Updates on the Field A Tensleep Study

A Collaborative Study between EORI & Company A

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Nick Jones, Matthew Johnson

Laramie, July 26, 2012
Wyoming Oil & Gas Fields

- Powder River Basin
- Bighorn Basin
- Wind River Basin
- Greater Green River Basin
- Hanna Basin
- Laramie Basin
- Shirley Basin
- Denver Basin
- Jackson Hole
- Overthrust Belt
- Field A Area
Key Objectives of the Field A Tensleep Study

- Organizing Field A Data into A Database (Led by Nick Jones)
- Evaluation of the residual oil zone (ROZ) in the Tensleep formation (Led by Peigui Yin)
- Evaluation of fracture effects on reservoir flow and production
- Evaluation of CO$_2$-EOR options in its main pay zone and ROZ
Project Updates

• Data Collection: **completed**
  • *Made the second trip to Company A library in Dallas in April*

• Data Gaps: **identified**

• Digitizing Well Logs: **70% completed**

• Digitizing Early Prod./Inj. Data: **80% completed**

• Database Development: **ongoing**
  • *A draft version of Field A database has been provided to Company A for reviewing*
Project Updates (cont’d)

• Sand Flow Unit Correlation: **completed**
  • 18 major sand/dolomite units are identified and correlated

• Core & Outcrop Fracture Study: **ongoing**
  • Led by Scott Cooper, core fracture description is completed

• TZ/ROZ Characterization: **ongoing**

• Identifying Local Fracture Patterns: **ongoing**

• 3D Geologic Model of Field A Tensleep: **ongoing**

• Sector Simulation Models: **ongoing**
## Oil and Reservoir Properties of Field A Tensleep

<table>
<thead>
<tr>
<th>Property</th>
<th>Value/Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Depth of Tensleep Top</strong></td>
<td>2548 ft</td>
</tr>
<tr>
<td><strong>Initial Reservoir Pressure</strong></td>
<td>NA, est. 1800 psi</td>
</tr>
<tr>
<td><strong>Average Core Porosity</strong></td>
<td>17%, Range 9-33%</td>
</tr>
<tr>
<td><strong>Oil Gravity</strong></td>
<td>25-28.3° API</td>
</tr>
<tr>
<td><strong>Average Core Permeability</strong></td>
<td>75 md, Range 0.1-1000 md</td>
</tr>
<tr>
<td><strong>Bubble Point Pressure (BPP)</strong></td>
<td>58-305 psi</td>
</tr>
<tr>
<td><strong>Average Pay Thickness</strong></td>
<td>100 ft</td>
</tr>
<tr>
<td><strong>Gas Oil Ratio at BPP</strong></td>
<td>33.2-66 SCF/STB</td>
</tr>
<tr>
<td><strong>Average Gross Pay</strong></td>
<td>200 ft</td>
</tr>
<tr>
<td><strong>Est. OOIP in Main Pay Zone</strong></td>
<td>215.7 MMBO</td>
</tr>
<tr>
<td><strong>Oil Column</strong></td>
<td>1300 ft</td>
</tr>
<tr>
<td><strong>Cum. Oil Production</strong></td>
<td>119.1 MMBO</td>
</tr>
<tr>
<td><strong>Oil/Water Contact</strong></td>
<td>NA, est. 450 ft above sea level</td>
</tr>
<tr>
<td><strong>Oil Recovery</strong></td>
<td>55.20%</td>
</tr>
<tr>
<td><strong>Reservoir Temperature</strong></td>
<td>96° F</td>
</tr>
<tr>
<td><strong>Well Spacing</strong></td>
<td>10 acre</td>
</tr>
<tr>
<td><strong>Primary Drive Mechanism</strong></td>
<td>Water and solution gas</td>
</tr>
<tr>
<td><strong>CO2 MMP</strong></td>
<td>Est. 1750 psi</td>
</tr>
</tbody>
</table>
Monthly Oil Production Rates at Field A Field (1928-1978)

