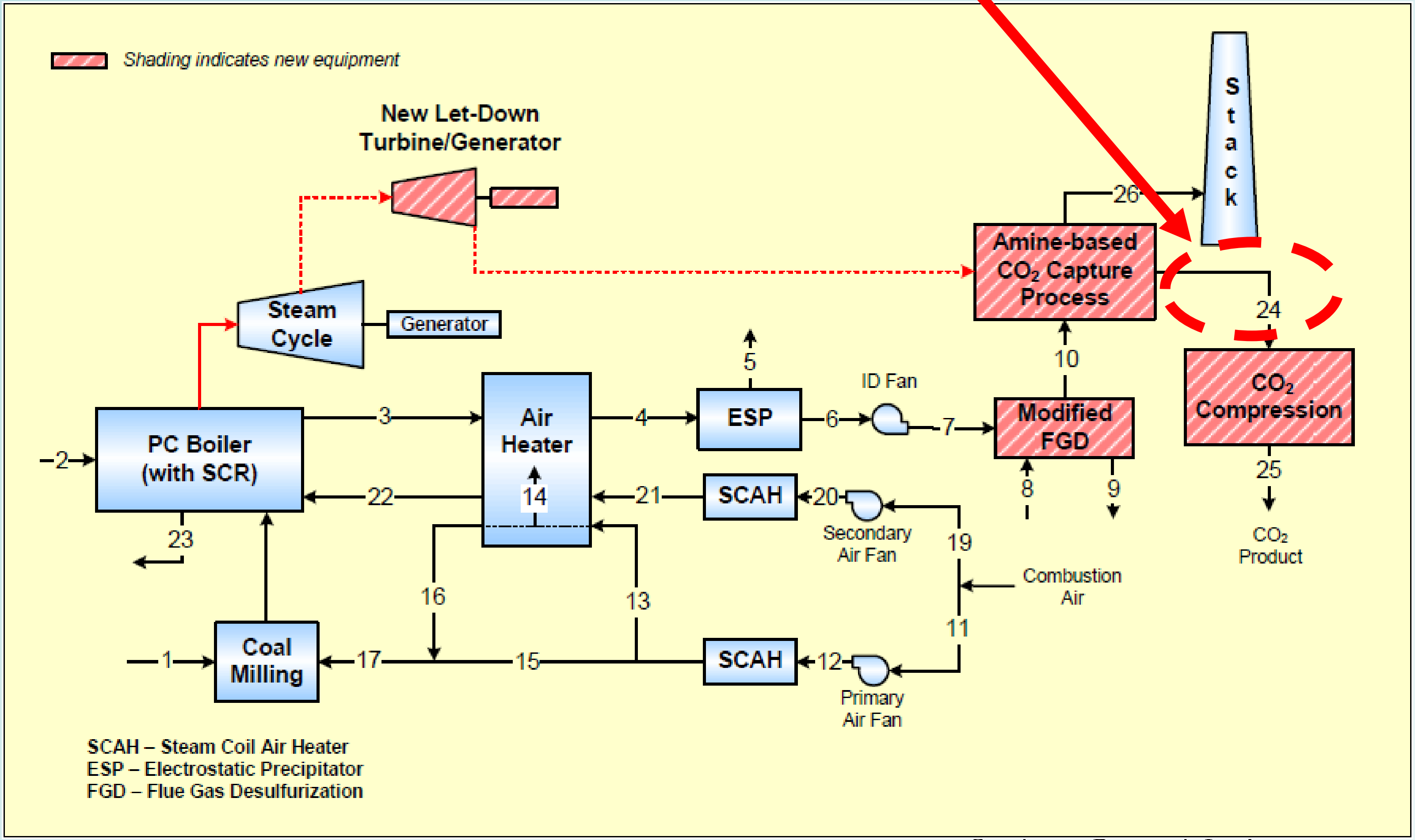
- CO_2 capture has a significant compression penalty - as high as 8 to 12%.
- Final pressure around 1,500 to 2,200 psia for pipeline transport or re-injection.
- Based on a 400 MW coal plant, the typical flow rate is ~600,000 to 700,000 lbm/hr.
- Project goal: Double-digit reduction of compression power for CO_2 capture
- Many thermodynamic processes studied.
- Several challenges with the application discussed.

Project Overview

- Phase I (Completed)
  - Perform thermodynamic study to identify optimal compression schemes
- Phase II (Complete in 2010)
  - Pilot testing of two concepts:
    - Isothermal compression (test underway)
    - Liquid CO_2 pumping (complete)

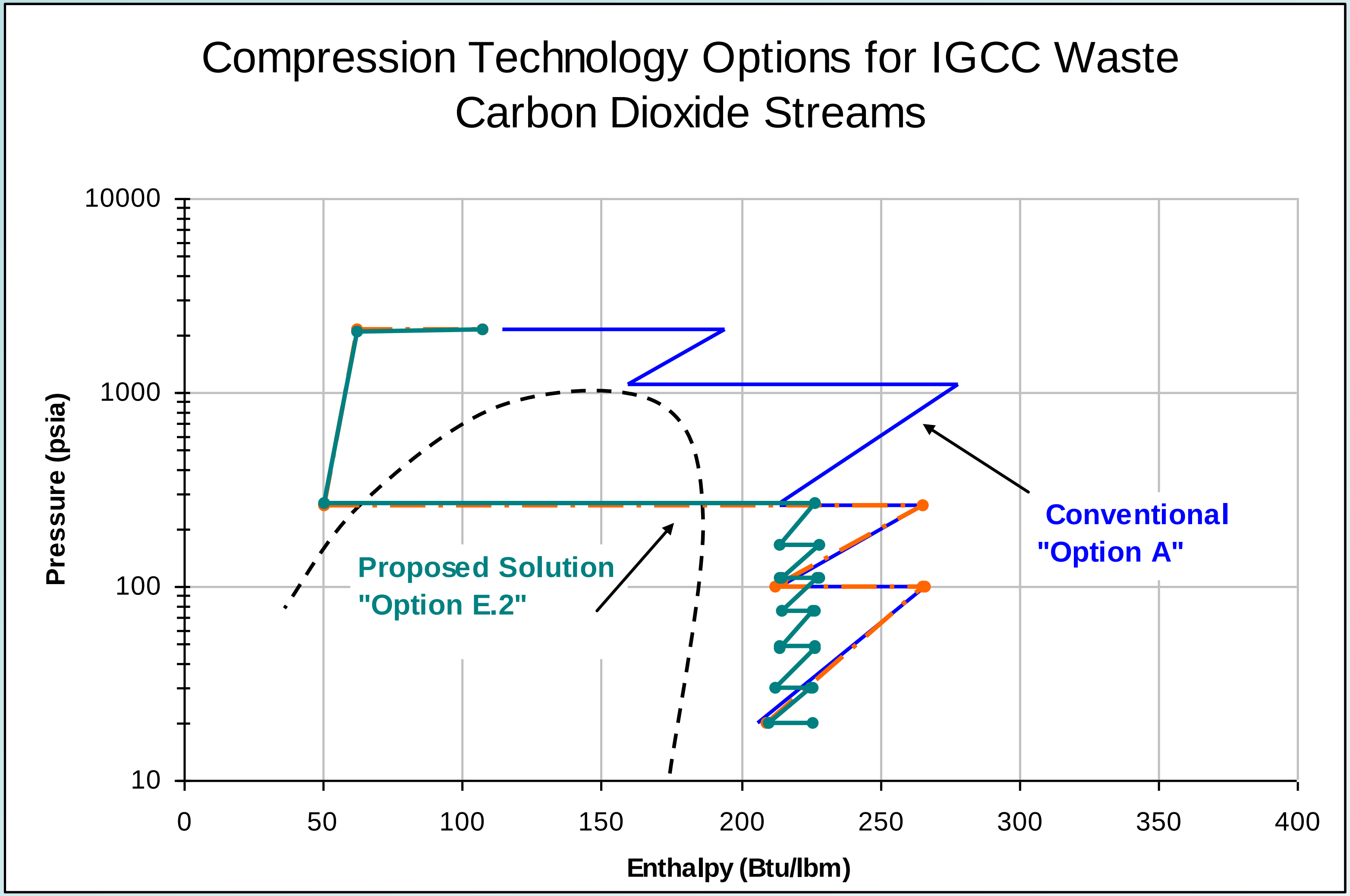
DOE PC Reference Case

- Only CO_2 stream considered



DOE/NETL report 401/110907

Proposed Solution for Optimal Efficiency



Optimal solution combines inter-stage cooling and a liquefaction approach.

Summary of Thermodynamic Analysis for IGCC Plant

Option	Compression Technology	Power Requirements	% Diff from Option A	Cooling Technology
A	Conventional Dresser-Rand Centrifugal 10-stage Compression	23,251 BHP	0.00%	Air-cool streams between separate stages
B	Conventional Dresser-Rand Centrifugal 10-stage Compression with additional cooling	21,522 BHP	-7.44%	Air-cool streams between separate stages using ASU cool N2 stream
C.1	Isothermal compression at 70 degF and 80% efficiency	14,840 BHP	-36.17%	Tc = 70 degF inlet temp throughout
C.4	Semi-isothermal compression at 70 degF, Pressure Ratio ~ 1.55	17,025 BHP (Required Cooling Power TBD)	-26.78%	Tc = 70degF in between each stage.
C.7	Semi-isothermal compression at 100 degF, Pressure Ratio ~ 1.55	17,979 BHP (Required Cooling Power TBD)	-22.67%	Tc = 100degF in between each stage.

Summary of Thermodynamic Analysis for IGCC Plant Cont.

