Fundamental study of Key Issues related to Advanced S-CO_2 Brayton Cycle

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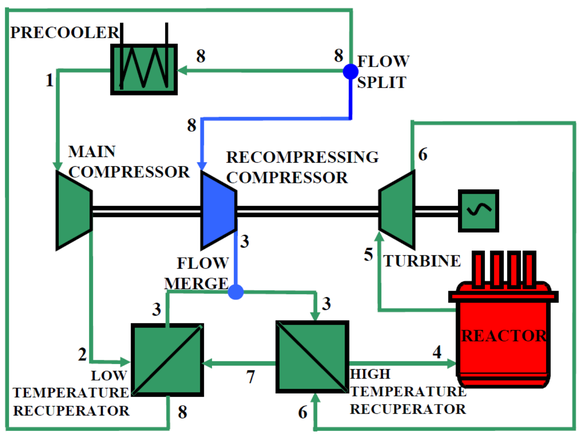
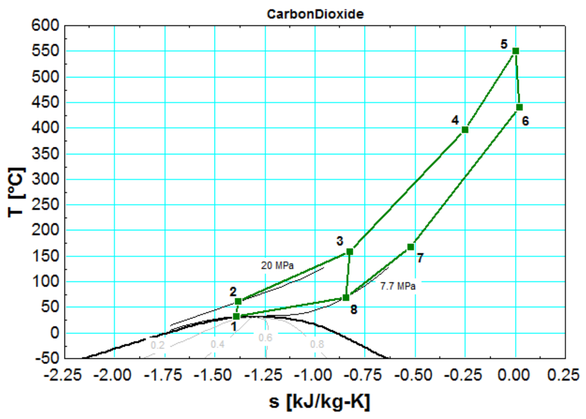
Supercritical CO_2 Brayton Power Cycle

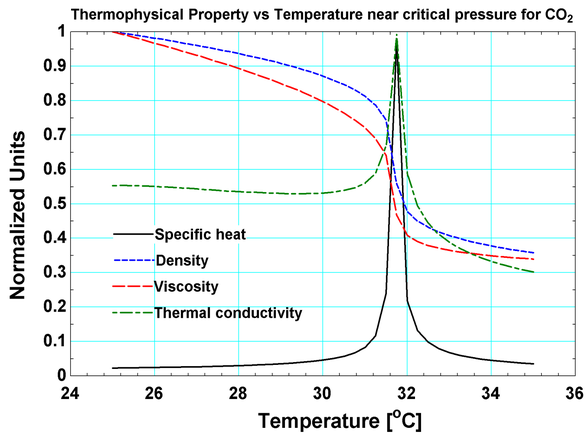
- U.S. Department of Energy (DOE) initiative for clean and efficient energy conversion for a variety of heat sources
- Properties of Supercritical CO_2 (S-CO_2):
  - Specific heat of the fluid reaches its maximum at the pseudo-critical temperature.
  - Strong property variations with temperature in the pseudo-critical region



Cycle Benefits

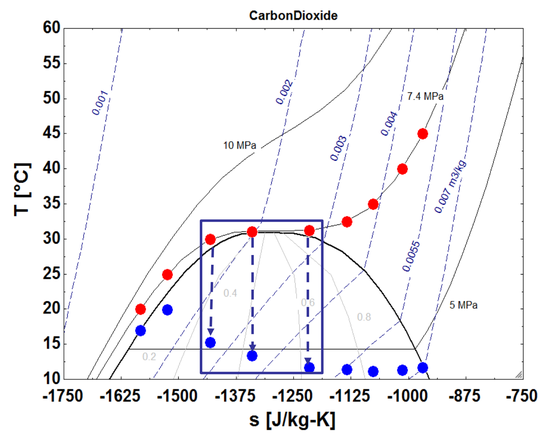
- ✓ Combines advantages from air Brayton and Rankine cycles
- ✓ Reduction in size of turbomachinery components
- ✓ Lower back work ratio improves cycle efficiency
- ✓ Efficiencies as high as **~50%** possible (For turbine inlet temperature ~ 650^{0}C)

