Characterization of Oxy-combustion Impacts in Existing Coal-fired Boilers

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Project Overview

• **Objective:** *Characterize and predict performance and operational impacts of oxy-combustion retrofit designs on existing coal-fired boilers*

• **Approach:** Utilize multi-scale testing and theoretical investigations to develop:
  
  – **Fundamental data** that describe flame characteristics, corrosion rates, and ash properties during oxy-coal firing
  
  – **Validated mechanisms** that describe oxy-combustion processes
  
  – **Firing system principles** that guide oxy-burner design and flue-gas recycle properties

• **Incorporate validated mechanisms into CFD software to evaluate full-scale oxy-combustion retrofit designs**
Retrofit Assessment Capability

Evaluate impact of oxy-firing design and flue gas recycle (FGR) ratio and composition on:

• Flame Characteristics
  – Heat transfer (temperature, emissivity, sooting)
  – Particle ignition, char burnout
  – NOx, SOx, fine particulates

• Surface Characteristics
  – Heat flux profiles
  – Slagging
  – Fouling
  – Corrosion

Recycle streams
R1 – ash, H2O, SO2, CO2
R2 – H2O, SO2, CO2
R3 – SO2, CO2
R4 – CO2

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## Project Team

<table>
<thead>
<tr>
<th>Team Member</th>
<th>Project Role</th>
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<tbody>
<tr>
<td>REI</td>
<td>program management, testing oversight, mechanism development, simulations</td>
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<tr>
<td>University of Utah</td>
<td>laboratory and pilot-scale testing, mechanism development</td>
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<tr>
<td>Siemens Energy</td>
<td>burner technology</td>
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<td>Praxair</td>
<td>oxygen and CO₂ supply</td>
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<td>Brigham Young Univ.</td>
<td>soot measurements</td>
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<td>Corrosion Management</td>
<td>corrosion tests, mechanism development</td>
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<td>Sandia National Labs</td>
<td>bench-scale testing, mechanism development</td>
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<tr>
<td>Vattenfall AB</td>
<td>mechanism development, validation data</td>
</tr>
<tr>
<td>PacifiCorp, Praxair, Southern Company, Vattenfall</td>
<td>Advisory Panel provides industrial perspective on R&amp;D needs, retrofit requirements and constraints, suggested assessment studies</td>
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Approach

• Development of Fundamental Data (Multi-Scale Experiments)
  • Development and Validation of Mechanisms
  • Firing System Principles
  • Assessment of Oxy-combustion Retrofit
Bench-Scale Optical Entrained Flow Reactor

(Shaddix, 2007)

- Temperature measurements of individual particles
- Rapid devolatilization under boiler relevant conditions
- Relevant gas temperatures and compositions

Experiments

Char Oxidation

Measurements

Particle Burnout (through collection and analysis)

Optical Sizing Pyrometry (particle size and temperature profile)
100 kW Oxy-Fuel Combustor (OFC)

- CO₂ from tank or FGR
- Optional particulate and SO₂ control
- Optional condensation
- Variable FGR temperature

Experiments
- Ash Deposition and Characterization
  - Soot Evolution

Measurements
- Low-Pressure Impactor Collection
- Computer Controlled Scanning Electron Microscope (CCSEM)
  - particle composition analysis
- Scanning Mobility Particle Sizer (SMPS)
- Two-Color Extinction Pyrometry
OFC Preliminary SMPS Data

AIR SMPS Mass Distribution

SMPS distribution for matched flame temp O2/CO2

SMPS Mass distribution of O2/CO2 high temp attached flame

SMPS = Scanning Mobility Particle Sizer
1.2 MW Pilot-Scale Furnace (L1500)

Experiments
- Fuel, Oxygen and FGR Mixing in Burner
- Corrosion, Radiation, Particle Deposition

Measurements
- Flame Stabilization Location, Temperature Profile, Flue Gas Composition, Unburned Carbon in Ash
- Real-Time Corrosion Rates of different materials using EN Technology
- Heat Flux
- Deposition Rate and Characterization

- Realistic burner turbulent mixing scale
- Realistic radiative heat flux conditions
- Realistic time–temperature profiles
- Retrofitted for flue gas recycle
Approach

• Development of Fundamental Data (Multi-Scale Experiments)

• Development and Validation of Mechanisms

• Firing System Principles

• Assessment of Oxy-combustion Retrofit
Char Oxidation Mechanism Development

Existing char oxidation model assumes reactions occur only at the surface (reaction limited). Data indicate O$_2$ film diffusion may be limiting for oxy-combustion (O$_2$ thru CO$_2$ slower than O$_2$ thru N$_2$).

