Oxy-fuel burner investigations for CO2 capture in cement plants

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CO₂ emissions in the cement industry

Cement emissions represent 5% of total anthropogenic CO₂ emissions

Source: ECRA
The need for CCS in Cement production

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

Reduction by:
- Increase of energy efficiency
- Alternative fuels use
- Reduction of clinker share

Global CO₂ emissions of the cement industry in Gt/a

- 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

Source: IEA Cement Roadmap
Project structure
Technologies to be tested - oxyfuel

**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

Partners:
- USTUTT, TKIS, SINTEF-ER
- USTUTT, VDZ, IKN, CTG
- IKN, HeidelC, VDZ

Source: ECRA
Outline

1. Validation of CFD models for oxy-fuel combustion.
2. Adaptation of test facility for cement kiln burner investigations.
3. Preliminary results of oxy-fuel investigations.
1. Validation of CFD models for oxy-fuel combustion.

- Simulation of USTUTT Combustion facility:
1. Validation of CFD models for oxy-fuel combustion.

- Simulation of oxy-fuel test at USTUTT Combustion facility with IFK burner:

<table>
<thead>
<tr>
<th>Test case</th>
<th>(O_2) in oxidizer [vol-% wet]</th>
<th>Stoichiometric ratio</th>
<th>(O_2) in stack [vol-% dry]</th>
<th>Fuel input [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>21</td>
<td>1,15</td>
<td>2,8</td>
<td>305</td>
</tr>
<tr>
<td>OF29</td>
<td>29,5</td>
<td>1,15</td>
<td>4,5</td>
<td>305</td>
</tr>
</tbody>
</table>
1. Validation of CFD models for oxy-fuel combustion.

- South African coal:

<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>O [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>an</td>
<td>1.65</td>
<td>14.36</td>
<td>27.22</td>
<td>56.77</td>
<td>67.83</td>
<td>4.77</td>
<td>4.59</td>
<td>1.77</td>
<td>0.44</td>
<td>9.35</td>
</tr>
<tr>
<td>raw</td>
<td>8.94</td>
<td>13.30</td>
<td>25.20</td>
<td>52.56</td>
<td>62.80</td>
<td>5.25</td>
<td>4.25</td>
<td>1.64</td>
<td>0.41</td>
<td>8.66</td>
</tr>
<tr>
<td>wf</td>
<td>-</td>
<td>14.61</td>
<td>27.67</td>
<td>57.72</td>
<td>68.97</td>
<td>4.67</td>
<td>4.67</td>
<td>1.80</td>
<td>0.45</td>
<td>9.51</td>
</tr>
</tbody>
</table>

![Graph showing volume-% and particle size distribution](image)

- Table showing elemental analysis and heat values:

<table>
<thead>
<tr>
<th></th>
<th>(H_{o,v}) [J/g]</th>
<th>(H_{u,p}) [J/g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>an</td>
<td>27.383</td>
<td>26.355</td>
</tr>
<tr>
<td>raw</td>
<td>25.444</td>
<td>24.316</td>
</tr>
<tr>
<td>wf</td>
<td>27.942</td>
<td>26.943</td>
</tr>
<tr>
<td>waf</td>
<td>32.721</td>
<td>31.551</td>
</tr>
</tbody>
</table>

\(H_{o,v} = HHV\) and \(H_{u,p} = LHV\)
1. Validation of CFD models for oxy-fuel combustion.
## 1. Validation of CFD models for oxy-fuel combustion.

### CFD input

<table>
<thead>
<tr>
<th>Ansys Fluent models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
</tr>
<tr>
<td>Code</td>
</tr>
<tr>
<td>Fluent 17.0</td>
</tr>
<tr>
<td>2D-Axisymmetric swirl</td>
</tr>
<tr>
<td>Mesh, number of cells</td>
</tr>
<tr>
<td>113757 (structured mesh)</td>
</tr>
<tr>
<td>Turbulence</td>
</tr>
<tr>
<td>k-epsilon, realizable, standard wall functions</td>
</tr>
<tr>
<td>k-omega SST</td>
</tr>
<tr>
<td>Chemistry</td>
</tr>
<tr>
<td>Species transport, Finite rate/Eddy Dissipation, 2-step reaction</td>
</tr>
<tr>
<td>Radiation</td>
</tr>
<tr>
<td>P1 with particle-radiation interaction</td>
</tr>
<tr>
<td>Furnace wall temperature</td>
</tr>
<tr>
<td>Profile calculated from IFK experiments. Implemented by an UDF</td>
</tr>
<tr>
<td>Inlets</td>
</tr>
<tr>
<td>Velocity inlet (constant velocity)</td>
</tr>
<tr>
<td>Outlet</td>
</tr>
<tr>
<td>Pressure outlet</td>
</tr>
</tbody>
</table>
Oxygen profile – Oxy-fuel Case

Carbon dioxide– Oxy-fuel Case
Carbon Monoxide profile – Oxy-fuel Case
2. Adaptation of test facility for cement kiln burner investigations.

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

- Scaling factor of 100 between industrial and pilot burner.
2. Adaptation of test facility for cement kiln burner investigations.

• Primary Gas (nozzles)
  o Velocity ca. 250 m/s
  o 8 nozzles
  o Angle: 0-40°

• Carrier gas (outer coal channel)
  o Transport air velocity ca. 15 m/s
2. Adaptation of test facility for cement kiln burner investigations.

b) Adapt test facility for oxy-cement processing

- Preheating of secondary gas
- Dry secondary gas
2. Adaptation of test facility for cement kiln burner investigations.

Test facility: 500 kW$_{th}$ KSVA (Pulverized Coal Combustion Plant)
2. Adaptation of test facility for cement kiln burner investigations.

- Secondary gas flow lines
- Gas storage tanks
- Quenching system
- Head of combustion chamber
- Preheater system
- Radiation probes
3. Preliminary results of oxy-fuel investigations.

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
3. Preliminary results of oxy-fuel investigations.

Fuel characterization: Petcoke

<table>
<thead>
<tr>
<th></th>
<th>Water (%)</th>
<th>Ash (%)</th>
<th>Volatiles (%)</th>
<th>C (%)</th>
<th>Hto (%)</th>
<th>H (%)</th>
<th>N (%)</th>
<th>S (%)</th>
<th>Cl (%)</th>
<th>H_{o,v} [J/g]</th>
<th>H_{u,p} [J/g]</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>
<td>32.237</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>
<td>33.894</td>
</tr>
</tbody>
</table>

H_{o,v} = HHV and H_{u,p} = LHV
Primary gas (nozzles)
Coal + Carrier gas

482 kW

Secondary gas

PG = 21%

Flue gas

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

λ = 1.12
O₂ = 2.2% vol,dry
CO₂ = 16.5% vol,dry
NOₓ = 536 ppm, dry

OXY-27

Primary gas (nozzles)
Coal + Carrier gas

482 kW

Secondary gas

PG = 24%

Flue gas

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

λ = 1.13
O₂ = 3.4% vol,dry
CO₂ = 84.6% vol,dry
NOₓ = 770 ppm, dry
3. Preliminary results of oxy-fuel investigations.

<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

• First simulation of test rig. Validation vs Experimental data was successful.
• Two turbulence models were tested, K-Omega produced better results.
• 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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