Engineered Water for Improvement of Oil Recovery from Fractured Reservoirs

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Program Overview

– Funding
  • DOE: $7,919,227
  • Cost Share: $1,979,808

– Overall Project Performance Dates
  • October 2019 – September 2023

– Project Participants
  • The University of Texas at Austin
  • Kinder Morgan CO2 Company

– Goal: Field test an engineered water (ionic composition, surfactant or nanoparticles) injection to improve oil recovery from a carbonate reservoir
Objectives

• To identify a modified brine composition to enhance oil recovery from Goldsmith-Landreth San Andres Unit (GLSAU) in West Texas
• To field test the novel EOR processes
• To evaluate the field test
• To develop criteria to apply these chemical processes economically in carbonate reservoirs
• Cumulative oil recovery < 20%
• Oil is bypassed due to
  - heterogeneity
  - oil-wettability
• Improve oil recovery by imbibing water into the bypassed regions
• Improve water-wettability by
  - ions
  - surfactants
  - nanoparticles

• Vuggy, slightly fractured dolomite
• Produced water salinity: 60,000 ppm
• $T \sim 35 \, ^\circ{C}$
Wett. Alt. Mechanisms in Carbonates

- Austad et al. (2006), Yousef (2010): Exchange of SO$_4$ ions with adsorbed naphthenic acid groups, low salinity
- Austad et al. (2000): Ion-pair formation of cationic surfactants with the naphthenic acid groups
- Gupta & Mohanty (2009): Micellar solubilization of naphthenic acid groups with anionic surfactants
- Chen & Mohanty (2011): Mineral surface dissolution
Advantages & Challenges

• Advantages
  – Depleted, low permeability, oil-wet, carbonate
  – Fractured and heterogeneous reservoirs

• Challenges
  – Low temperature, high salinity, rate of oil recovery
Technical Approach

• Task 1: Project Management & Planning (Month 1)
• Task 2: Chemical Formulation Development (Month 1-12)
• Task 3: Reservoir Characterization, Design of SW Tests (Month 1-12)
• Task 4: Single-Well Field Tests (Month 13-24)
• Task 5: Multi-Well Test Design (Month 25-36)
• Task 6: Multi-Well Field Test (Month 37-48)
• Task 7: Field Deployment Strategy (Month 37-48)

Sample Analysis
• Rock Mineralogy
• Oil Properties
• Brine Compositions

Salinity Optimization
• Zeta Potential
• Contact Angle

Surfactant Screening
• Aqueous Stability
• Contact Angle
• Interfacial Tension
• Imbibition, core flood

Micromodel Study
Progress: Task 2

<table>
<thead>
<tr>
<th>Dilution</th>
<th>PW</th>
<th>PW/2</th>
<th>PW/4</th>
<th>PW/8</th>
<th>PW/16</th>
<th>PW/32</th>
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</thead>
<tbody>
<tr>
<td>CA test side view</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
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<tr>
<td>CA test top view</td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
<td><img src="image11.png" alt="Image" /></td>
<td><img src="image12.png" alt="Image" /></td>
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<tr>
<td>Post-CA (dark area)</td>
<td><img src="image13.png" alt="Image" /></td>
<td><img src="image14.png" alt="Image" /></td>
<td><img src="image15.png" alt="Image" /></td>
<td><img src="image16.png" alt="Image" /></td>
<td><img src="image17.png" alt="Image" /></td>
<td><img src="image18.png" alt="Image" /></td>
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<td>Post-CA (clean area)</td>
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<td><img src="image20.png" alt="Image" /></td>
<td><img src="image21.png" alt="Image" /></td>
<td><img src="image22.png" alt="Image" /></td>
<td><img src="image23.png" alt="Image" /></td>
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</tbody>
</table>

