Oxycoal Swirl Flame Stability as a Function of Flue Gas Recycling Ratio

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Presentation Content

- OXYCOAL-AC project overview
- Oxycoal Swirl Burners and Test Facility
- Utility Scale Furnaces Simulations
- Conclusions
Oxyfuel Process

Cryogenic Air Separation Unit or Oxygen Transport Membrane (OTM)

Flue Gas (CO₂ & H₂O)

Coal

O₂

O₂ + CO₂ + H₂O

CO₂ compressor

Water

Steam

Condenser

H₂O

CO₂

OXYCOAL-AC
Membrane Based Oxyfuel Process

OXYCOAL-AC

Flue Gas
(CO₂ & H₂O)

Ash

Condenser

CO₂ compressor

Hot Gas Filtration

Steam

Steam

N₂

Air

O₂

O₂ + CO₂ + H₂O

Coal

OTM

OXYCOAL-AC

O₂

C02

H₂O


Topics:
- Coal Combustion in O₂/CO₂-Atmosphere
- High temperature membrane for oxygen supply
- Hot Gas Filtration

Long term planning:
Phase 1: (Sep 2004 to Jan 2008)
- Component development
Phase 2: (Feb 2008 to Feb 2011)
- Process integration and Component testing
**Oxygen Transport Membrane (OTM)**

![Diagram showing OTM process]

**Ceramic Perovskite Membranes:**

**Operating Parameters:**
- Temperature: 825 °C
- Mean Pressure Ratio: 20
- Mean Partial Pressure Ratio: 26
- Oxygen Separation Degree: 90 %
  (O₂ in depleted air: 2.5 vol.-%)

**Goal:**
Design, construct and integrate an O₂/N₂ separation membrane in an oxyfuel power plant process ➔ realise the process with highest efficiency
Goal:
Cleaning of the flue gas to a level suitable for the membrane and the recirculation fan.
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Cleaning of the flue gas to a level suitable for the membrane and the recirculation fan.
Combustion in CO₂ Atmosphere

Goal:

- Obtain stable and controlled oxycoal combustion at wide range of O₂-concentrations (15-30 vol.-%)

Starting point:

- Generic O₂/CO₂-mixture
- Thermo-physical and radiative properties
OXYCOAL-AC Test Facility

- **T = 300°C**
- **T = 850°C**
- Traversable burner
- Stack
- Compressor
- Window
- **O₂ injection**
- Cooler
- Hot gas filtration
- Ash
- **Coal**
- Wind box
- **Gas mixing unit**
- **CO₂**
- **O₂**
- Quench
- Water
- Stack
- Ash, quench water
OXYCOAL Tests
with Increased $O_2$- Levels

First approach:

- Utilizing a burner well-proven for air operation

pulsating flame
($O_2 < 34 \text{ vol.}-\%$)
Boudouard Equilibrium

Endothermic reaction (173 kJ/kmol)

\[ \text{CO}_2 + \text{C} \rightarrow 2 \text{CO} \]

Volume doubling (local oscillations)
Stabilising the flame: Oxycoal Burner

Measures to stabilise the flame:

- Constant flow velocities by stabilising the CO-production
- Strong internal recirculation of hot products to compensate for the increased heat capacity and the endothermic Boudouard reaction

Burner characteristics:

- Stable operation for $O_2$ concentration $\geq 18$ vol.-%
- Can also be operated with air
Development of Oxycoal Swirl Burner

Measures for oxycoal swirl flame stabilisation

CFD calculations

21 vol.-% O₂
19 vol.-% O₂
18 vol.-% O₂
Numerical Simulations (FLUENT®)  

- Heterogeneous and homogeneous reactions are modelled as UDFs:
  - Chemical reaction – turbulence interaction model: EDC + kinetics;
  - Devolatilisation models: 2 parallel reactions and CPD (+ LG sub-model);
  - Char-burnout models: apparent kinetics (CBK), Intrinsic and Langmuir approach

- Radiative Heat Transfer
  - Exponential Wide Band Model (11 Bands for CO₂, H₂O, CO) as UDF*

- Changes in the CFD algorithm for oxycoal conditions:
  - Parallel calculation of particle models (pyrolysis and char burnout)
  - Modelling of the heterogeneous reactions (char with O₂, CO₂, H₂O)

- Model validation
  - fluidised bed reactor for pyrolysis and char reactivity in CO₂
  - in-flame measurements at OXYCOAL-AC test facility**