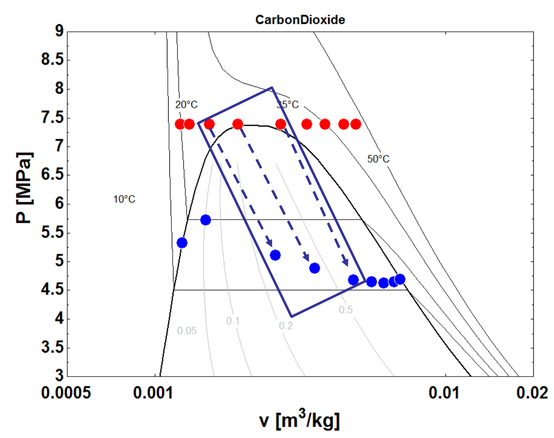




Nucleation in Supercritical Carbon dioxide

- 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^{o}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

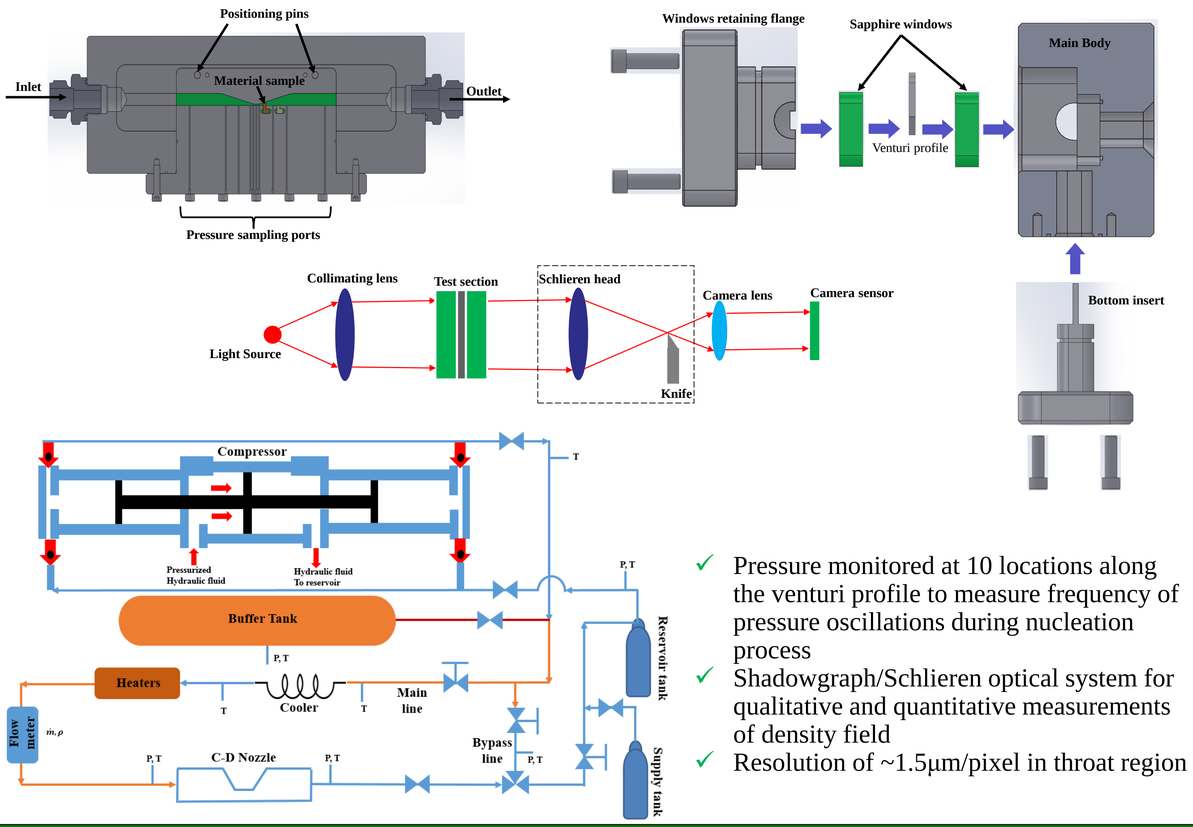




Goals

- ✓ 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

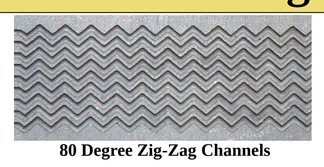
Venturi Facility



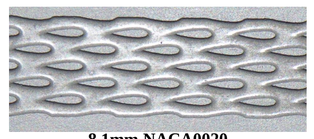
- ✓ Pressure monitored at 10 locations along the venturi profile to measure frequency of pressure oscillations during nucleation process
- ✓ Shadowgraph/Schlieren optical system for qualitative and quantitative measurements of density field
- ✓ Resolution of ~1.5µm/pixel in throat region

