

Design concepts, operating experiences and experimental results of the 200 kW_{th} Calcium-Looping Pilot Plant

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R&D Calcium Looping Process Roadmap

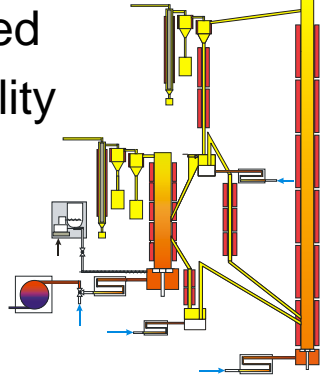
Process Simulation & Cost Calculations
 Hawthorne et al., Poboss et al., Abanades et al.

TGA Sorbent Characterisation
 Grasa et al.



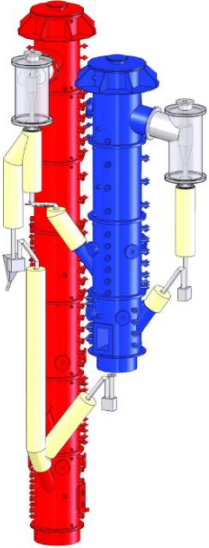
Process Characterisation
 Electr. heated
 10 kW_{th} facility

Charitos et al.,
 Abanades et al.

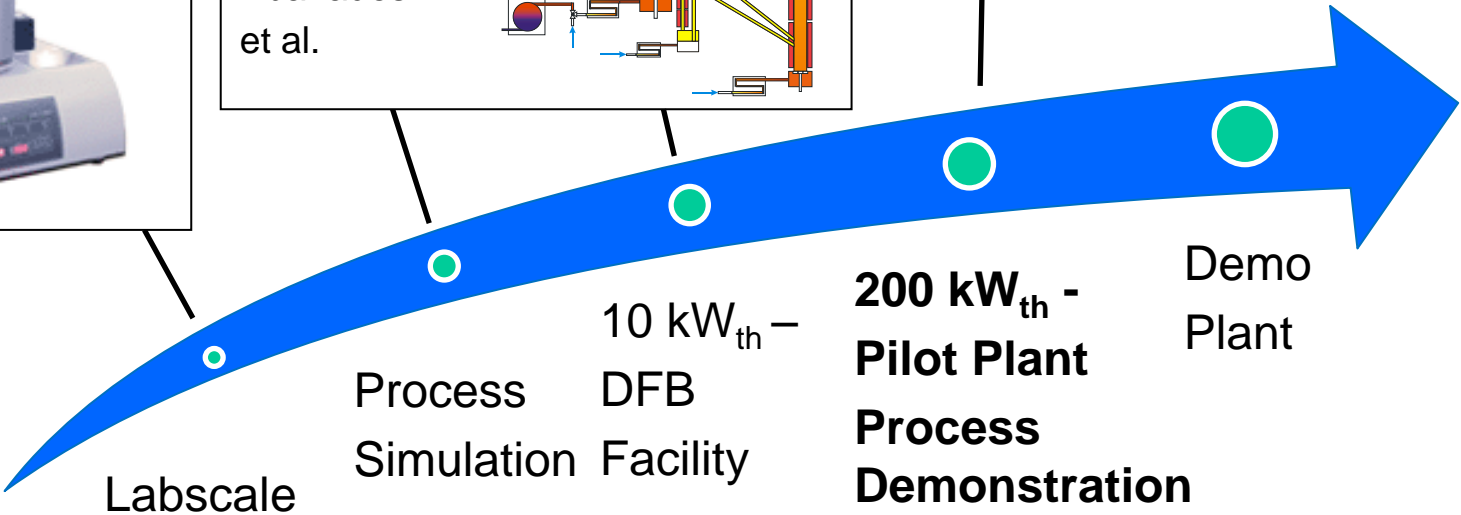


Process Demonstration:
 Realistic Process Conditions

- No external heating
- Real Flue Gas
- Oxyfuel Calcination
- Coal influence (S, ash)



