2nd Biennial CO2 for EOR
CO2 Conformance Controls

Senior Advisors:
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Dengen Zhou - ETC: IOR/EOR
Significant operations & the longest history in the industry with large-scale CO₂ miscible EOR projects

- Chevron installed the first large-scale CO₂ miscible EOR flood in the Permian basin at the SACROC project in 1973 & has had continuous, significant CO₂ flood operations from 1973 to present.

- Chevron presently operates 6 floods, 5 in the Permian basin, 1 in Colorado & has interests in 5 floods operated by others.

- Chevron operates large-scale recycle compression & natural gas liquids recovery plants to support these projects.

- We consider CO₂ miscible EOR project design & execution a core competency & dedicate significant resources to maintain & enhance these capabilities.
We design & operate large-scale CO₂ floods in a variety of reservoir settings with a wide range of fluid properties & reservoir conditions

<table>
<thead>
<tr>
<th></th>
<th>Reinecke</th>
<th>Mabee</th>
<th>Sundown</th>
<th>Vacuum</th>
<th>Dollarhide</th>
<th>Rangely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (feet)</td>
<td>6,700</td>
<td>4,700</td>
<td>4,920</td>
<td>4,600</td>
<td>7,800</td>
<td>6,400</td>
</tr>
<tr>
<td>Lithology</td>
<td>Limestone/Dolomite</td>
<td>Dolomite</td>
<td>Dolomite</td>
<td>Dolomite</td>
<td>Chert</td>
<td>Sandstone</td>
</tr>
<tr>
<td>Average Permeability (md)</td>
<td>170</td>
<td>4</td>
<td>5</td>
<td>22</td>
<td>17</td>
<td>8</td>
</tr>
<tr>
<td>Average Porosity (%)</td>
<td>10.4</td>
<td>9.1</td>
<td>12</td>
<td>12</td>
<td>13.5</td>
<td>12</td>
</tr>
<tr>
<td>API Gravity (degrees)</td>
<td>44</td>
<td>31</td>
<td>31</td>
<td>38</td>
<td>40</td>
<td>34</td>
</tr>
<tr>
<td>MMP (psi)</td>
<td>1,800</td>
<td>1,250</td>
<td>1,200</td>
<td>1,350</td>
<td>1,720</td>
<td>2,750</td>
</tr>
<tr>
<td>OOIP (MMBO)</td>
<td>180</td>
<td>430</td>
<td>429</td>
<td>470</td>
<td>146</td>
<td>2,200</td>
</tr>
<tr>
<td>Total Fluid Production (STBPD)</td>
<td>6,500</td>
<td>45,500</td>
<td>56,900</td>
<td>67,000</td>
<td>10,600</td>
<td>238,000</td>
</tr>
<tr>
<td>Gas Injection (MMCFPD)</td>
<td>52</td>
<td>25</td>
<td>74</td>
<td>71</td>
<td>38</td>
<td>200</td>
</tr>
<tr>
<td>Water Injection (STBPD)</td>
<td>14,000</td>
<td>48,000</td>
<td>60,000</td>
<td>44,000</td>
<td>8,000</td>
<td>146</td>
</tr>
</tbody>
</table>
Key Elements of design and operation

CO2 Flood Execution

• Effective reservoir management is critical for economic success
• Flood strategies are field-specific
  • Manage reservoir pressure within a narrow window
  • Maximize recovery while minimizing CO2 utilization
• Flood Strategy
  • Initial optimization is done in the design phase
  • Most optimization is normally done during project execution
• Effective optimization is technically very challenging

MidContinent CO$_2$ Floods

• 4 WAG Floods
  • Rangely
  • Vacuum
  • Slaughter
  • Mabee
• 2 Continuous CO$_2$ Injection
  • Dollarhide
  • Reinecke
A New Perspective on Applying a Conformance Lookback Analysis for the Central Permian Basin Fields

Carmen Hinds
Co Authors: Morteza Sayarpour & Adnan Hameed
- Chevron Corporation
Conformance and Associated Problems

Conformance: Non-uniform processing or any severe deviation from uniform volumetric sweep or depletion in a reservoir - areal or/and vertical
Why does It Matter to Us?

