A Staged, Pressurized Oxy-Combustion System for Carbon Capture

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Pressurized Oxy-Combustion

• The requirement of high pressure CO$_2$ for sequestration enables pressurized combustion as a tool to increase efficiency and reduce costs

• Benefits:
  – Latent heat of flue gas moisture can be utilized --> increased efficiency
  – Reduces flue gas volume --> lower capital and operating costs
  – Avoids air ingress
  – Reduces oxygen requirements
First Thoughts on Temperature Control

• Temperature in oxy-combustion is typically controlled by addition of RFG or water (CWS or steam)

• But, global combustion temperature is also a function of stoichiometric ratio
Fuel Staged Oxy-Combustion


- Flue gas recirculation reduced to 50%
- Higher heat flux to the wall observed
Fuel-Staged Oxy-Combustion

- Multiple boiler modules connected in series w.r.t. combustion gas
- Enables near-zero flue gas recycle
Benefits of Staged Combustion

• Near-zero flue gas recycle
  – Minimizes flue gas volume
  – Minimizes equipment size
  – Minimizes parasitic loads and pumping costs associated with RFG

• Maintain high temperature
  – Increased radiation heat transfer
  – With proper design, can yield maximum and uniform heat flux to the boiler tubes
Modeling Design Basis

- 550 MWe
- Combustion pressure: 16 bar
- Supercritical steam: 3500 psig/1100°F/1100°F (240 bar/600°C/600°C)
- Generic Midwest location, ISO ambient conditions
- PRB Sub-bitum. and Ill #6 bitum. coals considered
- 90% CO₂ recovery, EOR-grade CO₂: >95%v CO₂, < 0.01%v O₂
- Follows DOE baseline:

Cost and performance baseline for fossil energy plants volume 1: bituminous coal and natural gas to electricity
DOE/NETL-2010/1397, rev. 2
ASPEN Plus Results – Plant Efficiency

1. Cost and performance baseline for fossil energy plants volume 1: bituminous coal and natural gas to electricity DOE/NETL-2010/1397, rev. 2

2. Advancing Oxycombustion Technology for Bituminous Coal Power Plants: An R&D Guide. DOE/NETL - 2010/1405
Efficiency Gain Breakdown

- DCC - Thermal Energy Recovery
- Aux. Load Reduction
- ASU - Thermal Energy Recovery
- Rankine Cycle Improvements
- Base

Net Plant Efficiency % (HHV)

Atmospheric Oxy: 29.3%
SPOC: 36.7%

Illinois #6 Comparison Cases
Latent Heat Recovery

DCC wash column

cooling water (cw)

dried flue gas

wet flue gas

cw + condensate

<table>
<thead>
<tr>
<th>Pressure (bar)</th>
<th>Exit Temp (°C)</th>
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<tbody>
<tr>
<td>16</td>
<td>167</td>
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<tr>
<td>30</td>
<td>192</td>
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<td>36</td>
<td>199</td>
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Effects of Pressure

- Increase in Recoverable Heat from DCC (%)
- Increase in Recoverable Heat from ASU (%)
- Net Plant Efficiency Increase (%)
Effects of Fuel Moisture

Change in Net Plant Efficiency (%) vs. As-fired Fuel Moisture (%)
CFD Results - Wall Heat Flux

- 4 vessels of similar design, for 550 MWe plant
- Pressure = 16 bar
- Resulting peak heat flux within limits of traditional SC tube materials
Experiments – 1 atm

Advanced Coal & Energy Research Facility (ACERF)
1 MWth capacity

Initial experiments with high O2 concentration:

- Once-through, oxygen-enhanced combustion
- O2 injected into secondary stream only, coal is carried using air
- Portion of N2 is replaced by equal volume of O2
  - Increase stoich ratio to mimic staging
  - Adiabatic mixture temp held constant
Results

**Radiative Heat Flux [kW/m²]**
- Distance from Quarl Exit [m]
- Air Firing
- 40% O2

**Centerline Gas Temperature [°C]**
- Distance from Burner Quarl [m]
- Air-Firing
- 40% O2

**NOx (ppm)**
- Air
- 40% O2

Images:
- air
- 40% O2
Key Features of SPOC Process

- Increased radiative heat transfer
- Ideal for “lead chamber” process for NOx/SOx removal
- Reduced gas volume
- Modular boiler construction
- Near-zero recycle
- Increased performance of wet, low BTU fuels
- Reduced oxygen demand
- Higher efficiency through dry feed
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