



Bechtel Marine Propulsion Corporation
Bettis Atomic Power Laboratory
West Mifflin, PA

Practical Aspects of Supercritical Carbon Dioxide Brayton System Testing

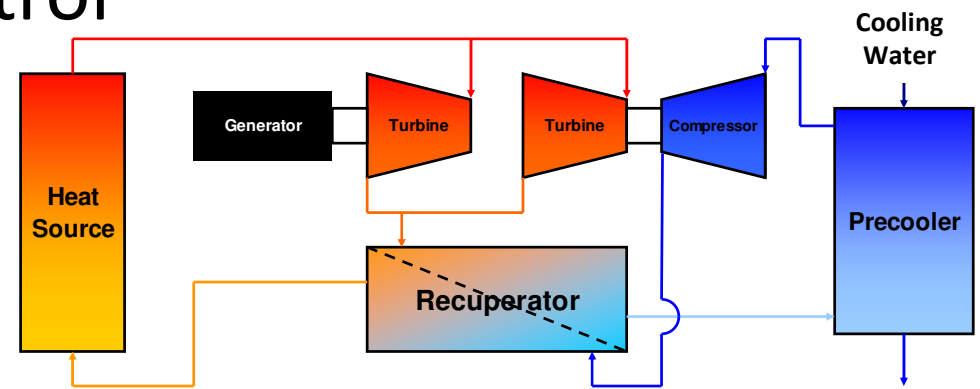
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Presentation Summary

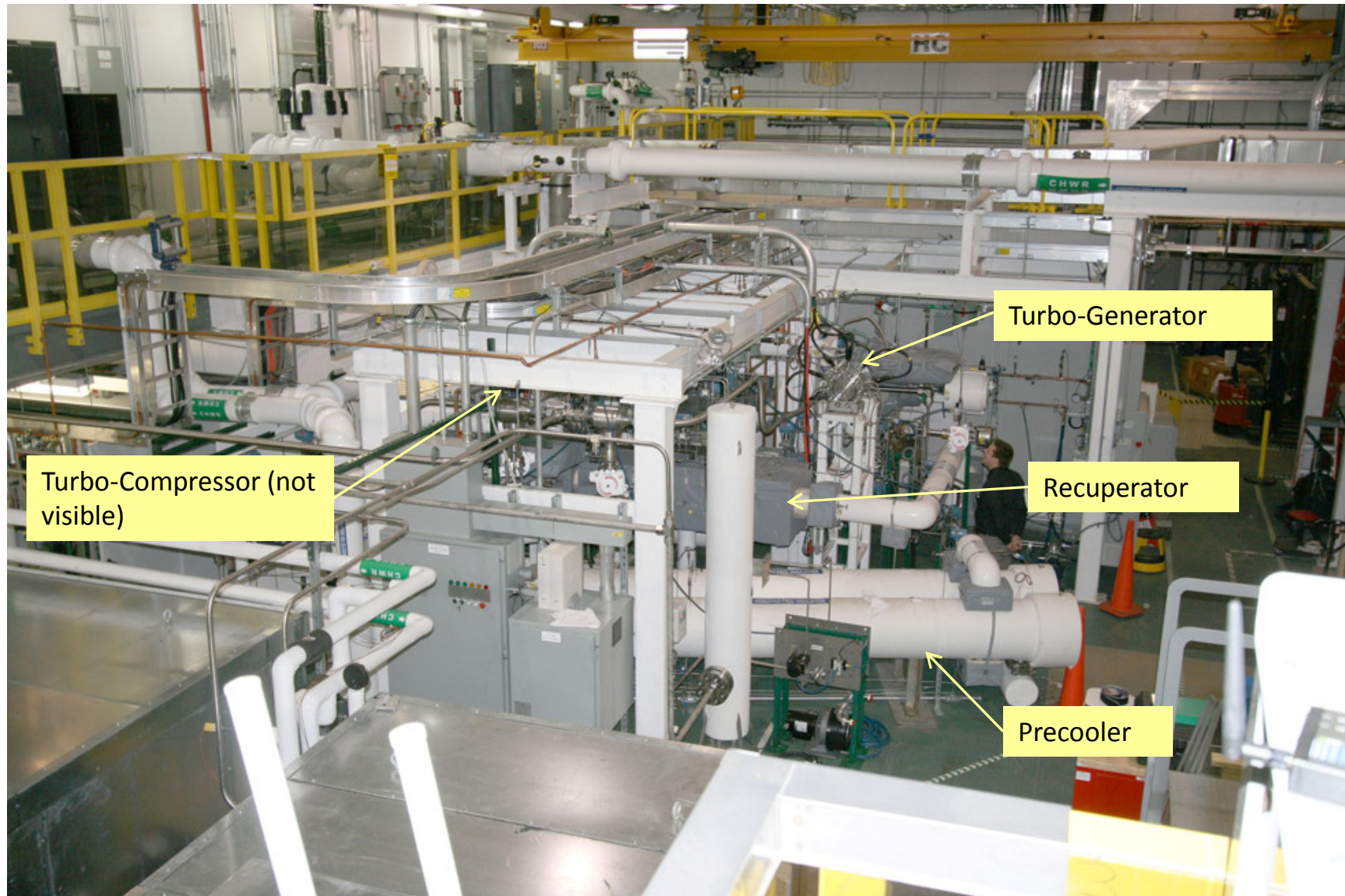
- S-CO₂ Brayton Cycle Integrated Systems Test (IST) Overview and Operating Experience
- Best Practices for S-CO₂ Power Cycle Operation
 - Design Considerations
 - Loop Cleanliness
 - System Fill and Leakage
 - Instrumentation
- Conclusions

