EOR as a Driver for CCS Projects in Mexico

Fernando Rodríguez de la Garza
Víctor Arana Ortiz

CCS in Mexico: Policy Strategy Options for CCS.
March 7-8, 2012
Outline

- Introduction
- Status of EOR in PEMEX
- Incremental Oil by CO2 EOR: Expectations from first round
- Final Thoughts
Introduction

- Status of EOR in PEMEX
- Incremental Oil by CO2 EOR: Expectations from first round
- Final Thoughts
The production of an oil field usually involves three main stages: Primary, Secondary and Enhanced Oil Recovery (EOR).
Enhanced Oil Recovery Methods

- PRIMARY RECOVERY
  - NATURAL ENERGY
  - ARTIFICIAL LIFT

- SECONDARY RECOVERY
  - WATERFLOODING

- ENHANCED OIL RECOVERY
  - THERMAL
    - Combustion
    - Steam
    - Hot Water
  - MISCIBLE
    - CO₂
    - Nitrogen
    - Fuel Gas
    - Hydrocarbon Gas
  - CHEMICAL
    - Alkali
    - Surfactant
    - Polymer
  - OTHER
    - Microbial
    - Acoustic
    - Electromagnetic
EOR Oil Production Costs

Resources available worldwide

- EOR Oil production costs are higher than primary or secondary production
- Oil produced by PEMEX mostly comes from primary production and some from secondary recovery methods

Source: IEA World Energy Outlook 2008, Oil & Gas Journal
CO2 has two main characteristics when used as EOR fluid:

- It is miscible, or partially miscible, with the oil
- Less expensive than other miscible gases

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>UNIT</th>
<th>AMOUNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>ft</td>
<td>&lt;9,800 and &gt; 2,000</td>
</tr>
<tr>
<td>Temperature</td>
<td>°F</td>
<td>&lt;250, but not critical</td>
</tr>
<tr>
<td>Pressure</td>
<td>psia</td>
<td>&gt;1,200 to 1,500</td>
</tr>
<tr>
<td>Permeability</td>
<td>mD</td>
<td>&gt; 1 to 5</td>
</tr>
<tr>
<td>Oil gravity</td>
<td>°API</td>
<td>&gt;27 to 30</td>
</tr>
<tr>
<td>Viscosity</td>
<td>cp</td>
<td>&lt;10 to 12</td>
</tr>
<tr>
<td>Residual oil saturation</td>
<td></td>
<td>&gt;0.25 to 0.30</td>
</tr>
</tbody>
</table>

Source: NETL, march 2010.
**Major benefits:**

- Solubility of CO₂ in the oil produces oil viscosity reduction and swelling.
- Interfacial tension reduction between oil and CO₂.
- Lower miscibility pressure requirement for CO₂, compared to other gases.
- CO₂ has water-like injectivity
- Standard injection facilities.

**Technical Challenges:**

- Large volumes of water and CO₂ produced.
- In heavy oil the Minimum Miscibility Pressure (MMP) is difficult to reach.
- Higher levels of corrosion.
- Gravity Segregation in the reservoir.
- Viscous fingering in the reservoir.
- Application in the Mexican naturally fractured reservoirs.

## Recovery Factors: Fields from Canada and USA

<table>
<thead>
<tr>
<th>Field</th>
<th>Oil Gravity (°API)</th>
<th>Oil Viscosity (cP)</th>
<th>Amount Injected (%HCPV)</th>
<th>RF, Incremental Recovery Factor (% OOIP)</th>
<th>Total Factor (Mcf/STB)</th>
<th>Net Factor (Mcf/STB)</th>
<th>Start</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dollarhide</td>
<td>40</td>
<td>0.4</td>
<td>30</td>
<td>14</td>
<td>2.4</td>
<td>11.1</td>
<td>6.3</td>
</tr>
<tr>
<td>East Vacuum</td>
<td>38</td>
<td>1.0</td>
<td>30</td>
<td>8</td>
<td>11.1</td>
<td>6.3</td>
<td>1985</td>
</tr>
<tr>
<td>Ford Gerldine</td>
<td>40</td>
<td>1.4</td>
<td>30</td>
<td>17</td>
<td>9</td>
<td>5</td>
<td>1981</td>
</tr>
<tr>
<td>Means</td>
<td>29</td>
<td>6.0</td>
<td>55</td>
<td>7.1</td>
<td>15.2</td>
<td>11</td>
<td>1983</td>
</tr>
<tr>
<td>North Cross</td>
<td>44</td>
<td>0.4</td>
<td>40</td>
<td>22</td>
<td>18</td>
<td>7.8</td>
<td>1972</td>
</tr>
<tr>
<td>Northeast Purdy</td>
<td>35</td>
<td>1.5</td>
<td>30</td>
<td>7.5</td>
<td>6.5</td>
<td>4.6</td>
<td>1982</td>
</tr>
<tr>
<td>Rangely</td>
<td>32</td>
<td>1.6</td>
<td>30</td>
<td>7.5</td>
<td>9.2</td>
<td>5</td>
<td>1986</td>
</tr>
<tr>
<td>SACROC (17 pattern)</td>
<td>41</td>
<td>0.4</td>
<td>30</td>
<td>7.5</td>
<td>9.7</td>
<td>6.5</td>
<td>1972</td>
</tr>
<tr>
<td>SACROC (4 pattern)</td>
<td>41</td>
<td>0.4</td>
<td>30</td>
<td>9.8</td>
<td>9.5</td>
<td>3.2</td>
<td>1981</td>
</tr>
<tr>
<td>South Welch</td>
<td>34</td>
<td>2.3</td>
<td>25</td>
<td>7.6</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Twofreds</td>
<td>36</td>
<td>1.4</td>
<td>40</td>
<td>15.6</td>
<td>15.6</td>
<td>8</td>
<td>1974</td>
</tr>
<tr>
<td>Wertz</td>
<td>35</td>
<td>1.3</td>
<td>60</td>
<td>13</td>
<td>13</td>
<td>10</td>
<td>1986</td>
</tr>
</tbody>
</table>

