INJECTION CONFORMANCE IN CO$_2$ FLOODS

Presented by Baker Hughes Water Management

Dan Pender
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Difference between Water and CO\textsubscript{2} Flooding

CO\textsubscript{2} flooding
- Initial reservoir pressures encountered are higher
- Injectant is corrosive
- More expensive
- Mobility ratios are higher
- Fractured/vuggy carbonates exhibit early breakthrough in secondary and tertiary recovery
- Rock dissolution leading to increased permeability
- Acts as a good tracer
What do you need for a successful CO$_2$ flood?

• Uniform permeability → Improved sweep
• Temperatures less than 250 °F
• High API oil
• Success rates mimic water flood response
• Adds 5-15% of OOIP to ultimate recovery
  – High $S_{or}$ post-water flooding

What can be changed?

Decreased sweep efficiency

Early CO₂ breakthrough leads to

- Well head freezing
- Higher OPEX
- Conversion of CO₂ floods to WAG floods to manage costs
- High GOR’s across field
Characteristics of Permian Basin reservoirs

Advantages

- Low geothermal gradient makes the pressure required for CO$_2$ miscibility with oil lower
- High degree of geological continuity between wells
- Reasonable injectivities
- Lengthy waterflood history with high $S_{or}$

Disadvantages

- High permeability in vuggy and fractured carbonates
- Early breakthroughs

Examples of CO$_2$ floods treated with polymer gels

- SACROC
- Weyburn, Saskatchewan
- Rangely Field, CO
- Means San Andres
- Denver Unit
- Wellman Unit
- Wertz, WY
- Vacuum Field, NM
- Salt Creek, TX and WY
- Mississippi
- SSAU
- Hockley Co, TX
- Ward Co, TX
- Cochran Co, TX
- Gaines Co, TX
- Andrews Co, TX
CONFORMANCE OPTIONS
Mechanical Water Shut-Off (WSO) Options

- Retrievable Bridge Plug
- Permanent Bridge Plug
- Cement Retainer
- Straddle System
- Retrievable Packer
- ISAP™
Cement Solutions - Near Wellbore Isolation

• Portland Cement
• Ultrafine Cement
• Foamed Cement
• Acid-soluble Cement
Advantages of Gel Treatments

- Crosslinked polymer gel solution (gelant) can penetrate deep in the reservoir to improve areal and vertical sweep
- Gel not affected by CO$_2$ or H$_2$S exposure
- Large volume treatments are relatively inexpensive
- Minimal well intervention – most treatments bullheaded
## Chemical Conformance Solutions

### Medium/High Molecular Weight Gel

<table>
<thead>
<tr>
<th>Application</th>
<th>Candidates</th>
<th>Benefits</th>
</tr>
</thead>
</table>
| • Reservoir conformance technology  
• Water floods  
• CO₂ floods  
• Injection wells for improved sweep  
• Production wells for favorable WOR | • Naturally fractured reservoirs  
• Temperature rating 200°F  
• High temperature gels (up to 300°F available) | • Modify flow in reservoir  
• Improved sweep patterns  
• Improved ultimate recovery  
• Reduced water and CO₂ production  
• Usually does not require isolation  
• Minimal equipment needed |
## Low Molecular Weight Gel

### Application
- Zone abandonments
- Casing leak repairs
- Behind pipe channels
- Chemical liner to seal open hole

### Candidates
- Near-wellbore treatments
- Temperatures up to 230°F
- Sandstone / Carbonate

### Benefits
- Penetrates reservoir
- Eliminates permeability
- Easy cleanout and minimal equipment needed
Thief zones and viscous fingering

CO$_2$

OIL

WATER
Injection Wells – Basic Design Thoughts

• More volume is better – its proven!

• Polymer volume must be balanced by gel concentration
  – How quick is the breakthrough to the producer?
  – What is the thief interval height?
  – What is the spacing?
  – What is the injection rate and pressure?

