Fundamental study of Key Issues related to Advanced S-CO₂ Brayton Cycle

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Supercritical CO₂ Brayton Power Cycle

- U.S. Department of Energy (DOE) initiative for clean and efficient energy conversion for a variety of heat sources
- Properties of Supercritical CO₂ (S-CO₂):
  - Specific heat of the fluid reaches its maximum at the pseudo-critical temperature.
  - Strong property variations with temperature in the pseudo-critical region

Cycle Benefits

- Combustion advantages from air Brayton and Rankine cycles
- Reduction in size of turbomachinery components
- Lower back work ratio improves cycle efficiency
- Efficiencies as high as ~50% possible (For turbine inlet temperature ~ 650°C)

Nucleation in Supercritical Carbon dioxide

- Nucleation might occur at the compressor inlet and turbine outlet causing material erosion of the components
- Either cavitation bubbles or condensate droplets can form within ±1°C temperature variation close to the critical pressure
- Close to the critical point small amount of sub-cooling or super-heating is required to reach metastable states

Goals

- Current focus is on designing a venturi system.
- Different material samples will be installed downstream of the throat to study material degradation.
- Optical access will be provided to capture the formation, growth, and collapse of nucleation phenomenon in the throat region

Venturi Facility

- Pressure monitored at 10 locations along the venturi profile to measure frequency of pressure oscillations during nucleation process
- Shadowgraph/Schlieren optical system for qualitative and quantitative measurements of density field
- Resolution of ~1.5 pixels per throat region

Heat Exchanger Facility

- A transient compressible Navier-Stokes solver, coupled with continuity & energy equation in OpenFOAM
- Fluid interpolation table (FIT) libraries integrated with OpenFOAM to model CO₂ properties.
- Homogeneous equilibrium model (HEM) used in the two-phase dome.
- Slip between phases, \( S = \left( \frac{\rho_{fg}}{\rho_{f}} \right)^{1/2} = 2 \text{ m/s} \), \(<\text{throat velocity ~ 100 m/s}

Computational Study

- Condensation was mostly present observed close to the walls indicating that the condensate droplets will stick to the walls
- Moving away from the walls vapor cavities can be expected as indicated by the computational model
- The complex density gradients in the flow will make optical diagnostics challenging

- Optimization of labyrinth seals for a fixed length
- Inlet conditions of (9MPa, 498 kg/m²) and outlet conditions of 5MPa
- Adding more seals will reduce the leakage rate up to certain point
- As the spacing between seals increase, the pressure loss due to recirculation in the cavities decrease which causes an increase in leakage through seals