Developing Membranes for Carbon Capture

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I work for a company that makes membrane gas separation systems

This is a talk by a membrane vendor
Outline

• Lessons from the current industry
• The need for compression
• MTR contactors
• Some process designs
• The take home message
The Current Industry

Membrane plant design as drawn by a membrane technologist
The Current Industry

Membrane plant design as drawn by a plant purchaser

- The cost of the membrane skid is rarely >30% of the plant cost
- The capital and operating cost of compression is key
The Pressure Ratio Issue

Feed 10% CO₂ 90% N₂ 5 bar

Residue 9.9% CO₂

Permeate 1 bar

Maximum CO₂ concentration in permeate is 50%

\[ P_{\text{permeate}} \times \text{permeate concentration} \leq P_{\text{feed}} \times \text{feed concentration} \]

\[ \frac{\text{Membrane enrichment}}{\text{Pressure ratio}} \leq \frac{50\%}{10\%} < \frac{5 \text{ bar}}{1 \text{ bar}} \]

This means:

– At least half the permeate must be the slow component (N₂)
– Permeation of the slow component determines membrane area
– Infinite selectivity = no slow component permeates
  = infinite membrane area
The Pressure Ratio Issue

\[
\frac{p}{\ell}_{\text{CO}_2} = 100 \text{ gpu}
\]

\[
\frac{p}{\ell}_{\text{N}_2} \text{ varies}
\]

\begin{figure}
\centering
\includegraphics[width=\textwidth]{pressure_ratio_graph.png}
\caption{Pressure ratio graph showing permeate % CO\textsubscript{2} vs selectivity of CO\textsubscript{2}/N\textsubscript{2}.}
\end{figure}
Selectivity Has to be Optimized to the Process

Optimum selectivity at this pressure ratio

Selectivity of CO$_2$/N$_2$ vs. Permeate % CO$_2$ vs. Relative membrane area vs. Pressure ratio.

Selectivity of CO$_2$/N$_2$ vs. Pressure ratio.
Preliminary Conclusions for CO$_2$ Capture Using Membranes

- Compressor power is the key issue
- The maximum affordable pressure ratio is about 5
- A selectivity of 30-50 seems optimum
- Excessively high selectivity needs too much membrane area and produces only a marginal improvement in separation
- A single-stage process is not going to work
- Membrane areas for CO$_2$ capture at power plants will be big – up to a million of square meters – membranes must be very permeable to CO$_2$
The MTR Contactor

A Way of Generating an Affordable (Partial) Pressure Difference

A separation is performed at no energy cost
Coal power plants operate with a 1.2 fold excess of air
A Coal Power Plant

- CO₂ enriched from 12 to 20%
- CO₂ recovery ~ 80-90%
- No compression required

18% O₂ air is OK with modern boilers
The MTR Process

In this process, compression is still the biggest cost.
The Process May Be Even Better for Natural Gas Turbines

Gas turbines usually use a large excess of air (2.5 times)
Partial flue gas recycle has been shown to work.
Recycle with a Membrane Contactor

Selective membrane recycle increases CO$_2$ concentration from 5 to 25% at no energy cost.
MTR Uses Composite Membranes Packaged as Spiral-Wound Modules

- Composite membranes are thin to provide useful fluxes

- Spiral-wound modules

Each module contains 20 to 100 m² of membrane
• Six-month test with coal-fired flue gas started in April 2010

• Membrane system captures 1 ton CO₂/day
Planned Future Development

Cholla II skid (20 tons CO₂/day or 1 MWₑ) is proposed to begin operation in late 2012
The Take Home Message

• To make useful membranes, you have to understand the process