IPER 2026:

CO2 Transport and Compression – Advancing Reliability through Testing at Off-Design and Multi-Phase conditions

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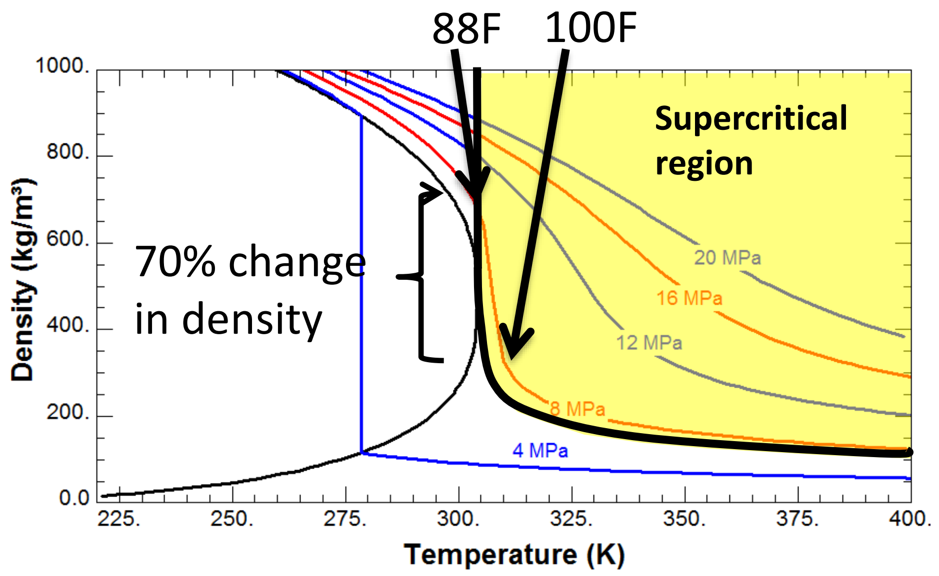
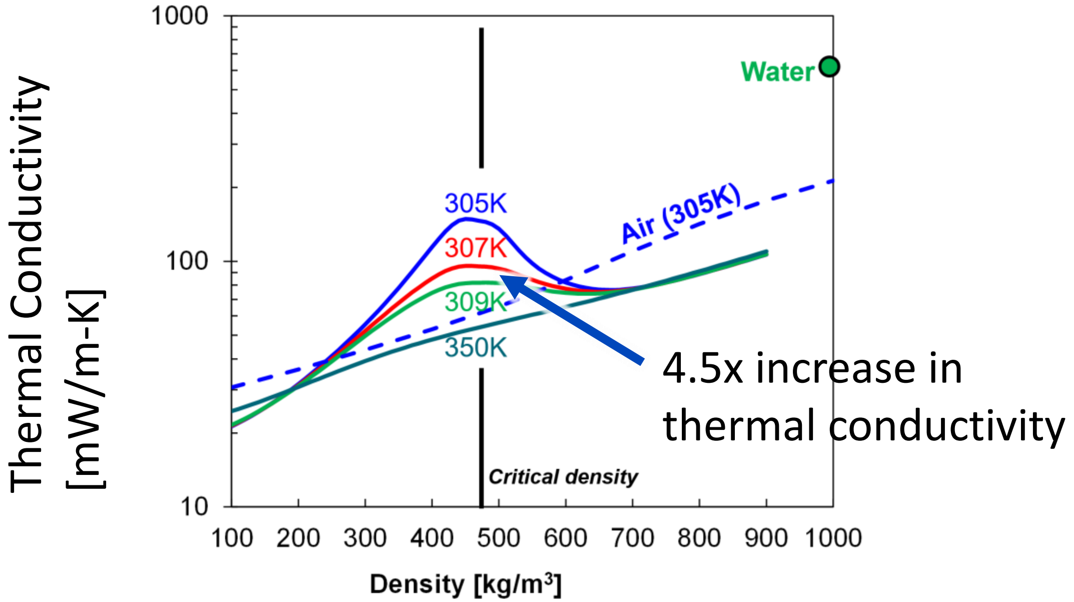
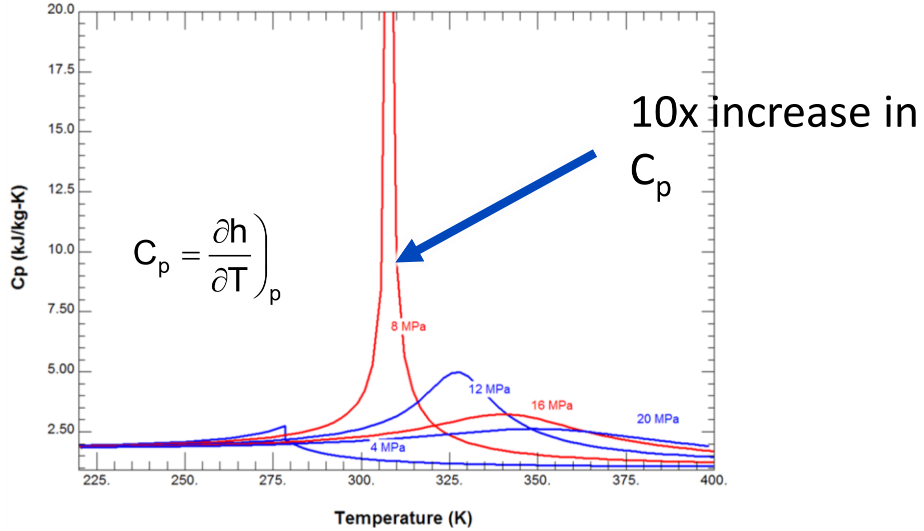
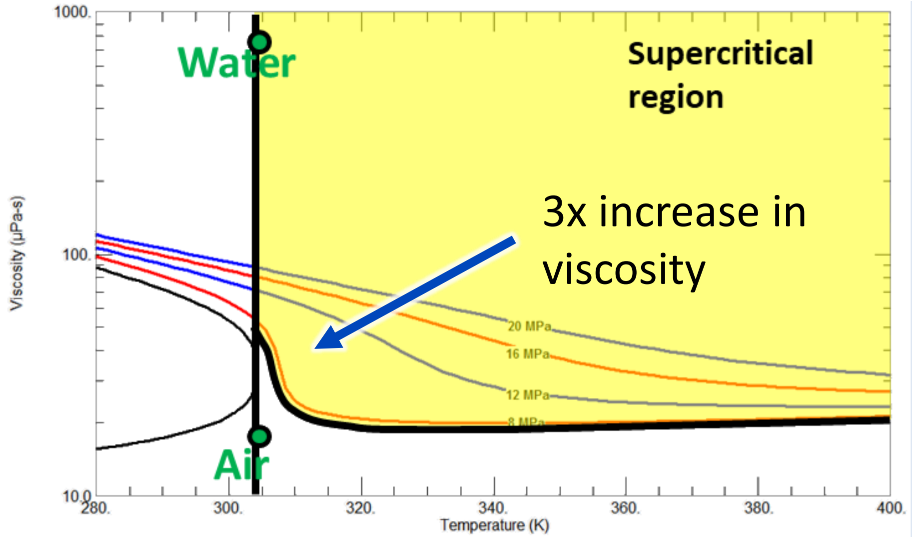
As we know, fluid properties for CO2 are interesting near the dome

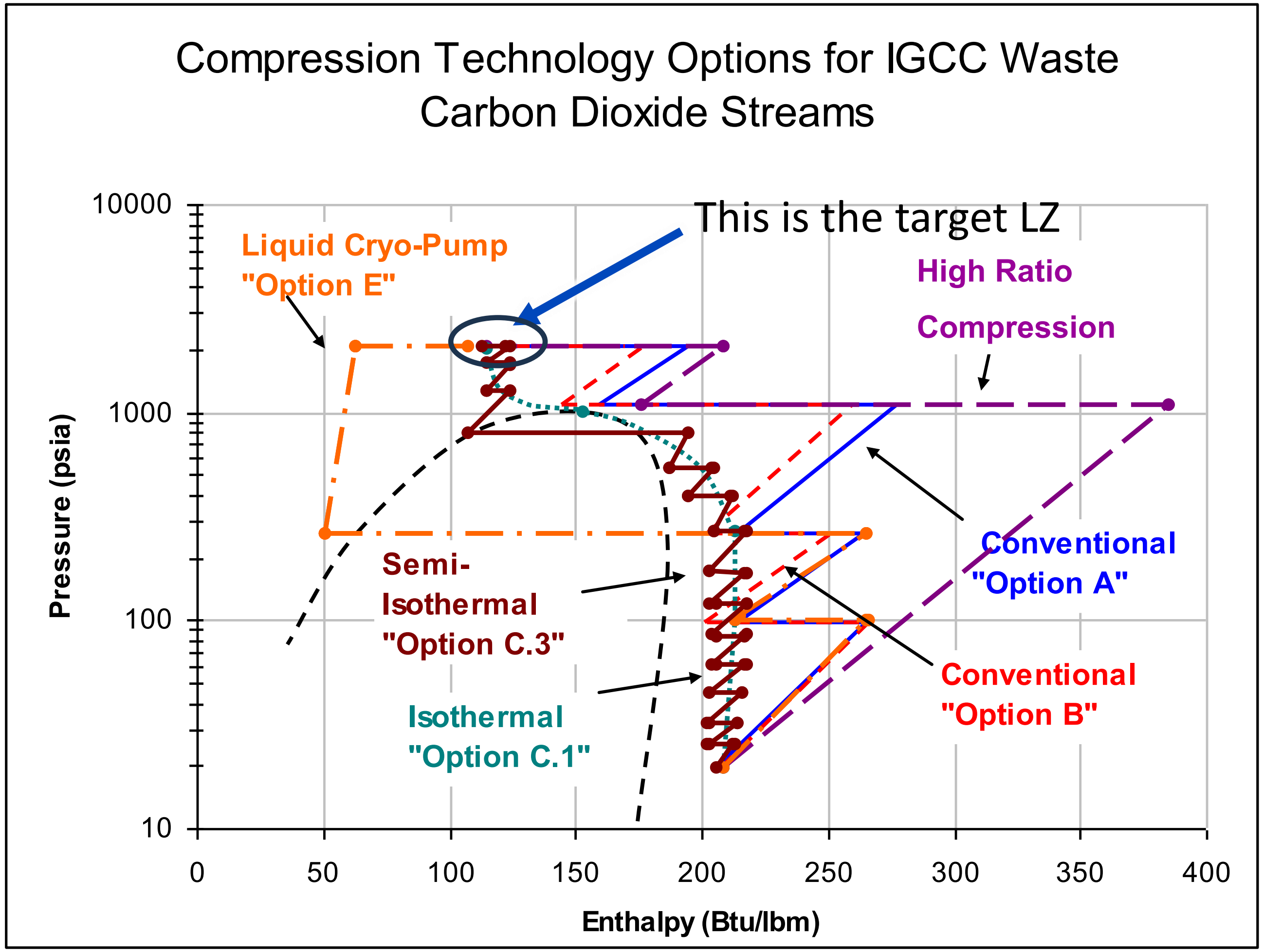








Depending on the path chosen, flexibility in operation near the dome provides many benefits



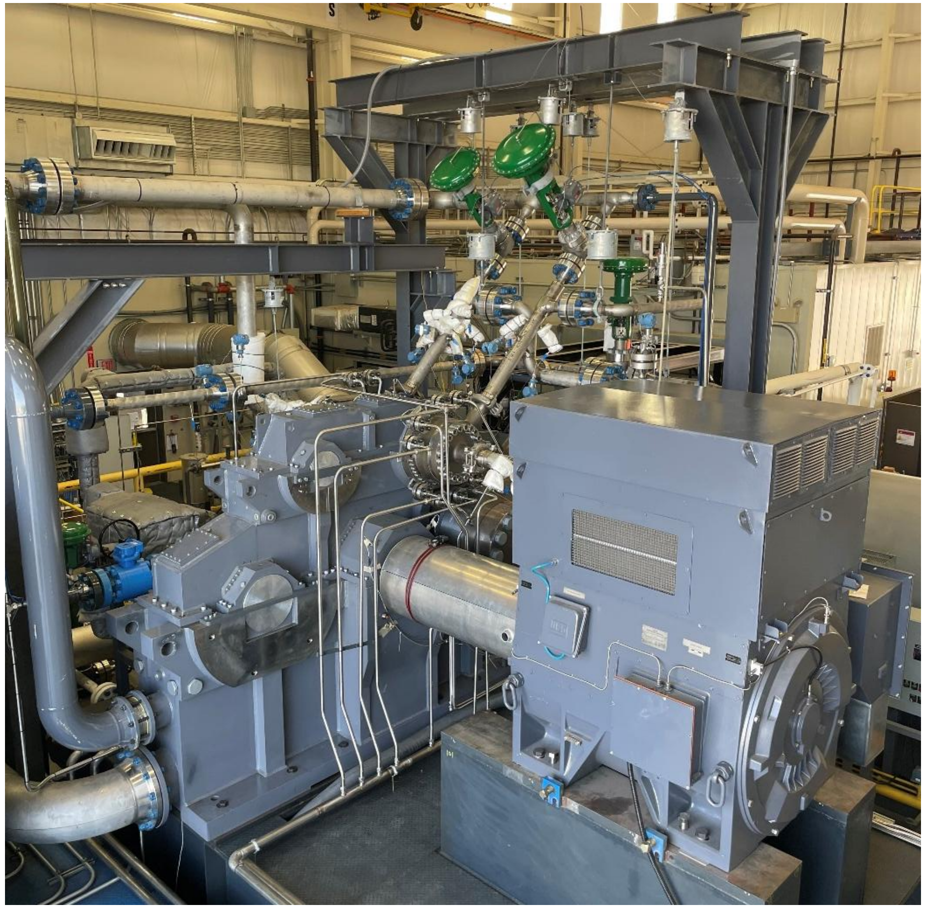
Adapted from Moore et al. 2009

- Compression in/near the Dome
  - Reduced cycle control
  - Greater process temperature flexibility
  - Improved compression power
  - Reduction in off-design margin
- Pumping in the dome
  - Resiliancy for compositional control/phase boundaries
- Concerns
  - Mechanical reliability
    - NPSHr
    - Cavitation
    - Bearing & Seal performance
  - Aerodynamic performance
    - Efficiency loss

In the past year, SwRI has been provided a unique opportunity to gain some experience in both of these operating zones.

