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2\textsuperscript{nd} Oxyfuel Combustion Conference, Yeppoon, 2011
Presentation Roadmap

• Program Overview (Pilot-Scale Testing of Oxy-Coal Combustion)

• Fire-Side Corrosion
  – Corrosion Probe Configuration
  – Summary of Corrosion Rates Air vs. Oxy
  – Temperature Effects
  – Effects of Stoichiometric Ratio

• Summary and Conclusions

• Acknowledgements

• Questions
Program Overview

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

- Utilize multi-scale testing and theoretical investigations to develop:
  - Fundamental data that describe flame characteristics, waterwall corrosion, and ash properties (slagging, fouling) in oxy-firing
  - Validated mechanisms that describe impacts of oxy-combustion
  - Firing system principles (effects of oxy-burner design, flue-gas recycle)

- Incorporate validated mechanisms into CFD models and evaluate full-scale oxy-retrofit designs
1.5 MW Pilot-Scale Furnace (L1500)

Unique L1500 Capabilities:
- Realistic Burner Turbulent Mixing Scale
- Realistic Radiative Conditions
- Realistic Time – Temperature Profile
1.5 MW Pilot-Scale Furnace Experiments

- Experiments were performed at a firing rate of 1.02 MW
- Three different coals were used for this program to provide a range of sulfur concentrations:
  - Utah, Skyline
  - PRB, North Antelope
  - Illinois, Shay #1
- Pulverized coal was fired with air and with O$_2$/FGR
- Conditions chosen for this program:
  - 3% excess O$_2$ for all conditions
  - Oxy-fired conditions with 27% O$_2$, wet in the overall O$_2$/FGR mixture
- Experiments have been performed using an Oxy-Research Burner developed by Siemens and REI, based on an existing Siemens air-fired design
- Burner behavior was evaluated in parametric testing preceding the corrosion testing
- Praxair provided O$_2$ and CO$_2$
- Corrosion Management provided corrosion probes and participated in corrosion testing and data analysis
1.5 MW Pilot-Scale Furnace Experiments

Experiments

Burner Parametrics
- Fuel/Oxygen/FGR Mixing in Burner

Fire-Side Corrosion
(Radiation, Soot Formation and Particle Deposition)

Measurements

Flame Stabilization Location

Flue Gas Composition and Concentrations

Unburned Carbon in Ash

Temperature Profile

Real-Time Corrosion Rate
- Electrochemical Noise (ECN) Technology
- Soot Volume Fraction
- Two-Color Pyrometry
- Heat Flux/Radiation Intensity
- Deposition Sampling
### Coal Analysis

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*all values in mass % unless otherwise specified

- Skyline is a western bituminous coal and was used for all burner parametric testing
- All three coals were used for corrosion testing
Corrosion Testing (Feb – April 2010)

Electrochemical Noise “Real Time” Measurements

- Corrosion materials were chosen that are “typical” in existing US Utility Boilers
- Air and Oxy-Fired conditions have been tested, staged and unstaged
- Simultaneous measurement of Heat Flux, Deposition and Gas Conditions

Water Wall Probe
One Probe, One Material
SA-210

Super Heat Probes
Installed @ 1255 K Gas Temperature
Corrosion element controlled @ 761 K

Super Heat Probe
Three Probes, Three Materials
T22, T91 and 347h

Water Wall Probe
Installed @ 1533 K Gas Temperature
Corrosion element controlled @ 655 K
## Corrosion Element Material Analysis

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*All values in mass %*
Corrosion Probes

Superheat Probes

Water Wall Probe

P91

347h

T22
Normal Operating Conditions

- **Probe Element Temperatures**
  - SA210 (655– 728 K)
  - T22 (761 – 839 K)
  - P91 (761 - 866 K)
  - 347h (761 – 978 K)

- **Gas Temperatures**
  - Water wall probe ~ 1533 K
  - Superheat probes ~ 1255 K

- **SO2 Concentrations**
  - Utah, Air ~ 500 ppmv
  - Utah, Oxy ~ 1,800 ppmv
  - PRB, Air ~ 100 ppmv
  - PRB, Oxy ~ 300 ppmv
  - Illinois, Air ~ 3,000 ppmv
  - Illinois, Oxy ~ 18,000 ppmv

- **Oxidizing / Reducing Conditions**
  - Water wall probe – Mostly reducing conditions (BSR = 0.9)
  - Superheat probes – Oxidizing conditions
Average Corrosion Rates

Baseline sensor element temperatures, probe locations and staging conditions

High corrosion rates for high SO₂ conditions (3,000 – 18,000 ppmv)

High corrosion rates for low-alloy T22 and Utah, Skyline coal

All other corrosion rates very low
Increase in Corrosion Rate Air $\rightarrow$ Oxy

Baseline sensor element temperatures, probe locations and staging conditions

Wow, Why?

Waterwall Probe $\downarrow$ Corrosion
Air $\rightarrow$ Oxy Combustion

Superheat Probes Generally $\uparrow$ Corrosion
Air $\rightarrow$ Oxy Combustion
Corrosion Signal Response to Air- and Oxy-Combustion

P91 Superheater Probe

Similar Air Response Across Multiple Days

Increased Corrosion Rate for Oxy-Combustion
Temperature Effects on Corrosion

Operation of 347H at subcritical temperatures in the presence of high SO$_2$ concentrations will produce extremely high corrosion rates.

Decomposition and volatilization of the trisulphate species (Viswanathan and Bakker, 2000)
347H Metallographic Results

Backscattered Electron Images of the 347H Corrosion Element

Sulfur is present in the post-test scale and steel

Nickel has been removed in the post-test scale
Temperature Effects on Corrosion

Temperature dependence of corrosion with reproducibility
Effect of Stoichiometric Ratio on Corrosion

Variable oxidizing and reducing conditions

Always oxidizing conditions

OFA

Super Heat Probes
Installed @ ~ 1394 K Gas Temperature
Corrosion element controlled @ 761 K
Effect of Stoichiometric Ratio on Corrosion

(AIR) T22 corrosion rate spikes when going from reducing to oxidizing

T22 corrosion rate spikes when going from oxidizing to reducing (Oxy)
Summary and Conclusions
Fire-Side Corrosion

• Waterwall (SA210) corrosion rates decreased when converting from air to oxy-firing for all coals

• Superheater (T22, P91 and 347H) corrosion rates generally increased when converting from air- to oxy-firing

• Corrosion rates for the lower alloyed materials (SA210 and T22) were shown to increase drastically during transients between reducing and oxidizing conditions
  - likely to contribute greatly to practical in-plant corrosion rates in the near-burner and near-OFA port regions
  - These effects cannot be resolved using coupon tests

• The presence of condensed sulfur species strongly increases the corrosion rate of the 347H material under high sulfur and low temperature conditions

• The dependence of corrosion rate on material temperatures was demonstrated along with the repeatable nature of the results
Acknowledgements

Thanks to Ryan Okerlund at the University of Utah for preparing and operating the pilot-scale furnace

Thanks to Tim Fout, our DOE program manager for his patients

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