Oxy-fuel Investigations with a Cement Kiln prototype Burner

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Oxy-fuel for cement production?

Without reduction measures: 2.4 Gt/a in 2050
BLUE MAP scenario (with CCS): max 1.6 Gt/a in 2050

Increase of energy efficiency
Alternative fuels use
Reduction of clinker share

Reduction by:
- CCS
- 2.5
- 2.0
- 1.5

Global CO₂ emissions of the cement industry in Gt/a

Source: IEA Cement Roadmap

- IEA target for 2050: 50 % of all cement plants in Europe, Northern America, Australia and East Asia apply CCS
- Cement plants typically have a long lifetime (30-50 years or more) and very few (if any) are likely to be built in Europe → Retrofit
CO₂ emissions in the cement industry

Source: ECRA
CEMCAP Project - technologies to be tested

**Oxyfuel burner**
Existing 500 kWth oxyfuel burner at USTUTT to be modified for CEMCAP

**Calciner test rig**
Existing <50 kWth entrained flow calciner (USTUTT) to be used for oxyfuel calcination tests

**Clinker cooler**
To be designed and built for on-site testing at HeidelbergCement in Hannover

*Source: ECRA*
Burner design

a) Design of a prototype oxy-fuel burner for cement kilns.

**Downscaling criteria**
- Flame momentum
- Primary gas velocity (ca. 250 m/s)
- Carrier gas velocity (ca. 15 m/s)
- Swirl angle: 0-40°

*Source: ThyssenKrupp - POLFLAME*

*Source: ThyssenKrupp*
Burner prototype manufacture

- Primary gas
- Angle adjustable
- Gas for ignition
- Fuel + carrier gas
Adaptation of test facility

a) Necessary adaptations

Adaptation regarding secondary gas:
- Temperature
- Velocity (5-10 m/s)
- Composition (dry recycling)
a) Facility adapted for cement conditions

- Synthetic recirculation from tanks
- Secondary gas preheater system
- Secondary gas housing
Previous results published by ECRA:

- Longer flame.
- Altered temperature profile.
- Altered heat flux profile to material bed.

Source: ECRA CCS Project
Proposed validation oxyfuel vs. air operation

**Target:** Operate the oxyfuel burner aiming to achieve equal heat fluxes over a defined combustion chamber length

**Constraint:** Feasible scale down of (air) industrial burner, identification of major influencing parameters

Source: ThyssenKrupp
Flame measurements during test campaign
**Goals:**

- Identify differences in heat transfer to the walls during both firing modes.
- Provide experimental data for validation of CFD models.

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**Matrix**

<table>
<thead>
<tr>
<th></th>
<th>Air</th>
<th>Oxy29*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Gas</td>
<td>67 m³/h</td>
<td>60 m³/h</td>
</tr>
<tr>
<td>%PA = 15 Air</td>
<td>15%</td>
<td>%PA = 24</td>
</tr>
<tr>
<td></td>
<td>70% O₂ + 30% CO₂</td>
<td>70% O₂ + 30% CO₂</td>
</tr>
<tr>
<td>Secondary Gas</td>
<td>328 m³/h</td>
<td>155 m³/h</td>
</tr>
<tr>
<td></td>
<td>700 °C</td>
<td>670 °C</td>
</tr>
<tr>
<td></td>
<td>Air</td>
<td>21% O₂ + 79% CO₂</td>
</tr>
<tr>
<td>Power input</td>
<td>482 kW</td>
<td>482 kW</td>
</tr>
<tr>
<td>λ (air-fuel equiv. ratio)</td>
<td>1.09</td>
<td>1.09</td>
</tr>
</tbody>
</table>

* Oxy29 equivalent to 67% recycle ratio => same adiabatic flame temperature
%PA = Primary air percentage in input combustion gases
Gross heat flux measurements

**Air case**: Radiation vs Total heat flux

Total heat flux = conduction + convection + radiation
Heat flux measurements

Radiative heat flux: Air vs Oxy-fuel

Difference due to:
- Gas radiation
- Particle concentration
Challenges for combustion with petcoke

- Weak flamefront

<table>
<thead>
<tr>
<th></th>
<th>Water [%]</th>
<th>Ash [%]</th>
<th>Volatiles [%]</th>
<th>Cfix [%]</th>
<th>C [%]</th>
<th>Htot [%]</th>
<th>H [%]</th>
<th>N [%]</th>
<th>S [%]</th>
<th>Cl [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>an</td>
<td>4,56</td>
<td>2,12</td>
<td>11,3</td>
<td>82,0</td>
<td>77,0</td>
<td>3,91</td>
<td>3,40</td>
<td>1,47</td>
<td>3,03</td>
<td>0,074</td>
</tr>
<tr>
<td>wf</td>
<td>-</td>
<td>2,22</td>
<td>11,9</td>
<td>85,9</td>
<td>80,7</td>
<td>3,56</td>
<td>3,56</td>
<td>1,57</td>
<td>3,17</td>
<td>0,078</td>
</tr>
</tbody>
</table>

\[
burnout = 1 - \frac{\gamma_{ash, coal}}{\gamma_{ash, sample}}
\]
Second experimental campaign:

- Optimized settings: burner position, swirling angle, and primary gas velocity.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Firsts experimental campaign</th>
<th>Second experimental campaign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>Petcoke</td>
<td>Petcoke</td>
</tr>
<tr>
<td>Total O₂ in input gases</td>
<td>29%</td>
<td>27%</td>
</tr>
<tr>
<td>Burner position</td>
<td>10 mm inside housing</td>
<td>90 mm outside housing</td>
</tr>
<tr>
<td>Swirl angle</td>
<td>40°</td>
<td>20°</td>
</tr>
<tr>
<td>Primary gas velocity</td>
<td>Air: 117 m/s</td>
<td>Air: 190 m/s</td>
</tr>
<tr>
<td></td>
<td>Oxy-fuel: 108 m/s</td>
<td>Oxy-fuel: 150 m/s</td>
</tr>
</tbody>
</table>
AIR CASE

Primary gas (nozzles)
Coal + Carrier gas

482 kW

Primary gas (nozzles)
Coal + Carrier gas

Primary gas (nozzles)
Coal + Carrier gas

PG = 21%

Secondary gas

T = 740 °C
v = 4.5 m/s
O₂ = 21%
N₂ = 79%

Flue gas

λ = 1.12
O₂ = 2.2% vol,dry
CO₂ = 16.5% vol,dry

CC Shell radiation

OXY-27

Primary gas (nozzles)
Coal + Carrier gas

Primary gas (nozzles)
Coal + Carrier gas

482 kW

Primary gas (nozzles)
Coal + Carrier gas

PG = 24%

Secondary gas

T = 712 °C
v = 3 m/s
O₂ = 21%
CO₂ = 79%

Flue gas

λ = 1.13
O₂ = 3.4% vol,dry
CO₂ = 84.6% vol,dry

CC Shell radiation

22% less flue gas volume (Nm³)
<table>
<thead>
<tr>
<th></th>
<th>Air Case</th>
<th>Oxy-fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel burnout</td>
<td>98.0</td>
<td>98.3</td>
</tr>
</tbody>
</table>
Summary

- Test facility was adapted for relevant oxy-cement tests.
- Burner prototype was designed and tested.
- Demonstration tests evinced suitability to obtain similar radiation profiles under oxy-fuel conditions.

Further Steps
- Additional testing with a higher volatile fuel.
- Simulation of additional oxy-fuel cases not investigated in facility.
Acknowledgements

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www.sintef.no/cemcap
Thank you!

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