IST Overview

- 100 kWe IST has been main S-CO₂ development focus of BMPC
- Simple Brayton cycle
 - Single variable speed turbine-compressor
 - Single constant speed turbine-generator
 - Single recuperator
- Focus on system control
 - Rapid startup
 - Power changes
 - Shutdown

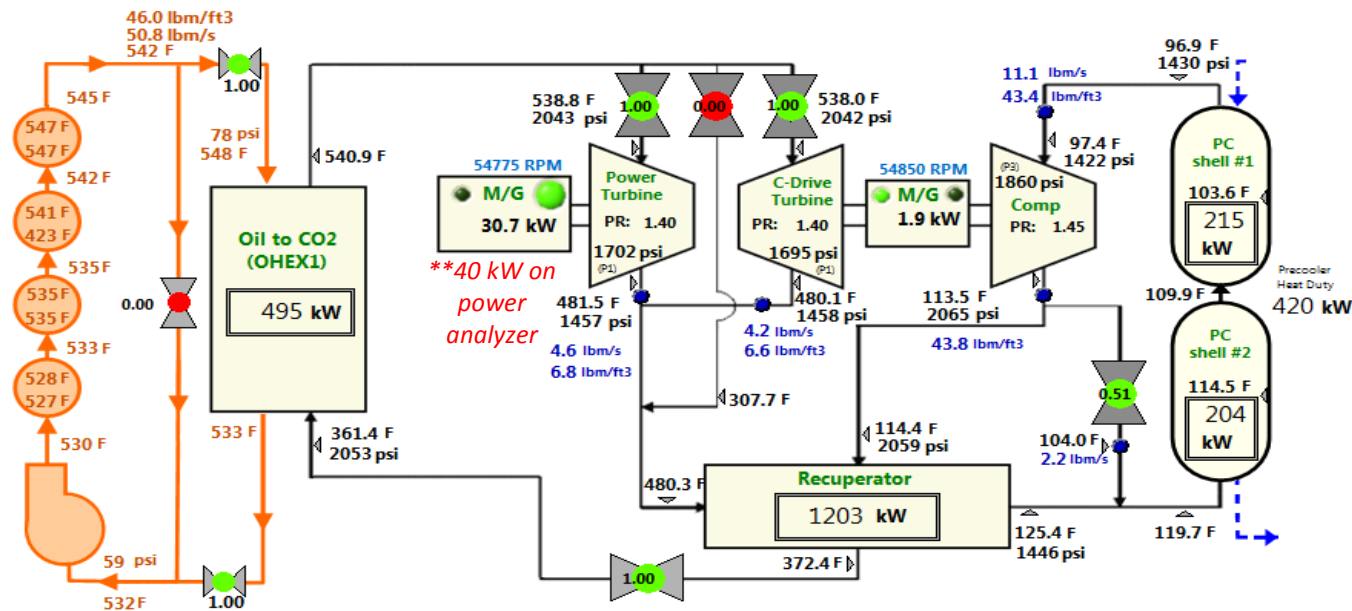


IST Physical Layout



Operational Experience

- Shakedown started in Fall 2011
- Brayton cycle operation started in Spring 2012
- Over 165 hours of Brayton system operation
- Achieved 40% of design power