Option	Compression Technology	Power Requirements	% Diff from Option A	Cooling Technology
D.3	High ratio compression at 90% efficiency - no inter-stage cooling	34,192 BHP	47.06%	Air cool at 2215 psia only
D.4	High ratio compression at 90% efficiency - intercooling on final compression stage	24,730 BHP	6.36%	Air cool at 220 and 2215 psia
E.1	Centrifugal compression to 250 psia, Liquid cryo-pump from 250-2215 psia	16,198 BHP (Includes 7,814 BHP for Refrigeration) [1]	-30.33%	Air cool up to 250 psia, Refrigeration to reduce CO2 to -25degF to liquify
E.2	Centrifugal compression to 250 psia with semi-isothermal cooling at 100 degF, Liquid cryo-pump from 250-2215 psia	15,145 BHP (Includes 7,814 BHP for Refrigeration) [1]	-34.86%	Air cool up to 250 psia between centrifugal stages, Refrigeration to reduce CO2 to -25degF to liquify

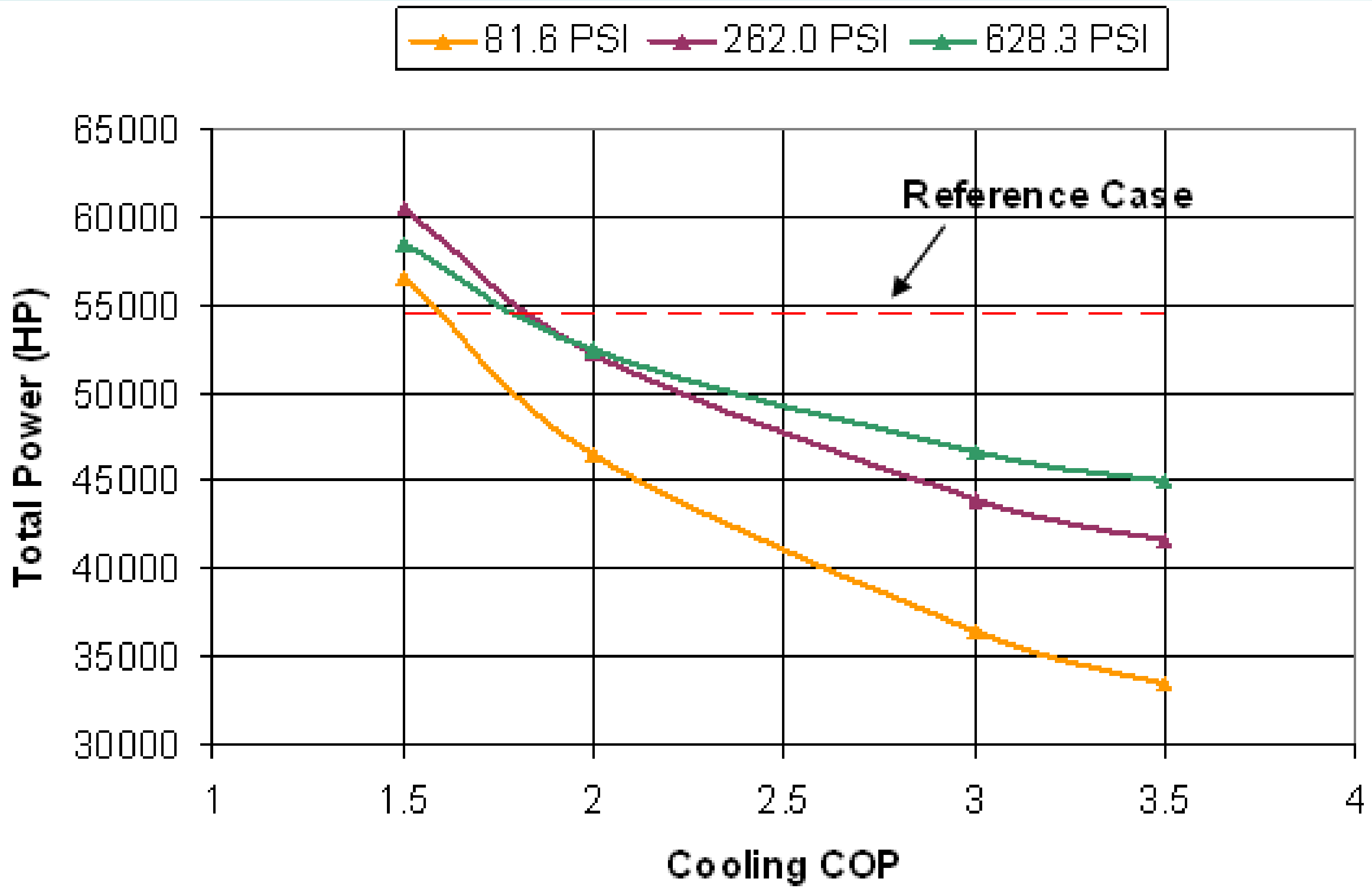
Note: Heat recovery not accounted for.

Summary of Thermodynamic Analysis

- Liquefaction process
  - Utilize a refrigeration system to condense CO_2 at 250 psig and -12ºF.
  - Liquid then pumped from 250 to 2,200 psig.
  - Requires significantly less power to pump liquid than to compress a gas.
  - The cost of the refrigeration system must be accounted for.

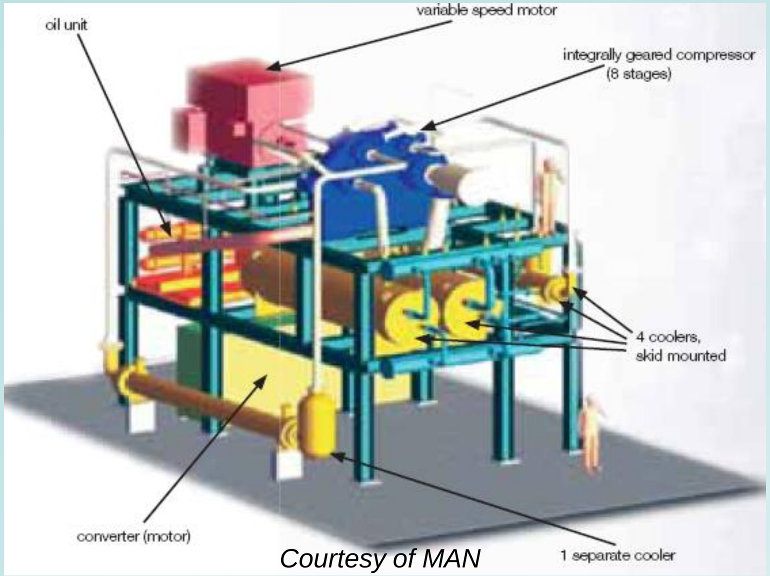
Compression Power for PC Plant

Liquefaction/Pumping Compression



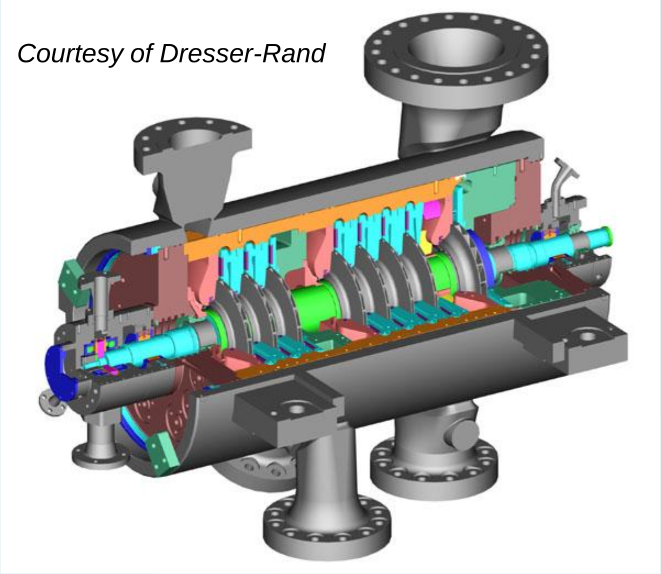
Challenges: High Reliability

Integrally Geared Isothermal Compressor



- Integrally geared can achieve near isothermal compression
- Can contain up to 12 bearings, 10 gas seals plus gearbox
- Typically driven by electric motor
- Impellers spin at different rates
  - Maintain optimum flow coef.

Single-Shaft Multi-stage Centrifugal Compressor



- Multi-stage centrifugal proven reliable and used in many critical service applications currently (oil refining, LNG production, etc.)
- Fewer bearings and seals
  - (4 brgs & seals for 2 body train)
- Can be direct driven by steam turbine

Project Goals

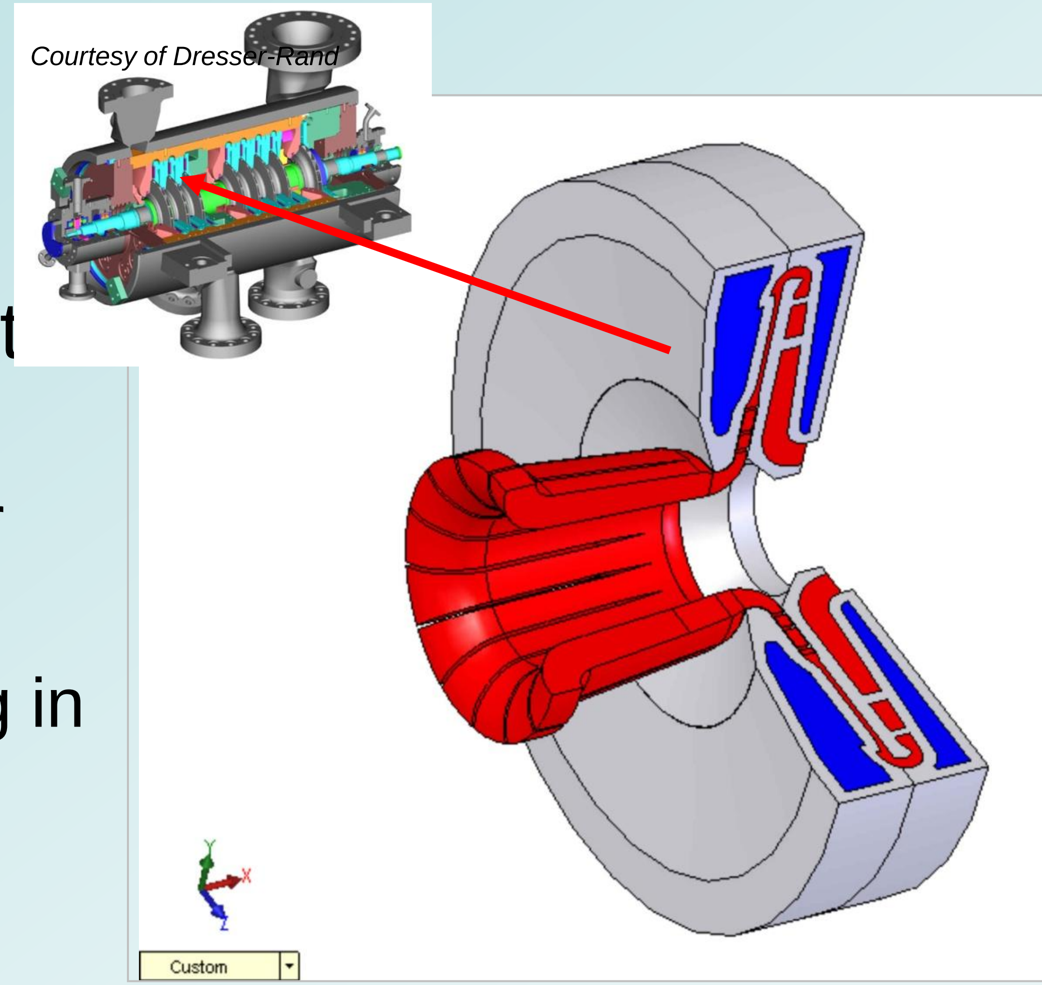
- Develop internally cooled compressor stage that:
  - Provides performance of an integrally geared compressor
  - Has the reliability of a in-line centrifugal compressor
  - Reduces the overall footprint of the package
  - Has less pressure drop than a external intercooler
- Perform qualification testing of a refrigerated liquid CO2 pump