Waterflooding started in Dec. 1970
Reservoir Pressure in January 1948
Monthly Production at Field A Field (after 1978)
Average Water Cut in 2011: 99%
Wettability Measurement on Field A Tensleep Cores

<table>
<thead>
<tr>
<th>Core #</th>
<th>$\phi$ (%)</th>
<th>$K$, md</th>
<th>Swi, %</th>
<th>Amott index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13.2</td>
<td>156.5</td>
<td>11.02</td>
<td>0.204</td>
</tr>
<tr>
<td>2</td>
<td>17.3</td>
<td>302.9</td>
<td>5.42</td>
<td>-0.046</td>
</tr>
<tr>
<td>3</td>
<td>15.5</td>
<td>196.5</td>
<td>10.4</td>
<td>-0.025</td>
</tr>
</tbody>
</table>

Data from the 1991 Conoco report

**Amott Index:** -1 $\leq$ Index $\leq$ -0.3  
-0.3 $<$ Index $<$ 0.3  
0.3 $\leq$ Index $\leq$ 1

- oil wet
- mixed wet
- water wet

The wettability of Field A Tensleep rocks varies between weakly water-wet and weakly oil-wet
Field A Tensleep:
Top of B Sand Unit
Field A Tensleep: Well XXX (perforated only in A Sand)
Field A Tensleep: Well XXX (perforated only in A Sand)
Field A Tensleep: Well XXX (perforated only in A Sand)
Field A Tensleep:
Top of B Sand Unit
Illustration of Southwest-Northeast Cross Section at Field A Field

Southwest

Northeast

~2,000 ft

13°

~9,000 ft

Main Pay Zone

TZ/ROZ
Fracture Interpretation of the Southeast Tensleep Outcrop at Alcova Anticline, Wyoming

Well #XXX was drilled and cored in 1988
Field A Tensleep Wells Shot with Solid Nitro Glycerin (SNG)
Field A Tensleep Wells Have Been Sand Fractured
(260 fracture treatments by 1990)
Field A Tensleep: Top of B Sand Unit
Injection Profile of Well XXX

A Sand
- 25%
- 45%
- 30%

B Sand

Enhanced Oil Recovery Institute
Injection Profiles of Well XX with Single or Dual Injection Configuration

<table>
<thead>
<tr>
<th>Date</th>
<th>Profile 1</th>
<th>Profile 2</th>
<th>Profile 3</th>
<th>Profile 4</th>
<th>Profile 5</th>
<th>Profile 6</th>
<th>Profile 7</th>
<th>Profile 8</th>
<th>Profile 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/17/72</td>
<td>Single</td>
<td>Single</td>
<td>Single</td>
<td>Dual</td>
<td>Dual</td>
<td>Single</td>
<td>Dual</td>
<td>Single</td>
<td>Single</td>
</tr>
<tr>
<td>5/22/73</td>
<td>Open hole</td>
<td>Open hole</td>
<td>Open hole</td>
<td>Linered</td>
<td>Linered</td>
<td>Linered</td>
<td>Linered</td>
<td>Linered</td>
<td>Linered</td>
</tr>
<tr>
<td>5/24/74</td>
<td>Open hole</td>
<td>Linered</td>
<td>Linered</td>
<td>Linered</td>
<td>Linered</td>
<td>Linered</td>
<td>Linered</td>
<td>Linered</td>
<td>Linered</td>
</tr>
<tr>
<td>8/8/74</td>
<td>Single</td>
<td>Single</td>
<td>Single</td>
<td>Dual</td>
<td>Dual</td>
<td>Single</td>
<td>Dual</td>
<td>Single</td>
<td>Single</td>
</tr>
<tr>
<td>11/6/75</td>
<td>Single</td>
<td>Single</td>
<td>Single</td>
<td>Dual</td>
<td>Dual</td>
<td>Single</td>
<td>Dual</td>
<td>Single</td>
<td>Single</td>
</tr>
<tr>
<td>8/10/79</td>
<td>Single</td>
<td>Single</td>
<td>Single</td>
<td>Dual</td>
<td>Dual</td>
<td>Single</td>
<td>Dual</td>
<td>Single</td>
<td>Single</td>
</tr>
<tr>
<td>7/18/85</td>
<td>Single</td>
<td>Single</td>
<td>Single</td>
<td>Dual</td>
<td>Dual</td>
<td>Single</td>
<td>Dual</td>
<td>Single</td>
<td>Single</td>
</tr>
</tbody>
</table>