* Erfurth et al., CCT 2009, Dresden, May 2009
** Toporov et al., Combust. Flame 155, 605-618, 2008
Burner Scale Up: CFD Results, 100 kW

Secondary stream, 21 vol.-% O₂

Coal + primary stream, 19 vol.-% O₂

Pyrolysis [kg/(m³s)]

CO mass source [kg/(m³s)]

Fast pyrolysis and particle ignition

≥ 1.1

1

0.5

0

0.2

0.1

0

0.1

0.2

m
New Burner Design:

40 kW

100 kW
80 kW Flames

Air

21 vol.-% $\text{O}_2$, rest $\text{CO}_2$ (dry)

21 vol.-% $\text{O}_2$, rest RFG (wet)
Combustion in CO$_2$ Atmosphere

- Large scale:
  - burners;
  - furnaces

Goal:
Design of an oxycoal boiler, accounting for the changed combustion atmosphere
The utility p.c. burner should be able to operate:

- in air combustion and

- within a wide range of $O_2$ vol.-% under oxycoal conditions

Not scale-up, but modification of conventional utility scale burners according to the measures for oxycoal swirl flame stabilisation
Utility Scale Burner (70 MW_{th})

Secondary / tertiary streams, 21 vol.-% O_2

Coal + primary stream, 21 vol.-% O_2

Pyrolysis
[kg/(m^3s)]

CO mass source
[kg/(m^3s)]

Fast pyrolysis and particle ignition
Oxycoal furnace performance compared to air-firing?

- Oxy-firing offers the possibility to vary a large set of parameters, e.g.
  - Temperature levels;
  - Oxygen concentration (recycle ratio);
  - Composition of recycled flue gas (wet or dry recycle)

- Impact on:
  - Heat transfer
  - Furnace exit temperature
  - Corrosion in the furnace
Utility Furnace (state-of-the-art USC) OXYCOAL-AC

- Thermal power: 1210 MW
- 18 burners → 70 MW each ($\lambda = 0.95$)
- 12 OFA nozzles ($\lambda_{\text{tot}} = 1.15$)
- Fired by South African bituminous coal
- 1,240,000 grid points
- 5 Cases:
  - AIR
  - Oxycoal, same oxygen: OXY21dry, OXY21wet
  - Oxycoal, same temperature: OXY30dry, OXY27wet
Temperature Fields, same O$_2$ vol.-%
Temperature Fields, similar $T_{\text{flame}}$

OXYCOAL-AC

<table>
<thead>
<tr>
<th></th>
<th>AIR</th>
<th>OXY30dry</th>
<th>OXY27wet</th>
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<tbody>
<tr>
<td>T [K]</td>
<td>2300</td>
<td>300</td>
<td>300</td>
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<td>300</td>
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**Notes:**
- The graphs illustrate temperature fields for different oxygen-enriched environments.
- The temperature range is from 300 K to 2300 K.
- The color scale indicates temperature variation.
CO Source from Particle Gasification, same O$_2$ vol.-%
CO Source from Particle Gasification, similar $T_{\text{flame}}$

\[
\log S_{\text{CO}} \quad [\text{kg}/\text{m}^3\text{s}]
\]

AIR

OXY30dry

OXY27wet
Surface Incident Radiation, same O₂ vol.-%
Surface Incident Radiation, similar $T_{\text{flame}}$

\[ q' = \text{[kW/m}^2\text{]} \]

AIR  OXY27wet  OXY30dry

Locally increased wall temperature
Comparison:
Normalised Surface Incident Radiation

![Graph showing comparison of O2 content and Q/Q_AIR for different conditions.

- AIR
- OXY21wet
- OXY21dry
- OXY27wet
- OXY30dry

Integrated over furnace walls:
- 23.8%
- 28.6%
Comparison: Temperature* and Enthalpy Flow (H)

* averaged at furnace exit
Summary

- Development, test and scale-up of a ~ 100 kW oxycoal swirl burner for stable operation in air- and oxy-firing:
  - within a wide range of O₂ vol.-% (18 to > 34 vol.-%)
  - with wet and dry recycling
- Measures derived for oxycoal swirl flame stabilisation successfully applied to utility scale single burner
- CFD simulations of a state-of-the-art furnace in air and oxy-firing of coal were conducted using a non-grey implementation of the EWBM
  - Same incident radiation as for air-firing obtained at oxygen content of:
    - ~ 24 vol.-% for wet recycle
    - ~ 28 vol.-% for dry recycle
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