Comparison of Flame Stability under Air and Oxy-Fuel Conditions for an Aerodynamically Stabilized Pulverized Coal Swirl Flame

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40th International Technical Conference on Clean Coal & Fuel Systems,
May 31st – June 4th, 2015, Clearwater, Florida

Introduction

Different „modes“ of coal combustion:

Air

Oxy-fuel (21 vol.-% O₂)

Oxy-fuel (25 vol.-% O₂)

- What determines the stability of air and oxy-fuel flames?
- Possible parameters: flow velocities, momentum flows, oxygen concentrations, etc. etc.
- Investigation of flame stability conducted

Experimental Setup: Combustion chamber

Experimental Setup: Measurement techniques

Flue gas analytics: CO content

- Flue gas analyzer installed at the stack
- Measurement of CO concentration (dry) by non-dispersive infrared spectrography (NDIR)
- CO concentration used as an indicator for stable combustion (low values → stable combustion)

Experimental Setup: Measurement techniques

Investigation of OH* chemiluminescence

- Detection of UV radiation emitted by excited OH* radicals at approx. 307 nm
- Indication of zones with high reaction rates and heat release
- Mapping of flame structures
- Investigation of the entire flame:
 - Placing the burner at different height positions
 - Recording multiple images and average them
 - Generate **one** chemiluminescence map of the entire flame by composing the averaged images

Experimental Setup: Measurement techniques

Laser Doppler Velocimetry

- Coal particles used as tracer particles
- Measurement of axial and tangential mean flow velocity components by two laser beam pairs of different wavelengths
- Positioning of the measurement volume:
 - Radial position adjusted by traversing a horizontally displaceable rack for the optics
 - Axial position adjusted by traversing the burner
- Only axial velocity components considered in this study

Experimental Setup: Swirl Burner Oxy-3

Very schematic sketch of design flame shape

Internal recirculation
backflow

Conical dispersing swirl
combustion zone

Settings and Investigated Cases

Local Oxygen Ratio at Burner vicinity

- Parameter characterizing the near burner flow field: Local oxygen ratio λ_{local} :

$$\lambda_{local} = \frac{\dot{m}_{O_2, \text{trough burner}}}{\dot{m}_{O_2, \text{required}}}$$

- Takes only the flows through the burner into account
- Remaining oxygen provided by staging flow
- Influenced by the Oxygen content x_{O_2} and the molar mass $M_{Oxydizer}$ of the oxidizer

$$\lambda_{local} = x_{O_2} \cdot \frac{M_{O_2}}{M_{Oxydizer}} \cdot \frac{\dot{m}_{Oxydizer \text{ trough burner}}}{\dot{m}_{O_2}}$$

- Applied values: $\lambda_{local} = 0.6; 0.8; 1.0$

Settings and Investigated Cases

Oxidizer Composition

- Investigated Oxidizer Compositions:
 - „Reference“ case with air (21 vol.-% O₂) (**AIR**)
 - Oxy-fuel case with 21 vol.-% O₂ and 79 vol.-% CO₂ (**OXY-21**)
 - Oxy-fuel case with 25 vol.-% O₂ and 75 vol.-% CO₂ (**OXY-25**)
- Reasoning for these parameters:
 - OXY-21: Same volumetric flow rates, velocities and O₂ content as for the AIR case
 - OXY-25: Same momentum flow rates $\dot{P}$ as for the AIR case

$$\dot{P} = \dot{m} \cdot v = \frac{\dot{m}^2}{\rho \cdot A_{cross}}$$

Normalized total momentum flow through the burner

λ_{local}	AIR	OXY-21	OXY-25
1.0	1.000	1.438	1.003
0.8	0.640	0.920	0.642
0.6	0.360	0.518	0.361

Observations and Results

Stability assessment from flue gas analytics

- Stable combustion:
 - Low values of CO concentration within the flue gas (single digit range)
 - Continuous and stable trend of the CO concentration
- Instable combustion:
 - Raised and fluctuating values of CO concentration within the flue gas (100 – 200 ppm)
 - Sporadic distinct CO concentration overshoots

λ_{local}	AIR	OXY-21	OXY-25
1.0	stable	stable	stable
0.8	stable	stable	Stable
0.6	instable	stable	instable

Observations and Results

Intensity maps of OH* chemiluminescence emissions for AIR (relative intensity units)

Observations and Results

Mean axial velocities measured by LDV for AIR

$$\lambda_{\text{local}} = 1.0$$

Internal recirculation backflow

Extending conical swirl region

$$\lambda_{\text{local}} = 0.8$$

No recirculation backflow at $x = 100$ mm

$$\lambda_{\text{local}} = 0.6$$

No extending swirl

Observations and Results

Intensity maps of OH* chemiluminescence emissions for OXY-25 (relative intensity units)

Observations and Results

Intensity maps of OH* chemiluminescence emissions for OXY-21 (relative intensity units)

Observations and Results

Intensity maps of OH* chemiluminescence emissions for OXY-21 (relative intensity units)

Interpretation: Change of flame structure

Conclusions

- Transition between the two observed flame patterns seems mainly governed by the momentum flow through the burner
- Different momentum flows caused by two effects
 - Increased molecular weight of CO_2 in comparison to N_2
 - Increase of O_2 concentration in the oxidizer streams results in reduced overall mass flows for same oxygen ratio λ
- Balance of these two effects causes similar flame characteristics and change of flame pattern for the AIR and OXY25 cases
- The increased momentum flow for the OXY21 cases sustains the intended flow field pattern
- Stability of the investigated flame mainly determined by aerodynamic effects
- Main parameter for similar flame behavior: momentum flow

Thank you for your attention!

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Acknowledgements

Deutsche Forschungsgemeinschaft
DFG (German Research Foundation),
Collaborative Research Center
SFB/Transregio 129 „Oxyflame“

DFG