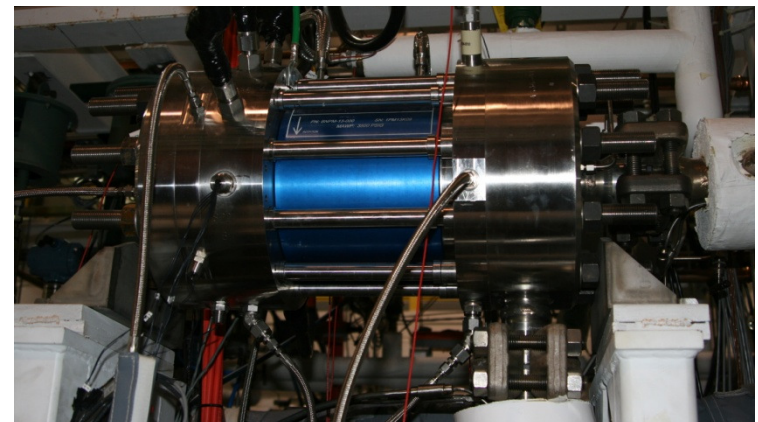


System Transient Modeling

- IST design supported by transient model predictions
 - Pipe size, valve resistance, valve stroke time, support equipment operating requirements
- Transient model valuable for startup and low power operation
 - Closed system more difficult to startup and get to full power condition than open Brayton cycle

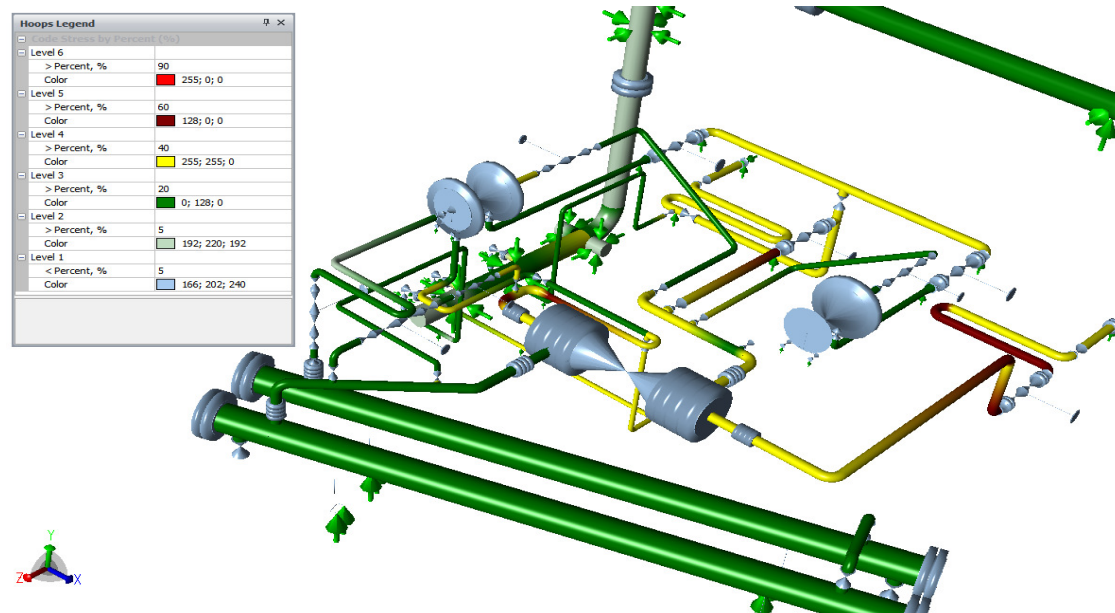
Mechanical Connections

- IST utilizes the following fittings in CO₂ systems
 - Grayloc fittings for main loop piping/component connections
 - ¼” Swagelok fittings welded to pipe for instrumentation
 - ¼”-2” Swagelok fittings and 2” ANSI flanges for support system connections
- Fittings all leak tight when installed properly
- Bolt selection considerations
 - Thermal fatigue from heatup and cooldown cycles
 - Brittle fracture from low temperature of leaking CO₂



