Bench-Scale Silicone Process for Low-Cost CO₂ Capture

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GE Energy
Milliken/SiVance

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Overview

27 Month, $3.75M Program to Develop a Silicone Process for CO₂ Capture

**Program Objective:** Design and optimize a new process for novel silicone CO₂ capture solvent and establish scalability and potential for commercialization of post-combustion capture of CO₂ from coal-fired power plants. A primary outcome will be a system capable of 90% capture efficiency with less than 35% increase in the cost of energy services (COE).

**Technical Approach**
- Design and construct bench-scale unit and obtain parametric data to determine key scale-up parameters
- Perform an EH&S and technical and economic assessment to determine feasibility of commercial scale operation
- Develop material manufacturing plan
- Develop scale-up strategy

**Outcomes**
- Strategy for future scale-up
- Technical and economic feasibility determined
- Environmental assessment

**Anticipated Benefits of the Proposed Technology**
- 90% CO₂ capture with <35% COE increase

• Continuation of previous DOE/NETL funded project (DE-NT0005310)
• Current project has 2 phases
  - Phase 1: 10/1/2011 to 12/31/2012
  - Phase 2: 1/1/2013 to 12/31/2013
Absorbent

GAP-0 (Liquid)

\[
\begin{align*}
&\text{H}_2\text{N} - \text{Si} - \text{O} - \text{Si} - \text{Me} - \text{Me} - \text{Me} - \text{Me} - \text{Me} - \text{NH}_2 \\
\end{align*}
\]

\( \xrightarrow{\text{CO}_2} \)

\[
\begin{align*}
&\text{H}_2\text{N} - \text{Si} - \text{O} - \text{Si} - \text{Me} - \text{Me} - \text{Me} - \text{Me} - \text{Me} - \text{O} - \text{H} \\
\end{align*}
\]

\( \Delta \text{-CO}_2 \)

\[
\begin{align*}
&\text{H}_2\text{N} - \text{Si} - \text{O} - \text{Si} - \text{Me} - \text{Me} - \text{Me} - \text{Me} - \text{Me} - \text{N} - \text{H} \\
\end{align*}
\]

GAP-0 Carbamate (Solid)

\[
\begin{align*}
&\text{\text{NO}_3} \text{Si} \text{Me} \text{Me} \text{O} \text{Si} \text{Me} \text{Me} \text{Me} \text{Me} \text{Me} \text{N} \text{H}_2 \\
\end{align*}
\]

\[
\begin{align*}
&\text{\text{NO}_3} \text{Si} \text{Me} \text{Me} \text{O} \text{Si} \text{Me} \text{Me} \text{Me} \text{Me} \text{Me} \text{N} \text{H}_2 \\
\end{align*}
\]

GAP-0 Carbamate (Solid)

GAP-0 Carbamate (Solid)

- GAP-0 demonstrates 17.7% wt gain of CO\(_2\) (10.2% wt gain for 30% MEA/H\(_2\)O)
- Co-solvent required to inhibit solidification (50 wt% triethylene glycol, TEG)
- Even in a 50/50 (wt/wt) mixture of GAP-0/TEG, eventually carbamate precipitates

GAP-1\(_m\) Absorbent Composition

- 40\% GAP-0
- 33\% GAP-1
- 19\% GAP-2
- 8\% GAP-3

GAP-1 (Liquid)

\[
\begin{align*}
&\text{H}_2\text{N} - \text{Si} - \text{O} - \text{Si} - \text{Me} - \text{Me} - \text{Me} - \text{Me} - \text{Me} - \text{NH}_2 \\
\end{align*}
\]

\( \xrightarrow{\text{CO}_2} \)

\[
\begin{align*}
&\text{H}_2\text{N} - \text{Si} - \text{O} - \text{Si} - \text{Me} - \text{Me} - \text{Me} - \text{Me} - \text{Me} - \text{O} - \text{H} \\
\end{align*}
\]

\( \Delta \text{-CO}_2 \)

GAP-1 Carbamate (Solid)

\[
\begin{align*}
&\text{\text{NO}_3} \text{Si} \text{Me} \text{Me} \text{O} \text{Si} \text{Me} \text{Me} \text{Me} \text{Me} \text{Me} \text{N} \\
\end{align*}
\]

Carbamate does not precipitate in a 60/40 (wt/wt) GAP-1\(_m\)/TEG mixture
Vapor Pressure

All aminosilicone materials tested exhibited vapor pressures < MEA

Lower absorbent vapor pressure simplifies CO$_2$ desorption process
Thermal Stability Measured by GC

- Thermal stability of GAP materials is high
- Carbamate materials have lower thermal stability
  - GAP-0 converts to higher MW GAP materials
  - Have discovered additives that greatly improve thermal stability
Isotherms

The maximum possible working CO$_2$ capacity can be determined.
Heat of Absorption of CO$_2$

Conditions:
- $T = 40 \, ^\circ C$
- 14 doses of 20 SCC CO$_2$
- Magnetically stirred

Heat of absorption (kJ/kg CO$_2$)

- 1887 kJ/kg CO$_2$
- 2263 kJ/kg CO$_2$

Error bars - 95% CI
Lab-Scale Schematic

Packed Absorption Column

Column
- 50 mm I.D.
- Packing height = 1.3 m
- 5 x 5 mm Raschig rings
- 2.5 L of packing

Rich Absorbant

Rich-Absorbent Reservoir

High-Pressure Pump

High-Pressure Desorption Vessel
- 500 ml

CO₂

Lean-Absorbent

Back-Pressure Regulator

Mass Flow Meter

Vent

Mass Flow Meter

Multi-Channel MS

Stripped Flue Gas

Low-Pressure Pump

Lean-Absorbent Reservoir

Throttling Valve

Mass Flow Meter

Vent
Lab-Scale System

- Successfully ran numerous multi-hour experiments where solvent was cycled continuously between the absorber and desorber
- Was able to achieve >90% CO₂ capture
Energy Penalty

- ASPEN Plus model built for CO$_2$ separation using GAP-1/TEG; Updated with experimental results
- GAP-1/TEG energy penalty for the overall system ~24% vs. ~30% for MEA
Bench-Scale Schematic

Flow Chart:

- **Flue Gas Generation**
  - 100 L/min (STP)
  - 40°C
- **Gas Preheater**
  - 1 L/min
  - 10 bar
- **Absorption Column**
- **Scrubbed Exhaust**
  - Pump
  - 84 L/min (STP)
  - 40°C
- **Cooling Water**
  - 1 L/min
  - 1 bar
- **Solvent In**
- **Solvent Out**
  - 1 L/min
  - 10 bar
- **Preheater**
  - CO₂
- **High Pressure Desorber**
  - 160°C
  - 10 bar
- **Gas Analyzer**
  - Vent
  - 16 L/min (STP)
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