CO$_2$ Emission Reduction Potential and Technological Aspects of the Oxyfuel Technology in Cement Clinker Production

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<table>
<thead>
<tr>
<th></th>
<th></th>
<th>AGENDA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Clinker burning process</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Integration of the Oxyfuel Technology and design aspects</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Impact on plant operation</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Impact on material conversion and product quality</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Cost estimation</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Summary and Outlook</td>
<td></td>
</tr>
</tbody>
</table>
1. Introduction - Clinker burning process

Flue gas
300 - 350 °C

Material CO₂
Fuel CO₂

CaCO₃, SiO₂, Al₂O₃, Fe₂O₃

CaCO₃ → CaO + CO₂

Cyclone preheater

850 °C

Raw meal

Calciner

Tertiary air duct
700 - 1000 °C

Fuel

200 °C - 350 °C

Cooler exhaust air

Cooler

Clinker

Fuel/air

Rotary kiln

2000 °C

Cooling air
2. General layout

Exhaust air cleaning

Raw Material

Pre-heater

Bag filter

Heat exchanger

CO₂ rich flue gas

Mixing gas

Fuel Preparation

Pre-calciner

Rotary Kiln

Oxidizer

Cooler

Gas Mixing

Air Separation Unit

Raw Mill

N₂

Clinker

Storage

Transport

CO₂ Compression

Condenser

CO₂ Purification
2. Retrofitting boundaries

- Important aspect for the application of oxyfuel in Europe
- Retrofitting an existing burner for oxyfuel application is unlikely, but replacement by a suitable design is possible
- Designing a gas-tight two-stage cooler is feasible
- False air intrusion could be reduced to the greatest possible extent by overhauling/ replacing inspection doors and similar devices (< 6%)
- New safety and controlling devices necessary
- Space requirements of ASU/CPU
- Conventional behavior in trouble shooting restricted (no opening of doors/flaps in the plant etc.)

Retrofitting is feasible
3. Impact on plant operation

- Influence on heat transfer and temperature profiles
- Adaptation of plant operation necessary
- Air separation and CO₂ purification are energy intensive
- Energetic integration required
- Recirculation rate: Fraction of total flue gas, which is recirculated to process
- Setting of oxygen level
- New installations
- Retrofitting existing plants
3. Impact of gas properties

- Stress on refractory
- Potential increase of coating formation

Graph showing the impact of gas properties on stress and potential increase of coating formation.
3. False air ingress and flue gas composition

Influencing parameters:
- Oxygen purity
- False air ingress
- Oxygen excess
- Fuel type

False air reduction of 6 - 8 % technically feasible by improved maintenance without additional sealing methods (like e.g. waste gas flushed systems)
3. Flue gas recirculation

- Fuel energy demand is depending on flue gas recirculation and treatment
- Decreasing recirculation rate includes less flue gas losses
3. Energetic consideration

Recirculation rate determines the energy distribution and therefore waste heat recovery potential.
3. CO₂ emission reduction potential

- Capture rates of 88 to 99 % feasible
- Capture rate independent of recirculation rate
- Reduction of capture rate possible by
  - Exhaust gas of the CO₂ purification unit (- 1 to 10 % capture)
  - Additional firing for raw material drying (- 1 to 2 % capture)
  - Leakage at cooler stage sealing (up to - 1 % capture)
4. Kiln operation – Impact on solid conversion

![Graph showing solid content vs. kiln length for different operations and compositions.](image)

- **Red**: Reference, C3S
- **Green**: Recirculation 21 vol.% O2, C3S
- **Blue**: Recirculation 23 vol.% O2, C3S
- **Orange**: Reference, C2S
- **Darker Green**: Recirculation 21 vol.% O2, C2S
- **Darker Blue**: Recirculation 23 vol.% O2, C2S
4. Limiting factors by quality and durability requirements

- No serious influence on clinker composition
- Slight differences in cement properties (caused by Fe$^{2+}$) are in range of assured quality
- No negative influence on basic refractory material detected
- Using non-basic materials an increasing thermo-chemical reaction expected
- Adaption of refractory brickwork necessary
- Long-term test for evaluation advisable

No barriers expected from clinker quality and refractory durability
4. Impact on decarbonation

Increase of temperature level:

- Problems with burning low-calorific fuels in calciner may occur
- Higher risk of coating formation in the calciner

**Conventional operation**

**Oxyfuel operation**

- $\Delta 80 \text{ K}$

**Graph:**

- temperature [°C]
- degree of decarbonation [-]

- $p\text{CO}_2 = 0.2 \text{ bar}$
- $p\text{CO}_2 = 0.4 \text{ bar}$
- $p\text{CO}_2 = 0.6 \text{ bar}$
- $p\text{CO}_2 = 0.8 \text{ bar}$
- $p\text{CO}_2 = 0.97 \text{ bar}$
4. Impact on cement properties

- Testing at five clinker types of different reactivity
- No influence on chemical-mineralogical composition
- Cement properties are not influenced
5. Cost Estimation

**Investment costs**

New installation (2 mio tpy annual clinker capacity):

- 2050: 270 - 295 Mio €

Remark: Costs for demonstration plant in 2020 would be significantly higher.

**Operational costs**

- Raw materials
- Coal
- Power
- Misc

Fixed operating costs

plus 8 to 10 €/t$_{\text{clinker}}$ on top of base case  
transport and storage excluded

Total cost increase of about 40 %

Additional costs per ton of avoided CO$_2$: 33 - 36 €/t$_{\text{CO}_2}$
6. Summary and Outlook

- Oxyfuel technology in the cement clinker burning process technically feasible
- Retrofit of existing plants is possible
- Cement properties are not impaired
- Optimum operational mode depends on local specification of the cement plant (e.g. raw material moisture)
- Capture rate between 88 and 99 %
- Production costs are increased by ~ 40% (excl. transport and storage)
- Oxyfuel technology will not be available in the cement sector before 2030
- ECRA CCS Project Phase IV.A is dealing with the further detailing of previous phases and the concept study of an oxyfuel pilot plant
Thank you for the attention!

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