Stability of Axial Pulverized Coal Flames Under Oxy-Coal Combustion Conditions

by:

Prof. Jost Wendt
University of Utah / Reaction Engineering, USA
Stability of axial pulverized coal flames under oxy-coal combustion conditions

Jost O.L. Wendt & Eric Eddings
University of Utah

Presented at
2nd Workshop of the Oxy-Fuel Combustion Network
Hilton Garden Inn, Windsor, Connecticut
January 25-26, 2007

Acknowledgements
To those that have actually done the work.

• University of Arizona
  – Gregory Ogden, Ph.D.,
• University of Utah
  – Jing-Wei (Simon) Zhang, Ryan Okerlund
• Funding
  – US Department of Energy, University of Utah Clean Coal Center (UC3, Co-Directors Ron Pugmire and Adel Sarofim)
  – US Department of Energy University Coal Research Program (to U. Arizona)
Scope of this presentation.

1. Sample of current oxy-coal combustion research at the University of Utah
   - Work in progress
   - Based on:
2. Previous completed research at University of Arizona
   - Oxygen enrichment
   - Coal fines

Oxy-Combustion:
Schematic of oxygen fired PC furnace with CO$_2$ recycle \((\text{Sarofim et al.}, 2004)\)

Can we predict ignition/kinetic/aerodynamic interaction at the burner?

How much residual N$_2$, NO, Hg, SO$_2$ trace metals etc. can be removed with the CO$_2$ to be sequestered?

Can we predict heat transfer profile under oxy-coal combustion conditions.
Oxy-fuel combustion issues

- Recycle gas volume
- Where to withdraw recycle gas
- Heat transfer
- Flame stability
- Ignition
- NO\textsubscript{x}, SO\textsubscript{x}, Hg, trace metals
- Model validation (coal, aerodynamics, heat transfer etc.)

Oxy-Coal Combustion Research at U of U:

**Vision for this project**

- Build experimental facility to address technical issues related to oxy-coal combustion with carbon sequestration.
- Focus on understanding (high temperature) processes involved rather than inventing devices (burners).
- Develop enabling technology to allow commercialization of oxy-coal combustion within the near term.
  - Existing units?
  - Build on current technology?
  - “Baby step” approach?
Oxy-Coal Combustion Research at U of U: Vision contd.

- Focus on *simulation validation* (for retrofit).
- *Well defined*, axial Type 0, pulverized coal diffusion flames (*no swirl*)
- Simulates large class of practically relevant near flame aerodynamics
  - Cement kilns
  - Tangentially fired boilers.
- *Systematic* control of axial burner variables
  - Momenta, flows, velocities (using sleeves)
  - Composition, $P_{O_2}$, $P_{CO_2}$ in
    - Transport fluid
    - Secondary oxidant
  - Wall temperature

---

Task Oxy 1.1 - Progress

Design, construct, and troubleshoot a new down-fired 100kW, oxy-coal combustion furnace.
Task Oxy 1-1: Design attributes

Location of combustor

Design temperature profile

Task Oxy-1: Completed (1st quarter)

1. Overall design of oxy-fuel combustor
2. Fabrication of structure containing combustor
3. Fabrication
   - Steel shell, with refractory lining
   - Control panel
4. Design of
   - Burner (axial, controlled momentum burner for
     - Air
     - O₂
   - Quartz window for visual observation
Task Oxy-1: Completed 1st quarter (continued)

Design and placement of electric wall heaters (24 840W flanged ceramic plate heaters - 3 rows and 8 heaters per row)

Design of quartz window for visual observation and (later) optical diagnostics

Current status

Overview

View of inside of upper chamber, showing electric heaters and view windows.
Still to be completed

Task Oxy 1-1
- Complete fabrication of combustor
- Light off with pulverized coal and air
- Complete O₂ delivery train

Task Oxy 1-2
- Coal jet ignition experiments
  - Minimum P₀₂ in primary jet to allow stable ignition
  - Effect of P₀₂ & P₂CO₂ in primary jet on flame attachment

Task Oxy 1-3
- Preliminary validation of coal jet ignition simulation models

UU work is continuation previous work at University of Arizona
- 17 kW, downfired, heated walls, quartz window
- O₂ enrichment and/or coal fines in primary jet.
- Also restrict to coaxial flames
  - Attachment of Type 0 Flames
    • No secondary air swirl
    • No internal recirculation zone
- Represents corner fired boilers and cement kilns
  - Well defined aerodynamically
  - Good prototype configuration to validate models through systematic variation of known parameters.
  - Flame standoff distance has been identified as key parameter for NOₓ emissions in cement kilns
Flame aerodynamic issues and $O_2$ enrichment: Questions addressed.
(Greg Ogden, Ph.D dissertation, University of Arizona, 2002)

- What is the relationship between $O_2$ enrichment, near-burner aerodynamics and flame detachment and how can that be measured?
- What effect does oxygen partial pressure in the transport stream have on flame stability, flame detachment and NO$_x$?
- How do coal fines affect combustion stability and pollutant emissions?
Project Motivation

• Flame attachment is a critical variable for optimum performance of low NO\textsubscript{x} burners for pulverized coal combustion

• Need to promote formation of fuel-rich combustion zone
  – Fuel-N devolatilization
  – Reduction to N\textsubscript{2}

