A New CO$_2$ Capture Platform:
Hollow Fiber Adsorbents for Post-
Combustion Recovery

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The Impact of CO$_2$ on Global Climate Change
September 3rd, 2009
Coal Power Production Facts & Effects

- ~600 coal fired power stations in the US
- 11 are in Georgia
- Releases 1 kg CO₂/kWhr of production
- That means a typical 500 MW unit releases ~9 tons of CO₂ per minute!
- US power stations responsible for ~0.3ppm/yr rise in CO₂ concentration
- 40% of CO₂ emissions are from power production!
Why not simply switch to less polluting power production? – *Scale.*
CO₂ capture from coal fired power plants is one bridging strategy to lower CO₂ emissions.

(values) in parentheses are atmospheric ppm levels of CO₂.

Source: Valerie Thomas
CO₂ Capture Strategies

• Post-Combustion Capture
  – Advantages
    • Straightforward retrofit
  – Disadvantages
    • Low CO₂ partial pressures
    • Large quantities of gas

• The majority of the USA’s power infrastructure cannot support other capture methods

• *Post-combustion capture is the single biggest target for effective carbon capture and storage*
Broad Routes for Post-Combustion CO$_2$ Capture

**Absorption**: Diffusion and/or reaction into a liquid (typically) to form a solution
- Examples: Liquid amines (monoethanolamine), chilled ammonia, ionic liquids

**Adsorption**: Accumulation of molecules on the surface of a material
- Examples: Zeolites, activated carbon, silicas, solid supported amines
Basic Energetic Comparison between Adsorption and Absorption

Fundamentally, adsorption processes have lower energetic needs than absorption processes
Issues with Packed Bed Adsorption Processes

Bed Pressure Drop:
Need very large beds to minimize flue gas pressure drop

Slow Response Times:
Need a high number (~50) of beds to ensure steady state operation

1x10^6 SCF per minute!
Hollow Fiber Sorbents

- **What is a hollow fiber sorbent?**
  - Hybrid material—polymer matrix with embedded sorbent particles
    - High solids loading
  - Designed for CO₂ capture
  - Novel lumen layer
  - Utilizes favorable adsorption energetics while mitigating typical adsorption process deficiencies

*Cooling water used to aid in sorption process. Plant steam used for desorption step.*

*Thin fiber wall allows for rapid heat transfer. Barrier layer prevents mass exchange between heat transfer agent and CO₂*
“Utilizes favorable adsorption energetics while mitigating typical adsorption process deficiencies”...but how?
Using Fiber Sorbents in Thermal Swing Adsorption Mode

1x10^6 SCFM, 10% CO₂ flue gas treated in ~1 min
Gas pressure drop through manifold: 1 psig
50 million fibers per manifold

140°C, 50 psig steam (or hot water) drives off 9.1 tons of CO₂ in ~1 min.
CO₂ comes out bottom of manifold in “waves”
# Adsorbent Selection

<table>
<thead>
<tr>
<th>Sorbent</th>
<th>Zeolite 13X</th>
<th>High Silica MFI</th>
<th>Anchored Amines</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ Dry Sorption Capacity</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>CO₂ Wet Sorption Capacity</td>
<td>Very Low</td>
<td>--</td>
<td>Medium</td>
</tr>
<tr>
<td>Heat of Sorption</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Diffusion Coefficient [cm²/s]</td>
<td>10⁻⁵</td>
<td>10⁻⁷</td>
<td>--</td>
</tr>
</tbody>
</table>

**Zeolite 13X**

**High Silica MFI**

**Anchored Amines**
Hollow Fiber Sorbents: Fabrication

- Extrusion through a concentric annulus
- Fiber characteristics are controlled by:
  - Extrusion rate
  - Fiber take up rate
  - Air gap height
  - Operating temperature
Fiber Sorbent Spinning: 75wt% Solids

**Spinning Conditions**

| Core flow rate | 1000 mL/hr |
| Bore flow rate | 250 mL/hr  |
| Bore Composition | 80/20 NMP/H₂O |
| Operating Temp. | 25°C |
| Take-up Rate | 11.7 m/min |
| Air Gap | 3.0 cm |

**Materials Used**

<table>
<thead>
<tr>
<th>Sorbent</th>
<th>Zeolite 13X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymer</td>
<td>Cellulose Acetate</td>
</tr>
<tr>
<td>Solvent</td>
<td>N-methylpyrrolidone</td>
</tr>
<tr>
<td>Non-Solvent</td>
<td>Water</td>
</tr>
<tr>
<td>Pore Former</td>
<td>Polyvinyl pyrrolidone</td>
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</tbody>
</table>

Fiber sorbent with correct dimensions

Zeolite 13X dispersed in cellulose acetate matrix
CO₂ Sorption Performance: Equilibrium, Cyclic, and Kinetic

Cycle time of ~25 seconds possible!
Barrier Layer Construction

Decreasing porosity in r-direction
- ~30 microns
- Gradient serves as a backstop for latex

Permeation Results:
- Uncoated: $N_2 \sim 60,000$ GPU
- Coated: $N_2 \sim 3.0$ GPU
- Expected: ~0.01 GPU
- ~5% steam/CO$_2$ losses

PVDC lumen layer on fiber sorbents

Neoprene/PVDC Barrier Layer
Future Work

• Improving barrier layer performance
• Extending fiber sorbent platform to new sorbents and polymers
  – MFI (sorbent) and Torlon (polymer)
• Fiber stability in constant water/steam cycles
• CO\textsubscript{2} capture costs and economics
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