Shimizu et al. 1999



Commerical Plant

Process Idea

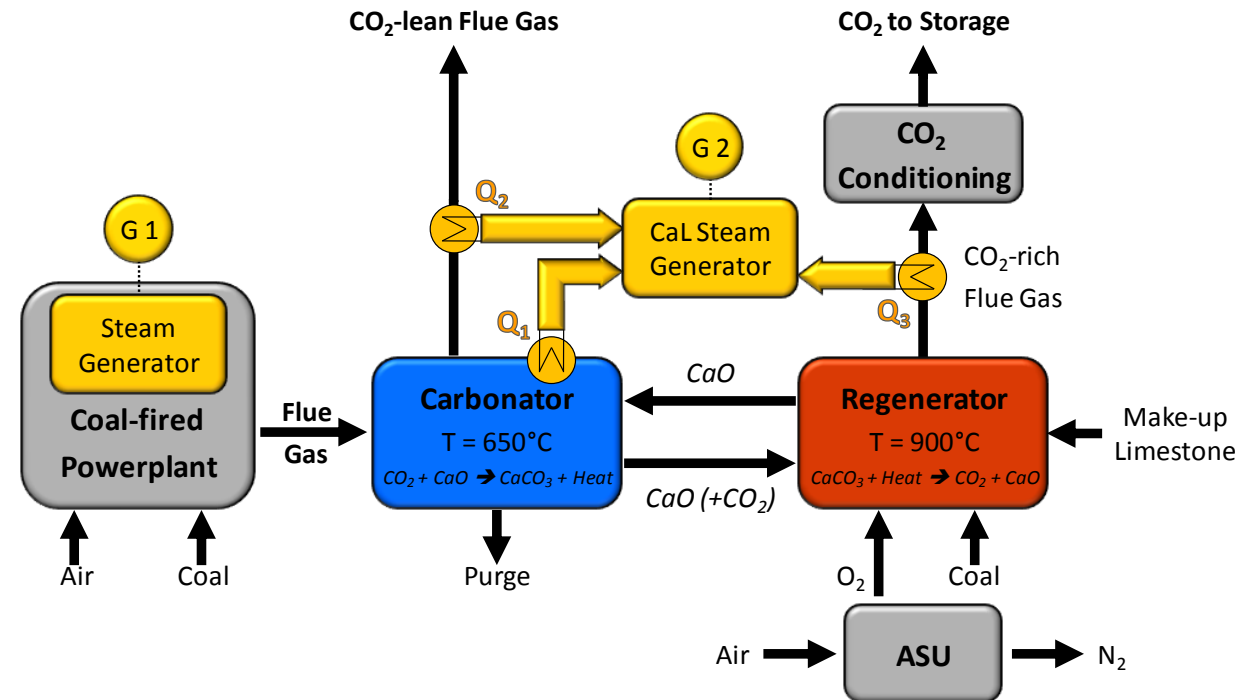
The Calcium Looping (CaL) Process

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 industry

Electricity Generation²:

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



¹ Poboss et al., Coorettec Final Report 2008; Abanades et al., Environ. Sci. Technol., 2007

² Hawthorne et al., Energy Procedia, 2009

IFK's

200 kW_{th} Calcium-Looping

Pilot Plant

-

Two facility configurations for high flexibility and broad operating windows

The 200 kW_{th} Calcium-Looping Pilot Plant

Configuration A

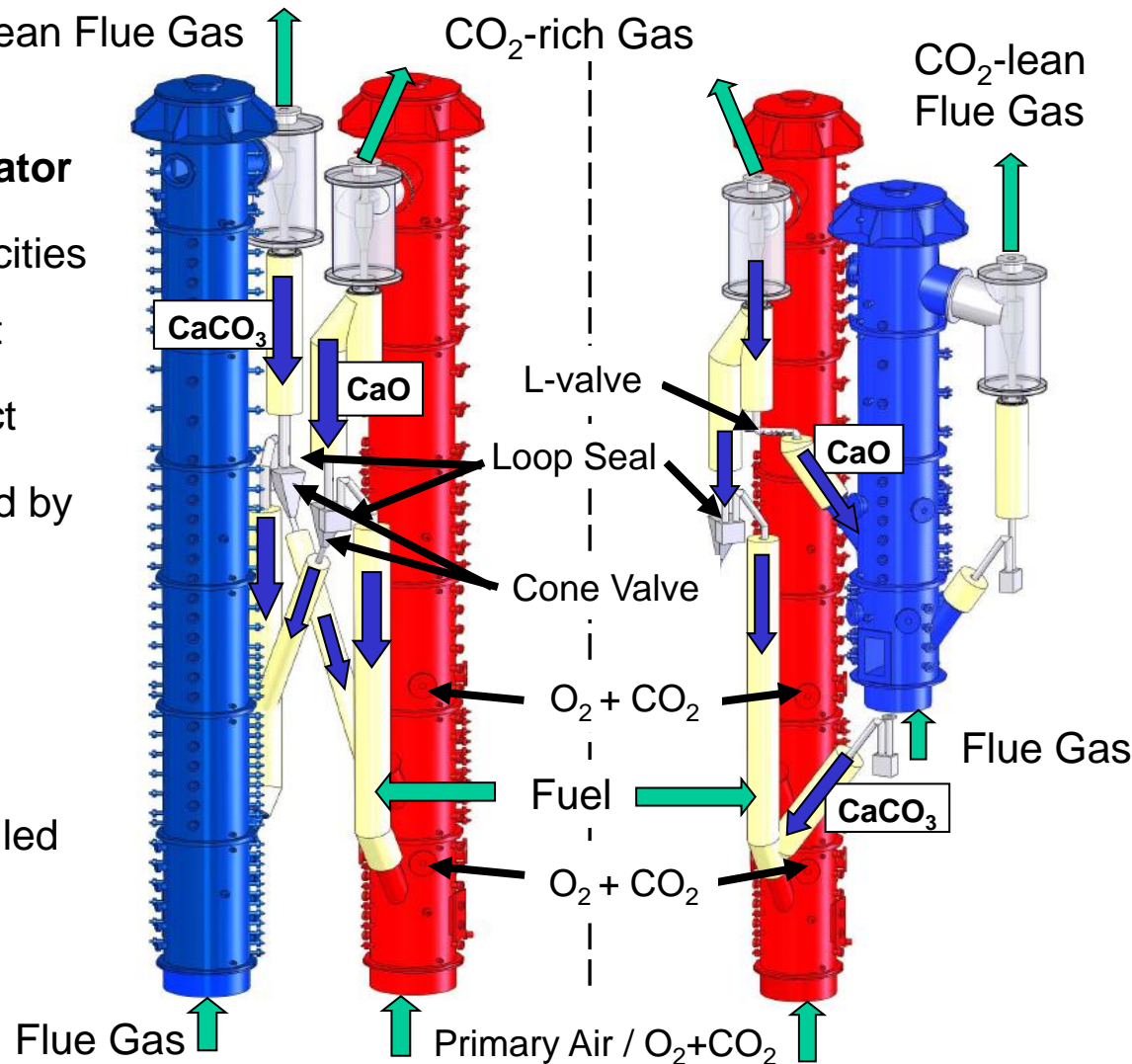
CO₂-lean Flue Gas

Fast fluidized Carbonator

- High carbonator velocities & flue gas throughput
- High gas-solid contact
- looping rate controlled by 2 cone-valves

CFB Regenerator

- Temperature controlled by oxy- combustion



Configuration B

Turbulent Carbonator

- good gas-solid contact
- lower entrainment than fast fluidized CFB
- Looping Rate controlled by L-valve