Thermal Stress Consideration

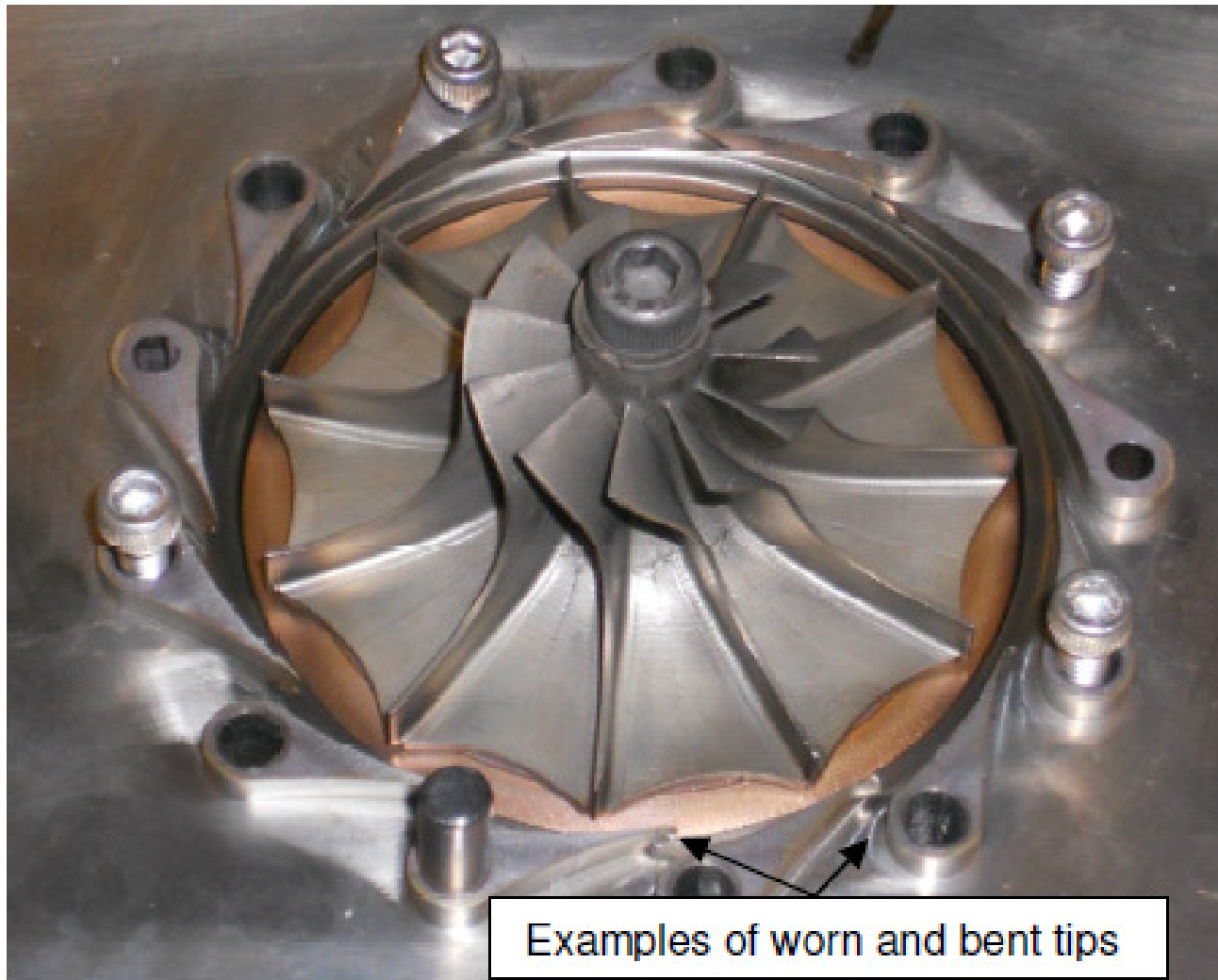
- Small equipment allows for compact system arrangement
- Compact arrangements can make thermal stress more difficult to accommodate
- IST design considered thermal stress from the beginning
 - 4 thermal expansion loops included in Brayton loop piping to accommodate thermal expansion



Material Quality / Cleanliness

- Supercritical CO₂ is a strong solvent
- Materials testing and loop operating experience has shown that some polymer materials are incompatible with the supercritical CO₂ environment
- BMPC test loops have implemented material quality and cleanliness controls which have shown effective at eliminating system contamination

