Experimental Analysis of Swirl Stabilized Oxyfuel Flames at Elevated Pressure

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Motivation

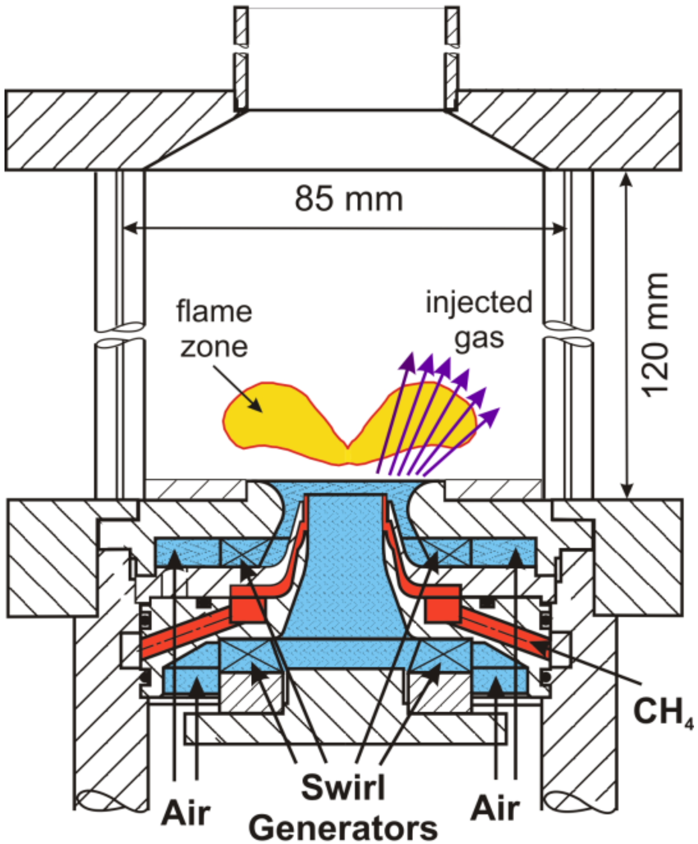
- Oxyfuel combustion for gas turbines connects the efficient combined cycle process with the post combustion capture option of the Oxyfuel process.
- It is suited for all kinds of fossil fuels, e.g. natural gas or syngas from coal.
- On paper, it is a highly efficient way to avoid CO_2 emissions while 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 N_2)
  - CO_2 is better absorber and emitter of radiative heat
  - Gas transport properties (viscosity, diffusivity, thermal conductivity)
- **Differences in chemical properties**
  - higher chaperon efficiency of CO_2 (enhances third body reactions)
  - Participation in chemical reactions like

$$CO + OH \Leftrightarrow CO_2 + H$$

Experimental setup



Burner:

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

Operation conditions:

- Fuel: CH_4
- Pressure: 1 - 10 bar
  Thermal power: 10 - 30 kW / bar
- O_2 fraction: 20 % - 40 %
- Fuel / oxidizer ratio: $\phi = 0.5 – 1$
- Fuel / oxidizer temp: 300 - 750 K

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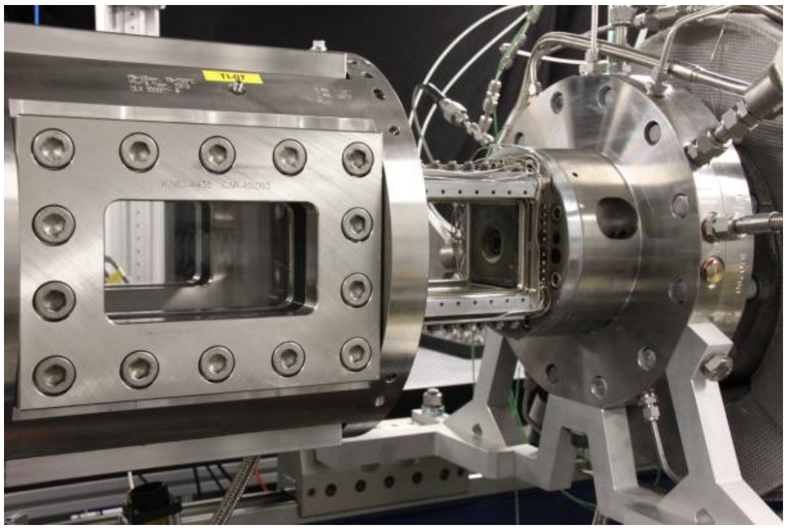
High pressure oxyfuel test rig