Dense phase CO_2 pump

Near dome CO_2 compressor

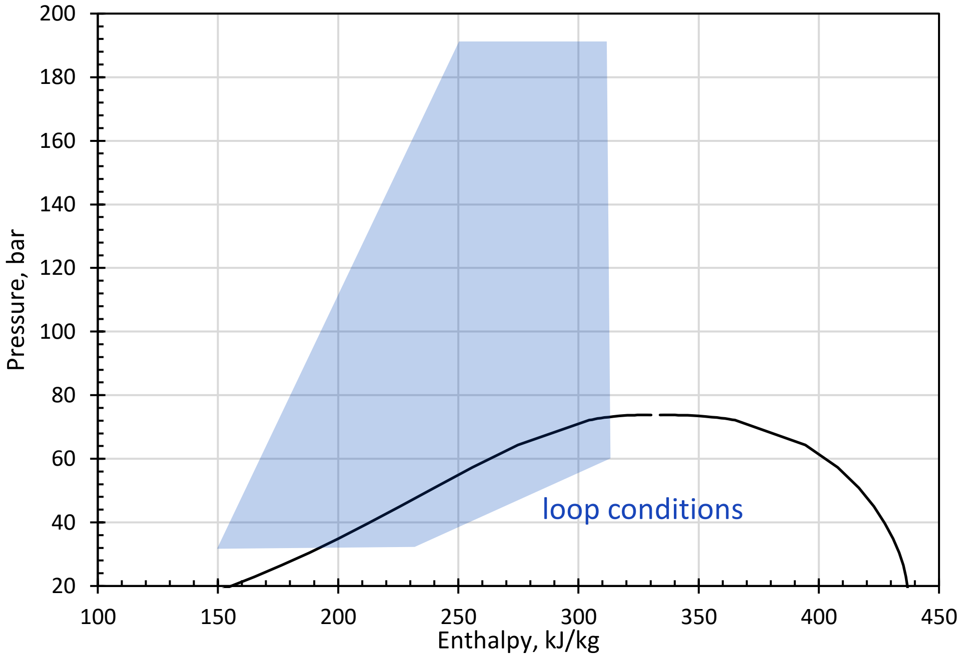


Multiphase CO2 Fluids Test Loop Summary

SwRI sCO_2 facility (liquid pump and cooler)

Objective: Advance the understanding of multiphase operation, enable wider operating ranges, and expand the operability and reliability of CO2 hardware

Simple, modular test loop to measure multiphase (liquid with some gas content) CO2 flows.

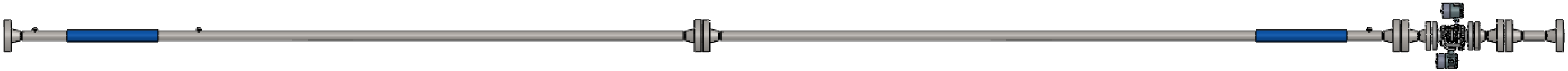


Test section conditions:

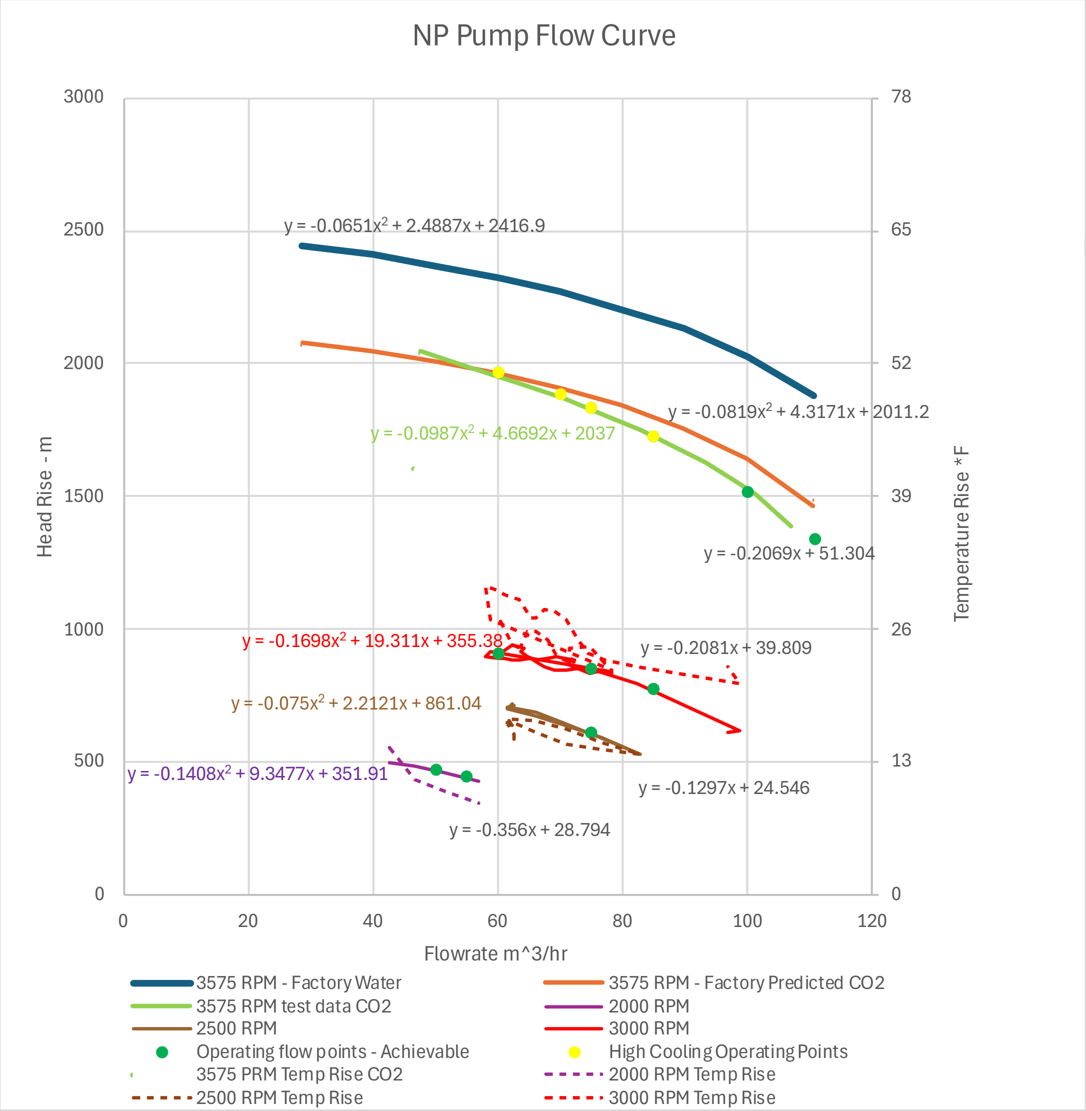
- Diameter: 3 in (75 mm)
- Horizontal Length: 50 ft (15 m)
- Vertical Length: 10 ft (3 m)
- Pressure: 3 to 8 MPa
- Quality: 4 to 30%
- Flow: up to ~65 m3/hr

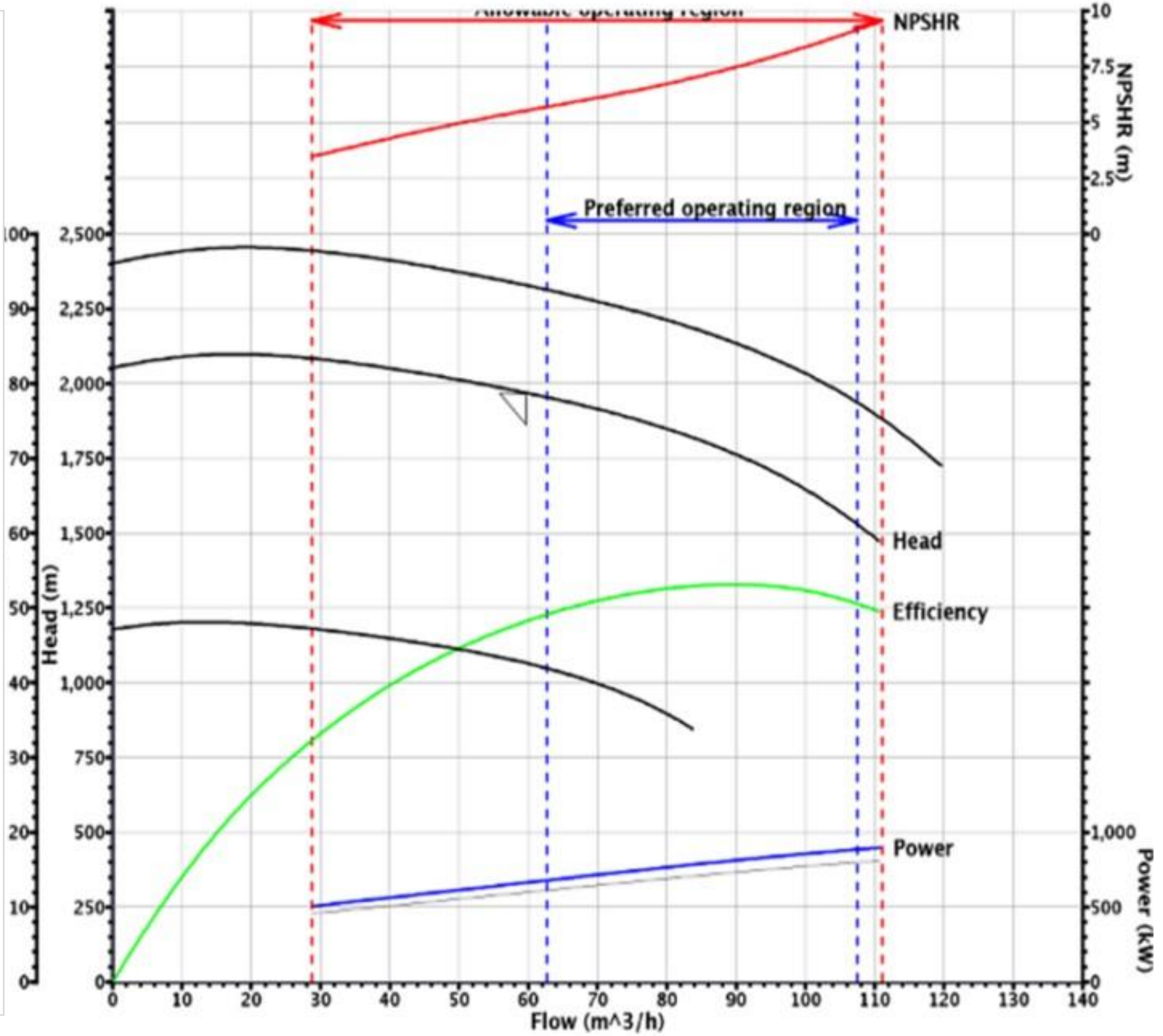
Baseline instrumentation:

- Orifice flow at pump discharge
- Pressure and temperature
- Two (2) differential pressure
- Two (2) densimeters
- Sight windows
- Gas Chromatagraph