Turbine Nozzle Erosion



System Fill and Leakage

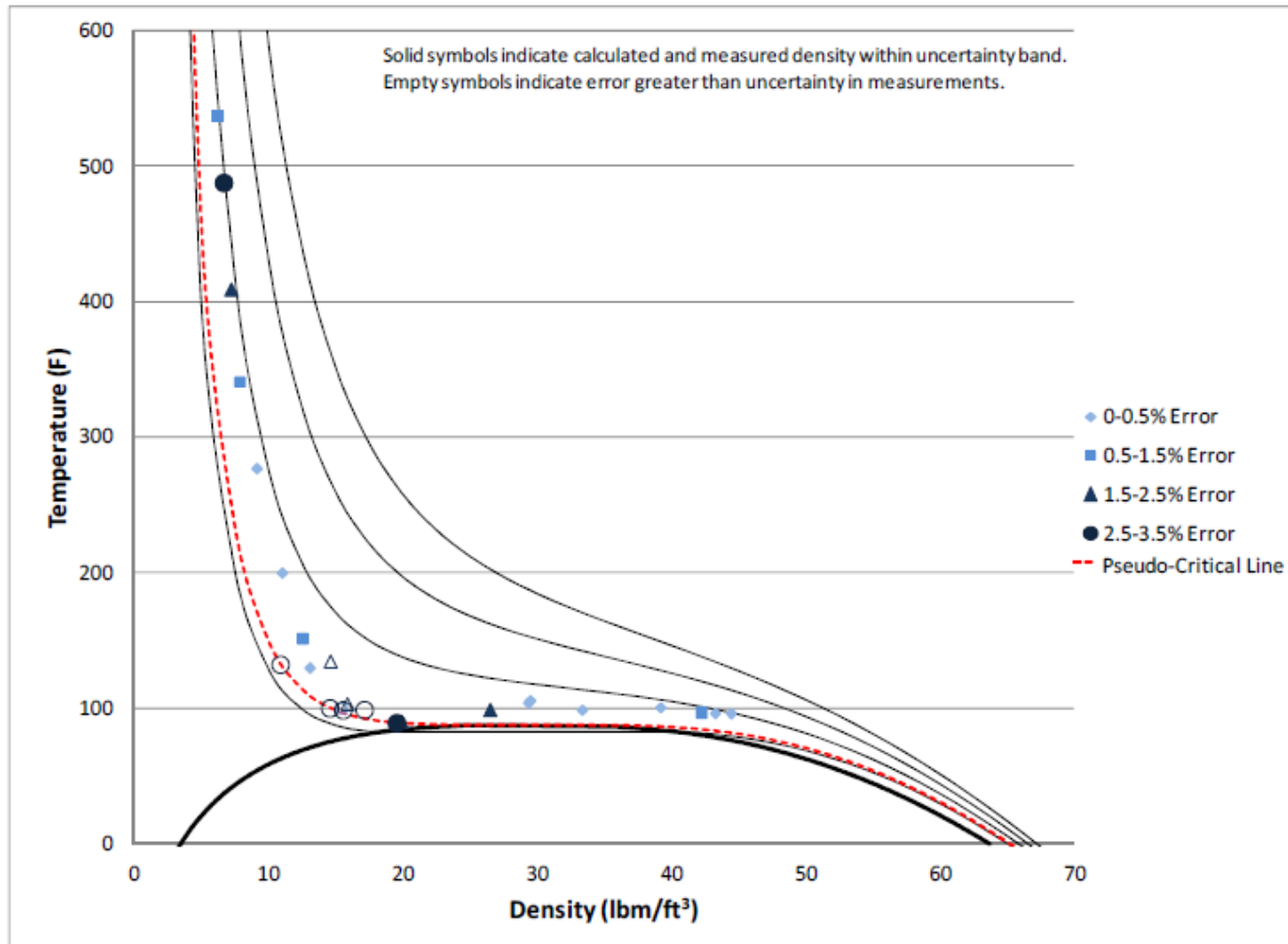
- IST uses Coleman Instrument grade (99.99%) CO₂ for fill
- Three cycles of pulling vacuum and filling to atmospheric pressure before full fill
- Low leakage levels from valve stem packing and large shaft seals

Instrumentation

- Temperature and pressure measurements give good indication of loop conditions
- Coriolis flow meters used to determine both flow rate and density of CO₂
 - Flow meters give good results for single phase or supercritical flow
 - Can give invalid readings during loop startup if installed orientation allows for low point for liquid collection



Density Calculations using REFPROP with T & P



Summary

- No inherent issues with S-CO₂ Brayton power cycle operation identified in IST operation
- Off-design operations, thermal stress analysis, instrumentation orientation, cleanliness, and material compatibility are important design considerations
- Experience from small-scale testing will minimize rework and operational issues for larger systems

Acknowledgements

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