- Pressure: max. 35 bar
- Thermal power: 300 kW

- Oxidizer:
  - Air: 2x 200 g/s
  - Oxygen: 40 g/s
  - CO_2: 120 g/s
  - preheated: up to 800 K

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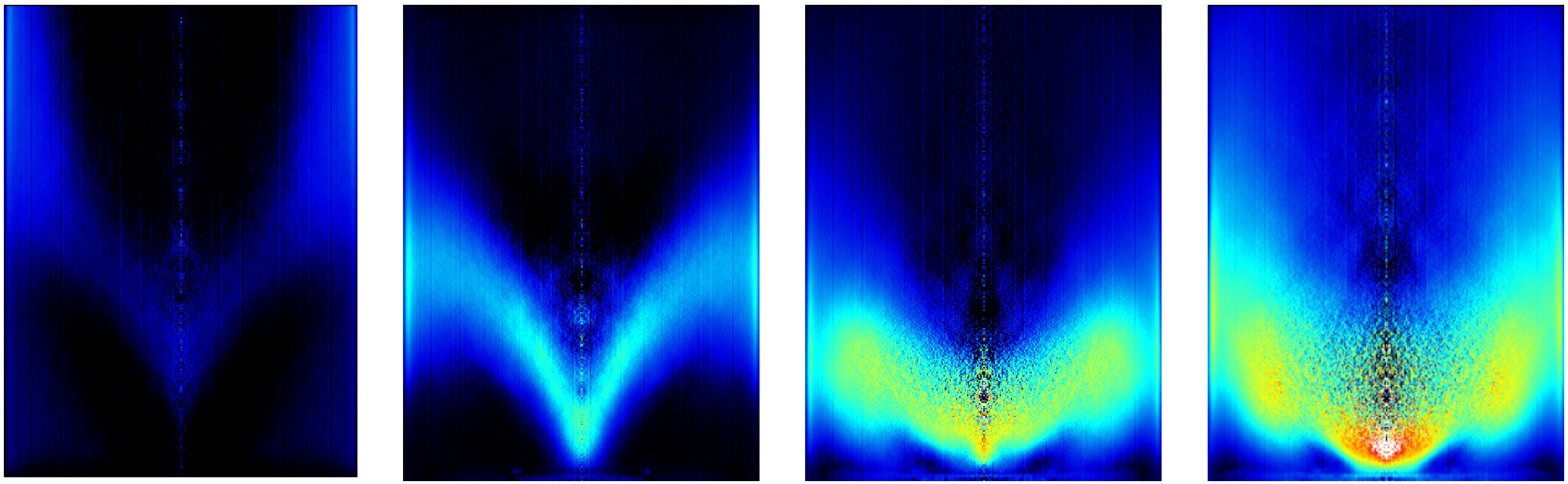
Influence of the oxygen concentration