The 200 kW_{th} Calcium-Looping Pilot Plant

Configuration A

CO₂-lean Flue Gas

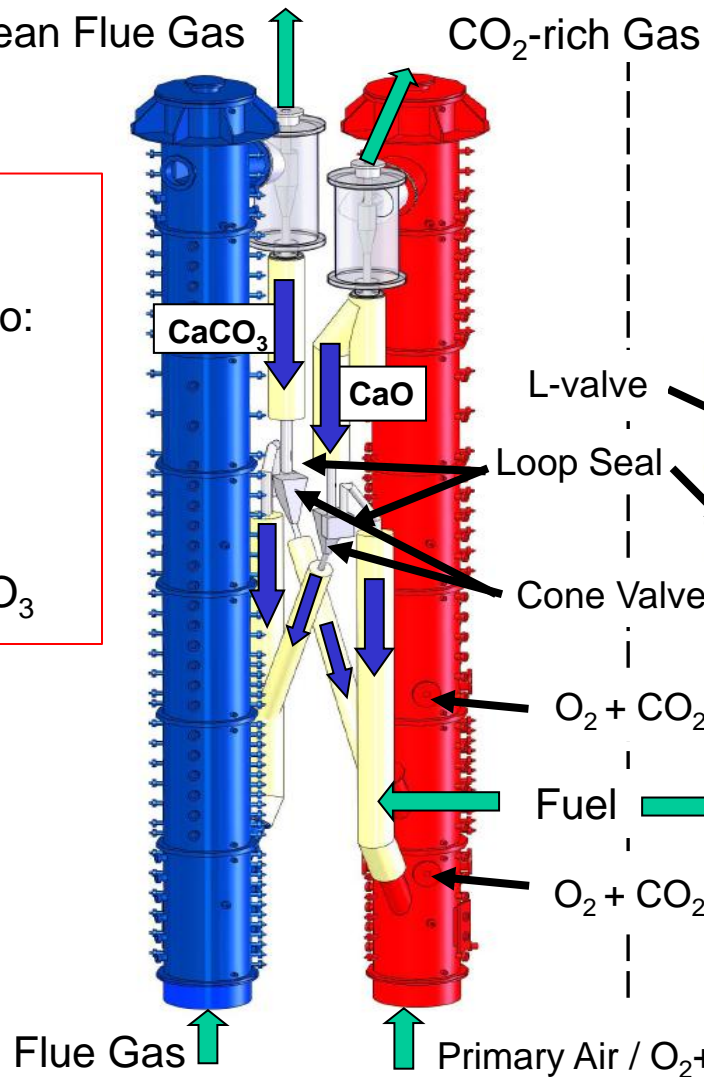
Operating Window

Sorbent Looping Ratio:

3-13 mol_{CaO}/mol_{CO₂}
(≈ 200-1000 kg_{Ca}/h)

Total Solid Inventory:

70-120 kg CaO/CaCO₃



Configuration B

CO₂-lean
Flue Gas

Operating Window

Flue Gas Load:

100 – 200 kW_{th}

Sorbent Looping

Ratio:

3-13 mol_{CaO}/mol_{CO₂}
(≈ 100-1000 kg_{Ca}/h)

Total Solid Inventory:

