Offshore CO2 EOR
The Sceptics/Realists View

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It’s not just money - though that’s key!

- EOR Screening
- CO2 EOR - How does it work?
- When it works, it works: The Permian Basin
- And what about the Geology (caution - I’m an RE)
- Can you see the problem yet?
- Facilities challenge
- The “best candidate” in Europe
- There are optimists
- And finally, economics
EOR High Level Screening

- Taber et al, SPE 35385

- Thickness & Permeability
  - Thickness - “Wide Range”
  - Permeability - “Not Critical”
  - Will discuss this shortly

- “Successful” W/F usually a pre-condition for CO2 EOR
  - But doesn’t guarantee it!!

### Thickness & Permeability Table

<table>
<thead>
<tr>
<th>Property</th>
<th>Operator</th>
<th>Good</th>
<th>Better</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil Gravity</td>
<td>Less Than</td>
<td>0.92</td>
<td>0.84</td>
<td>wrtWat=1</td>
</tr>
<tr>
<td>Viscosity</td>
<td>Less Than</td>
<td>10.0</td>
<td>1.5</td>
<td>cP</td>
</tr>
<tr>
<td>Oil Saturation</td>
<td>Greater Than</td>
<td>20.0</td>
<td>55.0</td>
<td>percent</td>
</tr>
<tr>
<td>Oil Composition</td>
<td>High % C5-C12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth</td>
<td>Greater Than</td>
<td>2500.0</td>
<td></td>
<td>ft</td>
</tr>
<tr>
<td>Formation Type</td>
<td>Sandstone/Carbonate</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Thickness & Permeability
- Successful W/F usually a pre-condition for CO2 EOR
- But doesn’t guarantee it!!
CO2 EOR - How does it work?

- If $P > 1071$ psi (73.9 bar) and $T > 31.1 \, ^\circ C$, CO2 is in Super-Critical (S/C) state
  - Density is liquid-like (but usually less than the target oil!)
  - Viscosity is vapour-like
- CO2 must “dissolve” in the remaining oil in place
  - First Contact Miscibility (FCM)
  - Vapourising Gas Drive
  - Condensing Gas Drive
- If it does dissolve
  - Incremental Recovery Factor (RF) 10-15%
  - Denbury Resources (Mississippi) get 20% by “carpet bombing” their fields

Swell the Oil
Reduce the Viscosity
Reduce the IFT
CO2 EOR - When it works, it works!

Since first flood in 1972 (SACROC) over 2 Billion barrels oil produced via CO2 EOR

Most CO2 (historically) from CO2 Fields, 65 Mt/yr
What about the Geology? Caution - I’m an RE

- The best (to date) North Sea reservoirs tend to be thick \((H)\) and have high permeability \((K)\) as production rate \(\propto KH\)

- Heterogeneity, heterogeneity, heterogeneity ...
  - If there’s a high permeability streak, the CO\(_2\) will find it
  - If the reservoir is thick and has vertical connectivity, its likely the CO\(_2\) will gravity override the target oil

- Viscosity of S/C CO\(_2\) \(\approx 0.05\) cP
  - 10 times more mobile than water
  - 10-100 times more mobile than the oil we seek

- It doesn’t fully dissolve in the oil - immiscible flood or displacement
  - RF is halved, say less than 5% incremental oil

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\[
\begin{align*}
I_T & = & 1 \\
V_i & = & K \frac{dP}{dx}
\end{align*}
\]

Ohm’s Law  Darcy’s Law

\[
i = \frac{1}{R} V
\]
Can you see the problem yet?

- Permian basin reservoirs are usually low permeability (less than 10 mD) carbonates, highly stratified (thin zones) with poor vertical communication
- Most important factor affecting RF is field scale sweep efficiency
  - Control by reducing inter-well spacing
  - Increase injection rate
  - Reconfigure well patterns
  - Increase CO2 slug size
  - Vary ratio of Water to CO2 slug sizes/timing (WAG)
- Onshore: Simulate, Lab Tests, Single Well Pilot, Single Pattern Pilot
  - Incremental spend, build confidence, reduce risk
- Offshore: It’s all or nothing, invest billions and hope it works!

Well Spacing
Onshore - 100’s m
Offshore - 1000’s m

And this has to stay afloat for another 20-30 years
Facilities Challenge

- If the process works, CO2-saturated oil will be produced
- It has to be processed, captured, and re-injected
  - Retro-fitting existing facilities ~ 3x cost of designing/fitting up-front
The “best candidate” in Europe

- Halfdan field, Danish Sector
  - Operator Maersk; Partners Shell & Chevron
  - STOIIP ≈ 2 Bstb, RF < 30% by Water-Flood
- Chalk: high porosity, very low permeability
  - Best $K \approx 2$ mD, hence 3 km long wells
  - About 150-200 m apart
  - Producer, Injector, Producer, ...
  - 10-15 Vertical Frac’s in plane of the well
- Relatively low heterogeneity
  - The $\text{CO}_2$ will probably contact most oil
- But time from injector to producer is ...
  - 4 years!
There are optimists

- US Department of Energy: National Energy Technology Lab
  - Google “CO2 EOR Offshore Assessment” (05 June 2014) aimed at Gulf of Mexico

- Benefits are offshore storage of CO2 from Gulf Coast Power & Industrial Plants
  - 15 Bstb of incremental recovery and 3.9 Gt of storage

- Requires “Next Generation” CO2 EOR Technology
  - Existing technology needs $100+ oil and recovers less than 1 Bstb

- Next Generation Technology being
  - Improved reservoir conformance
  - Advanced CO2 flood design
  - Enhanced Mobility Control
  - Increased Volumes of Injected CO2

Inject more (who pays?)
Control where it goes
And finally, ECONOMICS

- 20-30 years to perform a CO2 flood
  - Look at price volatility over last 10 years
  - Doesn’t include last month (less than $50/stb)
- Who pays for the CO2?
- Offshore costs prohibitive
  - Especially pipelines, wells & facilities
  - Existing facilities will probably need replacing
- Require stable fiscal setting
  - Do you trust politicians not to change the rules?
- How do you mitigate the risks?