Experimental Analysis of Swirl Stabilized Oxyfuel Flames at Elevated Pressure

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6th Trondheim CCS Conference - Trondheim, Norway - June 14-16, 2011
Motivation

- Oxyfuel combustion for gas turbines connects the efficient combined cycle process with the post combustion capture option of the Oxyfuel process.

- It is suited for all kinds of fossil fuels, e.g. natural gas or syngas from coal.

- On paper, it is a highly efficient way to avoid CO₂ emissions while using fossil fuels.

- Oxyfuel combustion for gas turbines has never been taken beyond thermodynamic calculations.
Differences between oxyfuel combustion and air combustion for gas turbines

- **Differences in physical properties**
  - Heat capacity (1.6 times higher than N₂)
  - CO₂ is better absorber and emitter of radiative heat
  - Gas transport properties (viscosity, diffusivity, thermal conductivity)

- **Differences in chemical properties**
  - Higher chaperon efficiency of CO₂ (enhances third body reactions)
  - Participation in chemical reactions like
    \[ CO + OH \rightleftharpoons CO₂ + H \]
Experimental setup

**Burner:**
- Gas turbine model combustor
- Two co-swirled oxidizer flows
- Fuel injection through a ring between the oxidizer inlets

**Operation conditions:**
- Fuel: \( \text{CH}_4 \)
- Pressure: 1 - 10 bar
- Thermal power: 10 - 30 kW / bar
- \( \text{O}_2 \) fraction: 20 % - 40 %
- Fuel / oxidizer ratio: \( \phi = 0.5 – 1 \)
- Fuel / oxidizer temp: 300 - 750 K
High pressure oxyfuel test rig

- Pressure: max. 35 bar
- Thermal power: 300 kW
- Oxidizer:
  - Air: 2x 200 g/s
  - Oxygen: 40 g/s
  - CO\textsubscript{2}: 120 g/s
  - preheated: up to 800 K
Influence of the oxygen concentration

OH*-chemiluminescence imaging, averaged (200 images), Abel transformed

- Oxygen concentration is an additional parameter to influence the combustion behaviour
- Flame speed grows significantly with increasing oxygen level
- To match turbine inlet conditions oxygen concentration is limited to 18%
Flame stabilization at atmospheric conditions

OH*-chemiluminescence imaging, averaged (200 images)

(a) Ox = 30% O₂
    T_{Ox} = 300 K
    p = 1 bar
    Φ = 0.71
    P_{th} = 21.4 kW

(b) Ox = Air
    T_{Ox} = 300 K
    p = 1 bar
    Φ = 0.70
    P_{th} = 20.0 kW

- At 30% O₂ the flame shape resembles the shape of a stable CH₄/air flame.
- The flame stabilizes in the shear layer between irz and inflow of fresh gas.
Flame stabilization at pressurized conditions

OH*-chemiluminescence imaging, averaged (200 images), Abel transformed

- Flame stabilizes close to the burner surface
- Flame burns manly in the outer recirculation zone
- No flame stabilization in the shear layer between irz and incoming fresh gas

(a) Ox = 30% O₂
   T_Ox = 300 K
   p = 1 bar
   \( \Phi = 0.71 \)
   \( P_{th} = 21.4 \text{ kW} \)

(b) Ox = 30% O₂
   T_Ox = 653 K
   p = 5 bar
   \( \Phi = 0.71 \)
   \( P_{th} = 157 \text{ kW} \)
Flame stabilization at pressurized conditions 2

OH*-chemiluminescence imaging, averaged (200 images), Abel transformed

- At stoichiometric conditions the combustion zone moves closer to the windows
- It was impossible to stabilize flames with less than 26% O₂ in this burner

(a) Ox = 30% O₂
T_{Ox} = 653 K
p = 5 bar
Φ = 0.95
P_{th} = 157 kW

(b) Ox = 26% O₂
T_{Ox} = 753 K
p = 5 bar
Φ = 0.90
P_{th} = 157 kW
Strategies for realizing Oxyfuel combustion

- **Staged combustion**
  - Flame with higher oxygen concentration and lean conditions
  - Fuel injection in the hot products of the first stage

- **Dilution of the exhaust gas**
  - Combustion with higher oxygen concentration at stoichiometric conditions
  - Dilution of the exhaust gas with CO₂ to reduce temperature

- **Alternative combustor design**, which overcomes the problems arising from low flame velocity and reduced ignition delay times
FLOX® Burner Concept

- Novel burner concept based on the FLOX® principle
- Partially premixed fuel oxidizer mixture
- Discharged through orifices arranged on a circle
- High momentum jets without swirl
- Intense recirculation/mixing in the combustion chamber
FLOX® Based Oxyfuel Combustion

- First numerical investigations show:
  - Stable operation with oxygen concentration with 20% $O_2$ possible
  - Flame stabilization is comparable to methane air flames in the same combustor type
Summary & outlook

- Combustion behaviour of different Oxyfuel / CH₄ flames in a swirl burner was characterized over a wide parameter range at atmospheric and pressurized conditions.
- At pressurized conditions flame stabilizes mainly in the orz.
- It was impossible to stabilize an Oxyfuel flame with 20 % O₂ in the swirl stabilized burner.
- Oxyfuel combustion based on the FLOX® burner concept, could be a promising option.

- The new Oxyfuel burner concept has to be tested at pressurized conditions to prove the usability.
Acknowledgements

The presented work forms a part of the BIGCO2 project, performed under the strategic Norwegian research program Climit. The authors acknowledge the partners:

Statoil, GE Global Research, Statkraft, Aker Clean Carbon, Shell, TOTAL, ConocoPhillips, ALSTOM, the Research Council of Norway (178004/I30 and 176059/I30) and Gassnova (182070) for their support.