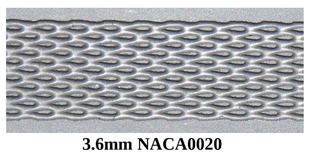
Heat Exchanger Facility


Straight Channels

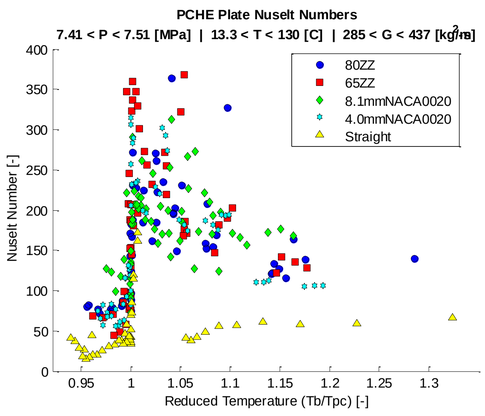

80 Degree Zig-Zag Channels


65 Degree Zig-Zag Channels

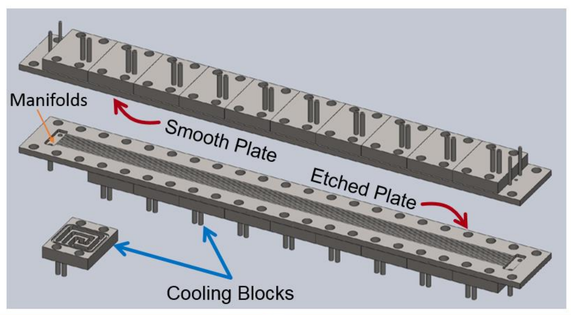

8.1mm NACA0020

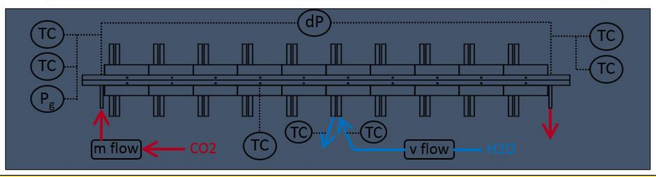

3.6mm NACA0020

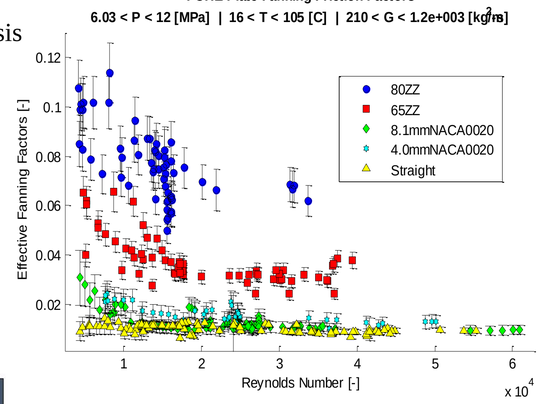

Rectangular Offset Fins



* Images and data from Matthew Carlson's UW-Madison thesis



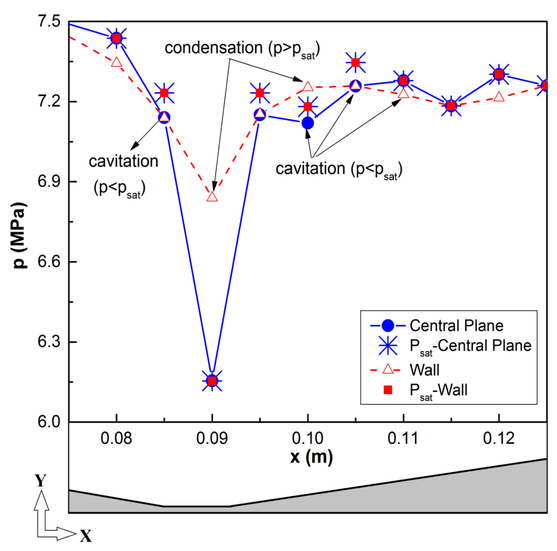


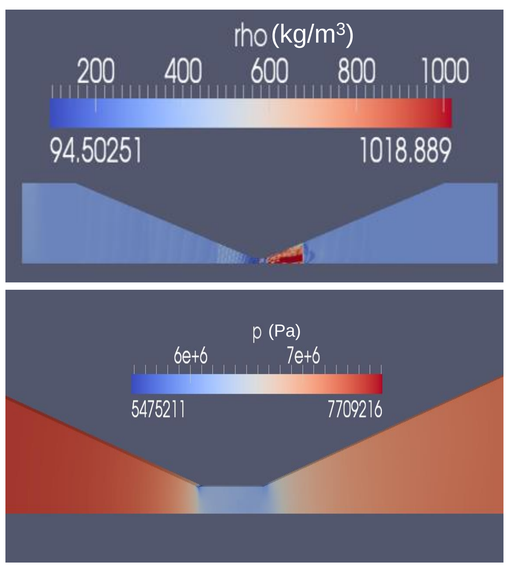


- ✓ Air foil channels look promising both in terms of reduced pressure drop and heat transfer*
- ✓ Tests will be performed for Rectangular Offset Fins and compared to existing surfaces

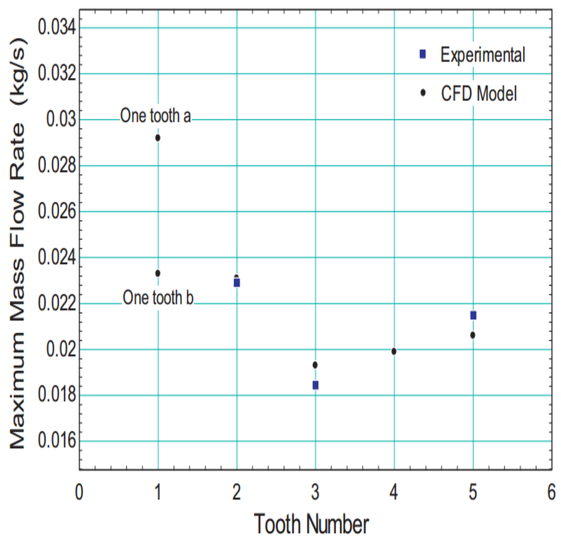