Introduction

Status of EOR in PEMEX

Incremental Oil by CO2 EOR: Expectations from first round

Final Thoughts
PEMEX EOR experience is mostly limited to lab and simulation studies: yet conducted CO2 pilots in Chicontepec fields and steam injection in Samaria Terciario field.

More than 350 EOR projects implemented worldwide: 2.2% share of the world oil production.

Very limited worldwide experience on EOR in Naturally Fractured Reservoirs. 92% of PEMEX oil production comes from NFR.

Nitrogen injection processes applied as secondary recovery, not enhanced.

Source: OGJ 2008, Websites of the companies mentioned
The EOR strategy of PEMEX is focused on the 19 biggest fields

- EOR implementation on the 19 biggest fields of Mexico will have a potential impact on 60% of the total OOIP of all fields

- These 19 fields involve onshore and offshore fields as well as non fractured clastic and fractured carbonate reservoirs

Source: Producción y Reservas por campo – Pemex 2008
**EOR Strategy in PEMEX E&P**

<table>
<thead>
<tr>
<th>Field</th>
<th>Field Test (Analogous)</th>
<th>Pilot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cantarell</td>
<td>Akal KL, Chac</td>
<td><strong>A</strong> Foamed Surfactant injection in the invaded zone by gas in Akal KL</td>
</tr>
<tr>
<td>Ku-Maloob-Zaap</td>
<td>Maloob</td>
<td><strong>B</strong> Solution surfactant in the invaded zone by water in Chac</td>
</tr>
<tr>
<td>AJB Complex</td>
<td>Cunduacan</td>
<td><strong>C</strong> CO₂ injection in Maloob</td>
</tr>
<tr>
<td>Abkatun-Pol-Chuc</td>
<td>Chuc</td>
<td><strong>D</strong> Foamed Surfactant injection in the Antonio J. Bermudez Complex</td>
</tr>
<tr>
<td>Jujo-Tecominoacan</td>
<td>Cardenas</td>
<td><strong>E</strong> Hydrocarbon gas in Chuc</td>
</tr>
<tr>
<td>Poza Rica</td>
<td>Poza Rica</td>
<td><strong>F</strong> Ain injection in Cardenas</td>
</tr>
<tr>
<td>Ebano</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Panuco</td>
<td>Samaria Terciario</td>
<td><strong>G</strong> Surfactant injection in Poza Rica</td>
</tr>
<tr>
<td>Cacalilao</td>
<td>Coyotes</td>
<td><strong>H</strong> Steam injection in Samaria Terciario</td>
</tr>
<tr>
<td>ATG North (6)</td>
<td>Soledad</td>
<td><strong>I</strong> CO₂ injection in Coyotes</td>
</tr>
<tr>
<td>Miquelita, Coyol, Humuapa, Remolino, Corralillo y Soledad</td>
<td></td>
<td><strong>J</strong> Air injection in Soledad</td>
</tr>
<tr>
<td>ATG South (4)</td>
<td>Agua fria</td>
<td><strong>K</strong> CO₂ injection in Ogarrio</td>
</tr>
<tr>
<td>Agua Fria, Tajin; Coapechaca, P. Alemán</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Will start with 11 pilot tests covering most of the EOR technologies.
- Results from pilots will extend to other analogous reservoirs.
- The air injection in NFR pilot is strategic since 50% of Mexico’s oil reserves come from NFR reservoirs.
Co2 EOR: Road Map

IMP Study. Analysis of CO2 available in Petrochemical Cosaleaque (Ammonia Production)

CO2 Supply Status (Geological)

Design in the Field Ogarrio

2010

Pilot Test in the Coyotes Fields

EOR Strategy in PEP

Design in the Field Poza Rica.