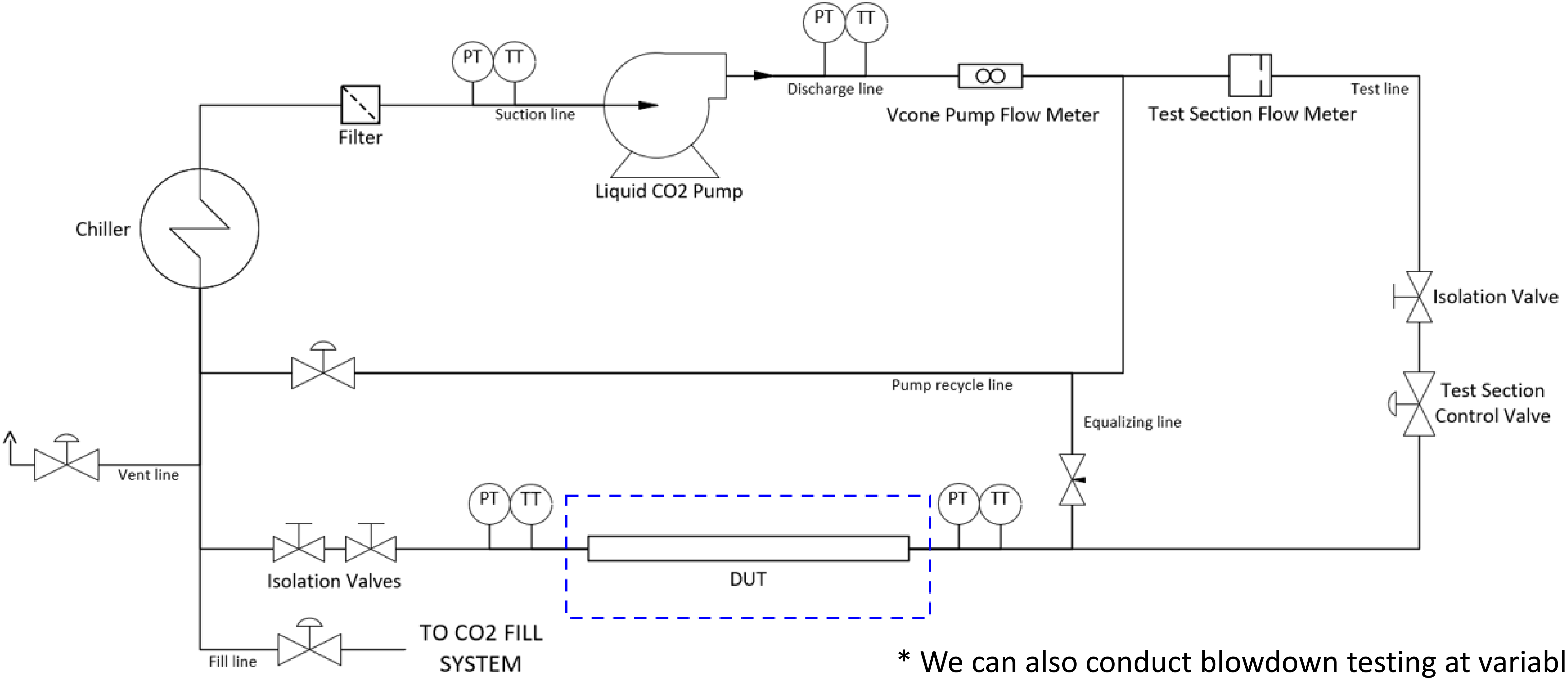


CO2 Factory Pump Curve





Test Loop PFD



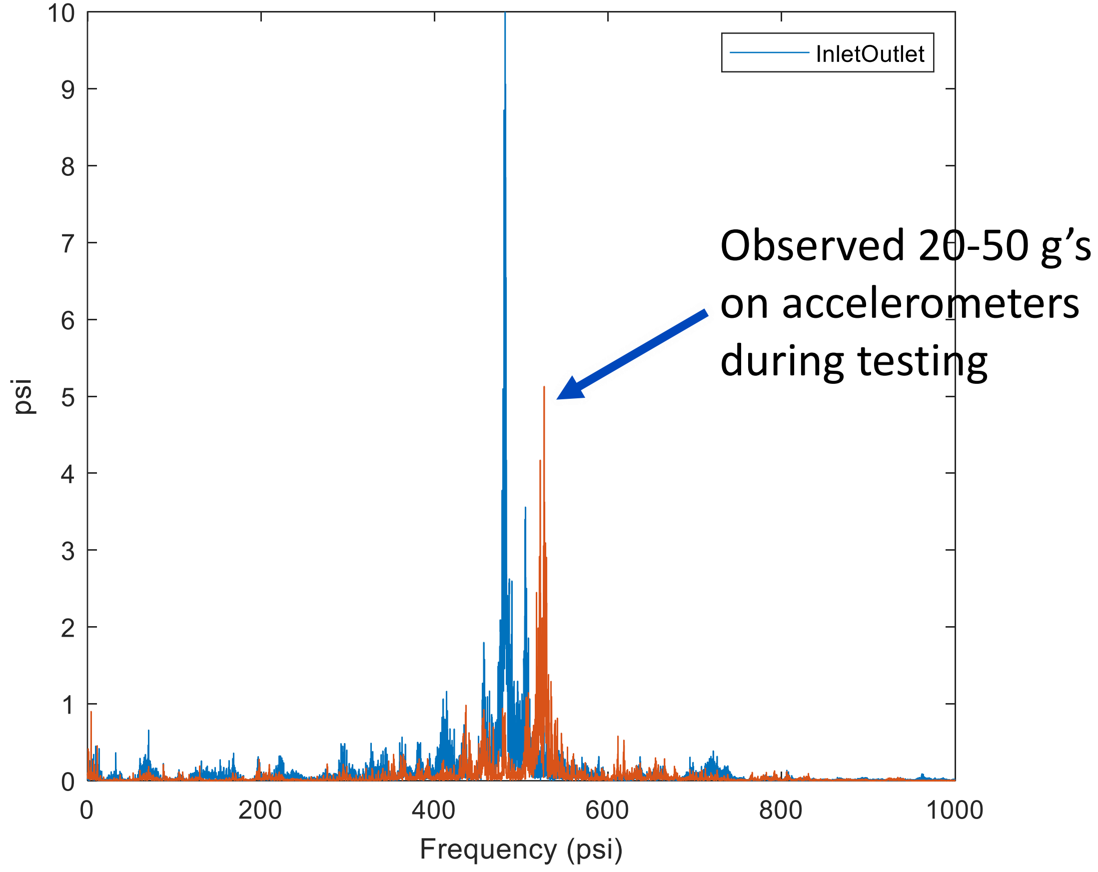
* We can also conduct blowdown testing at variable backpressures in an open loop configuration.

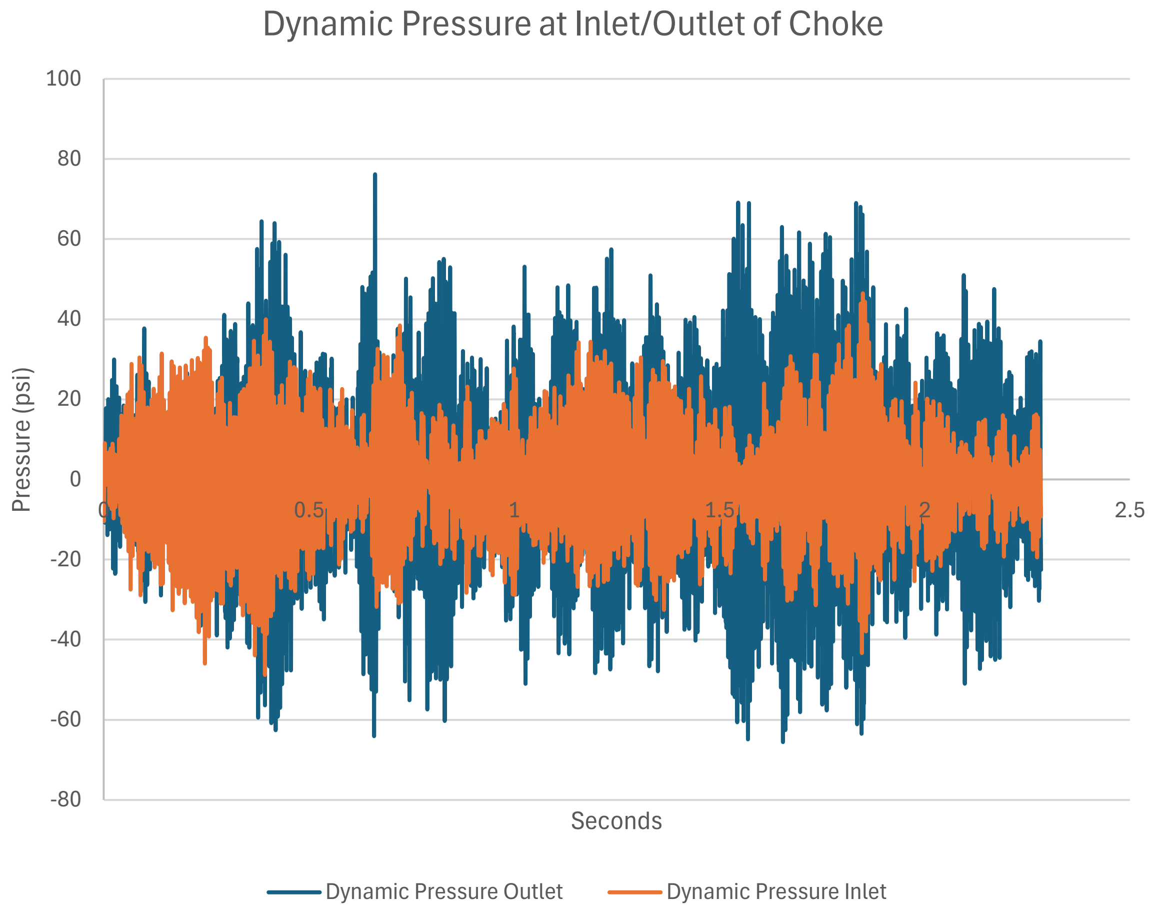
Test Article Instrument Locations

- Dynamic Pressure
- Strain
- Triaxial Accelerometer

**Note: This illustration depicts 1 potential setup and shows where instrumentation was placed in the past. The quantity and/or placement is at the discretion of the client.

Dynamic pressures and mechanical oscillations can reach dangerous values, causing small bore fatigue concerns



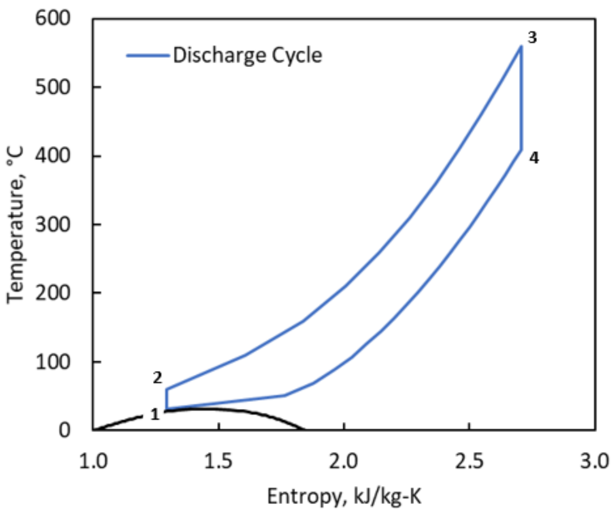


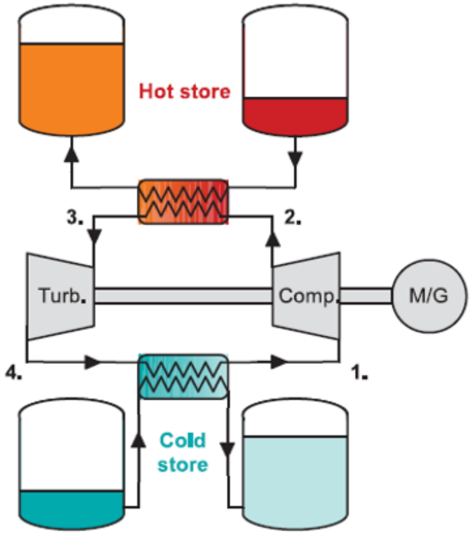
On many recent programs chokes have cause small bore failure in 10 minutes - 5 hours of testing

