Acid Diversion Technique and Perforation Job Design Improves Injection Profile in Carbonate Reservoir


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Carbonate Reservoir

- Continuous reservoir
  - Four layers
- Limestone – Dolomite mix
- Significant permeability variations

<table>
<thead>
<tr>
<th>Perf Interval</th>
<th>Top</th>
<th>Bottom</th>
<th>Length (ft)</th>
<th>Perm (md)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>x776</td>
<td>x798</td>
<td>22</td>
<td>9.5</td>
</tr>
<tr>
<td>2</td>
<td>x798</td>
<td>x828</td>
<td>30</td>
<td>44.7</td>
</tr>
<tr>
<td>3</td>
<td>x828</td>
<td>x882</td>
<td>54</td>
<td>16</td>
</tr>
<tr>
<td>4</td>
<td>x892</td>
<td>x912</td>
<td>20</td>
<td>3.6</td>
</tr>
</tbody>
</table>

Volumes: 10 PU/division
Gas Injection Profile in 2005
9 5/8” casing shot with 2” Deep Penetration Guns
2009 Workover

- Convert dual water string water injector into single string gas injector
- Cement 7” liner inside existing 9 5/8” casing
- Remove completion and squeeze perfs
- Re-perforate same intervals and stimulate
- Effort made to improve injection profile
Perforation Design
New 7” Casing Completion inside 9 5/8”

2” gun, 6 spf
Pen – 6.8”, avg EH – 0.17/0.13

4.5” gun, 5 spf
Pen – 21.3”, avg EH – 0.42/0.37
Inject Index (II) Modeled

- Predict II for each layer with each perforation option
- More consistent II with 2” gun in Layer 2
  - 4 ½” gun in layers 1, 3 and 4

<table>
<thead>
<tr>
<th>Gun size (in)</th>
<th>Phasing (deg)</th>
<th>spf</th>
<th>Formation Penetration (in)</th>
<th>Average Entrance Hole inner/outer (in)</th>
<th>Predicted Injection Index (mmscf/day/psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Layer 1 9.5 md</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>6</td>
<td>6.8</td>
<td>0.17/0.13</td>
<td>0.002</td>
</tr>
<tr>
<td>4 ½</td>
<td>72</td>
<td>5</td>
<td>21.3</td>
<td>0.42/0.37</td>
<td>0.008</td>
</tr>
</tbody>
</table>
Matrix Acidizing Design

- Considered 3 different acid scenarios
  - 15% HCl
  - 15% HCl + 5% Self Diverting Acid
  - 28% Emulsified Acid + 5% Self Diverting Acid
    • +15% HCl post flush

- 15% HCl typical in this area

- Modeled using proprietary PC based modeling software

- Acid and diverter placed with coiled tubing
  - Assists with diversion requirement
Radial Penetration Prediction

- 15% HCl
Radial Penetration Prediction

- 15% HCl + 5% self diverting acid

![Radial Penetration Plot]

- HCl 15%
- Self Diverting Acid 5%

*Mark of Schlumberger*
Radial Penetration Prediction

- 28% Emulsified Acid + 5% Self Diverting Acid + 15% HCl

Radial Penetration Plot

- Emulsified Acid 28%
- Self Diverting Acid 5%
- HCl 15%

*Mark of Schlumberger
Wormhole Length Prediction

- 15% HCl

--- Treatment Fluids ---
1 - HCl 15%

Acid Placement: Wormhole length vs. Volume by Zone

- Zone 1
- Zone 2
- Zone 3
- Zone 4
Wormhole Length Prediction

- 15% HCl, 5% Self Diverting Acid
Wormhole Length Prediction

- 28% emulsified acid, 15% HCl, 5% self diverting acid

--- Treatment Fluids ---
1 - 28% Emulsion Acid
2 - 5% Self Diverting Acid
3 - HCl 15%

Acid Placement: Wormhole length vs. Volume by Zone

--- Treatment Fluids ---
1 - 28% Emulsion Acid
2 - 5% Self Diverting Acid
3 - HCl 15%
Final Stimulation Design

28% emulsified acid, 5% self diverting acid, 15% HCl

• What happens in each stage?
Figure-13: Execution chart; pumping rate, CT depth and wellhead pressure versus operational time
Immediate Results: Injectivity test

Injectivity test before and after the job, 1 being before and 2 being after the job
RESULTS

PRODUCTION RUN LOGS RUN IN 2005 AND 2009 DURING WATER PUMP-IN TEST

PLT - 2005

PLT - 2009

X800

X850

X900
Well Injection Results

- Injection profile improved
- Injection rate maintained
- Injection effect seen in nearby well
  - Initial increase in oil production
Conclusions

• Unique situation where 2 completion strategies could be evaluated on the same interval
• Combination of the tailored perforating program + the acid matrix stimulation improved the injection profile
• Improve bottom zone with additional perforating or Dynamic Underbalance clean-up

• Good set of well data + a team approach to planning and execution = successful job
Questions?