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

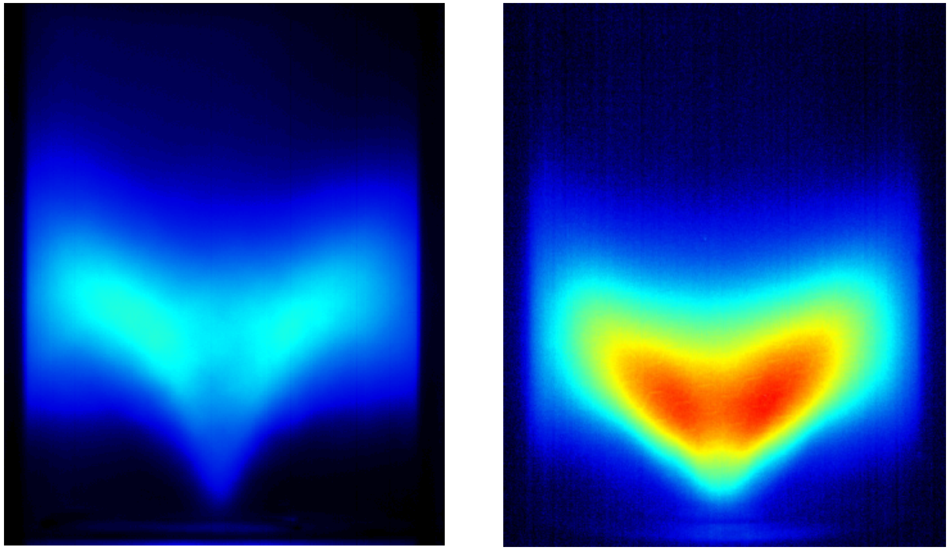


(a) 26 % O_2 (b) 30 % O_2 (c) 34 % O_2 (d) 38 % O_2

- 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% O_2
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% O_2 the flame shape resembles the shape of a stable CH_4/ air flame
- The flame stabilizes in the shear layer between irz and inflow of fresh gas

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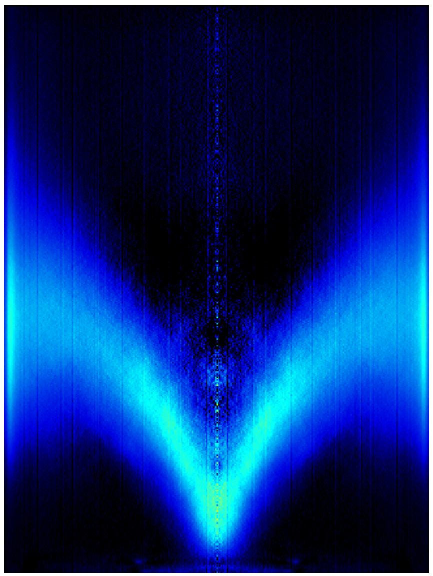
Flame stabilization at pressurized conditions

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



(a) Ox = 30% O_2
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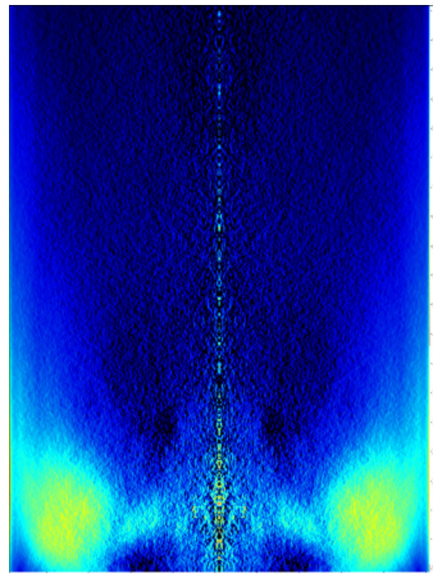

(b) Ox = 30% O_2
T_{Ox} = 653 K
p = 5 bar
Φ = 0.71
P_{th} = 157 kW

- 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

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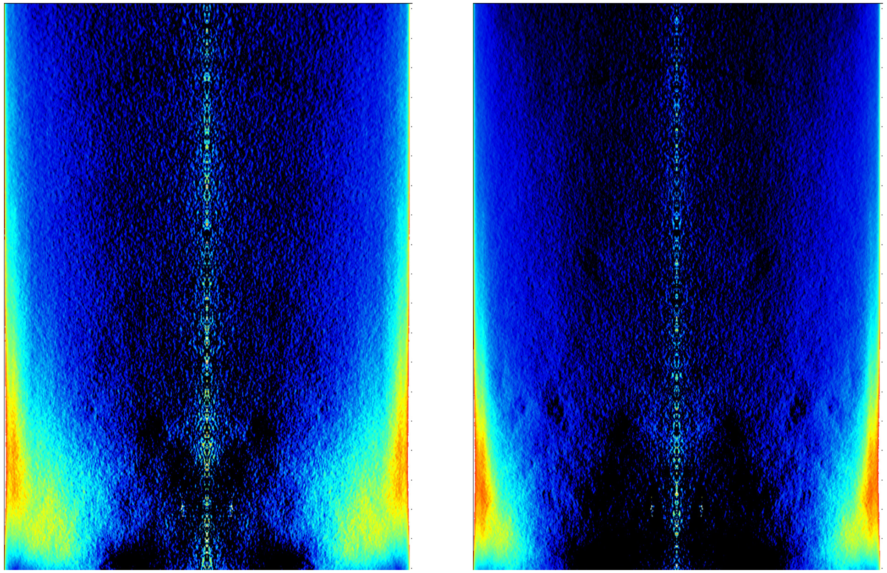
Flame stabilization at pressurized conditions 2

