Calcium Looping Post Combustion CO$_2$ Capture: A promising technology for emission free cement production

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Expertise in Lime based Fluidized Bed Processes

Fluidized Bed Processes
- Calcium Looping (CaL)
- Chemical Looping (CLC)
- Oxy-fuel CFB
- Sorption enhanced reforming (SER)
- Oxy-fuel SER

Fuels
- Biomass
- Waste
- Lignite / Coal

Measurement techniques
- Sorbent Characterization (TGA)
- Online gas analysis:
  - CO₂, CO, O₂, H₂, CH₄, SOₓ, NOₓ
- Non-condensable HC: GC
- Tar: wet chemical & online (FID)
- H₂S, HCl, NH₃: wet chemical

20 kWₜh DFB Pilot Facility

20 kWₜh electrically heated DFB System

5 kWₜh electrically heated FB batch System
Calcium Looping – Post Combustion CCS

- retrofitting to existing facilities
- low CO₂ separation cost
- low efficiency penalty
Calcium Looping – Post Combustion CCS

**General conditions**

- **Looping Ratio:** 2 - 10
- **Make-up Ratio:** < 0,1 - 0,4
- **Temperature**
  - $T_{\text{Calciner}}$: 850 - 1000 °C
  - $T_{\text{Carbonator}}$: 600 - 700 °C
- **Flue gas**
  - $\text{CO}_2$: ~ 15 %

![Diagram of Calcium Looping - Post Combustion CCS](image)
Calcium Looping – Pilot Plant (200 kW_{th})

**Operation Conditions**

- Flue Gas Load: 170 - 230 kW_{th}
- Sorbent Looping Ratio: 3 - 13 mol_{CaO}/mol_{CO_2}
- Total Solid Inventory: 70 - 120 kg CaO/CaCO_3
Operational Results – Carbonator

- **Over 90% capture efficiency** achieved over a wide range of operating conditions.
Operational Results – Oxy-fuel Calcination

- **O₂ Inlet Concentration**
  - recirculation rate: 28 %
  - \( \gamma_{\text{O}_2,\text{in},\text{dry}} \)
  - \( \gamma_{\text{O}_2,\text{in}} \)

- **CO₂ Outlet Concentration**
  - recirculation rate: 28 %
  - \( \gamma_{\text{CO}_2,\text{out},\text{dry}} \)

- **O₂ Excess Concentration**
  - recirculation rate: 28 %
  - \( \gamma_{\text{O}_2,\text{out},\text{dry}} \)

- **Calcination Temperature**

Graph showing temperature in °C versus height in m.
Operational Results – Oxy-fuel Calcination

- High inlet oxygen concentrations (> 50 vol.-%, dry) possible
- Lower recirculation rates for oxy-CaL calcination (additional CO₂ from calcination)
- Lower humidity of CaL flue gas
- Uniform isothermal conditions
Calcium Looping – Pilot Plant (200 kW$_{th}$)

Operation Conditions
- Flue Gas Load: 170 - 230 kW$_{th}$
- Sorbent Looping Ratio: 3 - 13 mol$_{CaO}$/mol$_{CO_2}$
- Total Solid Inventory: 70 - 120 kg CaO/CaCO$_3$

Carbonator
- CO$_2$ capture efficiency above 90 %

Calciner
- CO$_2$ outlet concentrations above 90 vol.-%, dry
- Inlet O$_2$ concentrations above 50 vol.-%, dry
- Excess O$_2$ outlet concentration below 3 vol.-%, dry
Cement Plant – Clinker Production and Properties

- Clinker composition
  - CaO: 60 - 70 %
  - SiO$_2$: 20 - 25 %
  - Al$_2$O$_3$: 2 - 6 %
  - Fe$_2$O$_3$: 0 - 6 %

- Structural change at 1400 °C (rotary kiln)
  - CaO + SiO$_2$ → (CaO)$_3$ · SiO$_2$ & (CaO)$_2$ · SiO$_2$

- Flue gas composition
  - high CO$_2$ concentration ~ 30 %
Cement Plant – CaL Integration

- synergy effect between cement plant and CaL-process

General conditions
- Looping Ratio: 2 - 4
- Make-up Ratio: > 1
- Flue gas
  - CO₂: 15 - 30 %
Summary

- Calcium looping for power plant application demonstrated at pilot plant scale
  - CO₂ capture efficiency over 90 %
  - CO₂ concentrations over 90 %

- Feasibility for cement plant application will be investigated at pilot plant scale
  - Effect of high CO₂ flue gas concentration
  - Influence of make-up ratio, sorbent looping ratio
  - Optimal operation conditions
Thank you for your interest!

Any Questions?

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Extra Slides
Operational Results – Hydrodynamics

- stable hydrodynamic conditions
Equilibrium: \( \text{CaO} + \text{CO}_2 \rightleftharpoons \text{CaCO}_3 \)

**Carbonation**

\[ \text{CaO} + \text{CO}_2 \rightarrow \text{CaCO}_3 \]

**Calcination**

\[ \text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2 \]

Outlet CO\(_2\) Conc. for 90\% Capture

Oxyfuel Flue Gas CO\(_2\) Concentration

Min \( T_{\text{Regenerator}} \)

Max \( T_{\text{Carbonator}} \)
Operational Results – Oxy-fuel Calcination

recirculation rate: 28 %

$y_{O_2, in, dry}$

$y_{O_2, in, wet}$

$y_{CO_2, out, dry}$

$y_{O_2, out, dry}$

O$_2$ Inlet Concentration in %

O$_2$ Outlet Concentration in %

O$_2$ Excess Concentration in %

Calcination Temperature

Height in m

Temperature in °C
Cement – CaL Integration

- synergy effect between cement plant and CaL-process

General conditions
- Looping Ratio: 2 - 4
- MakeUp Ratio: > 1
- Flue gas
  - $CO_2$: 15 - 30 %
Operational Results – Oxy-fuel Calcination

- Recirculation rate: 28%

*Graphs showing concentration data over time and height.*

*Diagram illustrating calcination temperature.*