• What are the pattern economics?
  – How quick did the wells respond and decline in the waterflood?
  – The throughput volume of the waterflood response is one indicator of polymer volume necessary
  – How much money do you want spend?
Injectivity Index Model

• Based on 40+ polymer treatments for a major Permian operator in a CO₂ WAG flood

• Reservoir is a limestone reef complex with an assortment of secondary porosity features

• Formula – Barrels/Day/PSI = Injectivity Index

• Used for high-rate/low-pressure injectors

• Also used for producers based on step-rate testing
Polymer Volume Estimates Based On Injectivity Index

<table>
<thead>
<tr>
<th>Injectivity Index</th>
<th>Volume/Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 2</td>
<td>1,000-2,000 bbls MMW with lower polymer loadings</td>
</tr>
<tr>
<td>Less than 4</td>
<td>4,000-5,000 bbls MMW with mid-range loadings</td>
</tr>
<tr>
<td>10-20</td>
<td>10,000 bbls MMW with higher-range loadings</td>
</tr>
<tr>
<td>20-60</td>
<td>18-20,000+ bbls MMW/MMW/ HMW with high-loadings</td>
</tr>
</tbody>
</table>
• Large CO$_2$ miscible WAG flood in NW Colorado

• Decline in oil production with increase in OPEX

• High perm features and fracture pathways responsible for poor sweep – Sandstone reservoir

• Technologies tried with mixed success
  – Selective injection
  – Straddle packers
  – Pattern re-alignment
  – Cement Squeezes etc.

Near wellbore treatments not effective
Range of polymer gel treatment responses

- Forty-four wells treated
- No apparent impact on injection or production
- Oil rate increase
- Reduction in water
- Reduction in gas
- Areal sweep improvement
- Reduction or elimination of oil decline rate
- Improved pattern CO₂ retention and utilization
- Smoothing of production
Why is smoothing production beneficial?

- Save on artificial lift costs
- Enables improved lift sizing and operation
- Surface separation equipment upsets minimized
- Pressure spikes on gathering lines reduced

These are not included in typical treatment evaluation
## Total and Average Incremental Production/Year

<table>
<thead>
<tr>
<th>District</th>
<th>Total Incremental Production (BPD. MCFPD)</th>
<th>Average Incremental Production (BPD. MCFPD)</th>
<th>Job Success</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Oil</td>
<td>Water</td>
<td>Gas</td>
</tr>
<tr>
<td>1</td>
<td>210</td>
<td>1650</td>
<td>550</td>
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<tr>
<td>2</td>
<td>235</td>
<td>450</td>
<td>1230</td>
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<tr>
<td>3</td>
<td>120</td>
<td>300</td>
<td>800</td>
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<tr>
<td>4</td>
<td>60</td>
<td>1130</td>
<td>370</td>
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<tr>
<td>Total</td>
<td>625</td>
<td>2930</td>
<td>2950</td>
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<tr>
<td></td>
<td></td>
<td>Incremental recovery</td>
<td>685,000 bbls</td>
</tr>
<tr>
<td>---------------------</td>
<td>-------------</td>
<td>----------------------</td>
<td>--------------</td>
</tr>
<tr>
<td><strong>Investment</strong></td>
<td>$2,060,500</td>
<td></td>
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<tr>
<td><strong>Rate of return</strong></td>
<td>365%</td>
<td>Success rate</td>
<td>80%</td>
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<tr>
<td><strong>Payout</strong></td>
<td>8 months</td>
<td>Water handling cost</td>
<td>$0.19/ bbl</td>
</tr>
<tr>
<td><strong>D.P.I</strong></td>
<td>3.63</td>
<td>CO₂ handling cost</td>
<td>$0.29/ mcf</td>
</tr>
<tr>
<td><strong>Net present value</strong></td>
<td>$3,226, 000</td>
<td>Project life</td>
<td>3 years</td>
</tr>
</tbody>
</table>
ROZ Performance after Main Pay Conformance

Polymer Gel Treatment
Final thoughts/ Challenges

- SPE 27825 - Wertz Field, WY (1994)
- SPE 35361
- SPE 39612 Rangely Field, CO (1998)

CO₂ conformance papers are 15-20 years old despite hundreds of successful treatments performed

- Gel treatments are proven to be low-risk, long-term and cost effective