A Few Acronyms

- SEA – Systems Energy Analysis Division at NETL
- PSER – Process Systems Engineering Research team in SEA
- sCO₂ – Supercritical CO₂
- RCBC – Recompression Closed Brayton Cycle
- STEP – Supercritical Transformative Electric Power. A 10 MWe net power demonstration plant being built at SwRI in San Antonio TX.
Presentation Overview

• SEA PSER sCO$_2$ Activities Overview
• Motivation for Control Studies of STEP Facility
• Control Methodology
  • Steady-State and Dynamic Simulation Framework
  • Control Objectives
  • Control Architecture
• Control Response Results
  • Ramp down and up in RCBC cycle MW demand
  • Heat rejection water cooler temperature control
• Future Work
SEA PSER $\text{sCO}_2$ Cycle Modeling Activities

• **Indirect Fired Cycles**
  
  • STEP pilot plant
    
    • Cycle models for dynamics
      
      • Recompression Closed Brayton Cycle (RCBC)
      
      • Simple Cycle – First year of facility operation, starting ~Oct 2020
    
    • Equipment models
      
      • Heat exchangers
      
      • Control of primary heat rejection water cooler
  
  • 550 MW commercial scale with circulating fluidized bed
    
    • Turbomachinery arrangement options
      
      • Off Design (Part-load, Ambient temperature) → Control

• **Direct Fired Cycle**
Process Overview

- External gas-fired heat source
- sCO₂ circulates in closed loop (noncondensing)
- Two stages of recuperation used to pre-heat compressed sCO₂ with hot turbine exhaust
- Cooler rejects heat that is not converted to power
- Coupled compressors, decoupled turbine expander
Motivation

• Understand control-related challenges of a MW scale sCO₂ Recompression Closed Brayton Cycle (RCBC)
  • Load changes, Startup, Shutdown, Trips
  • Operation close to sCO₂ critical point
  • Maintain turbine inlet temperature during load changes (high efficiency)
  • Other operational constraints, e.g. surge/stonewall limits

• Applicable to 10 MWe RCBC facility within Supercritical Transformational Electric Power (STEP) program
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Control Methodology

Steady-State and Dynamic Simulation Framework

- **Software Tools**
  - Aspen Plus/Dynamics/Custom Modeler (ACM) v10.0
- **Property Method**
  - NIST REFPROP
- **Aspen Library Models**
  - Turbomachinery (currently), piping, some heat exchangers
- **Aspen Custom Modeler (ACM) Models**
  - ACM compact heat exchangers models - microtube† and printed circuit††
- **Dynamic Model of 10 MWe sCO₂ RCBC Pilot Plant†††

Process Flowsheet

10 MWe sCO₂ RCBC
Control Objectives

0. Maintain NG-Furnace Combustion Temperature (1088 K)

1. Maintain Turbine Inlet Temperature @design (700°C)  
   Note: STEP design temperature is 715°C

2. Maintain Main Compressor Inlet Temperature @design (33.5°C) | Lower Constraint of 32°C

3. Maintain Main-Bypass Flow Split (design: 0.653) †

4. Meet Net-Work Demand (for Load-Following scenarios)

5. Inlet Valve – Used to divert sCO₂ from cycle toward inventory tank

6. Outlet Valve – Used to extract sCO₂ back into cycle from inventory tank

Controller Design

Overall Control Architecture

- Air
- Natural Gas
- Flue Gas
- CO2
- Cooling Water

Color Legend:
- Orange: Natural Gas
- Gray: Air
- Red: Flue Gas
- Green: CO2
- Blue: Cooling Water
- Dashed: Control Signal

Note: Recently changed approach to water bypass.
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Advanced Sensors & Controls Task 61: Control Strategies for a 10 MW sCO2 Power System

STEP Cycle Model Control Investigations

Technical Progress:

- Discussed previous NETL control studies and future interests with STEP development team (GTI, SwRI, GE)
Objective: Analyze water cooler CO₂ temperature control approaches being considered for STEP. A 1°C change in this temperature can effect temperature at turbine inlet by 10°C (if uncontrolled)

Technical Progress:
- Completed microtube type CO₂-water cooler 1D design and dynamic model using Aspen Custom Modeler
- Shell OD 20 in.
  11,000 tubes
- Tube L 5 ft.
- Tube OD 2.77 mm
- Performed control studies†.

Plot: Aggressive inlet CO₂ flow ramps (blue) of 1%/sec. Control of CO₂ outlet temperature (red) within 2.5°C of setpoint

†Liese E., Mahapatra, P., and Jiang, Y., “Modeling and Control of a Supercritical CO₂ Water Cooler in an Indirect-fired 10 MWe Recompression Brayton Cycle near Supercritical Conditions”, Proceedings of the ASME Turbo Expo, Phoenix, Arizona, June 17-21, 2019
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Future Work

10MWe sCO₂ Recompression Brayton Cycle

• Updating cycle model based on STEP design in progress
  • Added pipe models and prelim turbomachinery performance maps including compressor inlet guide vanes

• Simple cycle model development in progress

• Increase model fidelity with custom models using Aspen Custom Modeler (esp. heat exchangers)

• Numerous scenarios to investigate
  • Startup, Shutdown, Trips…

• Numerous control approaches to try

• Improve simulation robustness