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



(a) Ox = 30% O_2
T_{Ox} = 653 K
p = 5 bar
Φ = 0.95
P_{th} = 157 kW

(b) Ox = 26% O_2
T_{Ox} = 753 K
p = 5 bar
Φ = 0.90
P_{th} = 157 kW

- At stoichiometric conditions the combustion zone moves closer to the windows
- It was impossible to stabilize flames with less than 26% O_2 in this burner

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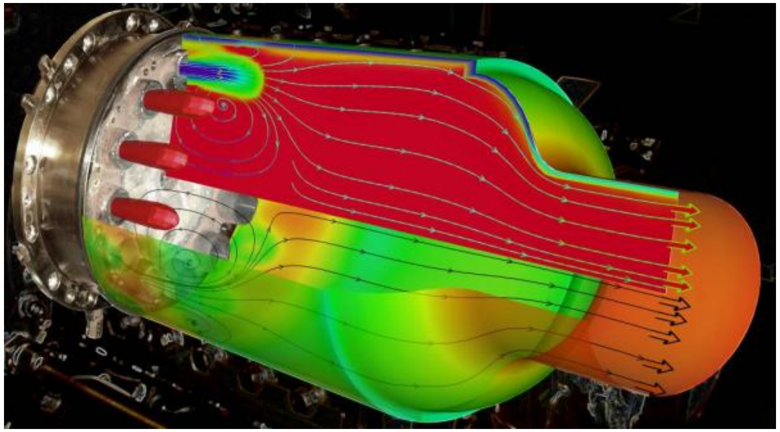
Strategies for realizing Oxyfuel combustion

- **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 CO_2 to reduce temperature
- **Alternative combustor design**, which overcomes the problems arising from low flame velocity and reduced ignition delay times

FLOX® Burner Concept

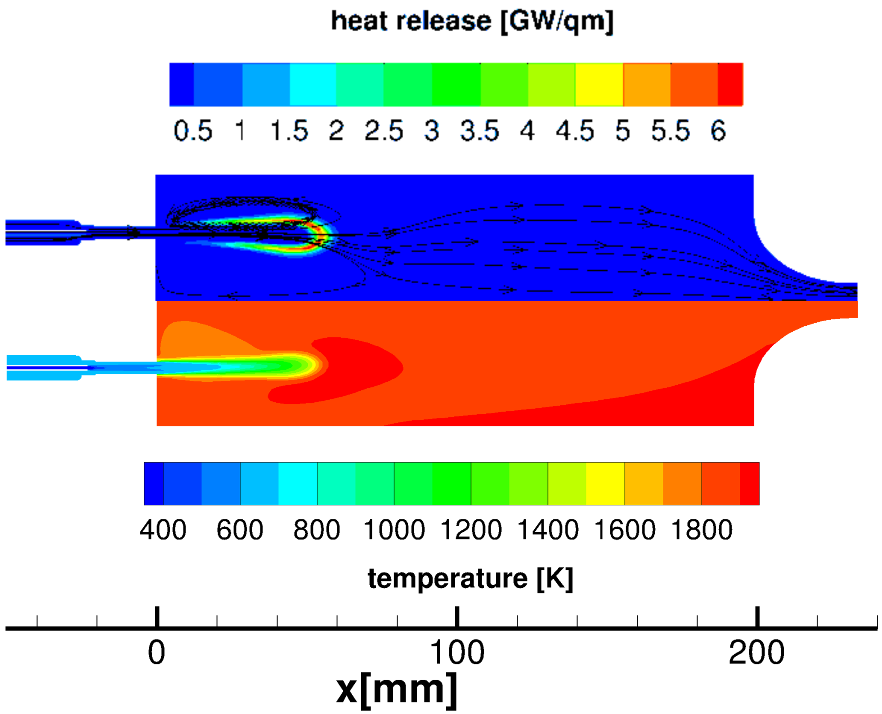
Novel burner concept based on the FLOX® principle

- 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 / CH_4 flames in a swirl burner was characterized over a wide parameter range at atmospheric and pressurized conditions.
- At pressurized conditions flame stabilizes manly in the orz.
- It was impossible to stabilize an Oxyfuel flame with 20 % O_2 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.

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