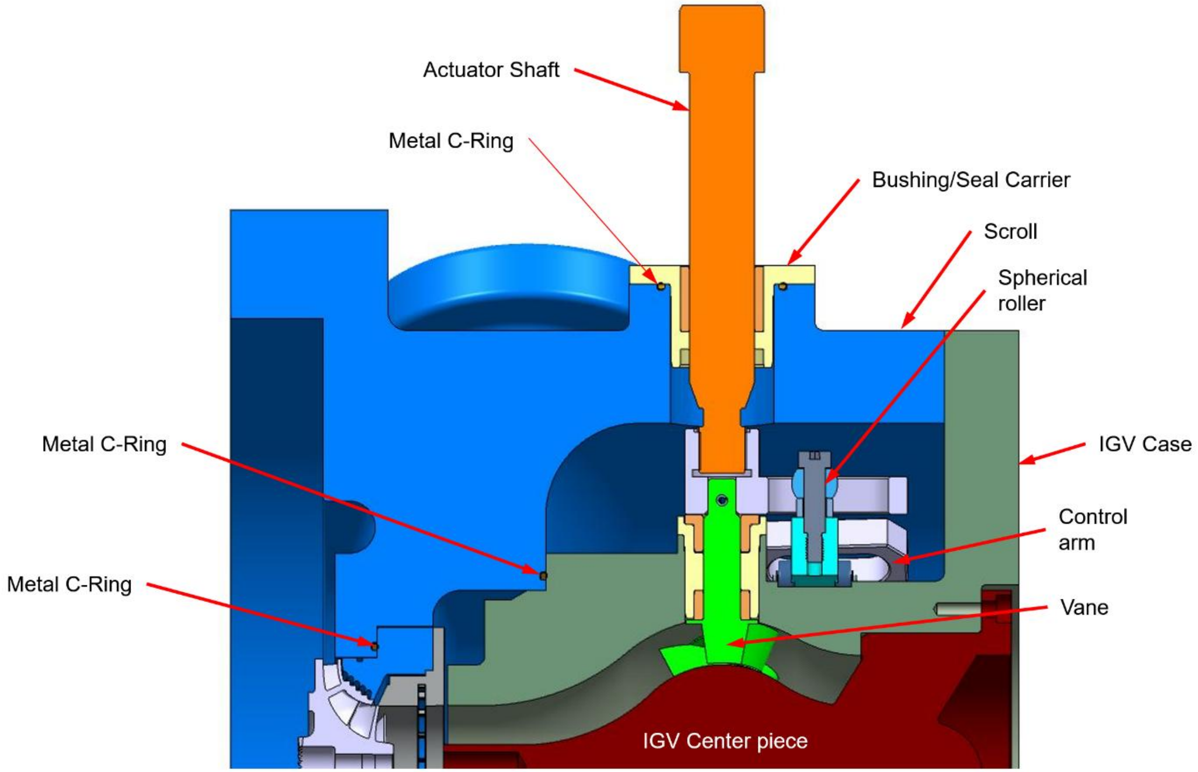
1.5” insertion thermowell fatigued at the root

½” tubing fatigued during testing

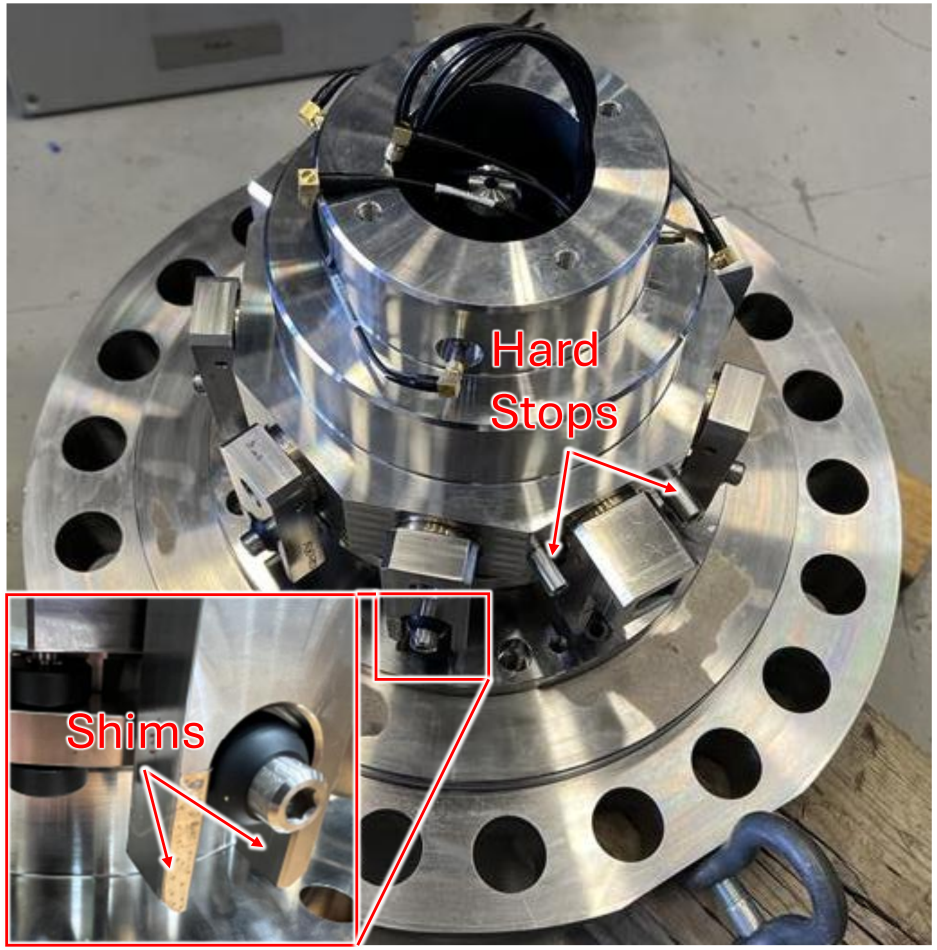
sCO2 power cycle compressors provide a useful vehicle for studying sequestration & pipeline compressors in near dome conditions

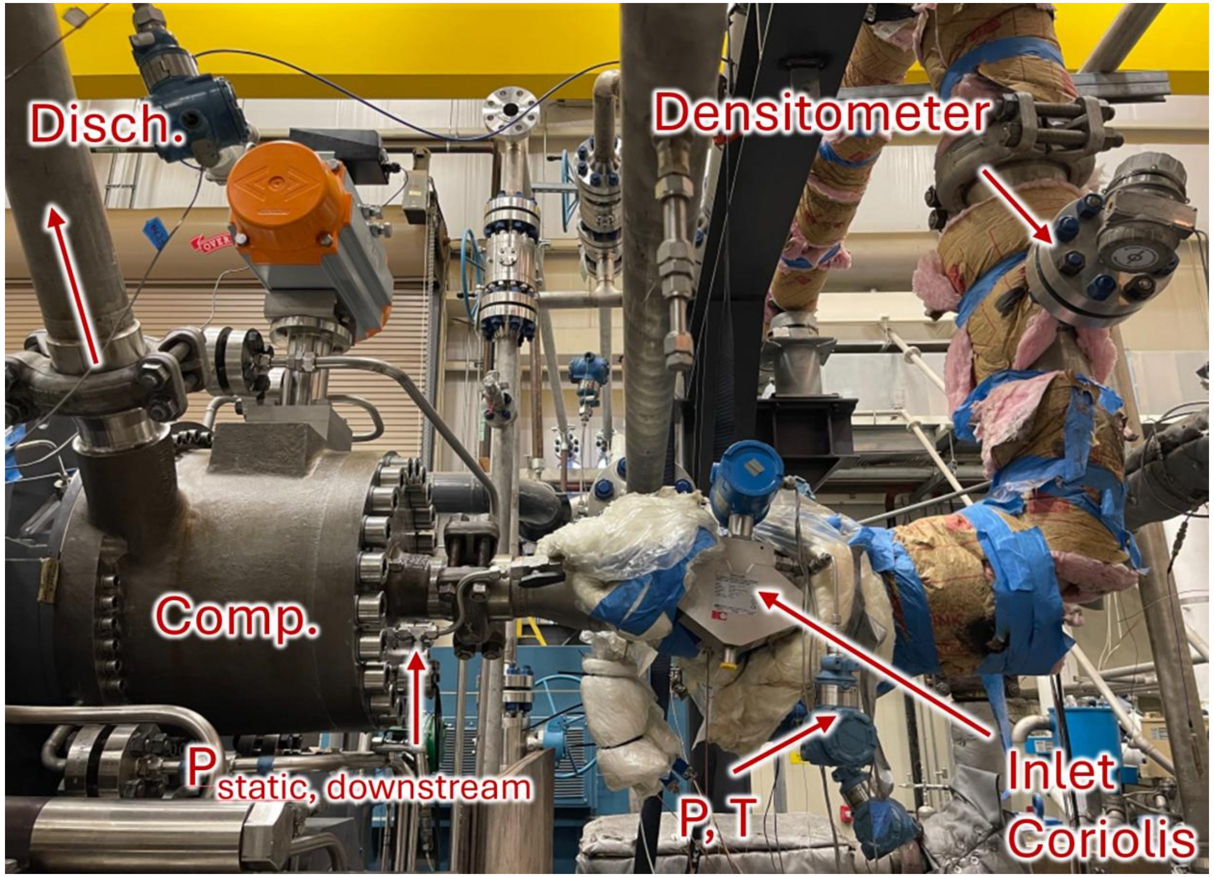






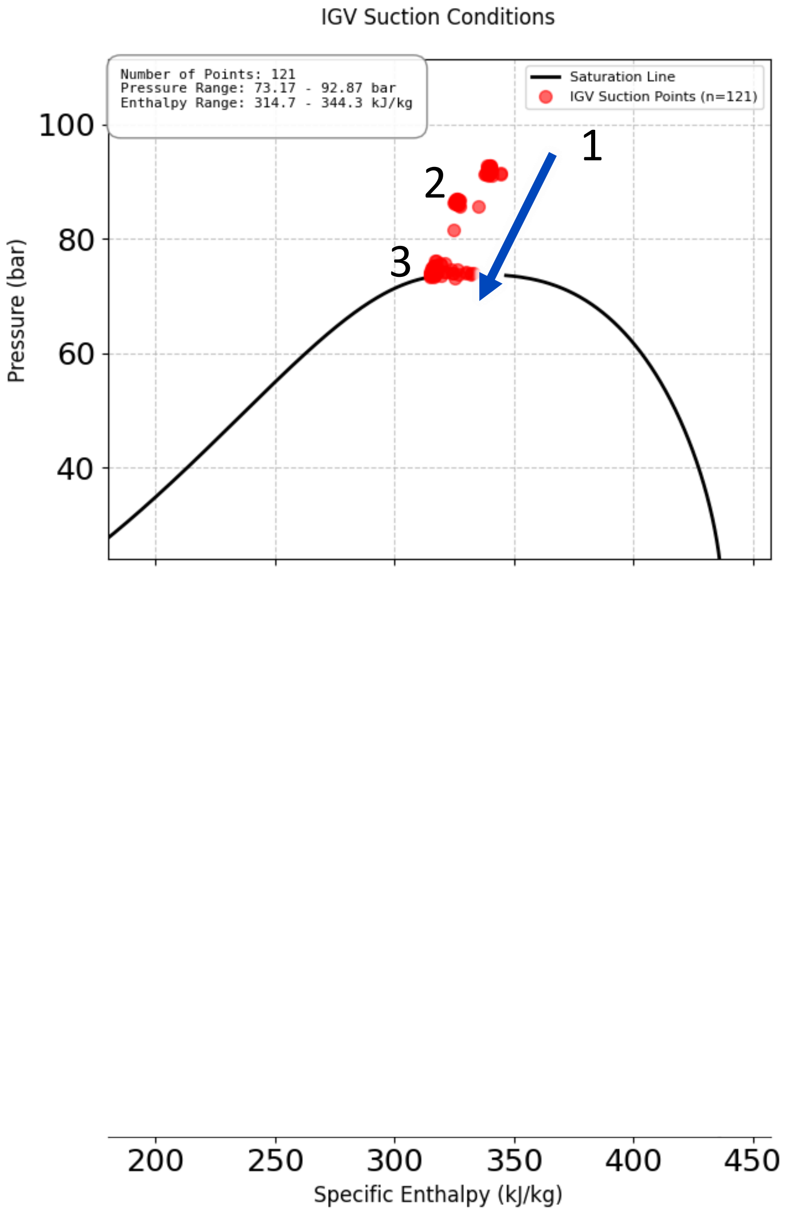
The IGV was a semi-conventional externally actuated straight vane IGV





The compressor was operated above the dome at various conditions prior to dipping into the dome

- IGV Angle: 15, 0, -15, -30, -45, -60
- Compressor Inlet Temperature 30.5°C, 37°C, 40.5°C
- Inlet Density: 550 kg/m^3
- 121 test points (~40 of which had an compressor inlet inside of the dome)



Head flow curves and IGV operation remained relatively similar at both temperature conditions