Measured data combined with Surface Kinetics in Porous Particles (SKIPPY) modeling to guide development of new mechanism.

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Soot Mechanism Development

Soot formation (through cracking of tars in coal volatiles) shown to be dependent on oxygen concentration in oxy-fuel flames.

Contribution of soot to flame emissivity, relative to CO₂ and H₂O, will be evaluated using the narrow band model Radcal.

REI’s existing soot model combined with Radcal data and soot measurements to develop improved mechanism for soot formation and radiation.
Slagging Mechanism Development

Slagging (deposition in radiant section)
Dependent on:
- Particle size and composition
- Surface and particle temperatures
- Radiation heat flux conditions
- Local oxygen concentration

[Diagram showing heat transfer and deposition processes]

Impacted by oxy-combustion conditions

New mechanism extended from REI’s current deposition mechanism, which tracks ash composition and size distribution
Fouling Mechanism Development

Fouling (deposition in convective section)

Dependent on:
- Gas-phase alkali sulfates concentration
- Particle and tube temperatures
- Particle size distribution
- Tube geometry and velocity field

Impacted by oxy-combustion conditions

New mechanism extended from REI’s current deposition mechanism, which tracks ash composition and size distribution

Dew Point < $T_{\text{gas}}$ < Melting Point (1157 K)
Becomes sticky and condenses
Corrosion Mechanism Development

Factors Important For Corrosion

- Temperature
  - Metal and gas temperature
  - Heat flux
  - Temperature gradient
  - Temperature fluctuations
- Fuel/Deposit Characteristics
  - Sulfur, chlorine, alkali metals
- Local Gas-Phase Stoichiometry
- Tube Metallurgy
  - Cr, Ni, Al, etc.
- Boiler Design & Operation
  - Tube spacing, tube location, etc.
  - Flue gas velocity

Extend current REI corrosion mechanisms for:
- Oxidation, Chloridation, Sulfidation (gaseous H₂S, deposited FeS, molten sulfate)

Review Carburization mechanism

Impacted by oxy-combustion conditions

Mechanism Validation

• All mechanisms will be validated against data taken in the experimental program and against other available data

• Mechanisms will be implemented into CFD coal combustion code Glacier

• Overall CFD model will be validated against available pilot-scale and full-scale furnace data
Approach

- Development of Fundamental Data (Multi-Scale Experiments)
- Development and Validation of Mechanisms
- Firing System Principles
- Assessment of Oxy-combustion Retrofit
Firing System Principles

• Determine firing system dependencies based on:
  – Theoretical calculations extending air-firing experience and oxy-firing properties
  – Pilot-scale testing
  – CFD modeling

• Sensitivities to be investigated include:
  – Composition and amount of flue gas recycle
  – Oxy-burner design

• Develop firing system principles and use them to guide full-scale firing system design
Preliminary Pilot-scale Burner Modeling
Gas Temperature Profiles

Existing Air Burner

Air fired

O₂-CO₂ fired (27% O₂)

Oxy Burner Iteration 1

O₂-CO₂ fired (27% O₂)

Oxy Burner Iteration 2

O₂-CO₂ fired (27% O₂)

(CFD graphics created with Fieldview software from Intelligent Light)
Approach

• Development of Fundamental Data (Multi-Scale Experiments)
• Development and Validation of Mechanisms
• Firing System Principles
• Assessment of Oxy-combustion Retrofit
Assessment Approach

Design and optimization criteria:
- Match air-fired heat duties
- Maximize combustion efficiency
- Minimize surface impacts (corrosion, slagging, fouling)
- Minimize trace pollutant emissions
Program Status

• OFC measurement equipment assembled and initial air-firing and oxy-firing testing started
• Char oxidation testing and SKIPPY modeling started
• Initial pilot-scale oxy-burner design completed and being evaluated
• Development of slagging, fouling and corrosion mechanisms on-going
• L1500 testing to begin in Program Year 2 (Oct 2009)
Questions?

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