70-120 kg CaO/CaCO₃

L-valve

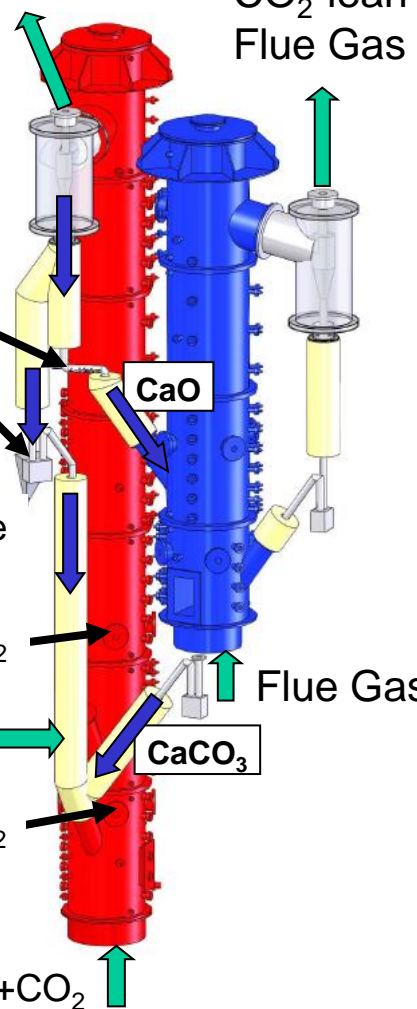
Loop Seal

Cone Valve

O₂ + CO₂

Fuel

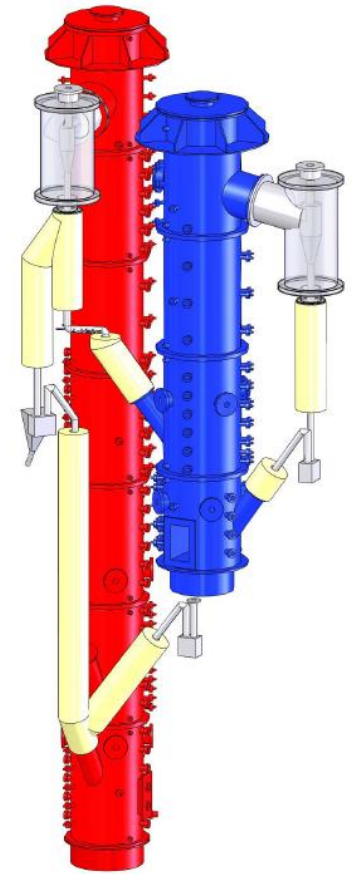
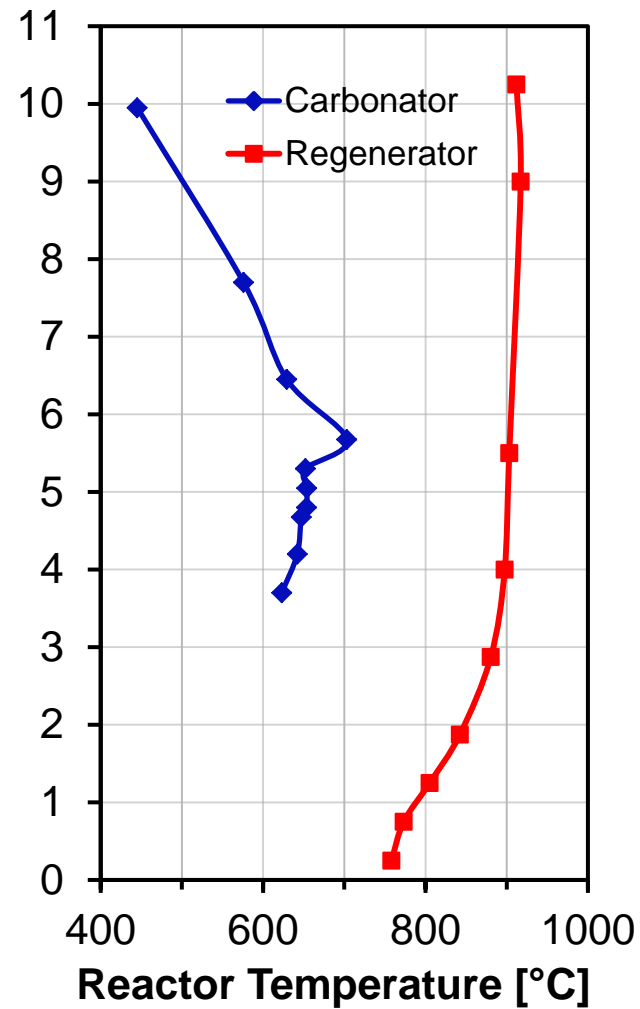
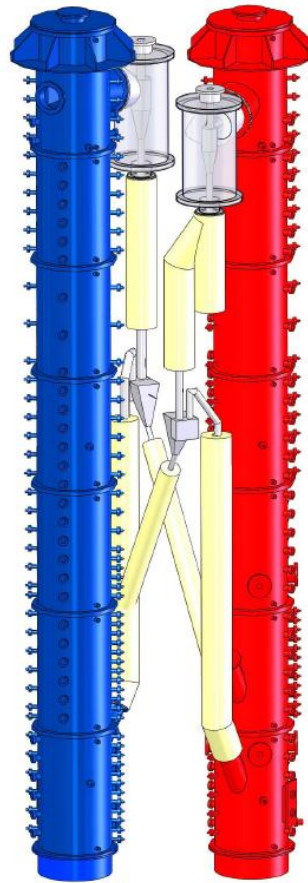
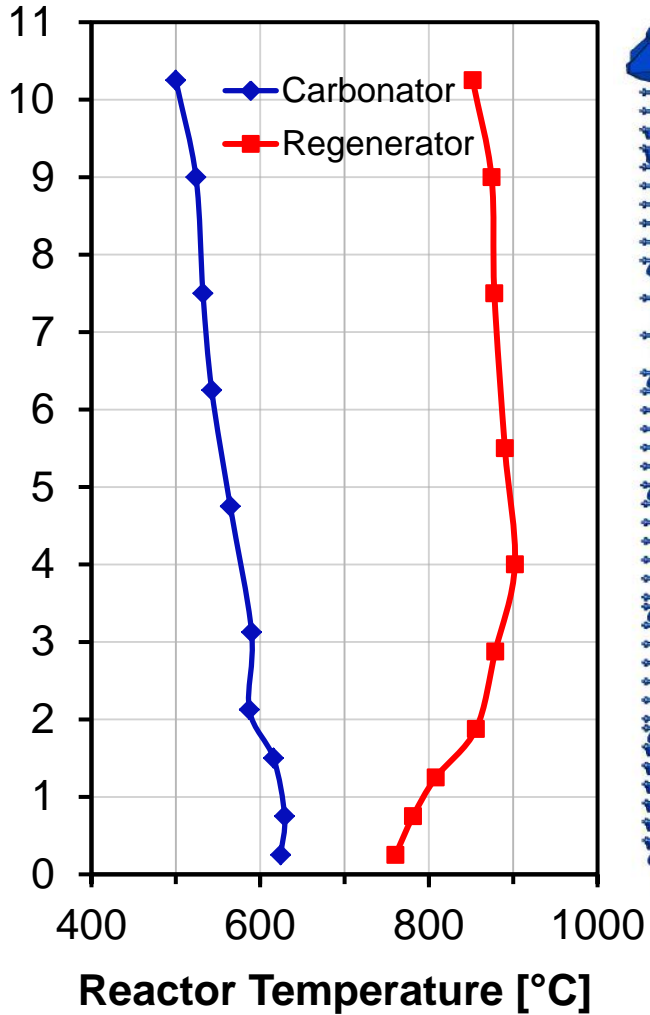
O₂ + CO₂



Pilot Plant operating experiences

- More than 600 h of operation completed
- High hydrodynamic stability of both configurations
- Stable sorbent transport by L-Valve and Cone-Valves
- High flexibility in operation
- Plant operated over a wide range of temperatures and looping rates