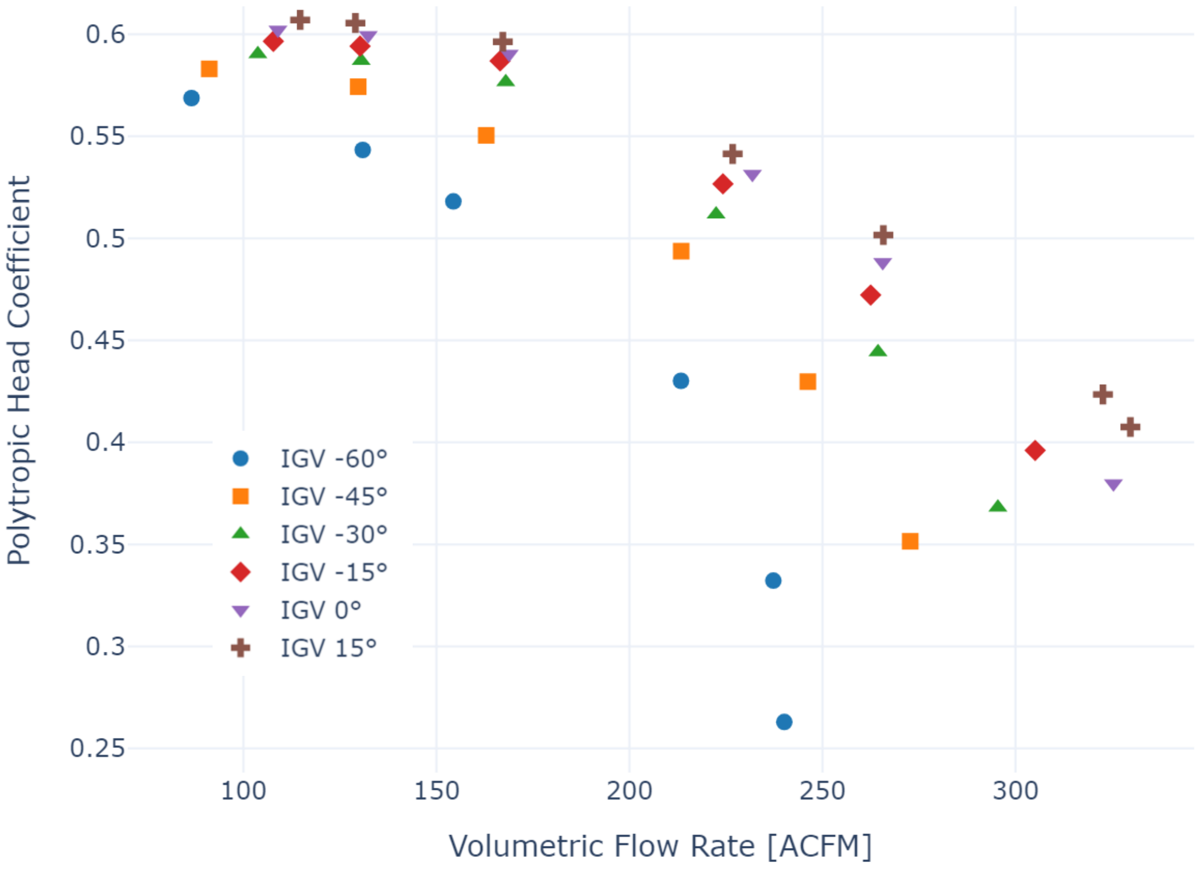


Figure 8: Polytropic Head vs. Flow (40.5°C)

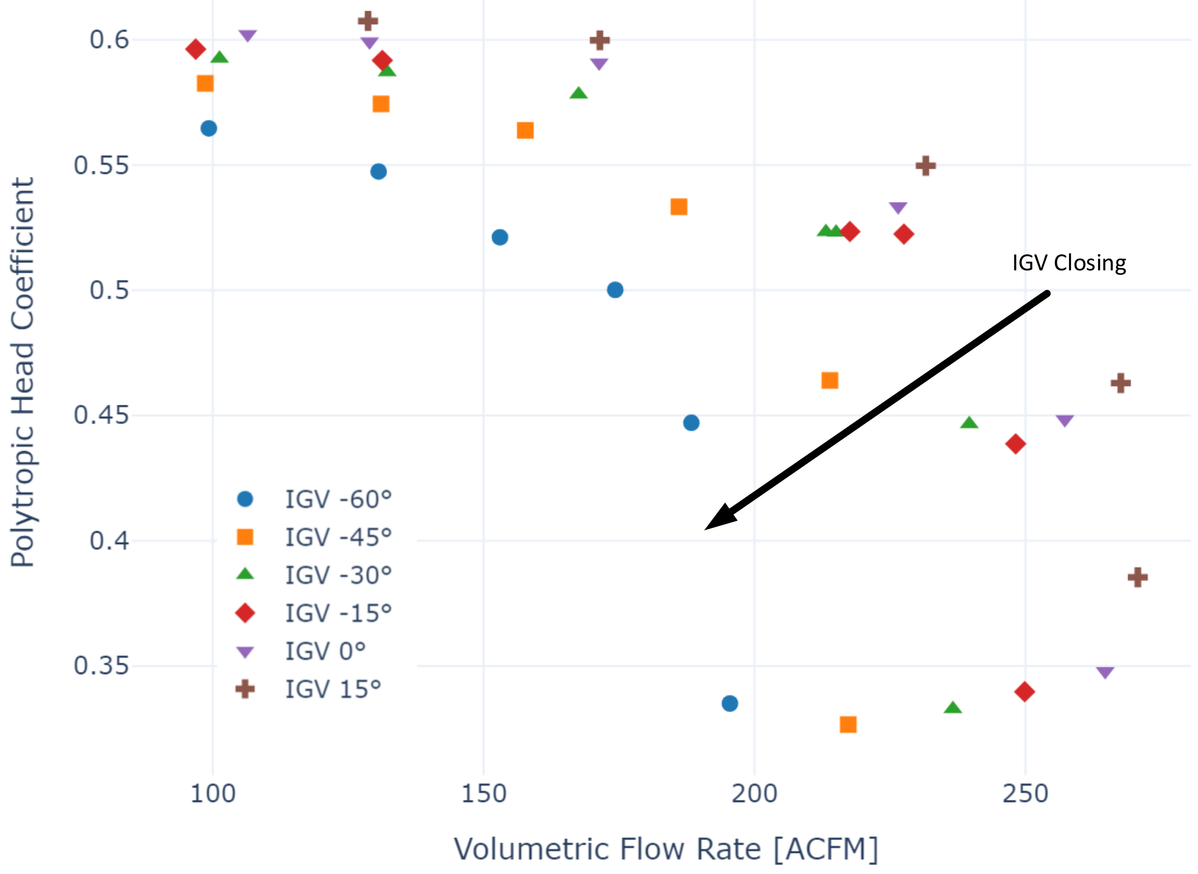
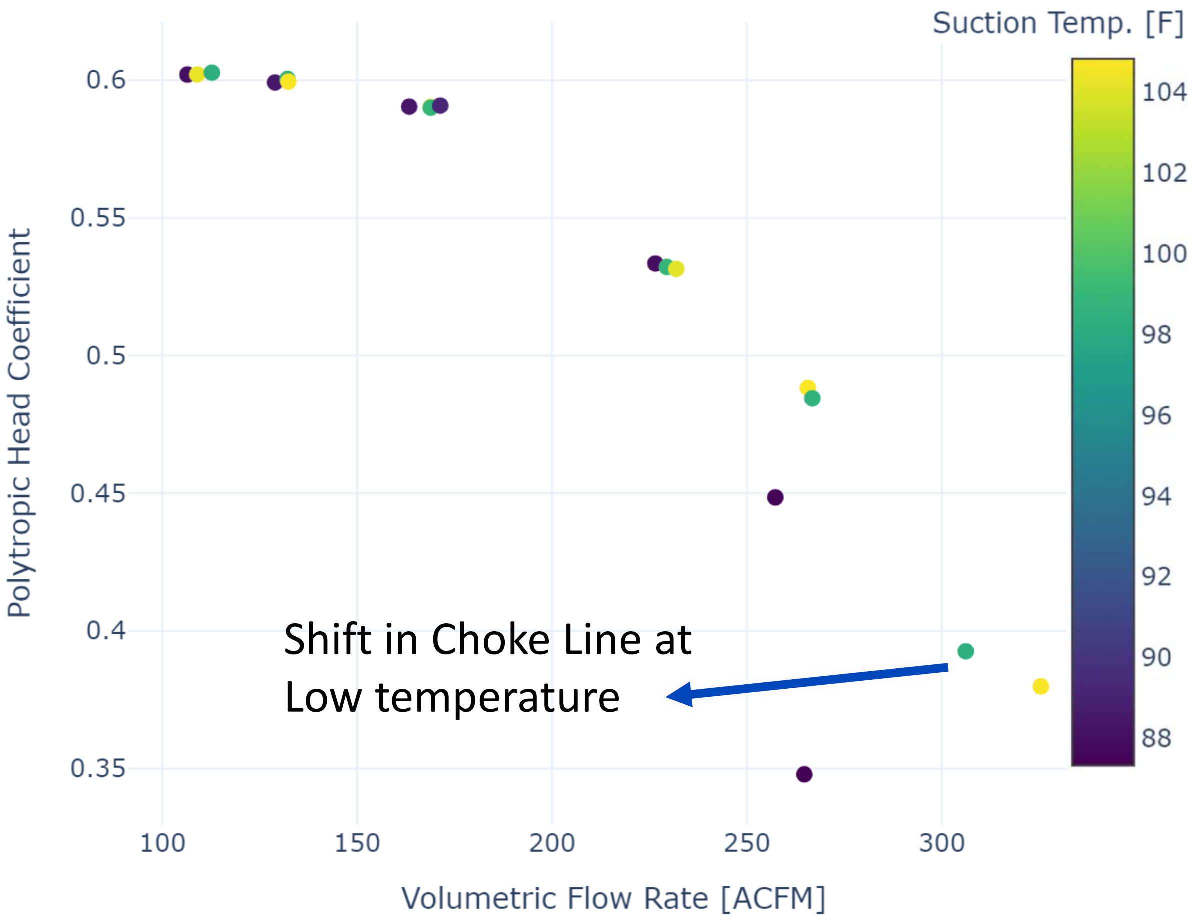
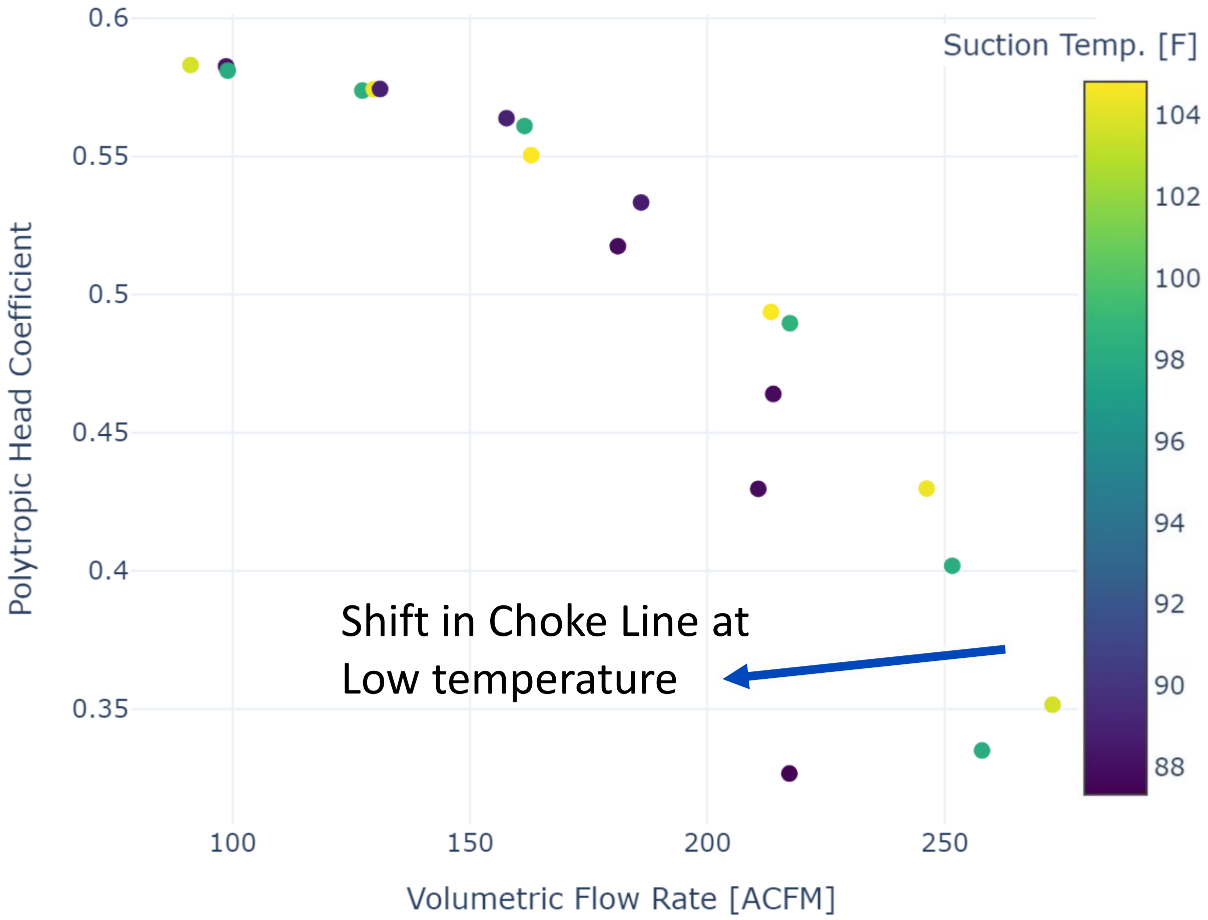


