Research Efforts at NETL for Supercritical CO$_2$ Power Cycles

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Current Research Efforts at NETL

• **Systems analysis**
  – Thermodynamic modeling of high temperature direct and indirect fired cycles for natural gas and coal. Steady state and dynamic models for performance, cost and transient analysis.

• **Materials**
  – High pressure autoclave (800°C, 275 bar) for exposure of coupons and welded/bonded specimens.
  – Low cycle fatigue and compact-tension of exposed specimens.

• **Combustion**
  – CFD modeling of injection, combustion and wall cooling.
  – High-pressure oxy-fuel combustor development: Designing a 300 bar, 1MW combustor.

• **CO₂ turbine blade cooling.**
  – Internal cooling designs (forced convection, thermosyphon, etc.)
  – Plans for initial testing of concepts in FY17.
Coal-Fired Direct sCO2 Power Plant
Performance Analysis

- Performance and sensitivity analysis of a commercial-scale direct sCO2 plant
- Using Shell gasifier with AGR and Sulfinol syngas cleanup
- NET Power type syngas-fired direct sCO2 cycle with heat integration
- Favorable efficiency vs. IGCC plant, with better CO₂ capture

<table>
<thead>
<tr>
<th>Parameter</th>
<th>IGCC</th>
<th>sCO2</th>
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<tbody>
<tr>
<td>Thermal Input (MW_{\text{th}})</td>
<td>1,591</td>
<td>1,493</td>
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<tr>
<td>Gross Power (MW_{e})</td>
<td>673.4</td>
<td>936.6</td>
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<tr>
<td>Auxiliary Power (MW_{e})</td>
<td>176.5</td>
<td>374</td>
</tr>
<tr>
<td>Net Power (MW_{e})</td>
<td>496.9</td>
<td>562.6</td>
</tr>
<tr>
<td>Net plant efficiency (HHV %)</td>
<td>31.2</td>
<td>37.7</td>
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<tr>
<td>CO₂ Capture Rate</td>
<td>90.1</td>
<td>98.1</td>
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Materials Research at NETL for Supercritical CO$_2$ Power Cycles

To enable the development of sCO$_2$ power cycles, NETL is

- Identifying and evaluating power plant materials for sCO$_2$ power cycles
- Evaluating fabrication methods for components of sCO$_2$ power cycles
- Investigating degradation of materials in sCO$_2$ power cycle environments

We are able to recreate sCO$_2$ power cycle environments to perform

- Corrosion tests of alloy samples
- Corrosion tests of joints (welded, diffusion bonded, brazed)
- Pre-exposure of mechanical test specimens to evaluate the effect of environment on the mechanical properties of power plant materials

Mechanical properties of materials pre-exposed to sCO$_2$

Fatigue
Creep
Creep-Fatigue

Supercritical CO$_2$ autoclave system capable of 275 bar up to 800°C
clamp
cap
3-zone heater
Diffusion bonding was demonstrated as a viable process to fabricate high-temperature, high-pressure microchannel heat exchangers. Sufficient mechanical strength of diffusion bonded stacks of alloy 230 sheet material was obtained through process modeling and experimental verification.

Oxidation of diffusion bonded H230 in CO₂ @700°C

- Similar and dissimilar metal welds
  - P22 – P91
  - P91 – 347H
  - P22 – Alloy 263
  - Alloy 625 – Alloy 263
  - 347H – Alloy 263
  - P22 – P22
  - P91 – P91
  - 347H – 347H
  - Alloy 625 – Alloy 625
  - Alloy 263 – Alloy 263

- Corrosion tests of welds
- Mechanical testing of welds
Oxy-Fuel Combustor Modeling

*CFD exploration of high-pressure oxy combustion in a swirl stabilized non-premixed research combustor. What if??*

- **P=300bar**
- **20%O2/80%CO2**
- **T=2050K**
- **Mdot=72 kg/s**
- **180 MW**

- **3.3M Cells**
- **LES (Dynamic Smagorinsky)**
- **1-step mechanism**

• Compressible LES formulation allows for simulation of combustion dynamics.
• Spontaneous thermo-acoustic instability @ 4000 Hz observed – azimuthal or “spinning” mode.

• Peak-to-peak pressure amplitude ~ 80% of mean combustor pressure. $P_{\text{avg}}=4,500$ psi, $P_{\text{pp}}=3,600$ psi.
Temperature and pressure contours at limit cycle operation.
Oxy-Fuel Combustor Modeling

Temperature (K)

Heat of Reaction (W)

Pressure (Pa gauge)

Tangential Vel (m/s)
Liquid rocket engine (NASA 1957)

Liquid rocket engine (NASA 1963)