Characteristic temperatures configuration A & B

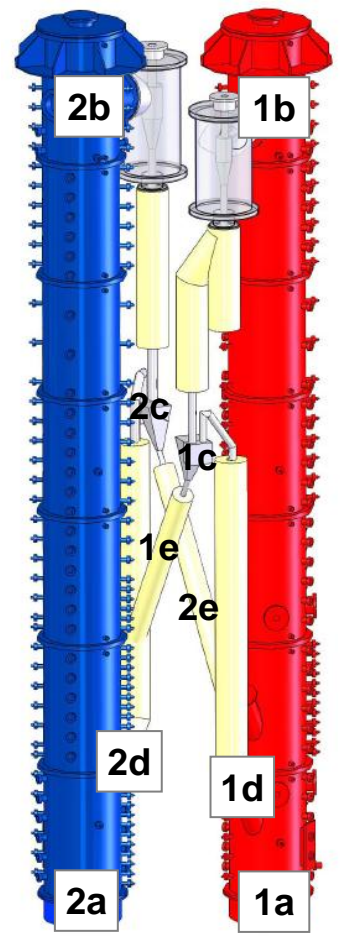
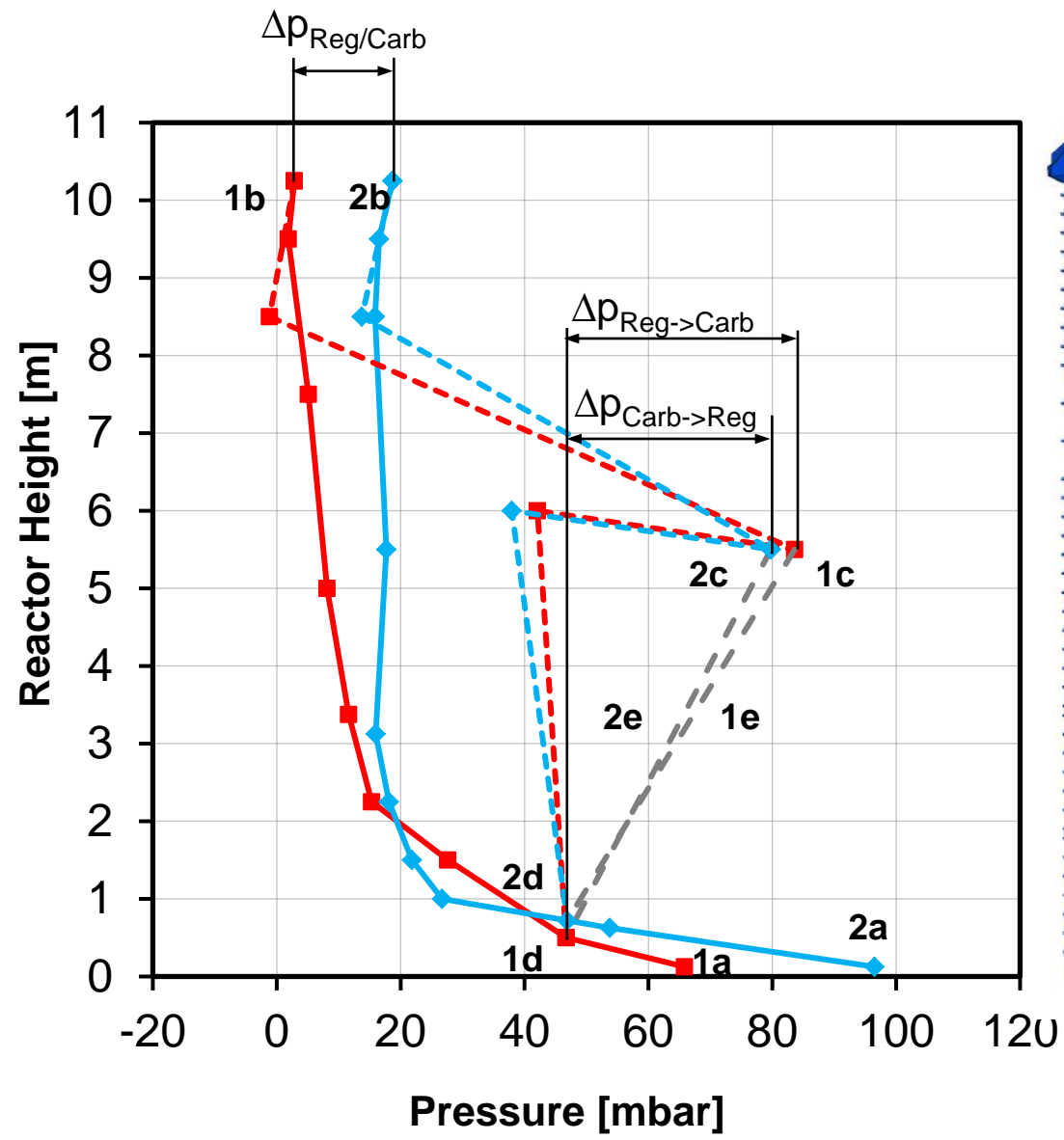


Characteristic pressure conditions configuration A



Facility Control:

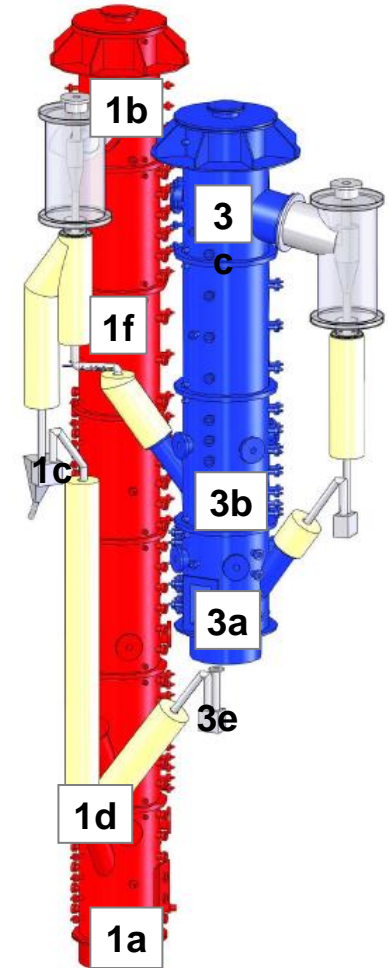
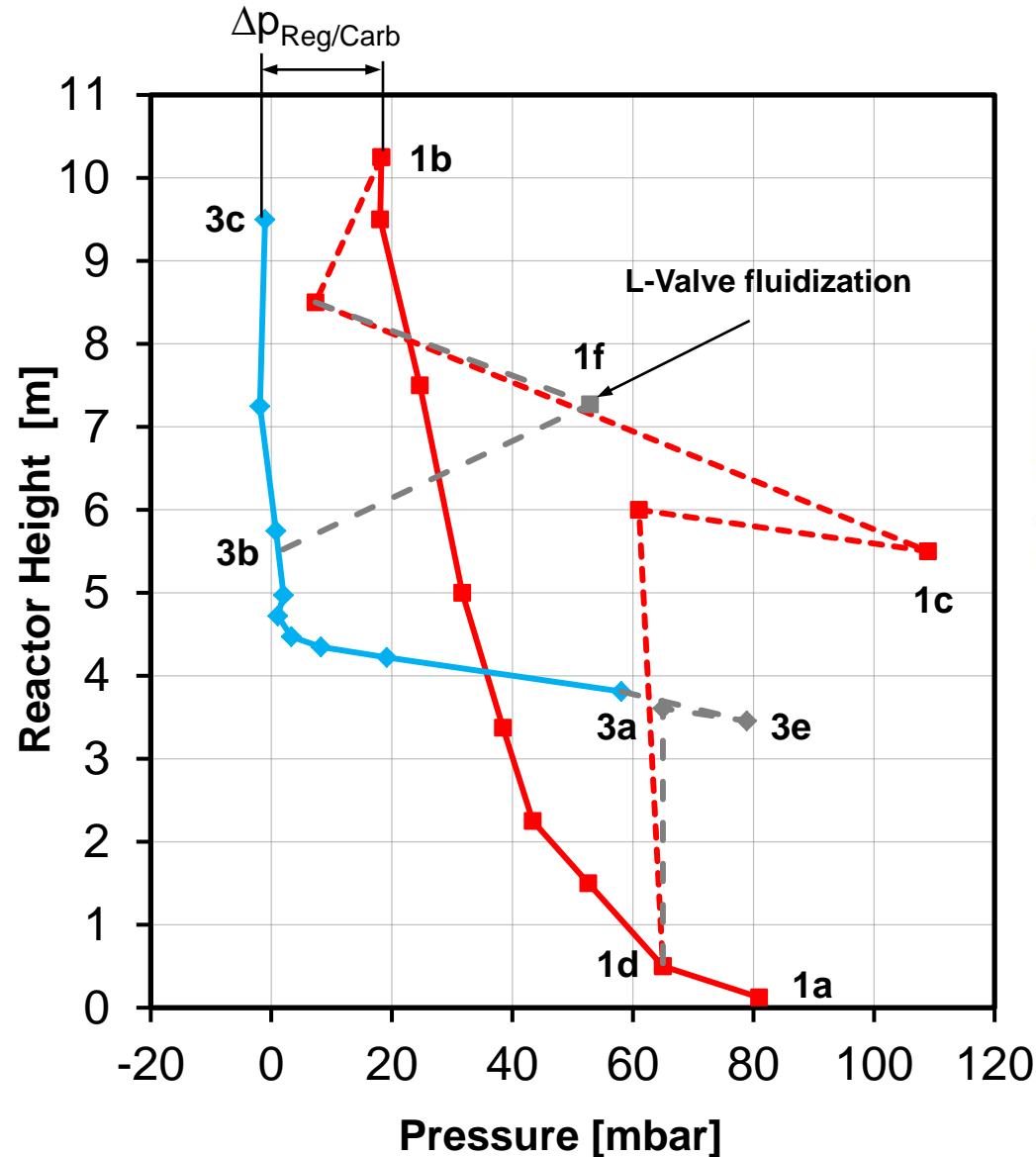
- Control of circulation by
 - (i) Cone-valve opening
 - (ii) $\Delta p_{\text{Reg} \rightarrow \text{Carb}} / \Delta p_{\text{Carb} \rightarrow \text{Reg}}$
- Bed distribution control:
 - (i) Cone-valve opening ratio
 - (ii) Reactor train pressure difference ($\Delta p_{\text{Reg}/\text{Carb}}$)
- Continuous solid flow measurement:
 - High temperature microwave sensor



Characteristic pressure conditions configuration B

Facility Control:

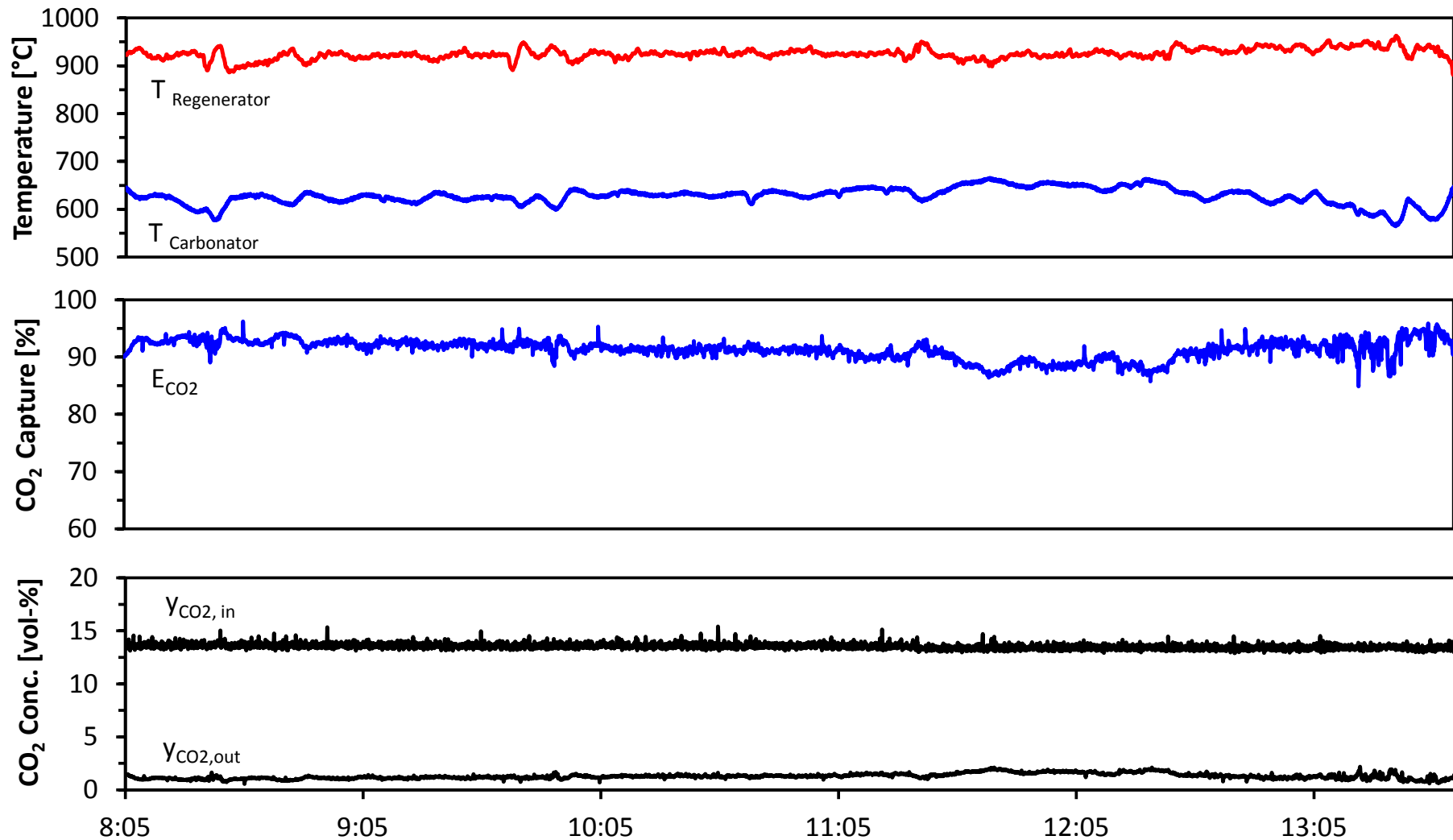
- Control of circulation by L-Valve fluidization
- Bed distribution control by reactor train pressure difference ($\Delta p_{\text{Reg/Carb}}$)
- Continuous solid flow measurement:
High temperature microwave sensor



