Industry Experience with CO2 for Enhanced Oil Recovery

Workshop on California Opportunities for CCUS/EOR

Don Winslow
June 27, 2012
Chevron Has Significant Operations with CO₂ EOR Projects

- Chevron installed the first large-scale CO₂ miscible EOR flood in the Permian basin at the SACROC project in 1972.
- Chevron presently operates 6 floods and injects roughly 450 MMCFPD of CO₂.
- Chevron produces about 30,000 BOPD from its CO₂ EOR projects, which represents about ~10% of all CO₂ EOR production in the US.
- Chevron operates large-scale recycle compression & natural gas liquids recovery plants to support CO₂ EOR projects.
Enhanced Oil Recovery: Comes after the “Easy Oil” has already been produced
Reinecke Unit: Production Decline Averted
Comparison of Oil Recovery due to various stages in Life of an Oilfield

Source: Steven Melzer
History of CO2 EOR

- First large scale demonstrations in early 1970s:
  - SACROC (1972) was a Chevron project
- Since then, projects implemented in multiple countries: Canada, Hungary, Turkey, Trinidad, France & Russia.
- Under consideration for fields in North Sea, UAE, Indonesia, Saudi Arabia & Abu Dhabi.

Current Status in US
- 120 projects
- Accounts for 350,000 bbls of oil per day in production
- CO2 supply ~ 3 billion cubic feet per day
- Significant growth in the Gulf Coast & Permian Basin
- 42 Billion barrels of recoverable reserves in the US
CO2 EOR Projects

US CO2 EOR Projects
(April 2012 O&GJ)

Oil Production

Number of Projects

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THE COMPONENTS OF CO$_2$ FLOOding

- Viscosity of oil is reduced providing more efficient miscible displacement

- Produced Fluids (Oil, Gas, and Water)
  - Separation and Storage Facilities

- Carbon Dioxide
- Injection Well
- Water Injection Pump

- Drive Water
- CO$_2$
- Water
- CO$_2$
- Miscible Zone
- Oil Bank
- Additional Oil Recovery

- Production Well

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Schematic Showing the CO2 EOR Process

Miscibility is Developed in This Region
(CO2 and Oil Form Single Phase)

Pure CO2  CO2 Vaporizing Oil Components  CO2 Condensing Into Oil  Original Oil

Direction of Displacement
Chevron Miscible Gas EOR Laboratory Capability
--- Slimtube/Coreflood System
Comparison of Optimal Depth for Various EOR Methods: CO2 is best for reservoirs > 3000 ft

Source: Larry Lake
Comparison of Optimal Oil Viscosity for Various EOR Methods: CO2 is best for low viscosity oil

<table>
<thead>
<tr>
<th>EOR Method</th>
<th>Oil Viscosity - Centipoise at Reservoir Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrocarbon-Miscible</td>
<td>0.1      1     10    100   1000   10000   100000</td>
</tr>
<tr>
<td>Nitrogen and Flue Gas</td>
<td>Very Good Good More Difficult</td>
</tr>
<tr>
<td><strong>CO₂ Flooding</strong></td>
<td></td>
</tr>
<tr>
<td>Surfactant/Polymers</td>
<td>Good Fair Very Difficult</td>
</tr>
<tr>
<td>Polymer</td>
<td>Good Fair Difficult</td>
</tr>
<tr>
<td>Alkaline</td>
<td>Good Fair Very Difficult</td>
</tr>
<tr>
<td>Fire Flood</td>
<td>May Not Be Possible Good Not Feasible</td>
</tr>
<tr>
<td>Steam Drive</td>
<td>(Can Be Waterflooded) Good Not Feasible</td>
</tr>
</tbody>
</table>

Source: Larry Lake
CO2 EOR is expected to continue to grow in the US: Forecast from US DOE (EIA)
Injection Well Design for CO2 EOR

Injection Well Design and Protective Mechanisms

- **Wellhead Injection Pressure**
- **CO2 Inflow**
- **Annulus Pressure**
- **Cement**
- **CO2 Injection Tube**
- **CO2 Injection Monitoring**
- **Packer**
- **Acid Resistant Cement**
- **Ground Surface**
- **Fresh Water**
- **Confining Zone**
- **Injection Zone**

**Injection Well**

*NOT TO SCALE*

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Characteristics of CO2 Enhanced Oil Recovery Projects

- Considered a “tertiary” process: typically applied after waterflooding
- Incremental recoveries due to CO2 can range from 8% to 18% with an average of 12%.
- Critical issue: need inexpensive source of CO2. This has historically been an issue in California.