Pilot Test in the Field Poza Rica.

Design in the Field Ayatsil-Tekel-Kayab

Pilot Plant Operation of 250 MW for CO2 capture2

Pilot Test in the Field Altamira.

Pilot Test in the Field Altamira.

Pilot Plant Operation of 2.5 MW for CO2 capture1

CO2 Supply Strategy Geologic study

Secondary Recovery Strategy of PEP

2011

2012

2013

2014

2015

CO2 EOR Strategy in PEP
Location of main sources of CO₂

- CFE, San Luis Potosí
  - MMPCSD: 114
- Cangrejera Complex
  - MMPCSD: 790
- Cadereyta, NL, Refinery
  - MMPCSD: 107
- Madero, Tamps., Refinery
  - MMPCSD: 120
- Miguel Hidalgo Refinery
  - MMPCSD: 159
- Guanajuato Refinery
  - MMPCSD: 251
- CEMEX Puebla
  - MMPCSD: 101
- CEMEX Hidalgo
  - MMPCSD:
- AHMSA
  - MMPCSD: 762
- Las Truchas
  - MMPCSD: 132
- Mittal Steel
  - MMPCSD: 263
- Burgos
  - MMPCSD: ~100
- Quebrache
  - MMPCSD: 260
- Carmito
  - MMPCSD: 50
- CFE, Valle de Mexico
  - MMPCSD: 126
- CFE Tula, Hidalgo
  - MMPCSD: 623
- CFE Tuxpan, Veracruz
  - MMPCSD: 390
Outline

- Introduction
- Status of EOR in PEMEX
- Incremental Oil by CO2 EOR: Expectations from first round
- Final Thoughts
11 out of the 19 priority fields are candidates for CO2 EOR

- CO2 EOR could be first implemented in fields that add up to 22 MMMB of OOIP (first round)
- Would represent 9% of the OOIP in all fields and 16% of the OOIP in the fields considered in the EOR strategic program

*Fields: Coyotes, Soledad and Humapa

**OOIP**

Million barrels

- **Cantarell**: 35,163
- **Maloob**: 5,950
- **Antonio J. Bermudez**: 10,782
- **Abkatun Pol Chuc**: 9,770
- **Ogarrio**: 1,006
- **Ebano Chapacao**: 3,782
- **Panuco**: 3,649
- **Cacalilao**: 3,216
- **ATG***: 13,594
- **San Andres**: 1,422

Source: Production and Reserves by field- Pemex 2008
Assuming an incremental oil recovery ranging from 3 to 8%, oil attributable to CO2 flooding will range from 600 to 1700 MMB for fields considered in the first round fields.

* Coyotes, Soledad and Humapa
CO₂ Volume by source²

**MMPCD**

- Considering a Utilization Factor of 10,000 SCF/Bl of incremental oil, a trivial analysis gives the CO₂ requirements.
- Fields considered: Maloob, ATG Fields, Ogarrio and San Andres.

<table>
<thead>
<tr>
<th>Source</th>
<th>CO₂ Volume (MMPCD)</th>
<th>Production²</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refinery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PEP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Petrochemical</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Res.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>8,732</td>
</tr>
</tbody>
</table>

8,732 = 3.2 TCF/year

High requirement (FR 8%)

1,758 MMB => 0.88 TSCF/year

Lower requirement (FR 3%)

628 MMB => 0.314 TSCF/year

---

* Fields: Coyotes, Soledad and Humapa
(1) 20 years of Time horizon analyzed
(2) SEMARNAT. CO₂ source emission 2007 (3) Utility factor of 10,000 CF/B of oil
Outline

- Introduction
- Status of EOR in PEMEX
- Opportunity to increase oil recovery
- Final Thoughts
CO₂ EOR is playing, and will play, an important role in the exploitation of oil reservoirs, and therefore, it could contribute in the near future with the development of CCS Projects.

After successful CO₂ pilot testing, CO₂ EOR could be an effective driver for strategic-large scale CCS projects.

CO₂ recycling has to be considered when deploying CO₂ EOR field-scale projects.

Reduction in CO₂ capture costs will impact positively the EOR projects of PEMEX.
EOR as a Driver for CCS Projects in Mexico.