Phase 2 Project Plan

- Experimentally validate thermodynamic predictions.
- Two test programs envisaged:
  - Liquid CO_2 pumping loop
  - Closed-loop CO_2 compressor test with internal cooling
- Power savings will be quantified in both tests.

Internally Cooled Compressor Concept

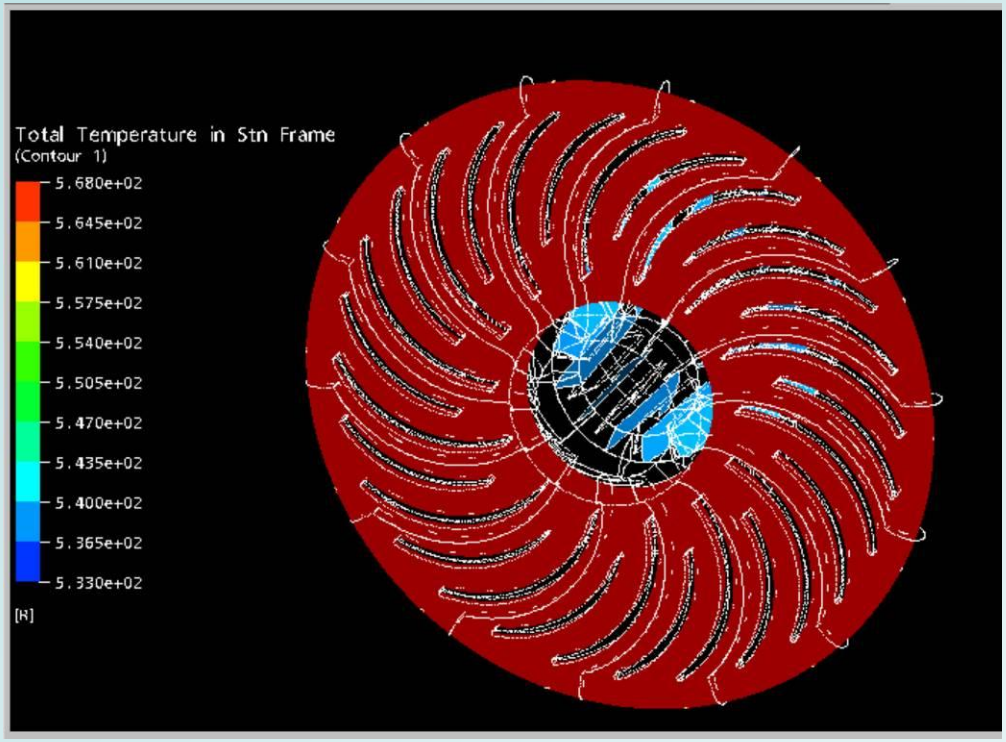
- Investigate an internally-cooled compressor concept
  - Red - CO_2 flow path through compressor stage
  - Blue - Liquid cooling in the diaphragm
  - Grey - Solid



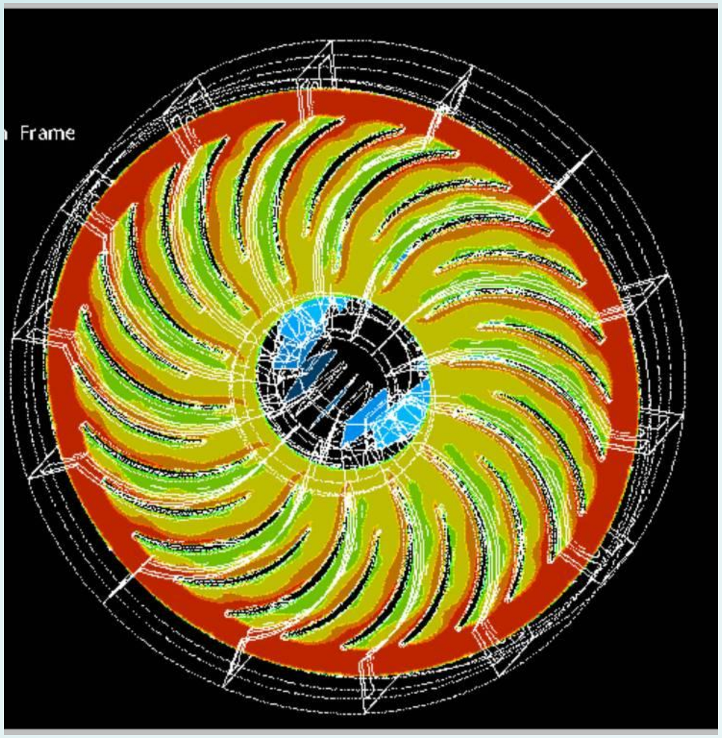
Conjugate Heat Transfer CFD Model

- Predicted temperature in return channel with and without internal cooling.

Without Heat Transfer

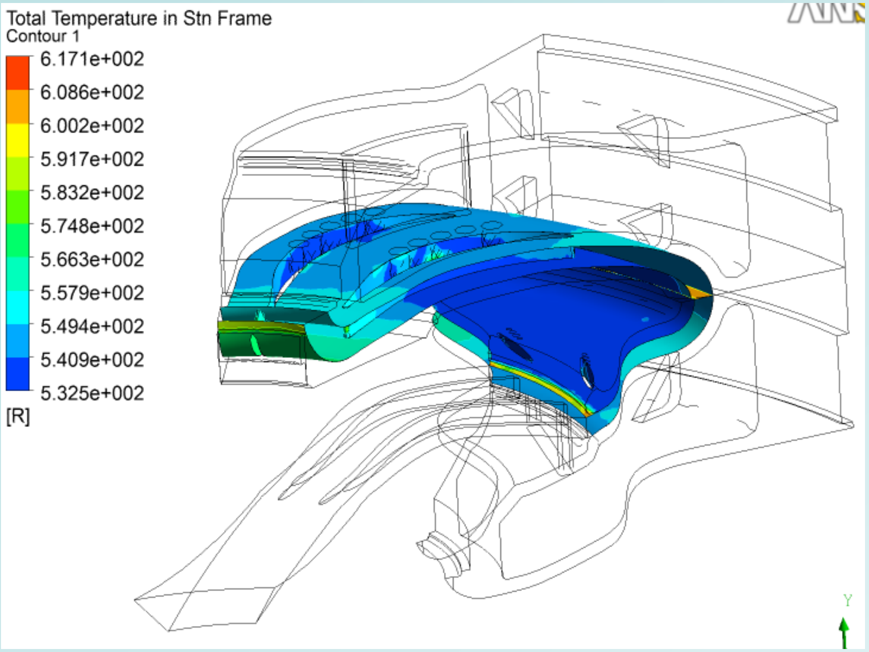


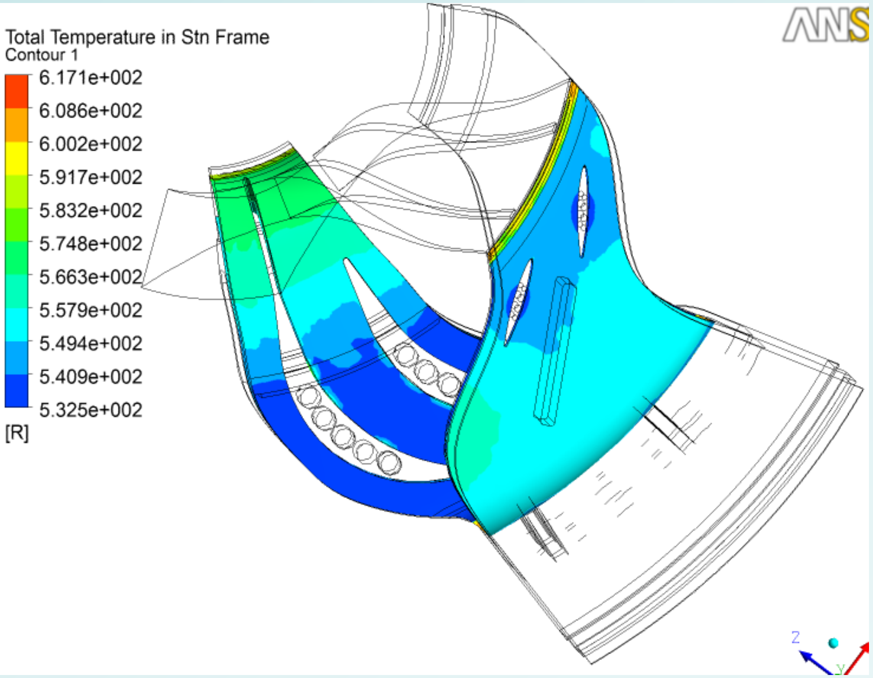
With Heat Transfer



Final Design

Case 4- Conjugate heat transfer model with enhanced heat transfer coefficients to simulate ribbed surfaces for the cooling liquid