Computational Study

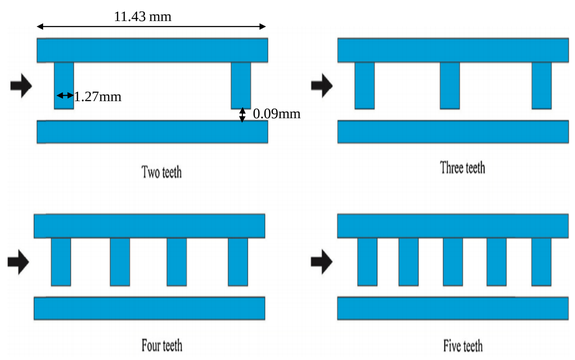
- A transient compressible Navier-Stokes solver, coupled with continuity & energy equation in OpenFOAM
- Fluid interpolation table (FIT) libraries integrated with OpenFOAM to model CO_2 properties.
- Homogeneous equilibrium model (HEM) used in the two-phase dome.
- Slip between phases, $S=\left(\frac{\rho_L}{\rho_G}\right)^{1/3} \approx 2$ m/s << throat velocity ~ 100 m/s





- 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





Labyrinth seals with different number of installed seals

- Optimization of labyrinth seals for a fixed length
- Inlet conditions of (9MPa, 498 kg/m^3) 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