Figure 8: Polytropic Head vs. Flow (30.5°C)

At 0 & high IGV settings the choke line shifts similarly with minimal change in flow stability at the low end



Polytropic Head vs. Flow (0° IGV)



Polytropic Head vs. Flow (45° IGV)

Efficiency becomes very uncertain as inlet conditions enter the dome

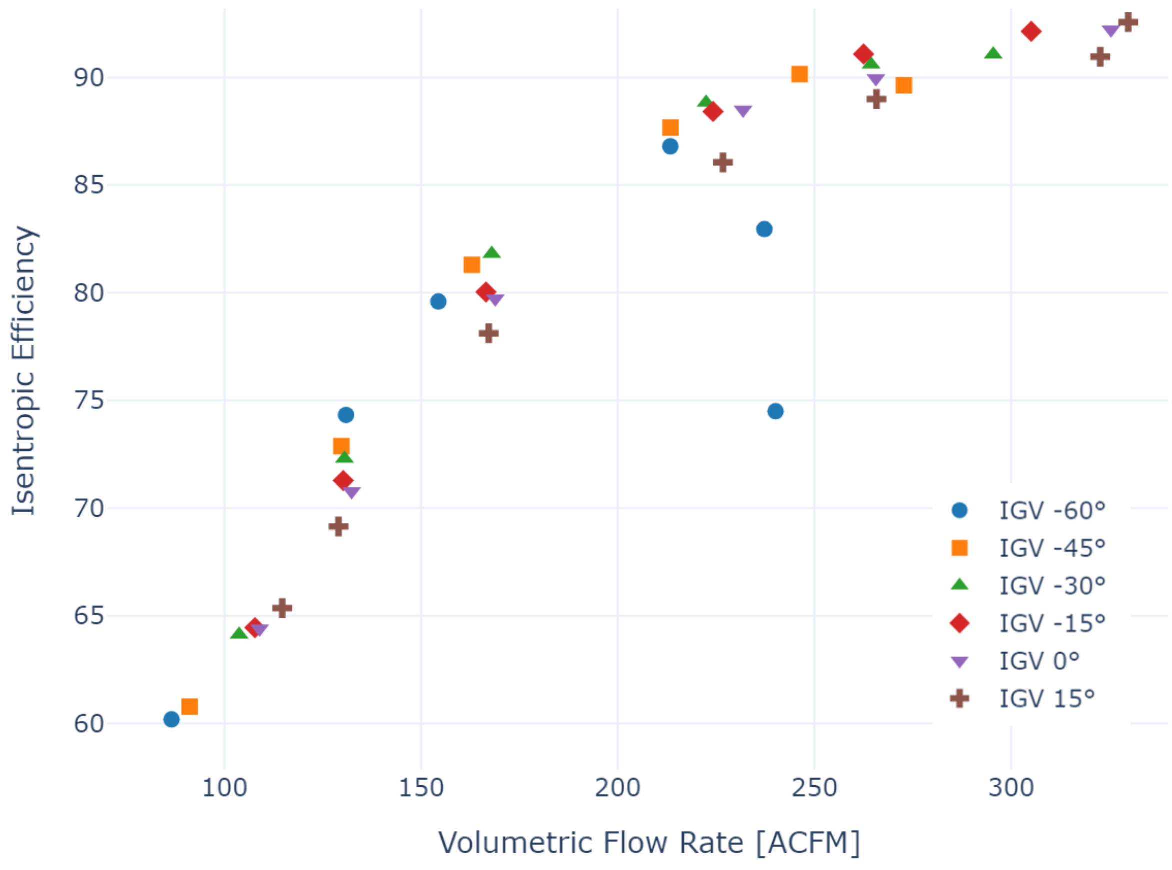


Figure 11: Isentropic Efficiency vs. Flow (30.5°C)

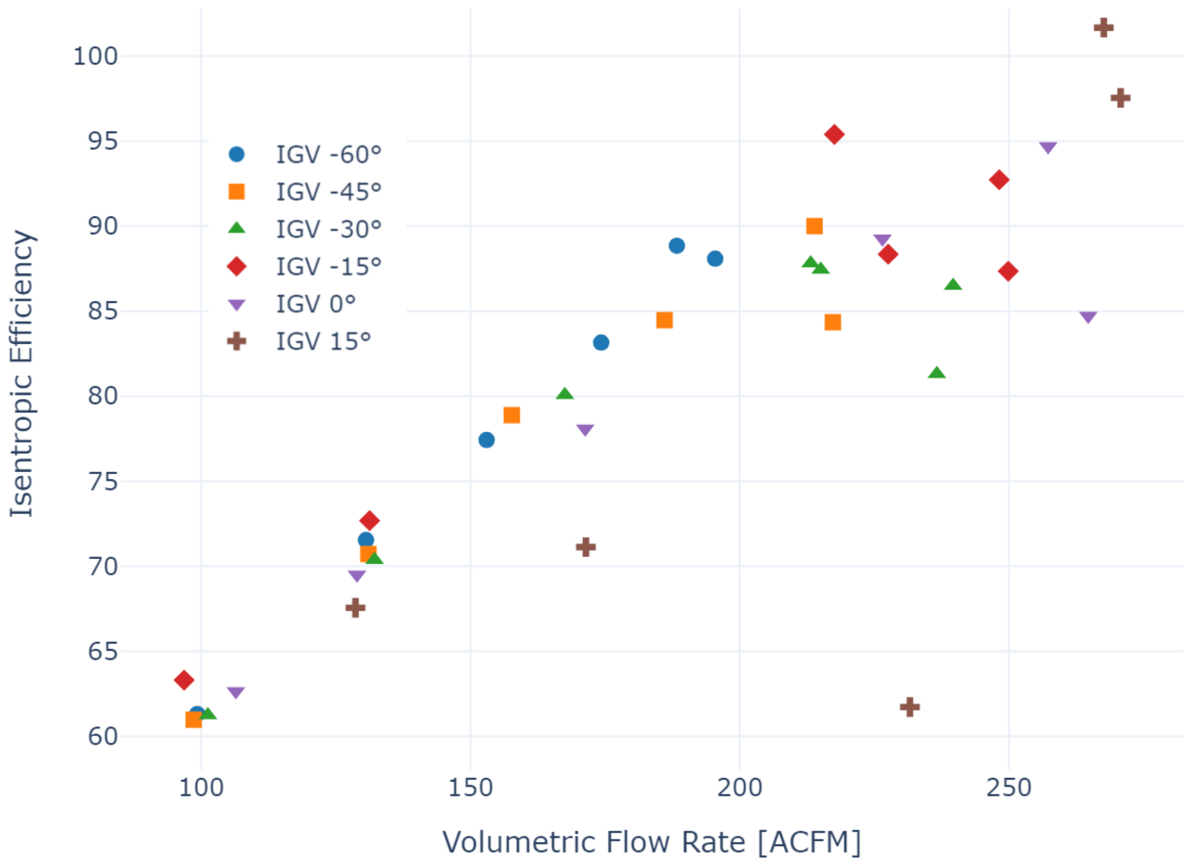
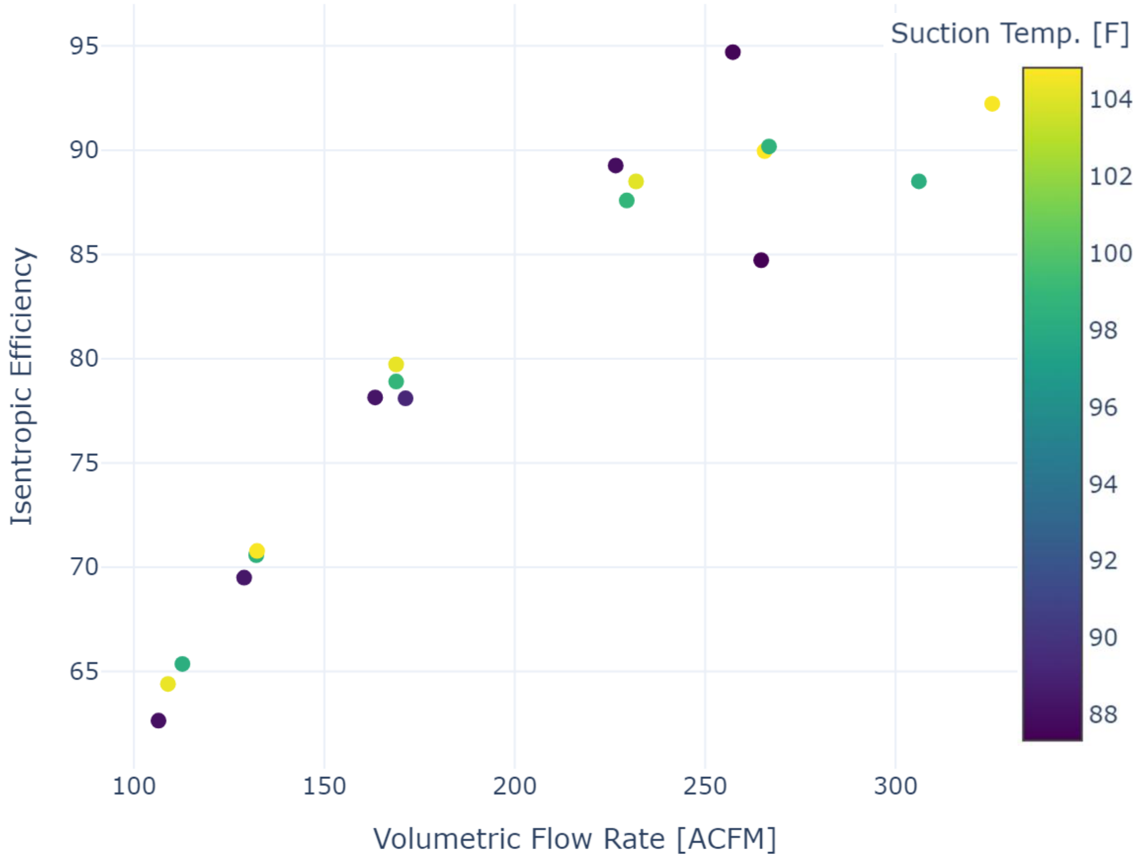
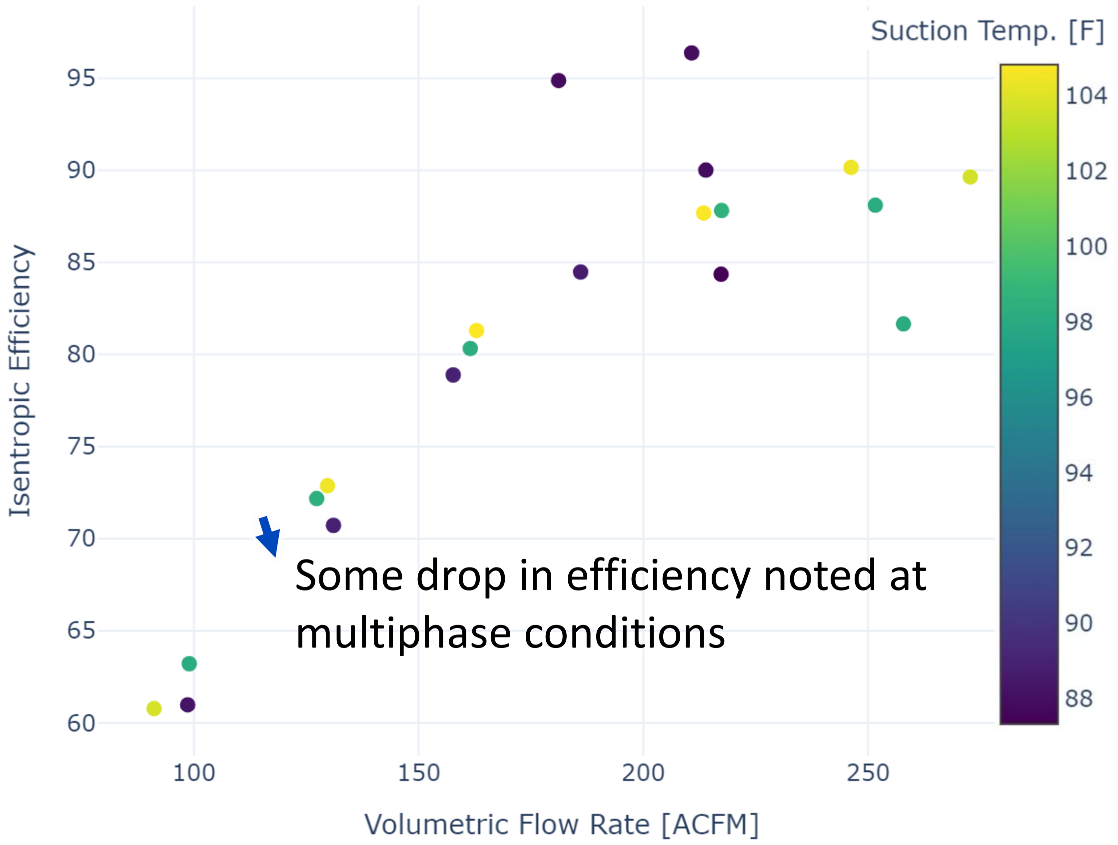