Approach

• Whereas, under well mixed conditions, oxygen enrichment are known to:
  – Increase combustion intensity, flame temperatures
  – Increase both Fuel and Thermal NO\textsubscript{x}

• Under diffusion mixed conditions, oxygen enrichment of only transport air
  – Should promote coal ignition and flame attachment
  – Reduce premixing
  – Reduce NO\textsubscript{x}
Approach-Cont’d

• Restrict to coaxial flames
  – Type 0 Flames
    • no secondary air swirl
    • No internal recirculation zone
• Represents corner fired boilers and cement kilns
  – Well defined aerodynamically
  – Flame standoff distance has been identified as key parameter for NOx emissions in cement kilns

Laboratory Furnace Details

• 18” ID hot wall furnace
  – Designed for “near flame” analysis
  – lightweight refractory
  – Air preheater
• 3’ Hot section
  – Multi-zone ceramic heaters
  wall temperatures to 1,300 K
  – Full length quartz window for flow visualization studies
  – 4 stationary sampling ports
Axial Burner

- Removable sleeves
  - Velocity is controllable
    - Fuel
    - Combustion air
  - Maintain constant momentum at different secondary air temperatures
  - Independently control velocity and momenta
- Supplemental gas injection if reqd.

Furnace Layout:
UA
17kW furnace
Oxygen Enrichment

- Varied transport air oxygen partial pressure ($P_{O_2}$)
  - 20-29% via $O_2$ enrichment
  - 13% via $N_2$ dilution
- Furnace wall temperature
  - 750° & 900°C
- General operating conditions
  - 2 kg/hr Utah coal, 1.2 SR overall
  - 450°C air preheat
  - $V_c \sim 31.2$ to 32.5 fps

Furnace Validation

Field Data (Crawford et al.)

- Open Symbols Represent Current Work
Flame Detachment
NO\textsubscript{x} Emissions Data

Open Symbols represent detached flame data

Temperature Effect on NO\textsubscript{x} Attached Flames

\[ \text{NO}_x = -0.0110T^2 + 25.6587T - 14649.7612 \]
\[ R^2 = 0.8961 \]
Subtle $P_{O_2}$ Effects

Coal Fines

- Investigate impact of fines fraction for a normal PC distribution
  - Fines-$d_p$ <10 microns
  - 0, 15% (base), 23% and 31% fines
  - 825 & 925°C walls
  - 21 & 29% transport air oxygen
Feeding Fines

Initial Setup

2M Furnace

Transport Air

Volumetric Feeder

Blending

2M Furnace

Transport Air

Volumetric Feeder

Blended Coal

Co-Feeding

2M Furnace

Transport Air

Volumetric Feeder

NO_x vs. Transport Air Oxygen

Transport Air Oxygen, %

NO_x, ppm (SR=1, Air)

0% Fines ▲ 15% Fines ▲ 31% Fines

Detached

Attached
Fines vs. NO\textsubscript{x} (attached flames)

Co-Feeding Base coal and Fines

Fines Reduce Flame Detachment

21% Transport Air Oxygen
Conclusions: Axial diffusion flame furnace

- Demonstrated the utility of the 2m laboratory combustor in examining near-flame combustion phenomena.
  - Full-length quartz window
  - Electrically heated walls
  - Axial burner
  - Allows for systematic adjustment and evaluation of individual parameters

Conclusions -Cont’d

- NO\textsubscript{x} emissions reduced through flame attachment
  - Up to 64% reduction
- Promote flame attachment by increasing
  - Transport air PO\textsubscript{2}
  - Fines
  - Wall temperature
Conclusions (Model B furnace)- Cont’d

• For always-attached flames
  – \( P_\text{O}_2 \) had only slight effect on \( \text{NO}_x \)
• For always-detached flames
  – Increasing \( P_\text{O}_2 \) reduced flame detachment
  – Slight increases in \( P_\text{O}_2 \) promoted flame stability
  – Increasing \( P_\text{O}_2 \) allowed otherwise detached flames to become attached and thus lower \( \text{NO}_x \)
  – Produced stable detached flames
Stability of axial pulverized coal flames under oxy-coal combustion conditions

Back Up – Additional Slides
Related research on oxy-coal combustion:

*Kinetic issues: premixed staged combustion (reactor mode – no diffusion flame)*

- Studies on down fired laboratory furnace firing ~2kg/h coal.
  - Model A: reactor mode for kinetic issues.
- O₂ enrichment and staged combustion of pulverized coal (Kinetic issues: Model A)

**Fuel NOₓ pathways**

[Diagram showing the pathways of fuel NOₓ formation, including volatile nitrogen, charcoal nitrogen, tar nitrogen, HCN, NH₃, and NO with reactions and pathways labeled.]

Oxygen enrichment in staged combustion

2 kg/h coal

- **First Stage**
  - Remove 10% of the total air
  - Replace 10% O₂ removed in first stage

- **Second Stage**
  - No change
  - All air removed in first stage

Flows are from a stoichiometric ratio of 1.2 overall, 0.7 in first stage.

**Kinetic Issues** and O₂ enrichment addressed through experimentation on Model A laboratory combustor. Exhaust NOₓ after staged combustion of pulverized coal vs SR in the first stage.

SR<sub>PRIM</sub> varied; SR<sub>EXHAUST</sub> = 1.2. Fixed staging location.