- Main cause of poor volumetric sweep efficiency
- 1/3 of OOIP not recovered due to conformance problems (Sydansk and Romero-Zeron, 2011)
- Even post tertiary recovery 35-65% of OOIP won’t be contacted by injected fluid and remains unswept (DOE 2012 report)
- A successful conformance improvement program can add 8-20% incremental recovery
Conformance Workflow

- Lookback ID Source of Problem: Vertical & Areal Heterogeneity
- Diagnostic & Screening
- Material Selection & Lab Tests
- Modeling: Optimum Slug Design / Placement
- Execution & Operational Consideration
- Surveillance & Performance Evaluation

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Conceptual Conformance Improvement Recovery

Improve Recovery ~ 8-20 %

- Recovery Factor
- Water Cut
- Treatment: < 1% PV

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Lookback Goals

- Identify any deviation from normalized baseline performance
  - Increase in normalized pattern oil production rate or oil-cut
  - Decrease in water or gas (CO$_2$) production,
  - Reduction of the decline rate
- Assess different types of conformance agents used and/or types of wells treated, treatment volumes and reservoir characteristic, etc.
How Could We Improve the Sweep Efficiency

- Improve reservoir management practices
- Historical effectiveness of conformance implementations
  - Review of 120 performed conformance jobs.
- Understanding of current conformance issues
- Execution!!!
Approach

- Establishing an unbiased procedure was the key to achieve an objective estimate of the success or failure of performed conformance control workovers.

- Baseline procedure was created and utilized to review well/pattern level.

- Lookback dashboard in Spotfire was designed and utilized for analysis.
Performance Evaluation

- A total of 30 months (split in five 6-months intervals) production history was considered for analysis of all conformance control jobs.

- Performance of 6-months before the conformance job was used as baseline keeping a constant fluid-to-oil ratio.

- Quantitative analysis was performed by normalized production and baseline decline rate to calculate incremental gains or losses after a conformance job.
Objective Approach
Pattern Results – Success Scenarios

Oil rate, STB/Day

<table>
<thead>
<tr>
<th></th>
<th>After - 6 Months</th>
<th>After - 12 Months</th>
<th>After - 18 Months</th>
<th>After - 24 Months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incr Oil</td>
<td>14</td>
<td>21</td>
<td>20</td>
<td>29</td>
</tr>
</tbody>
</table>

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Overview of Fields

Clastic Field:
- ~2 billion bbls OOIP
- Produced ~ 800 MMBBLS, 12 MMBBLS NGL's. Over 1 BB left in place after WF
- Tertiary Recovery

Carbonate Field:
- Produced over 460 MMSTBO
- Waterflood started in 1960
- RF ~26% of an OOIP of 1.8 BSTBO
- Secondary Recovery

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Summary Distribution of Previous Conformance Jobs

Most of the jobs were Marcit type gel average job size ranges from 8,000 to 14,000 bbls of gel (5,000 ppm)

Clastic Reservoir

- Total of 92 conformance control jobs performed (1994-1999).
  - 88 treated injectors
  - 4 treated producers

Carbonate Reservoir

- Total of 28 conformance control jobs with data available for analysis was performed 1980 – 2013. All jobs done on injectors.
- Reviews were done based on reservoir geological properties – High Quality Area and Low Pressure Area
**Field Challenges**

### Clastic Reservoir
- Several separate sands each with its own geological characteristics
- Natural fractures that act as thief zones due to directional trends
- Breakthrough occurs in two weeks
- Many open-hole completions & deteriorating wellbores

### Carbonates Reservoirs
- Lack of zonal separation
- Highly interconnected fractures and vugs
- Breakthrough occurs within days

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Conclusions

- Clastic and Carbonate reservoirs used the same Gel technology, (MARCIT gel) to block fractured and high-permeability flow paths.

- Utilizing unbiased workflow to evaluate past conformance work in both fields resulted in clear indications that MARCIT gel is more successful in fractured reservoirs.

- The analysis provides a deep insight on the importance of an integrated approach that requires standardized matching of technology to the right problem.

- Geology and treatment selection plays a crucial part in explaining why some conformance jobs are more successful in certain parts of fields.

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