Figure 11: Isentropic Efficiency vs. Flow (30.5°C)

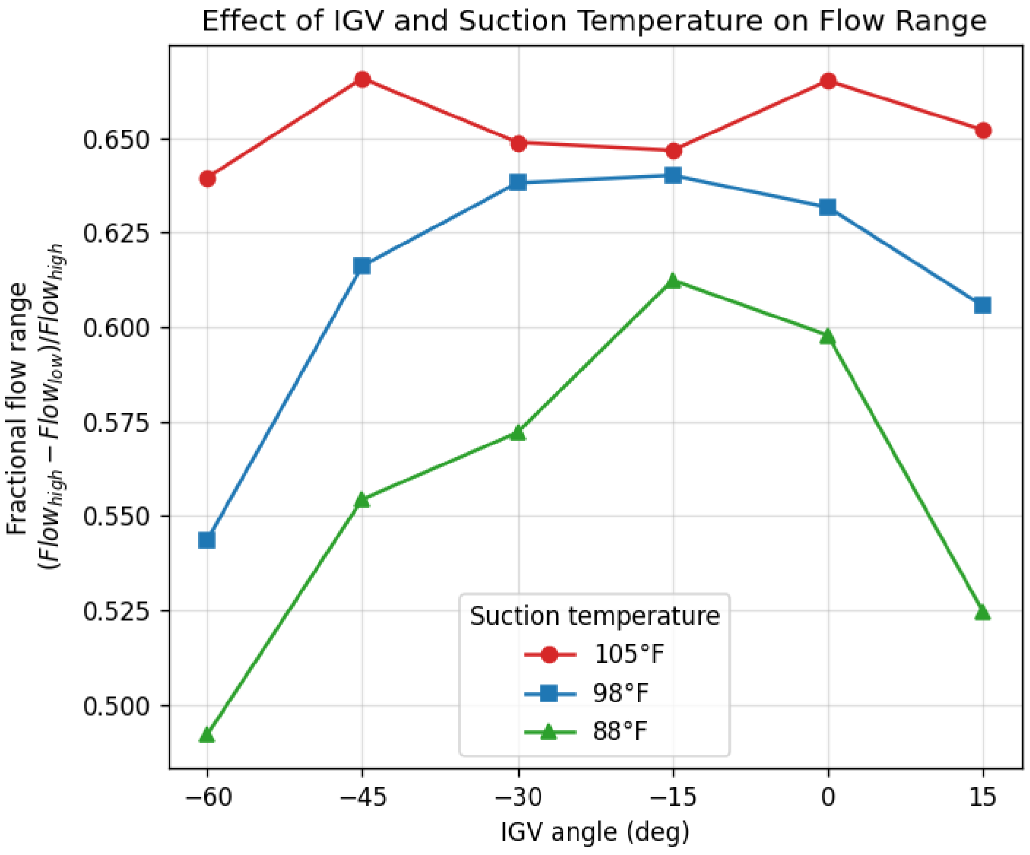


Isentropic Efficiency vs. Flow (0° IGV)

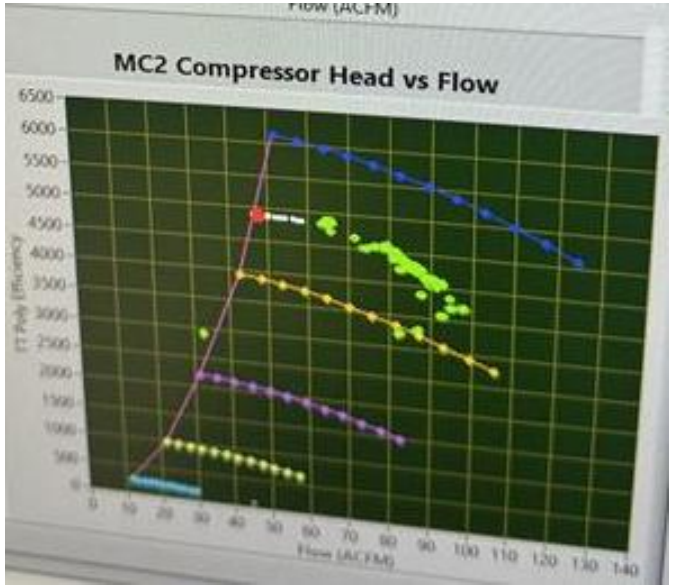


Isentropic Efficiency vs. Flow (40° IGV)

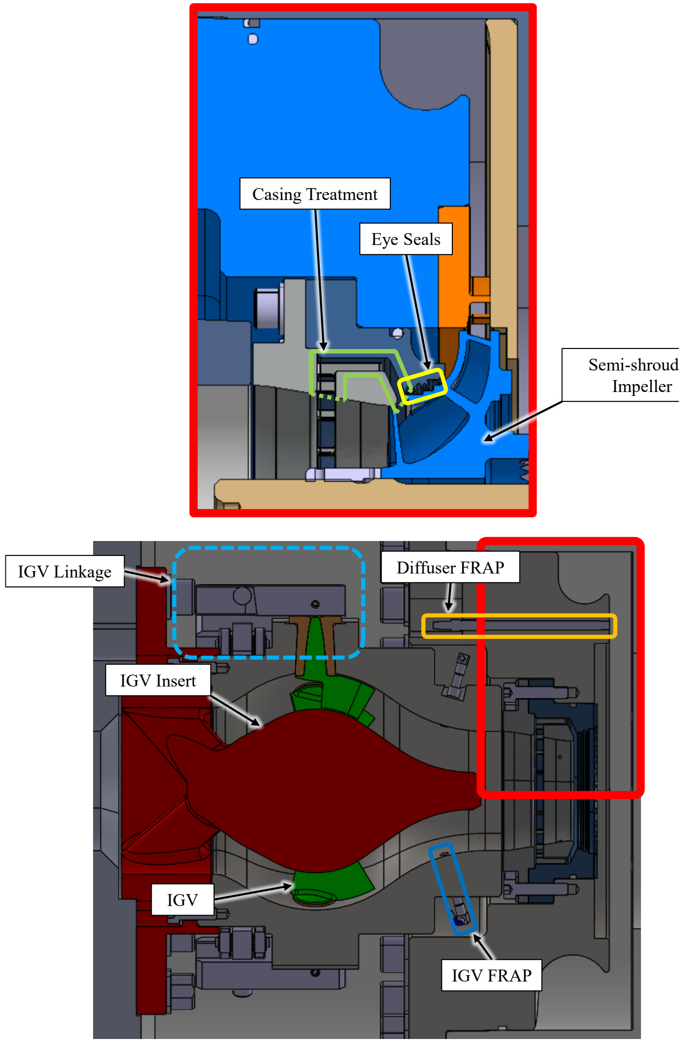
A Flow Range of ~60-65% was retained through most of the single phase test cases with lower temperatures only having a range of 50%



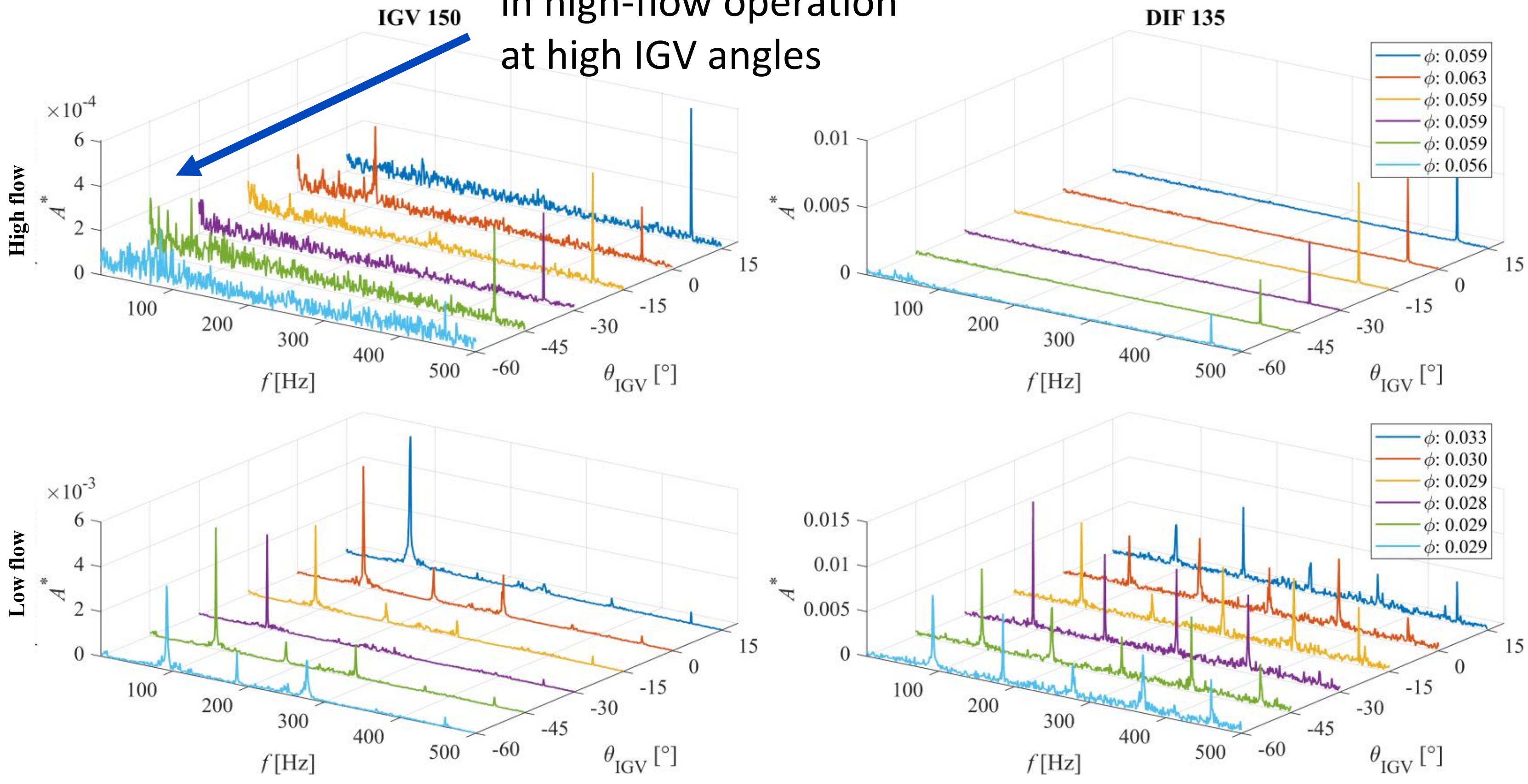
- This is complicated by the fact that in some cases the flow limitation was the second stage flow, discharge pressure, etc.
- Also, it was complicated by the fact that we didn't really want to find surge



We placed dynamic pressure transducers at the eye and diffuser of the stage one compressor



