Process design of post-combustion CO$_2$ capture from a natural gas combined cycle using Ca-looping process

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Integrated Assessment in BIGCCS

- Systematic benchmarking of CO₂ capture processes using consistent boundary conditions to
  - Identify potential of capture processes
  - Provide directions for future research such as material development

- Multi-scale modeling of processes for integrated assessment
Ca-looping cycle for CO$_2$ capture

- Significant number of studies for capture from coal fired power plants

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

\[\Delta H^\circ_r = -178 \text{ kJ/mol}\]

Baker (1962)
NGCC with Ca-looping CO₂ capture

[Diagram showing a process flow for NGCC with Ca-looping CO₂ capture, including primary steam cycle, CO₂ compression, secondary steam cycle, gas turbine, carbonator, calciner, and cryogenic ASU.]
Ca-looping cycle model

- Simple steady state heat/mass balance model in Excel
- Model allows to identify effect of different operating parameters of the Ca-looping process on overall process
NGCC with Ca-looping CO$_2$ capture
Parameters for 90% capture rate

► Sorbent
  ▪ Calcite

► Carbonator
  ▪ Carbonation efficiency: 19.9%
  ▪ Carbonation temperature: 600°C

► Calciner
  ▪ Make-up ratio: 0.06
  ▪ Calciner efficiency: 100%
  ▪ Calciner temperature: 950°C

► NGCC, steam cycle and auxiliaries
  ▪ European Benchmarking Task Force documents

Preliminary parameters! These were changed subsequently based on experience and feedback.
NGCC with Ca-looping CO$_2$ capture
Two power generating units?

- Fuel fed to Calciner: ~38% of total fuel to process
- Power generation from Ca-Looping cycle: ~35% of total power

Sources of CO$_2$ captured

- Exhaust from NGCC: 47%
- Oxy-combustion in Calciner: 39%
- Calcined make-up sorbent: 14%
Reference NGCC with and without CO₂ capture

- European Benchmarking Task Force (EBTF) reference cases are used as reference cases in BIGCCS benchmarking work
- EBTF NGCC without capture:
  - Generic F class gas turbine with 38.5% efficiency
  - 3 pressure level steam cycle with reheat
- EBTF NGCC with capture
  - 90% capture ratio
  - MEA post-combustion capture
Reference NGCC with capture
Process Efficiency comparison

- NGCC without capture
- NGCC with MEA capture
- Base case
Process improvements
Heat integration

► Recuperator
Process improvements
Heat integration

► Recuperator
► Integration of CO$_2$ compression heat
► Use of advanced steam and super-critical steam cycle for secondary steam cycle
Process Improvements
Steam cycle

Standard

Advanced

Super-critical
Process improvements
Heat integration

► Recuperator
► Integration of CO$_2$ compression heat
► Use of advanced steam and super-critical steam cycle for secondary steam cycle
► Hot recycle
Process Improvements
Hot recycle
Process Efficiency comparison

- NGCC without capture
- NGCC with MEA capture
- Hot recycle
- CO₂ comp heat
- Sp Crit SC
- Adv SC
- Recuperator
- Base case
Sorbent properties and modeling

 ► Performance of the Ca-looping process is dependent on sorbent properties
   ▪ Calciner heat requirement and sorbent make up ratio among others
 ► Sorbent undergoes decay with each cycle of process causing decrease in sorption conversion
 ► Decay model proposed by Grasa and Abanades (2006) used

\[
q_{\text{recovery}} = \frac{1}{(1 - q_{\text{degrad}})^{-1} + q_{\text{degrad}}} + q_{\text{degrad}}
\]
Sorbent properties and modeling

4 classes of sorbents

- Untreated: such as calcite and dolomite
- Class I sorbents: lifetime of the natural Ca-based minerals improved by promoting the minerals with other elements or by simple processing with other inorganics
- Class II sorbents: supported Ca-based sorbents prepared by wet impregnation of a calcium containing solutions onto a porous substrate followed by calcination
- Class III sorbents: the third strategy used is often linked to nano-materials where sorbent nanoparticles of CaO, Li₂O, Na₂O, etc. are stabilised by other nano-sized phases such as ZrO₂, CeO₂, TiO₂, SiO₂, Al₂O₃, etc.
Sorbent properties and modeling

Untreated and Class I sorbents
Sorbent properties and modeling

Untreated and Class II sorbents
Effect of sorbent properties on overall system

- Dolomite vs. Synthetic CaO

- Relative change from calcite

- Make-up flow
- Recycle flow
- Flue gas flow
- CO2 compression
- Caliner heat input
- Cryogenic ASU
- Carbonator heat output
- 2nd steam cycle output
- Net electric eff.

- 10% Dolomite
- 0% Synthetic CaO

- 5%

- 20%
Process Efficiency comparison

- NGCC without capture
- NGCC with MEA capture
- CO$_2$ comp heat
- Recuperator
- Hot recycle
- Sp Crit SC
- Adv SC
- Synth CaO
- Dolomite

Efficiency

- 60%
- 55%
- 50%
- 45%
- 40%

International CCS Research Centre
Integration of Oxygen Transport Membranes

► Motivation
- Cryogenic ASU contributes to ~30% of energy penalty
- Theoretical separation work for $O_2$: 49 kWh/ton $O_2$
- Separation work in cryogenic ASU: 190-200 kWh/ton $O_2$

► Oxygen Transport Membranes (OTM)
- Dense ceramic membranes (metal oxides).
- Membrane operation based on mixed conduction of ions and electrons.
- Separates $O_2$ from air with 100% selectivity.
- Operating temperature range: 800-1000°C.

► Challenge
- Proper integration
- $O_2$ recovery rate from OTM low (30-60%)
Integration of Oxygen Transport Membranes
Integration of Oxygen Transport Membranes in Ca-looping cycle
Process Efficiency comparison

- NGCC without capture
- NGCC with MEA capture
- CO₂ comp heat
- Recuperator
- Base case
- Hot recycle
- Dolomite
- Synth CaO
- Adv SC
- Sp Crit SC
- OTM
Summary

► Process design of Ca-looping cycle for CO₂ capture from NGCC is an on-going activity in BIGCCS
► The efficiency of the process has been improved by 8.4% points using heat integration, advanced sorbents and integrating OTM in the process
► The Ca-looping process has potential to reduce energy penalty of the capture process
► The systematic procedure also provides pointers for sorbent development by analysing the effect of sorbent properties on the overall process
Further reading


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