Final Design

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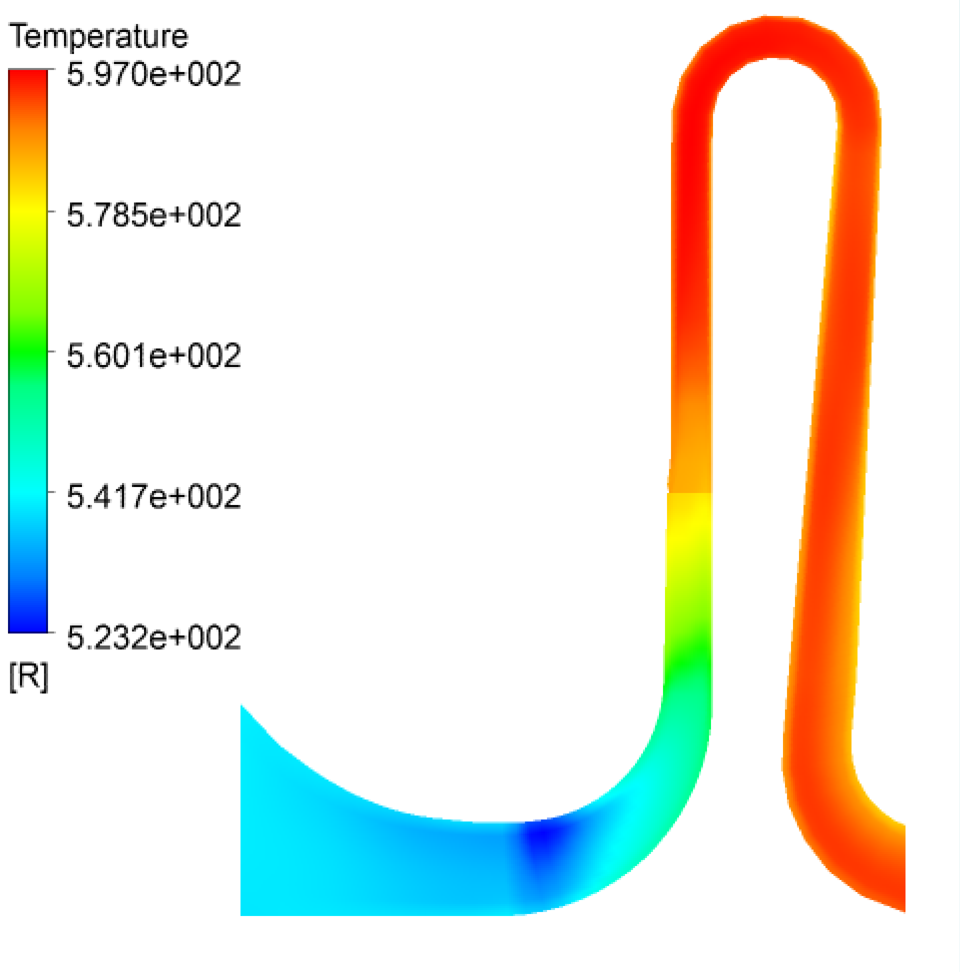
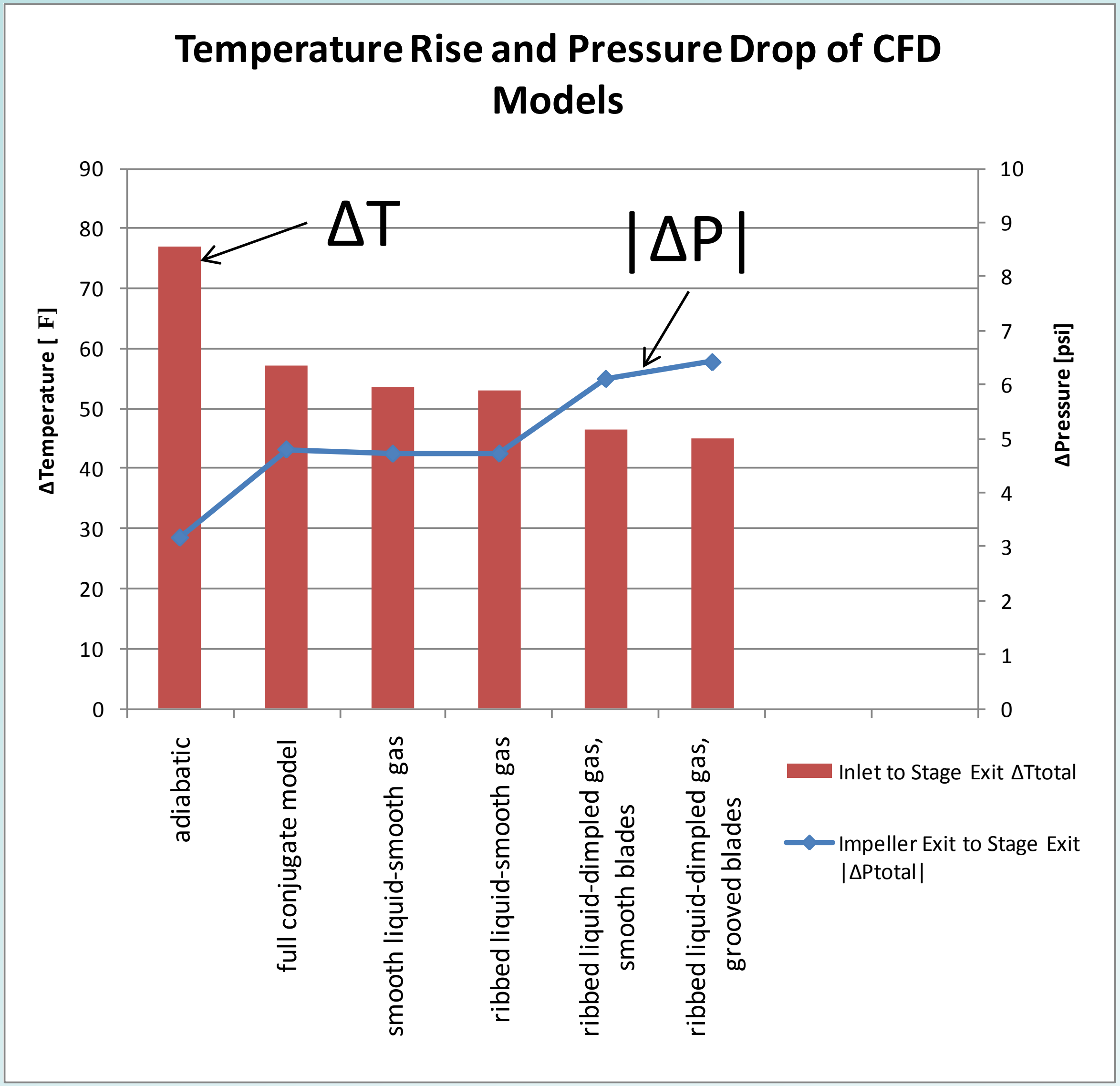
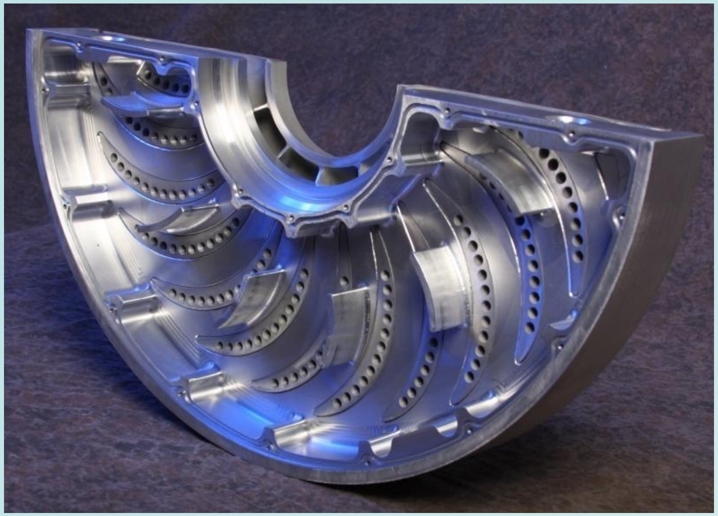
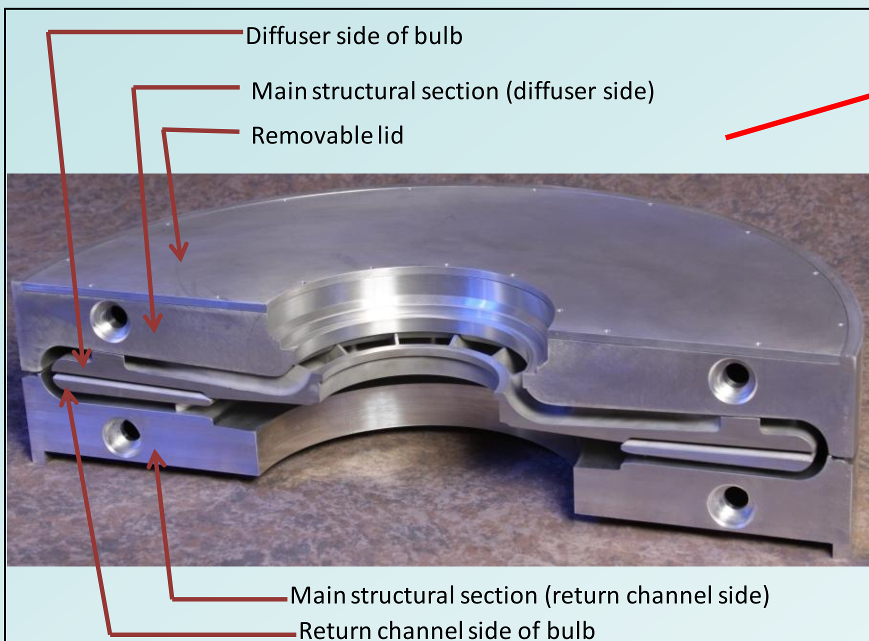