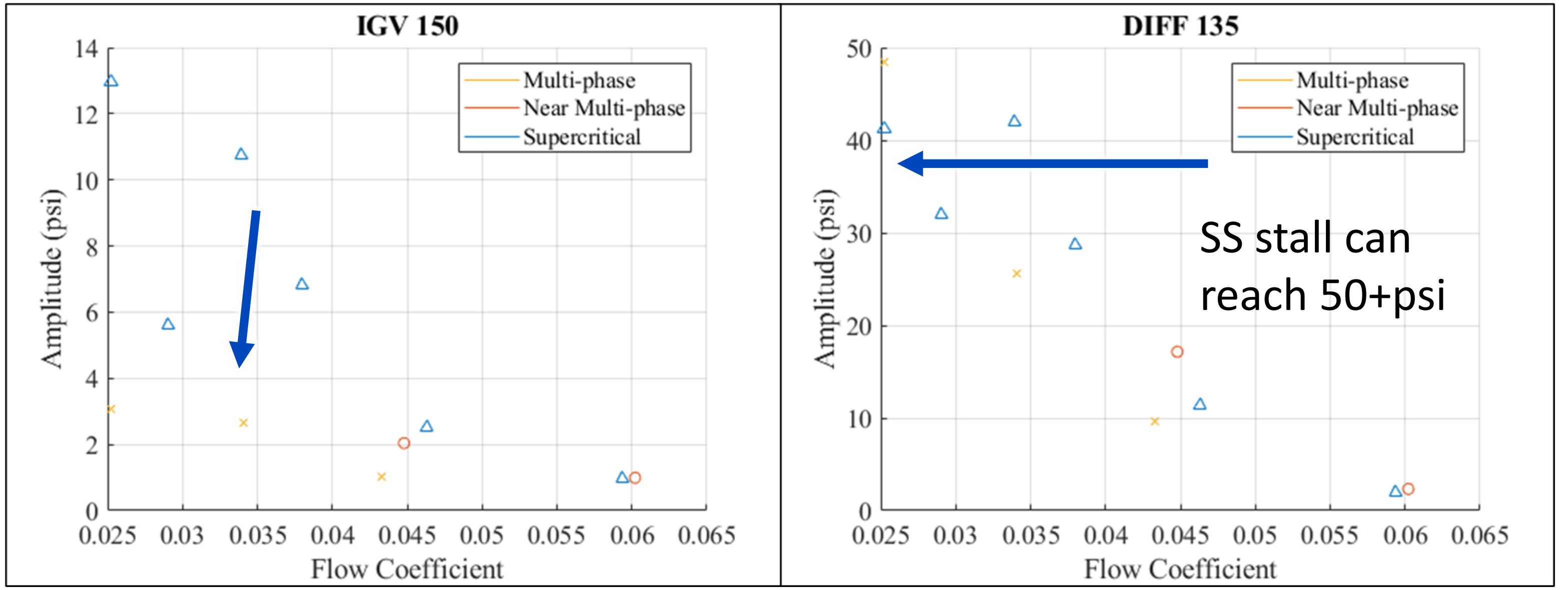
IGV wakes get strong in high-flow operation at high IGV angles



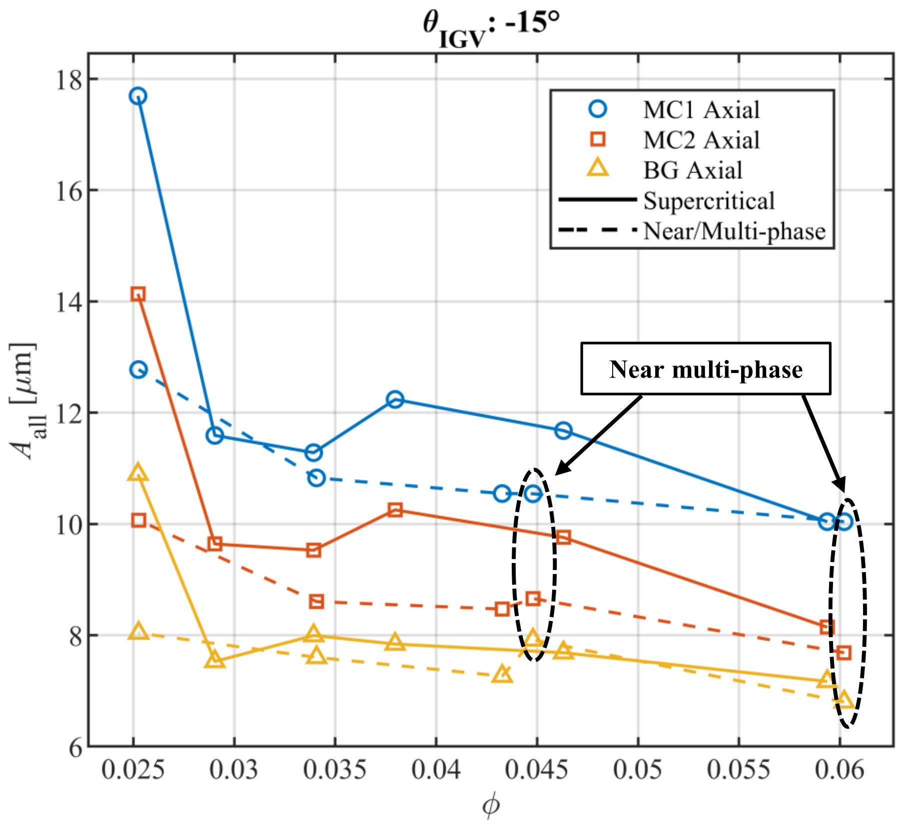
IGV and diffuser FRPT spectrums vs θ_{IGV}. Separate plots for high flow and low flow operating points are provided.

While we were worried about the machine health, overall, the machine seemed happier at near-multiphase operation

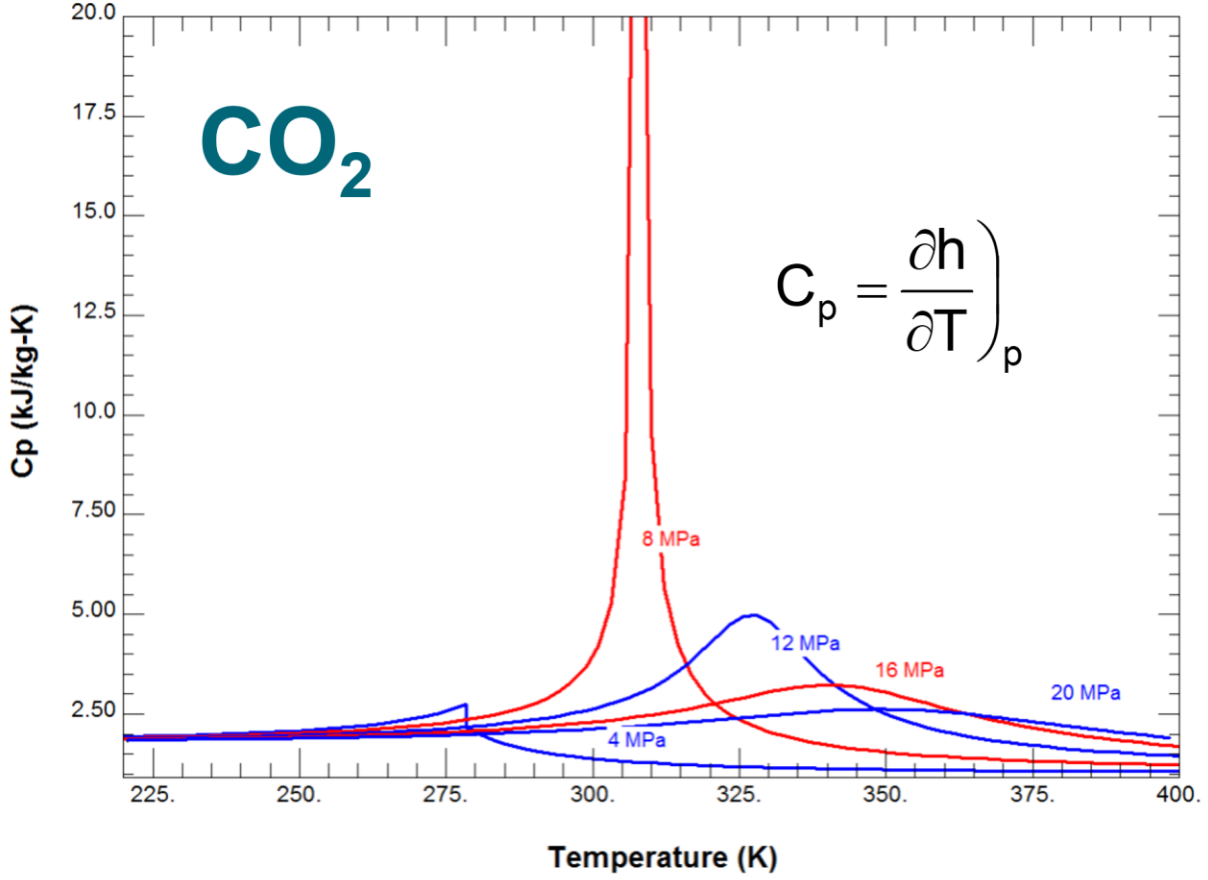
Dynamic pressures tend to decrease with multiphase flow

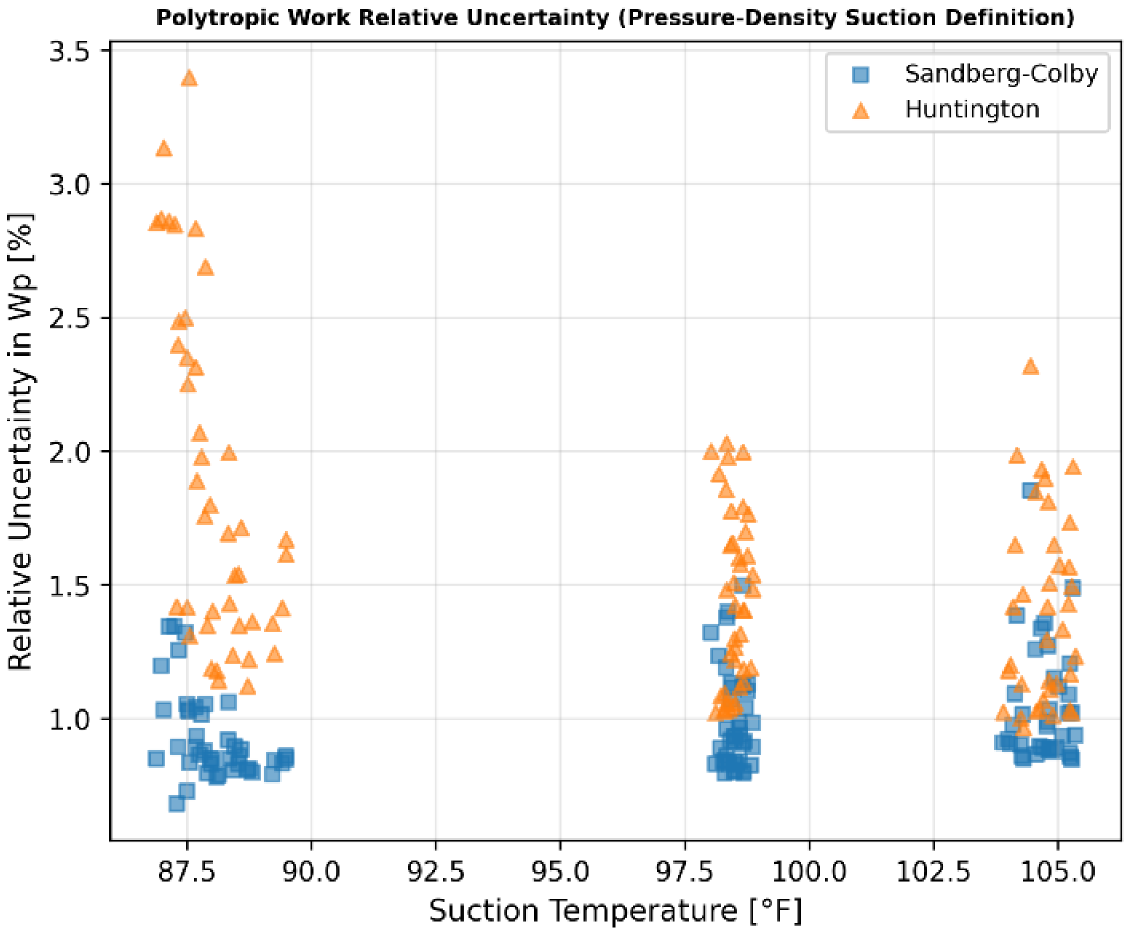


Overall sub-synchronous amplitude vs flow coefficient for supercritical, near multi-phase, and multiphase inlet conditions at a -15° IGV angle.



Performance measurement remains to be a challenge, and it isn't clear that the industry has a viable approach for compressor guarantees near the dome





Conclusions

- Dense phase pumping
  - Machine tends to operate well with a combination of impurities for CO_2; however, pressure ratio is heavily impacted by the addition of impure gases.
  - Restrictions cause high values of dynamic pressure, and can result in ringing of pipe/small bore fittings. Once a crack occurs, the depressurization across the crack often results in dry ice accumulation and brittle metal conditions
- Near Dome compression
  - External signs of compressor health tend to be good as in-dome operation is approached
  - Efficiency is challenging to measure as near-dome conditions exist
  - Stall at low flow conditions can create pulsations of 40-50 psi (0-peak)
  - To our credit… it didn't break.

Any questions?

- Acknowledgements
  - Many thanks to dozens of coworkers responsible for building, testing, and analyzing data on these machines.