Characterizing Impacts of High Temperature and Pressures in Oxy-Coal Combustion Systems

Department of Energy under Cooperative Agreement No. DE-FE0025168

2017 NETL CO$_2$ Capture Technology Project Review Meeting
Omni William Penn Hotel; Pittsburgh, PA
August 25, 2017
Key second generation candidates for CO$_2$ capture include high temperature and pressurized oxy-firing of coal.

Promising technologies because of potential to increase efficiency, lower capital costs, avoid air ingress and reduce oxygen requirements.

Unquantified challenges exist in the practical utilization of these technologies.
HTHP Timeline and Budget

September 1, 2015 – August 31, 2018

1.0 Project Management & Planning & Reporting
2.0 100 kW OFC no RFG Tests
3.0 1 MW Coal - Oxygen Burner Design & Construction
4.0 1 MW Pulverized Coal Furnace (L1500) Modification
5.0 1 MW Pulverized Coal Furnace (L1500) no RFG Tests
6.0 100 kW Oxy Fuel Combustor (OFC) Particle Tests
7.0 Mechanism Development
8.0 High Temperature Mechanism Validation
9.0 300 kW Pressurized Entrained Flow Gasifier (EFG) Modification
10.0 300 kW Pressurized Combustion Tests
11.0 High Pressure and Particle Mechanism Validation
12.0 Conceptual Furnace Design and Validation
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Total Budget
$1,570,596

Total Federal
$1,251,541

U of U Federal Share
$796,220

Cost Share
$319,055

REI Federal Share
$455,321

U of U Cost Share
$199,055

Praxair Cost Share
$60,000

Jupiter Oxygen Corp. Cost Share
$60,000
Program Approach

Experimental

- High Temp Atmospheric Thermal Profile
- High Temp Atmospheric Particle Behavior
- Elevated Temp High Pressure Thermal & Particle Behavior

Modeling

- Validate High Temp Mechanisms
- Design High Temp Firing System
- Validate High Pressure Mechanisms

Use CFD Modeling for Conceptual High Temp High Pressure Utility Boiler Design
Technical Approach

Experimental

High Temp (Minimum Recycle)

Experimental

Elevated Temperature & Pressurized (17 bar)

Oxy-fuel Combustor 100 kW – Atmospheric

L1500 Multi-fuel Furnace 1.5 MW – Atmospheric

300 kW Pressurized Entrained Flow Reactor

Modeling

Design High Temp Firing System

Modeling

Design Pressurized Firing System
CFD Tools: GLACIER

- REI’s in-house CFD software
- Developed specifically for application to solid fuel fired furnaces and boilers
- 3D, steady-state, turbulent flows
- Coupling between turbulent fluid mechanics, radiative and convective heat transfer, homogeneous and heterogeneous reactions
- Statistical description of particles including particle dispersion
- Pollutant formation kinetics for NOx, SOx, CO, Hg and fine particles
- Continually evolving including recent developments for atmospheric pressure and pressurized oxy-coal applications
100 kW Oxy-Fuel Combustor

Specifications

- 100 kW (0.25 MBtu/hr) Firing Rate
- Main Burner Zone 20 in x 48 in
- Quartz Windows for Optical Access of Flame
- Vertical Height 12.5 ft
- Horizontal Convective Section 12 ft

Research

- Ash Formation
  - Aerosols
  - Deposition
  - Trace Elements
- Sorbent Development
- Optical Diagnostics
  - Flame, Radiation & Flow Field
CFD Model Predictions (Validation)

Burner 2

Burner 8

Burner 11

Gas Temperature (°F)
- 4000
- 3250
- 2500
- 1750
- 1000

Plane shown
- northeast window
- southwest window

Burner 2

Burner 8

Burner 11
CFD Model Predictions (Validation)

K-type thermocouples located in the top section (3 flush with the inside wall, 3 at the midpoint between the inside wall and outside shell).
Ash aerosol PSD and deposits (vertical, inside and outside)

Horizontal deposits:
Outside deposits: loosely bound, easily removed by vigorous shaking.
Inside deposits: tightly bound, removed only by scraping.
Sample ash deposition rate results from DOE Cooperative Agreement No: DE-FE0025168

Ref.
1.5 MW CFD-Based Burner Design

Pulverized Coal Combustor (L1500)

Unique L1500 Capabilities:
- Realistic Burner Turbulent Mixing Scale
- Realistic Radiative Conditions
- Realistic Time – Temperature Profile
Leveraging Strengths of Project Partners

Jupiter Oxygen Corporation High Temperature Oxy-Combustion

Gas Temperature (ºF)

4900
4000
3100
2200
1300
400
1.5 MW CFD-Based Burner Design

- **Elongated Heat Release**
- **Rapid Mixing**

**Design Case** (Peak 4385 °F)

**Highly Mixed Case** (Peak 4822 °F)

**Gas Temperature (°F)**:
- 4000
- 3300
- 2600
- 1900
- 1200
- 500

**Wall Temperature (°F)**:
- 3000
- 2700
- 2400
- 2100
- 1800
- 1500
Results: Air-Fired Flame
1.5 MW CFD Model Predictions
July, 2016 High Temperature Oxy-Coal Tests
Experimental Results: Furnace Heat Balance

Coal
3.00 MBtu/hr

Preheated Gas
0.01 MBtu/hr

Flue Gas
0.33 MBtu/hr

Cooling Panels
0.59 MBtu/hr

Cooling Coils
0.94 MBtu/hr

Cooling Jackets
0.31 MBtu/hr

Wall Heat Loss
0.80 MBtu/hr

Heat Loss From Furnace
2.69 MBtu/hr

Measured Heat Removal
2.64 MBtu/hr

1.3 % Difference
Wall surface temperature was an important determining factor for burner design.

- CFD model predictions of wall temperature are in good agreement for the un-swirled and swirled conditions through Section 7 of the furnace.
Conduct experiments at University of Utah’s Entrained Flow Pressurized Reactor

Validate simulations of high pressure

Next Steps
Two years into the program: eight of eleven technical tasks have been completed

100 kW simulations provide a good representation of the thermocouple data and wall heat flux as measured by multi-depth thermocouples in the wall

Submicron particle concentration is directly correlated with formation rates of the initial deposit layer, which subsequently facilitates the capture of larger particles

A model-based approach was used to represent the physical and thermochemical phenomena associated with ash transformation

The predicted mass of the submicron particles is comparable to the experimental data in both absolute value and relative value

CFD model predictions of deposition of the submicron particles are consistent with the experimental data in terms of trend and magnitude

1.5 MW simulations for multiple parameter variations based on a simple burner concept in the L1500 have been completed

Burner design efforts to increase peak flame temperatures are typically counter to efforts to distribute heat axially

Extended heat release correlated to particulate burnout and the percentage of exit CO\textsubscript{2} evolved indicate best performance for protecting combustion components

CFD model predictions of wall temperature are in good agreement for the un-swirled and swirled conditions through Section 7 of the furnace

Experimental campaign for elevated temperature and high pressure oxy-coal combustion has begun
Acknowledgment

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Thank You