Development of Staged, Pressurized Oxy-Combustion

Presented by:
Akshay Gopan

Co-Authors:
WUSTL: Z. Yang, A. Adeosun, B.M. Kumfer, R.L. Axelbaum
EPRI: J. Philips, D. Thimsen

IEA Oxy-fuel Network Meeting, Wuhan, China
Oct. 28, 2015
1st Generation Oxy-Combustion

Image: ALSTOM
Pressurized Oxy-Combustion

• The requirement of high pressure CO₂ for sequestration enables pressurized combustion as a tool to increase efficiency and reduce costs.

• Benefits of Pressurized Combustion
  – Recover latent heat of flue gas moisture ➔ improved efficiency & cost
  – Combine latent heat recovery ➔ reduced cost
    with integrated pollution removal
  – Reduce gas volume ➔ reduced equipment size
  – Avoid air-ingress ➔ reduced CO₂ purification costs
  – Higher P₀₂ ➔ reduced oxygen requirements for burnout
  – Optically dense atmosphere ➔ improved control of radiation HT
Fuel-Staged Oxy-Combustion

Multiple boiler modules connected in series w.r.t combustion gas

Enables near-zero flue gas recycle

Maintains high average temperature – increased radiative over convective heat transfer.
AG2  Check some other presentation might have a better figure with the S.R. bold
Gopan, 18/10/2015
SPOC Process Flow Diagram

Dry Pumps or Lockhoppers

Coal Milling

Coal Feeders

Dry N₂ to Cooling Tower

Moist N₂

Air

ASU Cold Box

N₂

Steam Cycle

O₂

Compressor

O₂

Steam Cycle

Steam Cycle

Steam Cycle

Steam Cycle

Coal

Vent Gas

Cooling Water

CO₂ Boost Compressor

CO₂ Pipeline Compressor

CO₂ to Pipeline

Direct Contact Column

SO₃ and NOₓ removal

Std. ASU: O₂ P = 1.1 bar
Process Modeling Results – Net Efficiency

- More than 6 percentage points increase in net plant efficiency over 1st generation oxy-combustion process.

- Independent study shows more than 2.5 times increase in efficiency improvement over other pressurized oxy-combustion process

\[ \text{Increase in Efficiency:} \quad 2.3\ \text{pts} \quad \rightarrow \quad 6.2\ \text{pts} \]

\[ \text{Net Plant Efficiency:} \quad \sim 38.3\% \quad \rightarrow \quad 29.5\% \quad \rightarrow \quad 35.7\% \]

\[ \text{Sources:} \ a \text{Scaled (IECM \& DOE/NETL);} \ b \text{DOE/NETL 401/093010;} \ c \text{Gopan et al (2014) Applied Energy;} \ d \text{Hagi et al (2014) Energy Procedia.} \]
Add EDF results.
Gopan, 19/10/2015
Desired Characteristics of a Pressurized Boiler

- Long combustion zone for distributed heat release
- Avoid flame impingement.
- Keep max. radiant heat flux below material constraints for standard materials.
- Minimize ash deposition and slagging
  - axial flow (no swirl), low mixing sufficiently high velocity

Source: NETL
Effects of flame shape on wall heat flux

Xia et al., Eastern States Section of the Combustion Institute, 2013
1 atm. Burner Performance Test with Propane

Diagram showing a burner with dimensions labeled as follows:
- φ2.37"
- φ6.6"
- 30"
- 18"

To Filter & Blower

Comparative images:
- Pure Oxygen
- 50% Oxygen
Pulverized Coal Combustion in $O_2$

- 25 kW thermal input
- CO$_2$ carrier gas
- Pure O$_2$, S.R. = 4

Wall Deposition Probe

1/4000 s shutter speed
AG5  I think I prepared this for either Joerg or EPRI.
Gopan, 19/10/2015
Full-Scale Conceptual Design: CFD Results

1536 MW thermal input
Fuel Distribution and Heat Flux

<table>
<thead>
<tr>
<th>Thermal input</th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
<th>Stage 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>340 MW</td>
<td>302 MW</td>
<td>385 MW</td>
<td>513 MW</td>
<td></td>
</tr>
</tbody>
</table>

![Graph showing heat flux distribution across stages](image)
Radiant Heat Transfer

Optically thick medium

Oxidizer
Fuel
Oxidizer

Flame

Incoming radiation

Incident radiation

Scattered

Emitted

Outgoing radiation

\[ \text{CO}_2 \]
\[ \text{H}_2\text{O} \]
\[ \text{Char/ash} \]
Fundamental study on radiation

Effect of absorption coefficient on radiation with profiles

Only 10% of transmission occurs at optical thickness of 2.3

$$\zeta = \int_0^s k_a ds$$
Demonstration of Radiative trapping

First 30 m of full scale SPOC Stage 1

\[ \zeta = 2.3 \]

\[ x = 10 \text{ m} \]
Conclusions

- A high efficiency carbon capture process was described and the improvements in efficiency shown.
- An axial and centered flame demonstrated with the new burner & furnace design.
- Flame impingement on wall avoided.
- Radiative trapping as a means to control radiative heat flux described.
- Full scale SPOC boiler models with manageable wall heat flux shown.
Acknowledgements

Funding

U.S. Department of Energy: Award # DE-FE0009702

Wyoming Advanced Conversion Technology Research Program

Consortium for Clean Coal Utilization, Washington Univrsity in St. Louis

Sponsors: Arch Coal, Peabody Energy, Ameren
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