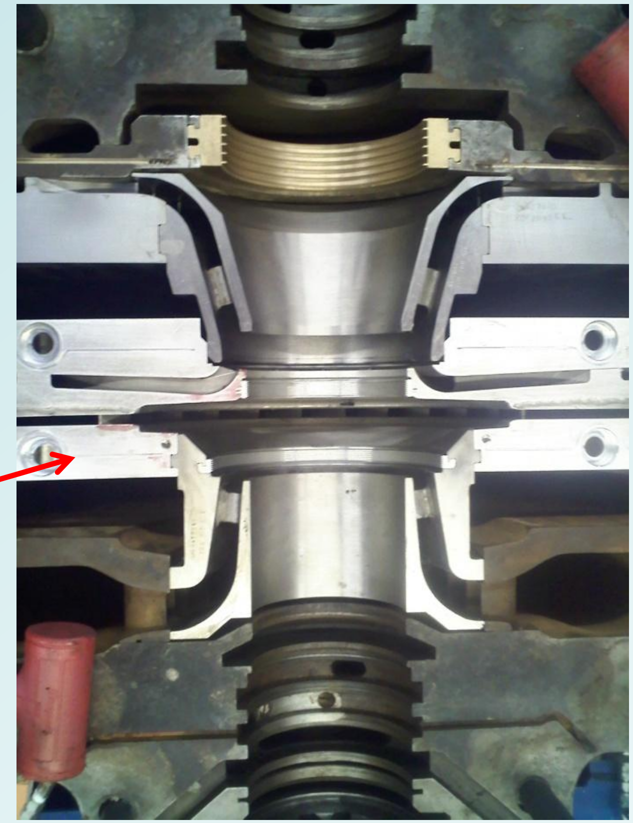
Summary of CFD Results



Test Rig Construction





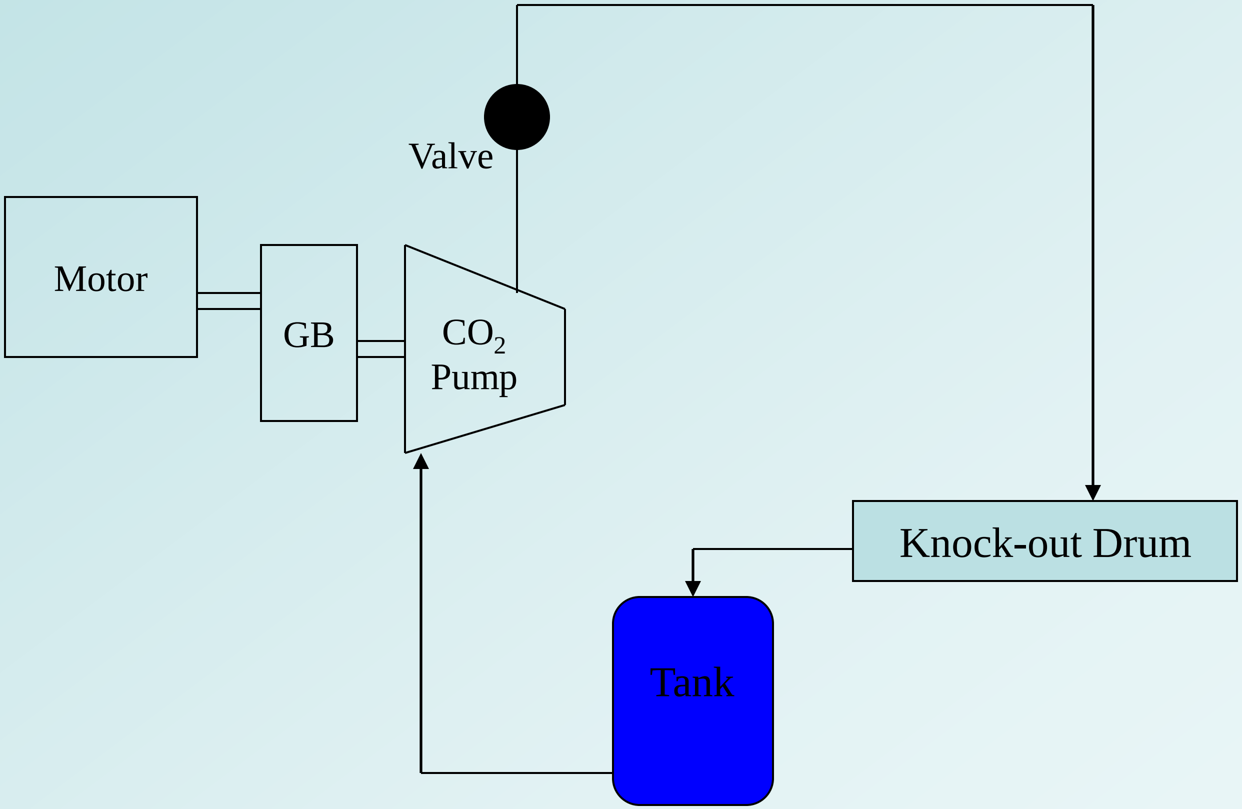


Closed Loop Test Facility

- Driven by 700 hp electric motor through gearbox
- Torquemeter installed to measure power
- Loop rated to 300 psi suction and 500 psi discharge
- Test speeds up to 14,300 rpm
- Instrumentation measures:
  - Total temperature and pressure at stage inlet and discharge
  - Total temperature and pressure at internal locations within the stage
  - Flow rate, power, and speed
  - Cooling water flow rate and delta-T
- Testing to begin later this month

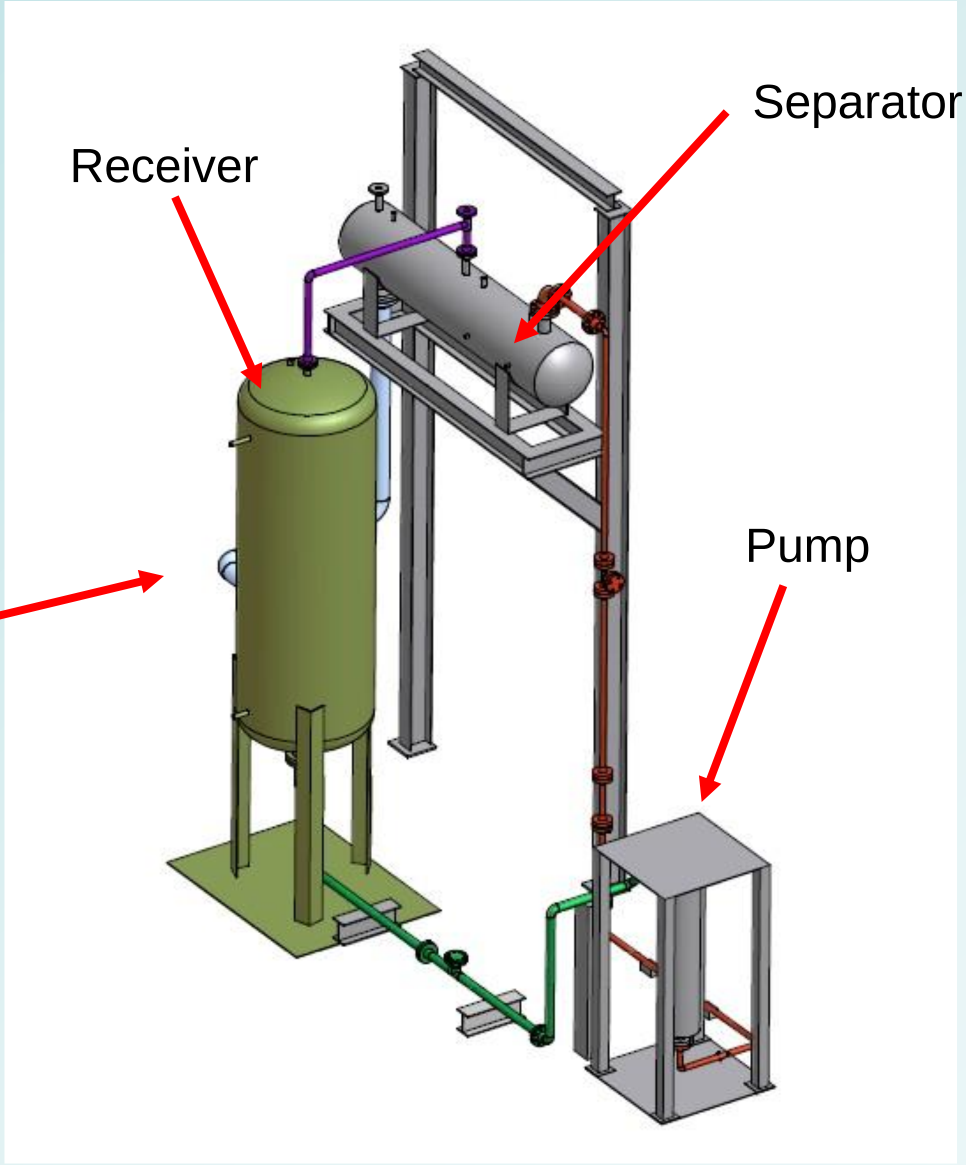
Liquid CO_2 Pumping Pilot Scale Testing

- Testing will measure pump efficiency
- Validate pump design
- Measure NPSH requirements looking for signs of cavitation
- Cryostar will supply the pump
  - 250 KW, 100 gpm, 53,000 lbm/hr



