Calcium looping for CO$_2$ capture in the cement industry – pilot scale experiments

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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 gasification (SEG)
- Oxy-fuel SER

Fuels
- Biomass
- Waste
- Coal / Lignite

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
Calcium Looping – Basics

- CO₂ capture by cyclic calcination and carbonation of Calciumcarbonat (CaCO₃)
- High energy efficiency due to high temperature level
Calcium Looping – Cement Plant Integration

- Cement plants’ raw meal completely calcined by CaL process
- Flue gas similar to power plant application
- High make-up ratio realizable
- Higher energy efficiency and higher complexity compared to tail-end
Calcium Looping – Cement Plant Integration

- Part of raw meal calcined in CaL process
- CO₂ flue gas concentration ~ 20 - 35 %
- Easy integration
- Reduced energy efficiency
Experimental facility – 200 kW$_{th}$ pilot plant (MAGNUS)
Fluidized Bed Research Facilities – MAGNUS

200 – 230 kW\textsubscript{th} pilot scale facility (3 reactors)

Bubbling bed reactor (1x)
• diameter: 330 mm
• height: 6 m

Circulating fluidized bed reactor (2x)
• diameter: 200 mm
• height: 10 m

Possible reactor configuration: CFB-CFB, BFB-CFB

No electrical heating (heated by combustion)

Gas analysis (H\textsubscript{2}, CO, CH\textsubscript{4}, O\textsubscript{2}, CO\textsubscript{2}, C\textsubscript{x}H\textsubscript{y}, SO\textsubscript{2}, NO\textsubscript{x})
MAGNUS – CFB-CFB configuration

- CFB reactors coupled by cone valves installed in loop seals
- Synthetic flue gas mixed by air, CO\(_2\) and steam
- Hot flue recirculation in case of oxy-fuel operation
- Solid transfer measured by microwave sensors
MAGNUS – BFB-CFB configuration

- Coupling by conveyer screw in loop seal stand pipe and bottom loop seal
- Solid transfer proportional to rotation speed
- Various sampling ports for gas analysis and solid sampling
Experimental conditions

Carbonator (CFB, TFB):
- Flue gas:
  - $y_{H2O} \sim 15\%$
  - $y_{CO2,\text{dry}} \sim 15\%^*$

Calciner / Regenerator (CFB):
- Oxy-fuel: hot recirculated flue gas from calciner mixed with $O_2$
- Staged oxidant feeding
- Fuel: Columbian hard coal
- Sorbent: Limestone from western Germany

Gas analysis:
- Confirmation of calibration every 24 h
- NDIR online gas analyzers
- Periodic cleaning of gas filters
Experimental results – Hydrodynamic

- Hydrodynamic is essential for stable operation
- Internal recirculation enables self-stabilizing of CFB reactors
- Bed inventory is adjustable by pressure difference between the reactors
- Homogeneous solid distribution in CFB risers
- Dense region at bottom of TFB carbonator
Experimental results – Temperature profile

- Calcination reaction of limestone moderates calciner temperature
- Uniform reaction conditions beneficial for
  - sorbent properties
  - combustion performance
Experimental results – Calciner operation

- Increase in thermal duty with make-up due to endothermic calcination reaction
- High O$_2$ demand required to obtain a consistent velocity
- Low recirculation of calciner off gas (< 30 %)
Experimental results – CO₂ capture

- CO₂ capture was limited by the equilibrium CO₂ capture
- High CO₂ capture rate above 90 % reached
- High sorbent activity due to high make-up flows
Summary, Outlook, Conclusion
Conclusion and Outlook

- Beneficial Calcium Looping operation conditions due to reutilization of sorbent in cement plant
- >90 % CO₂ capture in carbonator achieve over a wide range of parameters
- High make-up rates cause an increased thermal load of the calciner and require higher calciner oxygen concentrations

- Calcium Looping highly promising for CO₂ capture from cement manufacturing
- Experiments on tail-end Calcium Looping CO₂ capture form cement manufacturing ongoing
Thank you!

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