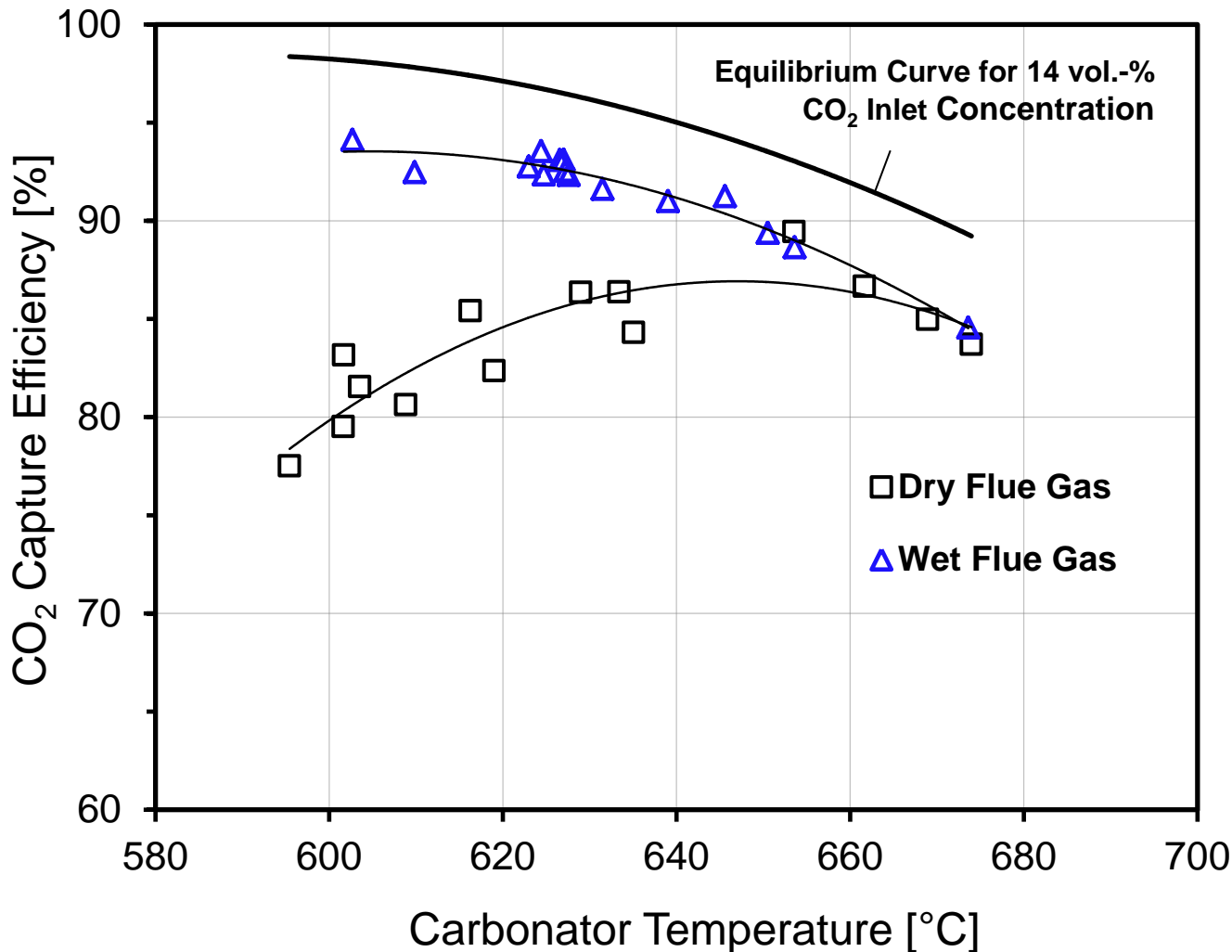
Pilot Plant results

Pilot Plant operational results – configuration B

- Over 90% capture efficiency achieved over a wide range of operating conditions



Results Summary: Effect of Temperature



Each data point is a steady state where

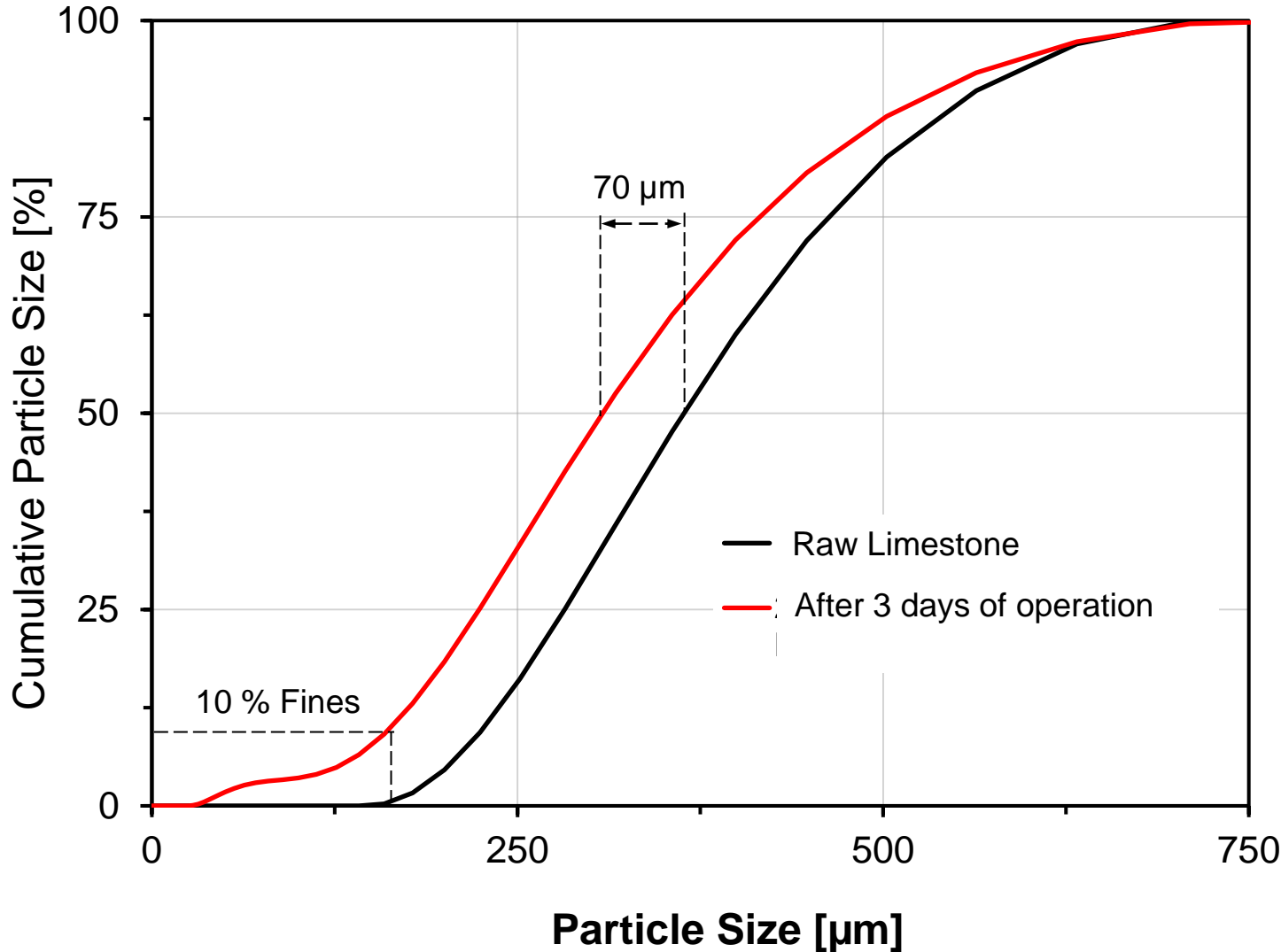
- Solid samples taken & analyzed
- Circulation rate measured
- CO₂ capture measured

Capture efficiencies for dry flue gas decrease below 640°C

Capture efficiencies for wet flue gas are close to equilibrium value

⇒ **Wet flue gas enhances carbonation reaction**

Sorbent Attrition



- Decrease of mean particle size (d_{50})
⇒ 70 μm
- Fines due to attrition
⇒ 10 wt-%
- Low sorbent loss due to attrition
⇒ 3 wt-% bed/h

Calcium Looping process successfully demonstrated on a 200 kW_{th} pilot facility:

- Over 600 hours of operation completed
- DFB Plant hydrodynamically stable and robust in operation
- High flexibility in operation and good controllability (Solid looping rate)
- CO₂ capture efficiency over 90 % achieved
- Full sorbent calcination in oxy-fired regenerator achieved
- Low sorbent loss due to attrition, i.e. ~ 3 wt.% bed/h

Recently obtained results and upcoming R&D topics:

- Influence of Make-up and Looping Rate on CO₂ capture efficiency
- Influence of sulfur and coal ash on sorbent activity and pilot operation
 - Tests completed and will be published in the near future

Acknowledgements

The results from the 200 kW_{th} Calcium Looping pilot plant were produced as part of a joint university-industrial research & development project funded by EnBW Kraftwerke AG.