Liquid CO_2 Loop Design

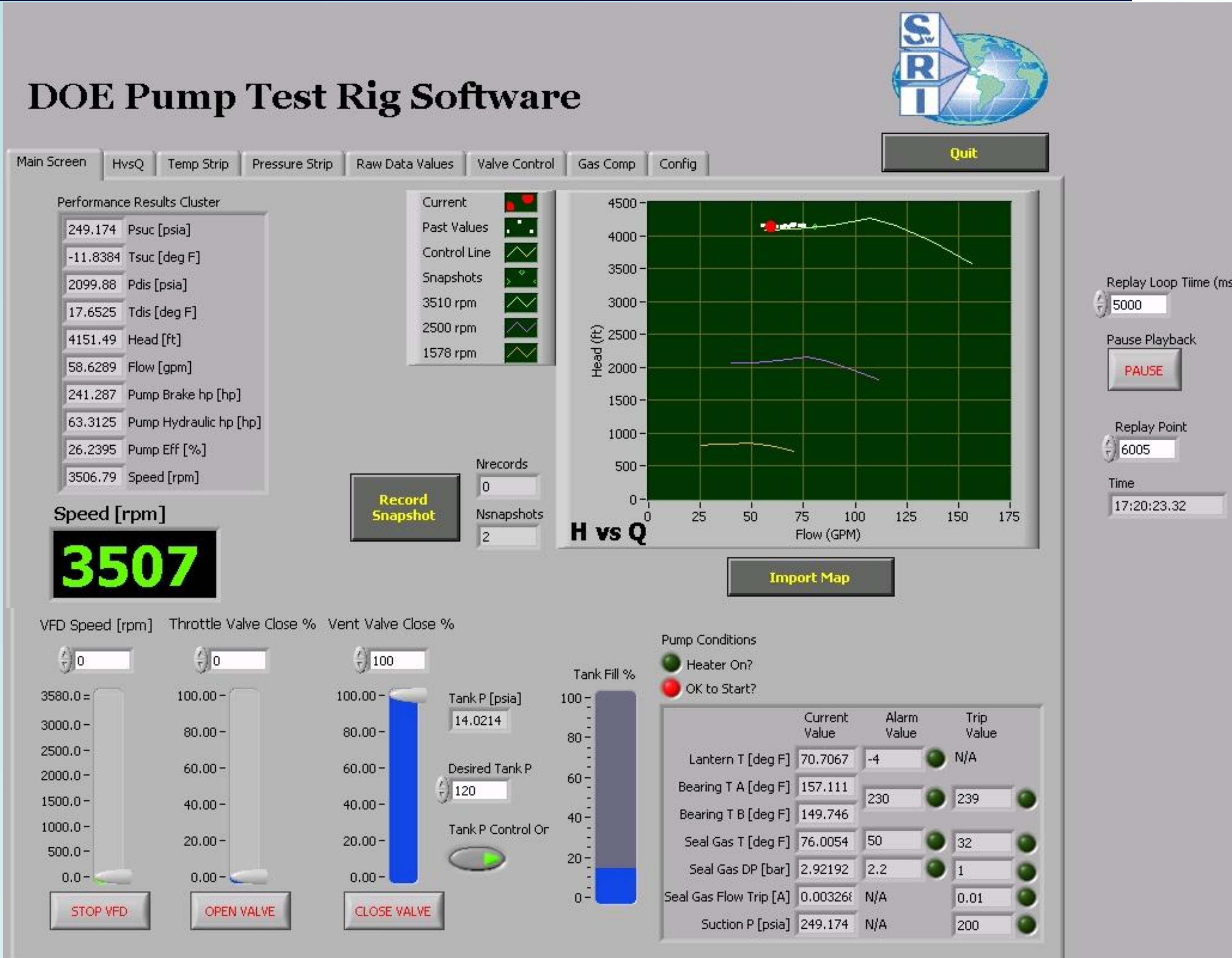
- Vessel layout showing elevated reservoir and knock-out drum
- Pump is mounted at ground level.
- Orifice run located between pump and control valve (in supercritical regime)



