Large scale oxy-fuel systems: The role of laboratory combustor research.

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Project Activities Contribute to the Near-Zero Emission Energy Plant

Virtual Simulation

Systems Integration

Gasification & Combustion

Advanced Materials

Oxygen Membrane

Modeling - Combustion

Turbines & Fuel Cells

Modeling - Gas/Particle Flow

CO2 Sequestration

Hydrogen Membrane
Combustion: Schematic of oxygen fired PC furnace with CO$_2$ recycle (Sarofim et al, 2004)
Oxyfuel combustion issues

- Recycle gas volume
- Where to withdraw recycle gas
- Heat transfer
- Flame stability
- Ignition
- $\text{NO}_x$, $\text{SO}_x$, Hg
Related research on laboratory combustors:
Kinetic and aerodynamic issues

- Studies on two down fired laboratory furnaces each firing ~2kg/h coal.
  - Model A: reactor mode for kinetic issues.
  - Model B: axial diffusion flame mode for coupled aerodynamic issues.
- O₂ enrichment and staged combustion of pulverized coal (Kinetic issues: Model A)
- Effects of O₂ enrichment on pulverized coal axial diffusion flames (Coupled aerodynamic issues: Model B)
  - Flame attachment
  - NOx
Wall-Fired Burner

Tertiary staging air/ reburning fuel

Coal nitrogen mechanism gradually changing $SR_{1b}$

Ignition stand-off distance (determines $SR_{1a}$)
Fuel NO\textsubscript{x} pathways
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.
$O_2$ enrichment and coal N *kinetic issues*: Exhaust NO$_x$ after staged combustion of pulverized coal vs SR in the first stage.

$S_{R\text{PRIM}}$ varied; $S_{R\text{EXHAUST}} = 1.2$. Fixed staging location.
O₂ enrichment and flame aerodynamic issues: Questions addressed using Model B laboratory combustor.  
(Greg Ogden, Ph.D dissertation, University of Arizona, 2002)

- What impact do near-burner aerodynamics have on flame detachment and how can it be measured?
- What effect does oxygen partial pressure in the transport stream have on flame stability, flame detachment and NOₓ?
- How do coal fines affect combustion stability and pollutant emissions?
Project Motivation

• Flame attachment is a critical variable for optimum performance of low NO_{x} burners for pulverized coal combustion

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

• Whereas, under well mixed conditions, oxygen enrichment and firing micronized coal 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 and/or increasing fines content of regular coal
  – 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 $\text{NO}_x$ emissions in cement kilns
Type 0 Flames

Type-0
EXTERNAL RECIRCULATION
ATTACHED DIFFUSION FLAME

Lifted Type-0
PARTIALLY PREMIXED FLAME
Furnace Layout
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 Validation

Montana Coal-Pershing

Kentucky Coal-Pershing

Field Data (Crawford et al.)

Open Symbols Represent Current Work

NO, ppm (3% O2)
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
Attached

Detached

Coal stream
Flame Detachment
NOx Emissions Data

Open Symbols represent detached flame data
Subtle $P_{O_2}$ Effects
Temperature Effect on $\text{NO}_x$
Attached Flames

$$\text{NO}_x = -0.0110T^2 + 25.6587T - 14649.7612$$
$$R^2 = 0.8961$$
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

Co-Feeding

Blending

2M Furnace

LWF

Transport Air

Volumetric Feeder

Vol. Feeder

LWF

Transport Air

Volumetric Feeder

2M Furnace

Blended Coal
Fines Reduce Flame Detachment

21% Transport Air Oxygen
NO\textsubscript{x} vs. Transport Air Oxygen

![Graph showing the relationship between NO\textsubscript{x} and transport air oxygen. The graph includes data points for different transport air oxygen percentages and fines concentrations. The y-axis represents NO\textsubscript{x} ppm (SR=1, Air), and the x-axis represents transport air oxygen as a percentage. The graph shows data split into categories for 0% Fines, 15% Fines, and 31% Fines, with distinct markers for attached and detached conditions.]
Fines vs. NO$_x$ (attached flames)

Co-Feeding Base coal and Fines
Conclusions: Model B furnace

- Demonstrated the utility of the 2m laboratory combustor (Model B) 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 (Model B furnace) - Cont’d

- $\text{NO}_x$ emissions reduced through flame attachment
  - Up to 64% reduction
- Promote flame attachment by increasing
  - Transport air $\text{Po}_2$
  - Fines
  - Wall temperature
Conclusions (Model B furnace)-Cont’d

- For always-attached flames
  - \( \text{Po}_2 \) and fines had only slight effect on \( \text{NO}_x \)
- For always-detached flames
  - Increasing fines reduced flame detachment
  - \( \text{Po}_2 \) and fines had only slight effect on overall \( \text{NO}_x \)
- Slight increases in both fines and \( \text{Po}_2 \) promoted flame stability
  - Attached otherwise detached flames
  - Produced stable detached flames
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