Oxy-Fuel sCO2 Cycle Injector Design & LH₂ Facility Design

UTSR 2017 Gas Turbine Industrial Fellowship Program

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Introduction

• Southwest Research Institute is an independent, non-profit research company whose expertise spans a wide range of technologies.

• Div. 18 Mechanical Engineering
  • Fluid & Rotating Machinery
    • Performs combustion, flow and rotary testing.
  • Owns and operates a 10MW scale sCO₂ demonstration loop
Supercritical CO$_2$ Brayton Cycle

- Similar to Brayton (Gas Turbine) and Rankine (Steam Turbine) power cycles commonly employed for power generation
- Supercritical CO$_2$ as a working fluid provides a number of advantages
  - Theoretical efficiencies much greater than traditional Rankine cycle
  - Flow components approx. ten times smaller
- Direct-Fire (combustion within the working fluid, as in a gas turbine) possible, allowing greater efficiency, and direct carbon sequestration
- See cycle process diagram, left
Objective

- Injector Design for Direct-fire sCO2 Combustor
  - One of the main goals of the fellowship was to design an injector for the inlet of oxygen, methane and carbon dioxide to combustor.
  - Main purpose of the design was for numerical flow simulation to assist in combustor development.
- Combustor window design
  - An objective of the proposed combustor was to provide optical access to the flame for analysis. Required access from 3 sides.
  - 3-walled combustor (consisting of 2 inner liners and a pressure container) required 3 window designs.
- LH₂ Facility Component Specification
  - Planning of facility to test components of a liquid hydrogen transfer system
Injector Design

• Injection of dilute Oxygen in sCO₂ and methane into combustor
• Swirl Stabilized Combustor
  • Central recirculation zone anchors flame in the combustor
  • Swirl Number (S) is a measurement of the swirl intensity
    • Ratio of tangent to axial momentum flux
    • Most practical combustors S = 0.6 - 1.5
    • S approx. for straight-vane swirler:
      \[ S = \frac{2}{3} \frac{1 - (d_h/d)^3}{1 - (d_h/d)^2} \tan \phi \]
• Multiple injector geometries produced
• Final Specifications: 25m/s injection velocity, S=1
Flow Simulation

• FLUENT simulation
  • Transient solution required for convergence
  • Strong recirculation zone between two jet diameters downstream
Flow Simulation

- Precessing Toroidal Recirculation Zone
  - Recirculation biased to one side of combustor, but rotates about central axis in time.
Combustor Windows

- The cylindrical combustor consists of three layers, which all must be transparent to obtain optical access
  - Full cylindrical transparent section for innermost liner, flat windows for outer
  - Pressure rated site glass for outermost pressure container.
- Window material selection to obtain transparency up to 4000nm (mid-IR)

*Fused Quartz Average Transmittance Curves*

*WAVELENGTH, NANO METERS*
Liquid Hydrogen Test Facility

- Planning for new LH$_2$ Facility included:
  - Specification of system components for LH$_2$, gaseous H$_2$, and He.
    - Line sizing for flowrates, tank sizing, insulation
  - Data acquisition
  - Power requirements for backup systems
  - Fire and safety code compliance, siting restrictions.
Facility P&ID

Color Code:
- Red Lines – LH₂
- Black Lines – GH₂
- Orange Lines – He
- Black Components – SwRI Procure
- Green Components – Customer Provided
- Relief Valves for all enclosed volumes not shown
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