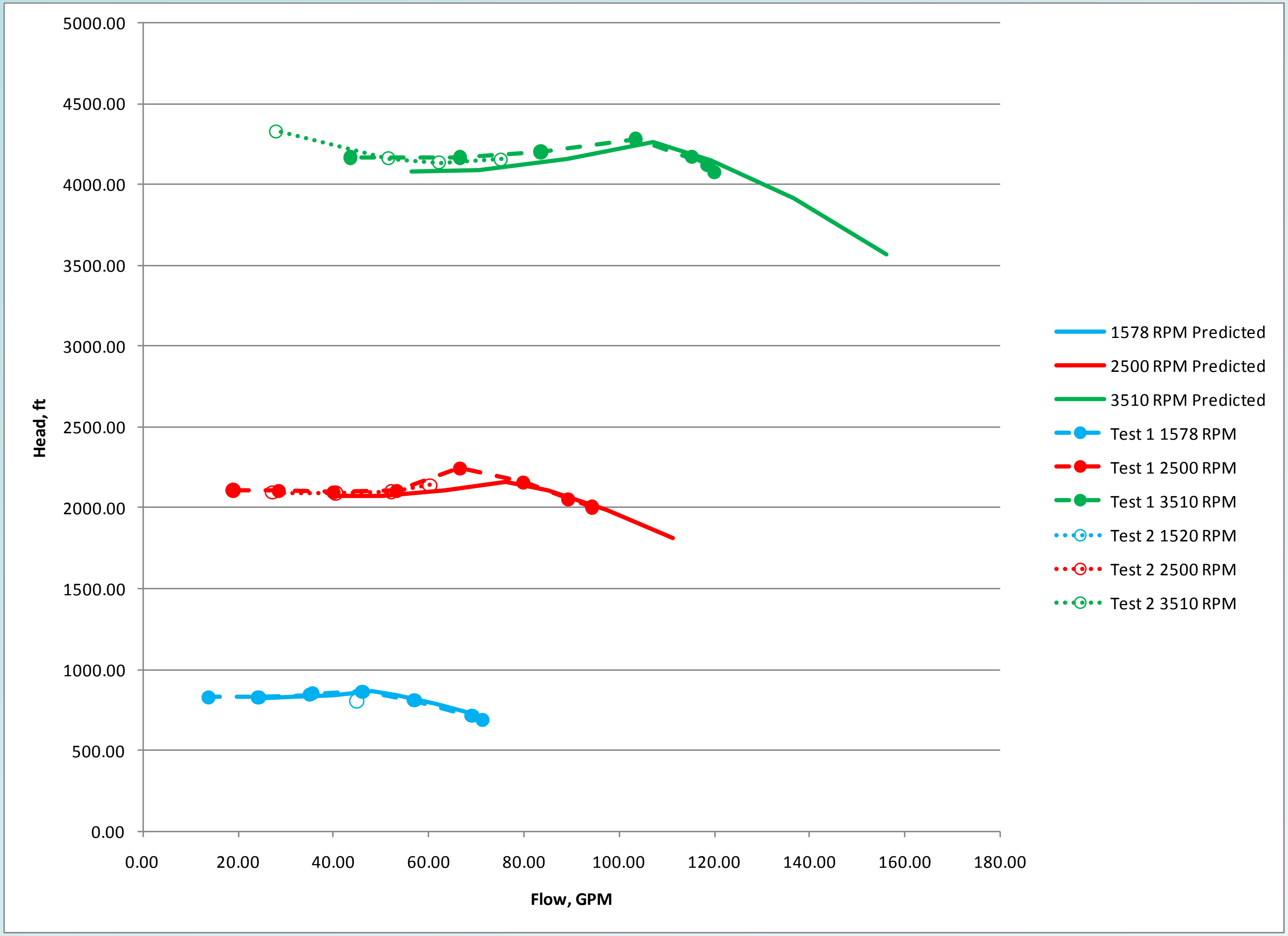
Loop Construction

Loop Completed

Data Acquisition Code



Test Results



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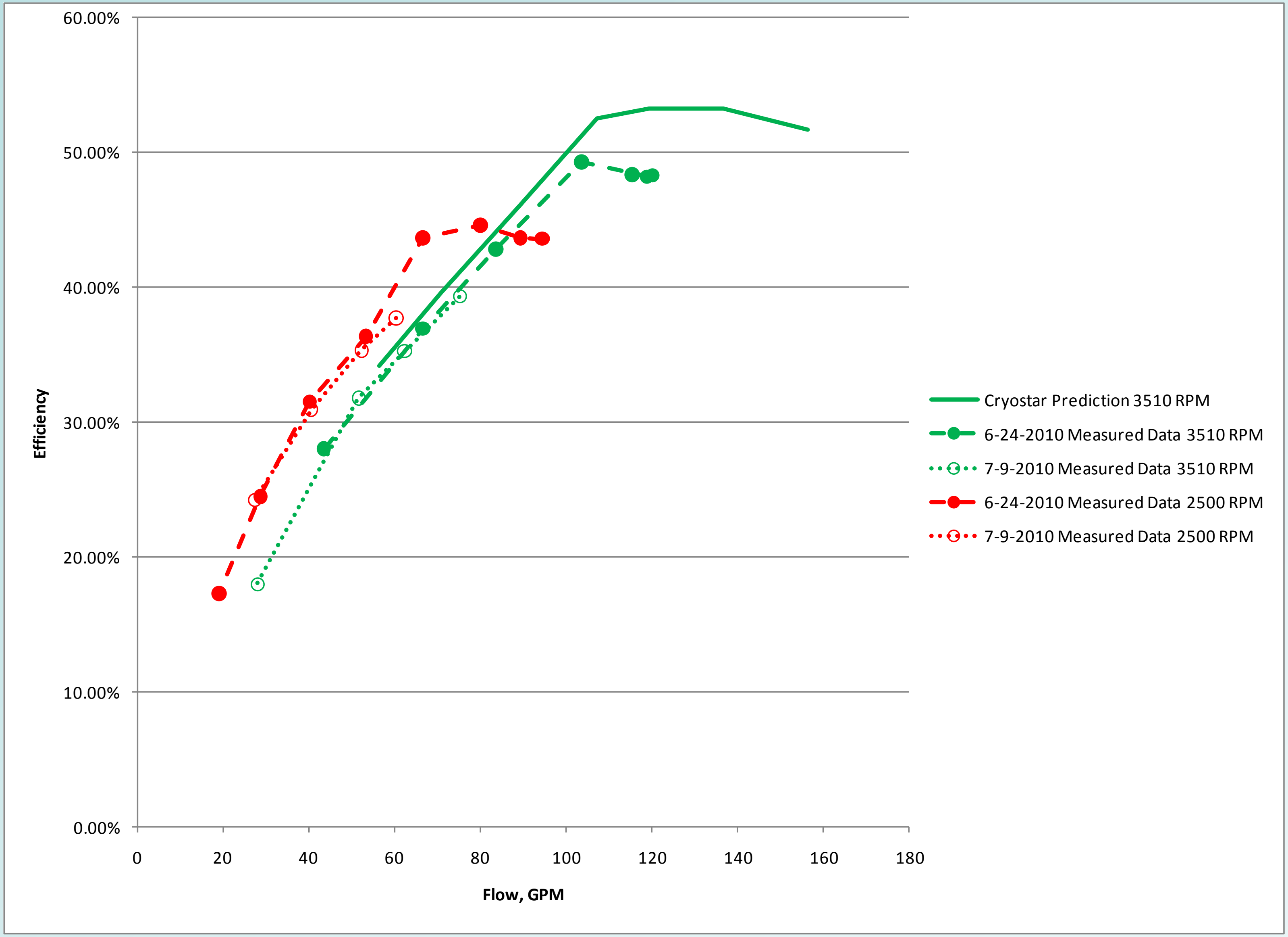
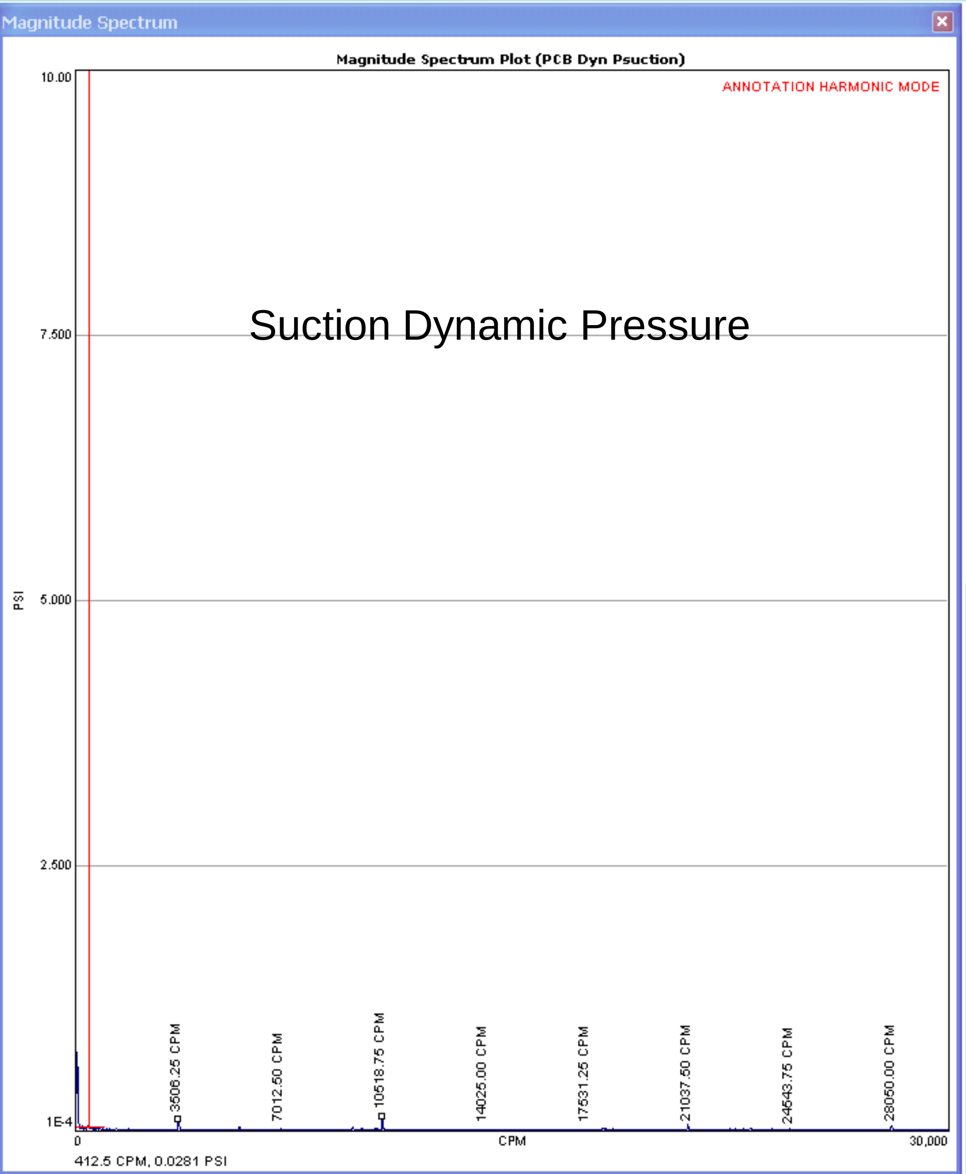
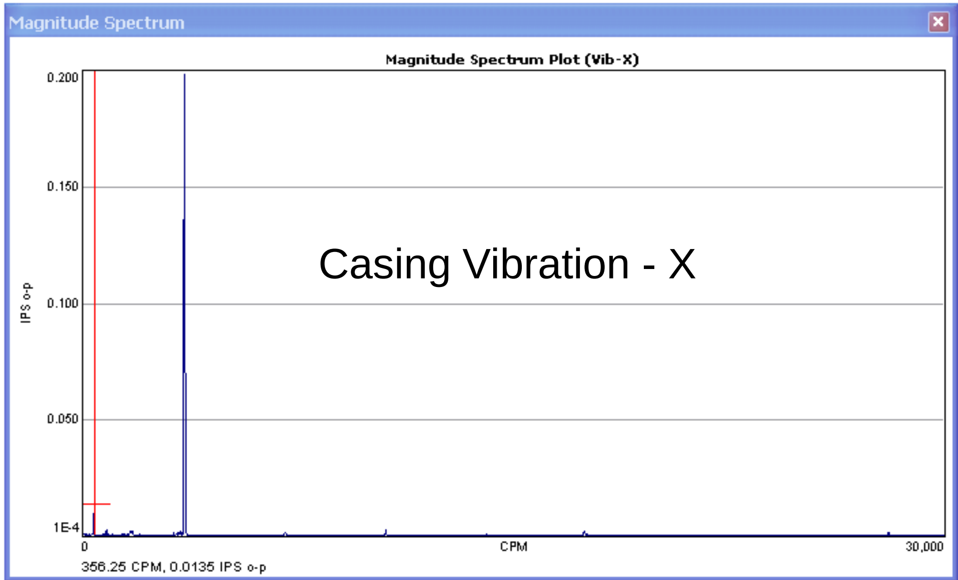
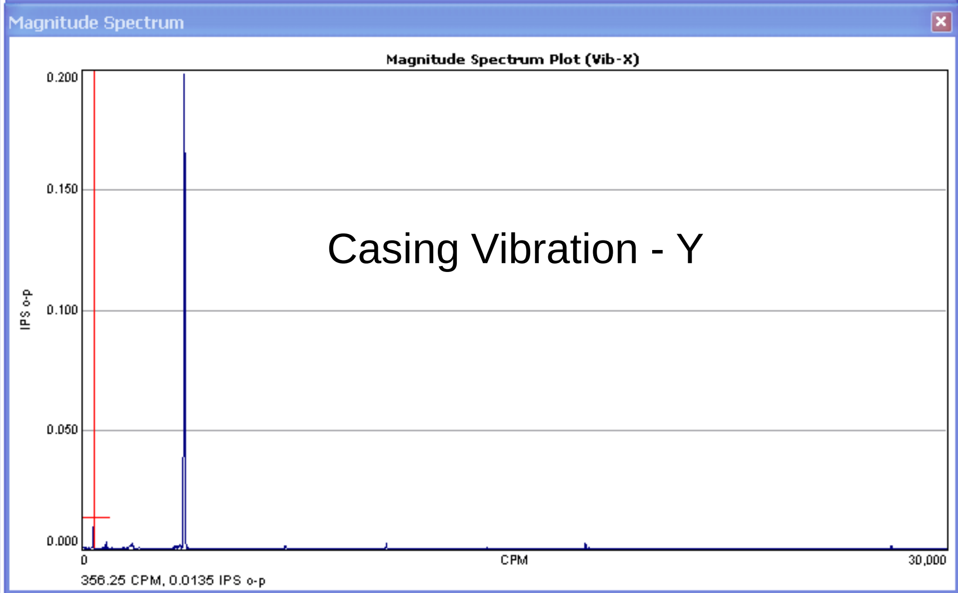