GAMMA RAY API
0.00
150.00

PERFORATIONS
-100.00
0.00
Initial Oil Saturation

Matrix Oil Sat.

0.24

0.72
Matrix Oil Saturation after 35-year Production
Fracture Oil Saturation after 35-year Production
Purchasing of EORI’s New Computer Cluster

- $250K funded by SER to purchase a 19-node HP cluster via Schlumberger
- Eclipse Parallel reservoir simulators installed, a software donation of $20 million from Schlumberger
- Up and running in April 2012
- Capable to run large models of up to 100 million cells

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Nodes</td>
<td>15</td>
<td>19</td>
</tr>
<tr>
<td>Cores per Node</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Total Cores</td>
<td>30</td>
<td>152</td>
</tr>
<tr>
<td>Computing Speed</td>
<td>1 time unit</td>
<td>0.3 time unit</td>
</tr>
<tr>
<td>Maximum Model Size</td>
<td>2~3 million cells</td>
<td>100 million cells</td>
</tr>
<tr>
<td>Optimal Number of Cores for Parallel Computing</td>
<td>~12</td>
<td>~32</td>
</tr>
</tbody>
</table>
Summary of Findings

- The Field A dataset of Company A is comprehensive and provides us the necessary data for the study.
- Direct evidence shows that, at different locations of the structure, natural fractures are developed in a variety of orientations, laterally and vertically.
- DST measurements indicate a pressure communication among all Tensleep zones, assumably by vertical fractures.
- Most of Tensleep wells have been hydraulically fractured and, to some extent, are connected to natural fracture networks. However, well-to-well fracture conduits can change with time depending on at-the-time wellbore configurations and injection/production intervals.
- Compiling an accurate timeline of well workover history appears to be difficult. Records of well treatments, especially after 1991, still need to be collected.
Summary of Findings (cont’d)

• The wettability of Field A Tensleep rocks varies between weakly water-wet and weakly oil-wet.
• At current production of high water cut (99%), the majority of produced oil is possibly resulted from spontaneous imbibition.
• The original oil-water-contact (OWC) is unknown. However, core oil saturation of 40% or higher has been observed in all Tensleep sand units from off-structure wells.
• The electromagnetic propagation log used in conjunction with the density/neutron logs is useful in quantifying oil saturation in TZ/ROZs.
• Historically high aquifer influx rate ranges from 14,000 to 20,000 bbls/day.
• Due to the combination effect of fractures and strong aquifer influx, both injectors and producers should be treated for water shut-off to reduce water cycling.
Summary of Findings (cont’d)

• For highly fractured Tensleep reservoirs, single porosity model (SPM) is unable to accommodate the difference of multi-phase flow dynamics in matrix and fracture.

• SPM is unable to simulate imbibition-dominated matrix-fracture fluid transfer.

• Dual porosity/permeability model (DPPM) is needed to match the fast aquifer water encroachment via the fracture systems in the Field A Tensleep formation.

• Modeling wellbore connection to fracture conduits is much easier in DPPM than in SPM.
Main Challenges to Achieving An Optimum Performance of CO$_2$ Flood at Field A

- Small pressure interval (between the MMP and fracturing pressure) for miscible CO$_2$ flood
- Problems of wellbore integrity in old wells
- Poor displacement efficiency caused by natural fracture conduits
- Conformance issues with CO$_2$ injection into multiple sand units
- The effect of strong hydrodynamic flow, especially in TZ/ROZ
- Uncertainty of current remaining oil distribution
Thank You!