Salinity Optimization: Produced water/16
Surfactant Screening: Aqueous Stability

30 out of 37 surfactants are stable
### Surfactant Screening: CA & IFT

<table>
<thead>
<tr>
<th>Surfactant</th>
<th>Type</th>
<th>pH</th>
<th>Advancing CA (°)</th>
<th>IFT (mN/m)</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>STEPANQUAT 3712W</td>
<td>Cationic</td>
<td>7.9</td>
<td>95-120</td>
<td>1.942</td>
</tr>
<tr>
<td>CTAC</td>
<td>Cationic</td>
<td>7.93</td>
<td>80-115</td>
<td>0.861</td>
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<tr>
<td>DTAB</td>
<td>Cationic</td>
<td>8.38</td>
<td>85-115</td>
<td>1.696</td>
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<tr>
<td>Aspiro 6420</td>
<td>Cationic</td>
<td>3.92</td>
<td>80-110</td>
<td>0.210</td>
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<tr>
<td>Soloterra 982</td>
<td>Anionic</td>
<td>7.7</td>
<td>105-120</td>
<td>2.597</td>
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<tr>
<td>Calimulse AOS</td>
<td>Anionic</td>
<td>8.6</td>
<td>N/A</td>
<td>0.872</td>
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<tr>
<td>RD 219591</td>
<td>Anionic</td>
<td>7.25</td>
<td>N/A</td>
<td>0.186</td>
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<tr>
<td>Aspiro 1275X</td>
<td>Non-ionic</td>
<td>7.64</td>
<td>N/A</td>
<td>3.588</td>
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<td>Aspiro 1415X</td>
<td>Non-ionic</td>
<td>7.56</td>
<td>120-130</td>
<td>1.720</td>
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<td>Aspiro 1651X</td>
<td>Non-ionic</td>
<td>7.46</td>
<td>N/A</td>
<td>1.749</td>
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</tbody>
</table>
Imbibition Test: Surfactants in PW/16

- CTAC
- DTAB
- Stepanquat
- Aspro 6420
- Calimuse AOS
- Soloterra 982
- RD 219591
- Aspro 1275
- Aspro 1651
- Aspro 1415
- PW
- PW/16

Graph showing oil recovery (%) over time (days) for various surfactants.
Chemically Functional Micromodel

- Calcite deposition
- Dolomite conversion

Raman

XRD
Task 2: Reservoir Characterization and Design of Single-Well Test

a. Developed subsurface data workflows for data checking, debiasing and scale corrections, and spatial continuity modeling.
b. Calculation of multiple stochastic models integrating debiased statistics, expert knowledge and all salient uncertainty sources.
c. Workflow performance metrics have been met for planned workflow development and model calculation, along with quantitative metrics to evaluate model performance.
d. Current focus is on identification, prioritization of local study candidates to direct detailed physics-based modeling.

Quantitative model checking with representative, corrected target statistics.
Model Results: Flux Pattern Map

- Streamline model
- Rates between well pairs
- Oil allocation to inj-prod pairs
Model Results: Injection Efficiency

- Efficiency of each injector pattern
- Oil production associated with each injector
- Good vs. poor use of injected fluid
Candidates for Well Tests

- Initial screening yields following candidates for potential well test
- Candidates may change upon further scrutiny after model analysis

- Single well test (Huff & Puff type)
  - 172W and 178W
  - Very low GOR – not exposed to CO2
  - Workover needed to convert

- 83W well to well with 83R
  - Restore 83R
  - Injection profile
  - Tracer survey/PTA
  - Supply fresh water
  - Pre/Post saturation log

- 225W Pattern
  - Injection profile
  - Tracer survey/PTA
  - Supply fresh water & produced water
  - Pre/Post saturation log

- 152W Pattern
  - Restore pattern wells
  - Injection profile
  - Tracer survey/PTA
  - Supply fresh water
  - Pre/Post saturation log
Summary

• Brine composition has been optimized
• Four chemicals have been identified that can recover oil from bypassed regions
• Developed dolomite-micromodels
• Developed geostatistical reservoir characterization
• Two wells have been identified for single well tests
• One well-pair and two well patterns have been identified for multi-well tests

➢ Single-well chemical tests will be conducted in the next phase
➢ Well patterns will be characterized further before multi-well test