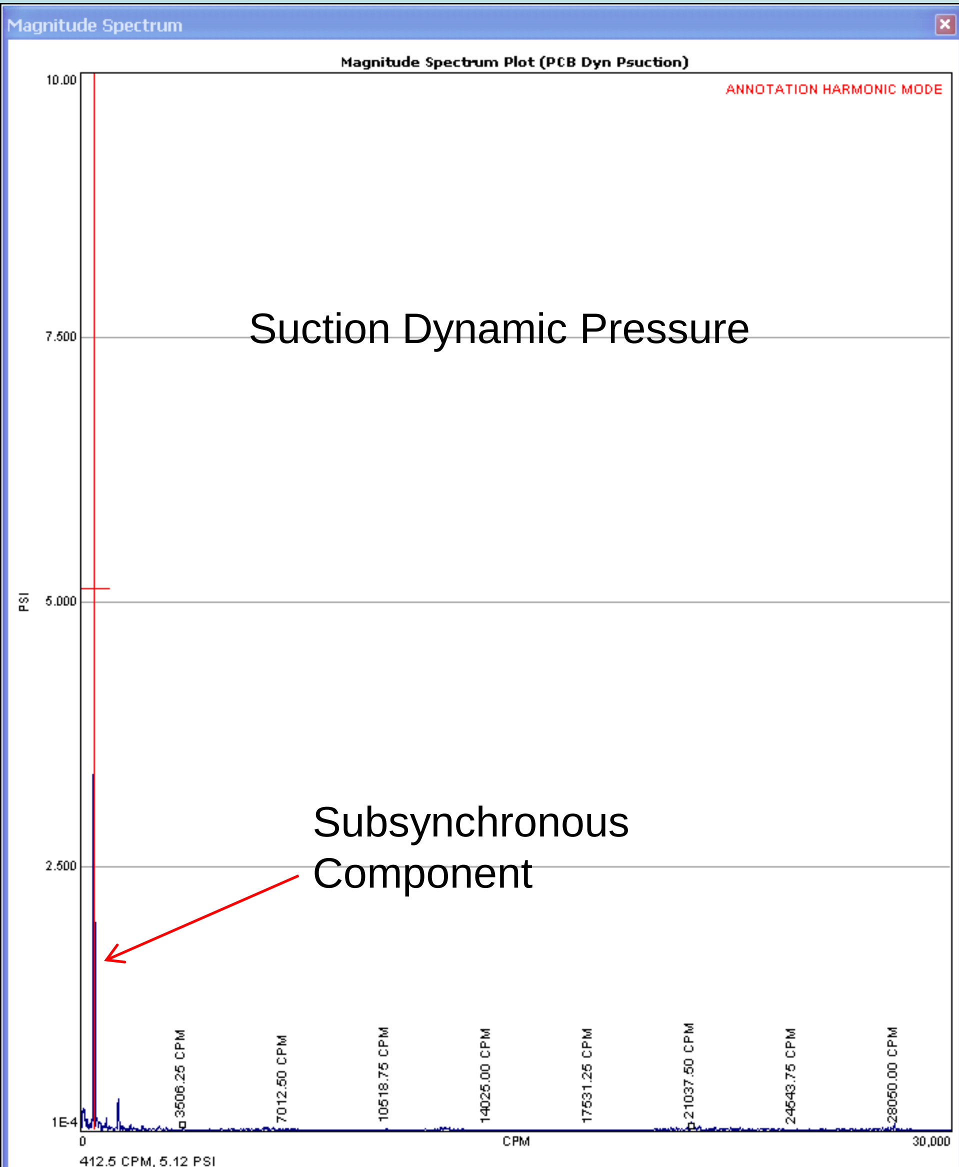
Dynamic Data – Design Point

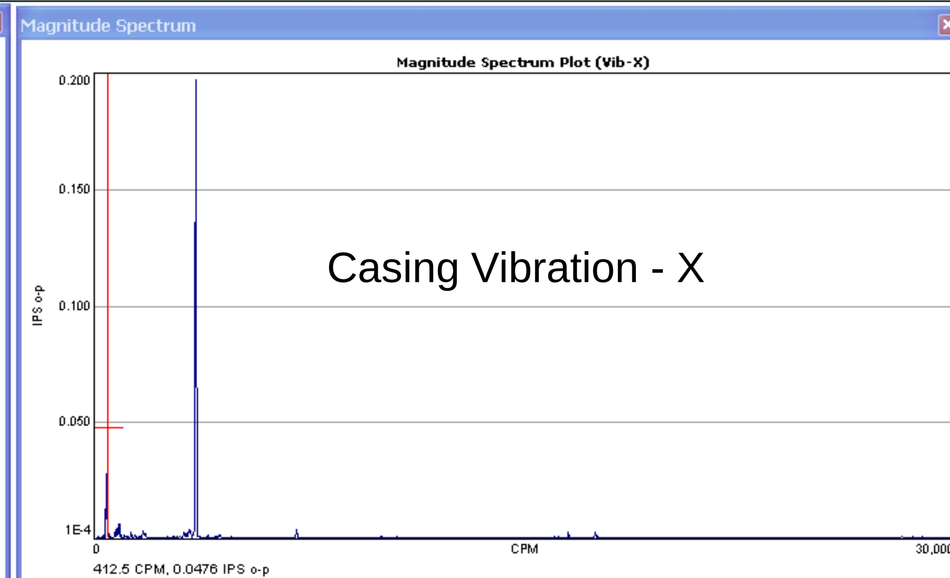


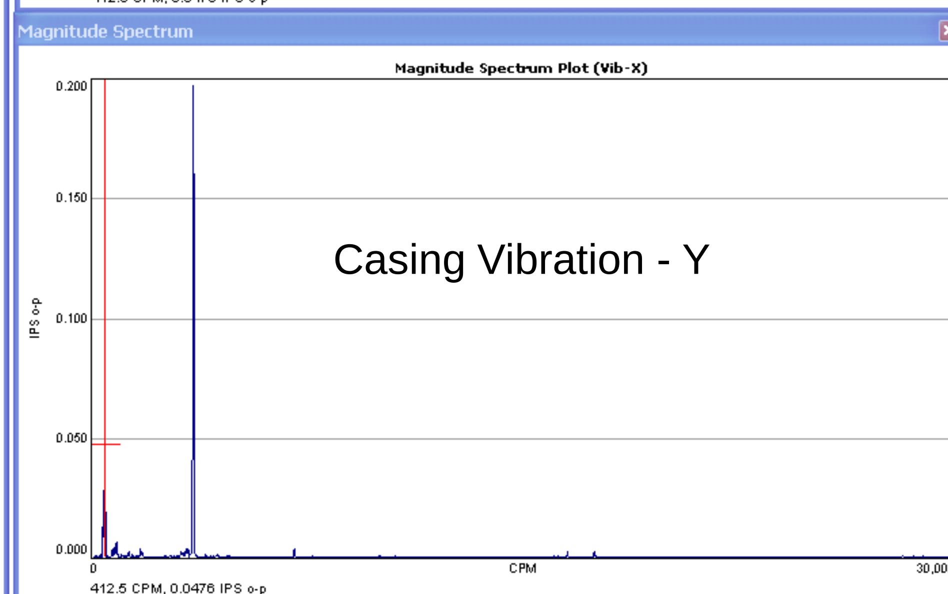




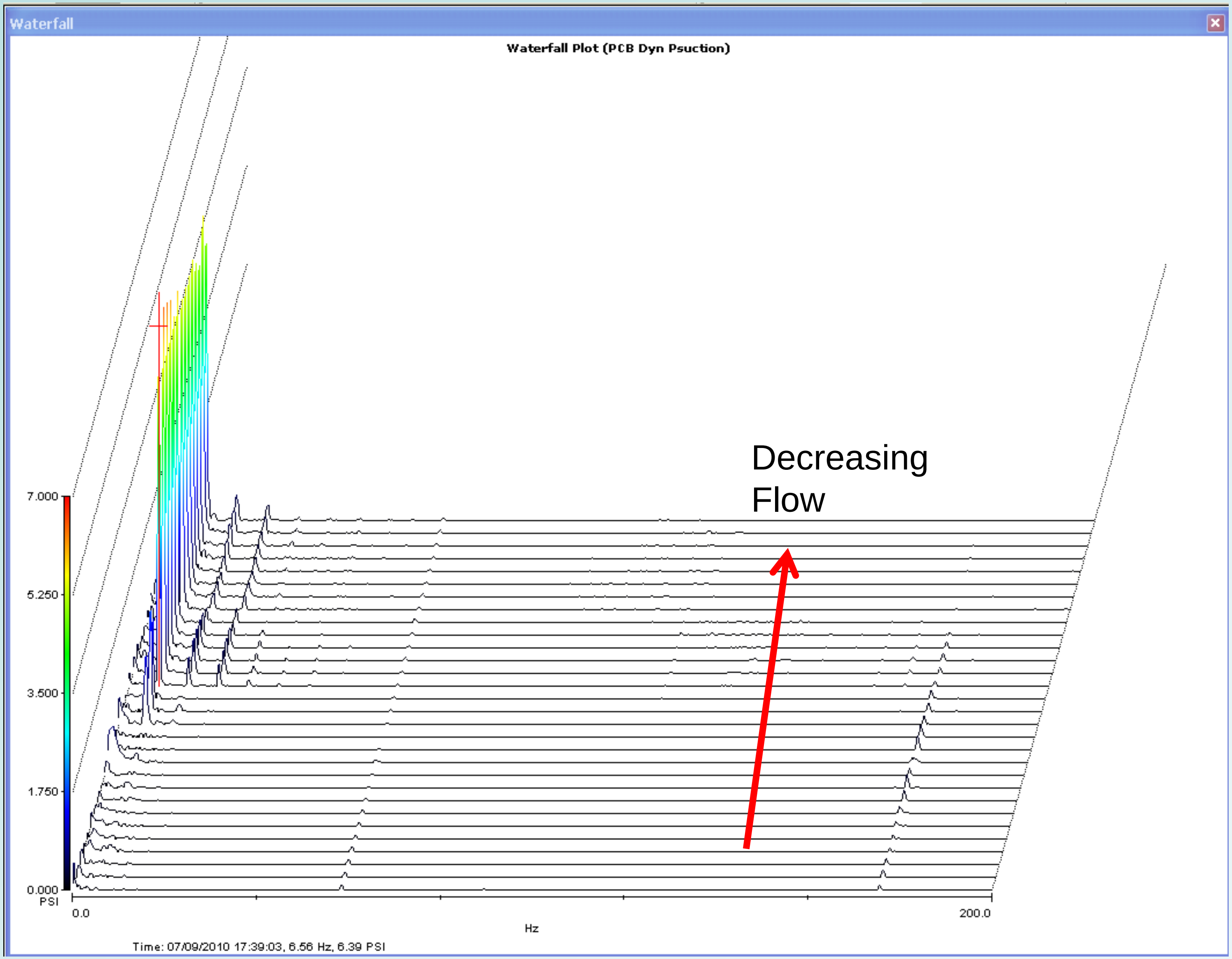
Dynamic Data – Minimum Flow Point







Dynamic Suction Pressure Waterfall while Throttling



Phase 2 Testing Summary

- Pump Testing
  - Pump performed well matching the measured performance during factory testing on LN2
  - Met discharge pressure goals
  - LCO2 introduced no mechanical issues for the pump
  - Vibration levels were reasonable
  - A subsynchronous vibration occurred at minimum flow point but only at very low flow rates
- Compressor Testing
  - Intercooled diaphragm designed and fabrication complete
  - Internal instrumentation being installed
  - Testing later this month
  - Patent has been filed

Future Testing

- Pump Testing
  - Perform testing at lower suction pressure
    - Demonstrate performance of the pump over a wider operating range
  - Will record performance, dynamic suction pressure, and vibration throughout test
- Compressor Testing
  - Repeat tests at higher suction pressure
  - Obtain heat transfer effectiveness at high Reynolds numbers

Questions???

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