Demonstration of the Calcium Looping Process: High Temperature CO$_2$ Capture with CaO in a 200 kW$_{th}$ Dual Fluidized Bed Pilot Facility

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- The Calcium Looping CO$_2$ Capture Process
- The 200 kW$_{th}$ Calcium Looping Pilot Plant
- Pilot Plant Results
- Conclusions and Outlook
The Calcium Looping (CaL) Process

**Coal-fired Powerplant**
- G 1
- Steam Generator
- Coal-fired Powerplant
- Air
- Coal

**Carbonator**
- T = 650 C
- \( CO_2 + CaO \rightarrow CaCO_3 + \text{Heat} \)
- Pure Flue Gas
- Purge

**Regenerator**
- T = 900 C
- \( CaCO_3 + \text{Heat} \rightarrow CO_2 + CaO \)

**CaL Steam Generator**

**CO₂-rich Flue Gas**

**CO₂ to Storage**

**Make-up Limestone**

**ASU**
- Air
- N₂
The Calcium Looping (CaL) Process

CO₂ Capture Costs¹:
- Over 90% CO₂ Capture efficiency demonstrated
- CO₂ Avoidance Cost ~ 20 €/t CO₂
- Cost of Electricity ~ 40 €/MWh
- Purged material can be efficiently utilized in cement or FGD processes

Electricity Generation²:
- Plant electric efficiency including CO₂ capture and compression calculated at 39.2%
  - 6.4% penalty
- Power output increases ~ 45%

² Hawthorne et al., Energy Procedia, 2009
R&D Calcium Looping Process Roadmap

Process Idea

Labscale

Process Simulation & Cost Calculations
Hawthorne et al., Poboss et al., Abanades et al.

TGA Sorbent Characterisation
Grasa et al.

Process Characterisation
Electr. heated
10 kW_{th} facility
Charitos et al., Abanades et al.

Commerical Plant

Process Demonstration:
Realistic Process Conditions
- No external heating
- Real Flue Gas
- Oxyfuel Calcination
- Coal influence (S, ash)

Shimizu et al.
1999

10 kW_{th} – DFB Facility

200 kW_{th} - Pilot Plant
Process Demonstration

Demo Plant
**Carbonator:**
- Turbulent CFB Reactor
- Good gas-solid contact
- Lower entrainment than fast fluidized CFB
- Looping Rate controlled by L-valve
- Bottom loop seal regulates bed inventory
- Temperature controlled by Looping Rate and Fluidized Bed Heat Exchanger

**Regenerator:**
- Fast fluidized CFB calciner
- Temperature controlled by oxy-combustion
Overview of Pilot Plant Operation

- 3 measurement campaigns completed with over 300 h of successful operation
- Dual Fluidized Bed system proved flexible and robust
  - Operated over a wide range of temperatures and looping rates
  - L-valve & loop seal system delivers stable sorbent looping rate
Overview of Pilot Plant Operation

- **Over 90% capture efficiency** achieved over a wide range of operating conditions
- Oxyfuel Regenerator performed well as a combustor:
  - High fuel burnout (low CO), good controllability and uniform temperature profiles
  - Complete calcination of incoming carbonated sorbent and make-up CaCO₃
Pilot plant operates as designed:

- Facility responds quickly to set point changes, e.g. inlet CO$_2$ vol.-% concentration
- Capture efficiencies are constant over time once system stabilized
- CO$_2$ capture close to equilibrium
Results Summary: Effect of Temperature

Every data point is a steady state where:
- Solid samples taken & analyzed
- Circulation rate measured
- CO$_2$ capture measured

All capture efficiencies are close to maximum equilibrium value

Highest CO$_2$ capture achieved between 635-660°C for inlet concentrations of 10-15 Vol.-% CO$_2$

- Over 90% capture efficiency in steady state pilot operation

Ref: Hawthorne and Dieter, High Temperature CO$_2$ Capture with CaO in a 200 kW$_{th}$ Dual Fluidized Bed Pilot Facility. 2nd Efficient Carbon Capture for Coal Power Plants, June 2011.
Calcium Looping process successfully demonstrated on a 200 kW$_{th}$ pilot facility:

- CO$_2$ capture efficiency over 90 % achieved
- Plant showed robust performance and flexibility over 300 h of operation
- Full sorbent calcination in oxy-fired regenerator achieved
- Low sorbent loss due to attrition, i.e. ~ 5 wt.% bed/h

Recently obtained results and upcoming R&D topics:

- Influence of Make-up and steam content in flue gas on CO$_2$ capture efficiency
  - Tests completed and will be published in the near future
- Influence of sulfur and coal ash on sorbent activity and pilot operation
Acknowledgements

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