Criteria for Appropriate Reservoirs for CO2 Flooding:
- Greater than 2000 feet deep
- Producing “light” oil, that is, oil with an API gravity > 25 degrees
- Pressure that has been maintained through waterflooding
- Homogenous reservoir – so that the CO2 does not channel through” thief zones
Source of North American CO$_2$ Deliveries for EOR

- Natural Gas Plants: 12.0%
- Ammonia (Fert.): 1.9%
- Coal Synfuels: 7.2%
- Ethylene: 0.1%
- Natural Sources: 78.8%
Sources of Carbon Dioxide for EOR

- Naturally Occurring CO2 reservoirs
- Natural Gas Separation Plants
- Ammonia Plants – Texas & Oklahoma
- Ethanol Plants – Kansas
- Ethylene Plants - Alberta
- Coal Gasification
  - North Dakota (providing CO2 to Weyburn)
  - Texas Clean Energy Project (planned)
  - California: Hydrogen Energy (planned)
- Potential Sources:
  - Refineries
  - Power Plants (post combustion capture)
Picture of a CO2 Pipeline
California Oil Basins
## California CO2 Injection Pilots

<table>
<thead>
<tr>
<th>Field</th>
<th>Basin</th>
<th>Started</th>
<th>Stopped</th>
</tr>
</thead>
<tbody>
<tr>
<td>East Coyote</td>
<td>Los Angeles</td>
<td>1982</td>
<td>1984</td>
</tr>
<tr>
<td>Huntington Beach</td>
<td>Los Angeles</td>
<td>1981</td>
<td>1982</td>
</tr>
<tr>
<td>Wilmington (various projects)</td>
<td>Los Angeles</td>
<td>1981</td>
<td>1987</td>
</tr>
<tr>
<td>Ventura</td>
<td>Ventura</td>
<td>1988</td>
<td>1988</td>
</tr>
<tr>
<td>North Coles Levee</td>
<td>San Joaquin</td>
<td>1981</td>
<td>1984</td>
</tr>
<tr>
<td>Lost Hills</td>
<td>San Joaquin</td>
<td>2000</td>
<td>2001</td>
</tr>
<tr>
<td>Elk Hills</td>
<td>San Joaquin</td>
<td>2005</td>
<td>2005</td>
</tr>
</tbody>
</table>
Concluding Remarks

✓ CO2 EOR is a proven technology: the industry has had 35+ years of experience with no major incidents.

✓ CO2 EOR has become the leading EOR method in the world. It has the potential to lessen the US dependence on foreign oil.

✓ Oil companies are motivated to closely monitor the fate of the CO2 they inject - it is a valuable commodity that they purchase.

✓ CO2 EOR cannot be applied to all fields. For example, it cannot be applied to “heavy” oil fields such as those in Kern county.

✓ A critical factor for a successful CO2 EOR project is access to an inexpensive source of CO2.
Backup
Oil Resources...

But costly to produce, and may be CO2 intensive

Source: IEA
## Potential for Worldwide Unconventional Oil Production

<table>
<thead>
<tr>
<th>Option</th>
<th>MM bbl/d</th>
<th>Key Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2 EOR</td>
<td>3-6</td>
<td>USA</td>
</tr>
<tr>
<td>Oil Sands</td>
<td>4-5</td>
<td>Canada</td>
</tr>
<tr>
<td>Ultra-Heavy Oils</td>
<td>4-5</td>
<td>Venezuela</td>
</tr>
<tr>
<td>Syngas-to-liquids from remote natural gas</td>
<td>2-3</td>
<td>Middle East</td>
</tr>
<tr>
<td>Syngas-to-liquids from coal or biomass</td>
<td>1-2</td>
<td>China &amp; USA</td>
</tr>
</tbody>
</table>

Source: SFA Pacific