Reservoir Sourcing: Is Prevention better than Cure?

Produced Water Club Meeting
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Introduction

Presentation Outline

- Reservoir Sourcing Introduction
- Sourcing Study Workflow
  - SourSimRL
  - SourSimRL validation
- New field development
- Low-sulphate water injection
- Conclusions
Introduction

Reservoir Souring Schematic

- Sulphate + Nutrients
- Water swept + H₂S
- Thief zone / fracture
- Oil
- Retardation of H₂S transport by residual oil + H₂S adsorption
- Investment well m-SRB biofilm
- Water swept

Legend:
- Oil
- Injection water cooled
- Water swept + H₂S
- Mesophilic SRB
- Thermophilic SRB / Archaea
Souring Study Workflow

Development of Sourcing Mitigation Strategy

- High Quality Field Data (oil, water, gas)
- Reservoir Simulation
- Water Management Workshop
- Facilities & Operations; Material selection & H₂S limits; H₂S scavenging; HSE
- SourSimRL Simulations
- Injection Water Treatment e.g. nitrate, SRM
- Evaluation
- Sourcing Mitigation Strategy
Souring Study Workflow

**SourSimRL (SSRL) Sourcing Simulator**

**Pre-Processor**
- Reservoir Simulator Interface; Eclipse, etc.

**SourSimRL**
- Sourcing Kernel; Temperature distribution; SRB growth; \( \text{H}_2\text{S} \) generation, partitioning and transport; Nitrate module; Oil biodegradation
- User Input: e.g. formation & injection water chemistry
- Parallel / distributed simulation; Sensitivity handling

**Visualisation**

**Surface Facilities**

**H\(_2\)S Partitioning**

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SourSimRL Validation
North Sea Field Case

- Seawater injection
- Field gas $\text{H}_2\text{S}$ concentration currently $\sim$150 ppmv
- Individual wells can be in excess of 600 ppmv and wells have been shut-in due to high $\text{H}_2\text{S}$, because of safety and SSC considerations
- Increasing number of high (>400 ppmv) $\text{H}_2\text{S}$ wells since 2007
SourSimRL Validation

History Match

- Dual source of H₂S
  - SRB activity in near injection wellbore region using carbon from residual oil
  - SRB / Archaea activity deeper in the reservoir using carbon from formation water
- Straight forward to match at field scale
New Field Development
Subsurface Properties

- Offshore development
- High API, low oil viscosity
- Reservoir pressure close to bubble point
- Good waterflooding properties
- Important to maintain pressure via water injection voidage replacement

<table>
<thead>
<tr>
<th>Lithology / Depositional Type</th>
<th>Siliciclastic sandstone deposited in a fluvial to shallow marine environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Depth</td>
<td>9,100 ft</td>
</tr>
<tr>
<td>Reservoir Temperature</td>
<td>79 C</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reservoir Oil</th>
<th>Mol%</th>
<th>Formation Water (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N₂</td>
<td>0.29</td>
<td>Chloride 7,160</td>
</tr>
<tr>
<td>CO₂</td>
<td>0.03</td>
<td>Sulphate 50</td>
</tr>
<tr>
<td>H₂S</td>
<td>0.00</td>
<td>VFA (acetate, etc.) 430</td>
</tr>
<tr>
<td>C1</td>
<td>52.7</td>
<td>Barium 6</td>
</tr>
<tr>
<td>C7+</td>
<td>35.8</td>
<td>Calcium 1,291</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TDS 12,866</td>
</tr>
</tbody>
</table>

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Limits of between 240 and 400 ppmv $H_2S$ on flexible risers

Commercial consideration
  - Low delivery $H_2S$ specification

Options for seawater pre-treatment
  - Sulphate removal unit (nanofiltration)
  - Reverse osmosis unit (hyperfiltration) – low salinity waterflood
    - EOR potential application
  - Continuous nitrate dosing
  - Biocide batch dosing is required for MIC control

Options for gas treatment
  - Liquid scavenger
  - Offshore and / or onshore amine unit
New Field Development
Treatment Options

Options without Water Pre-Treatment

Options with Water Pre-Treatment

- Two different approaches:
  - Inject water without pre-treatment, and deal with H₂S in production facilities
  - Pre-treat the injection water to minimise H₂S scavenging requirements
- Project selected PWRI in alignment with Chevron Environmental Performance Standard
- SourSimRL cases run to evaluate different injection water treatments and associated H₂S scavenging requirements

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New Field Development

P90 Field H$_2$S Profiles

Formation Gas H$_2$S Concentration

- 2,900 mg/l Sulphate
- 50 mg/l Sulphate
- 20 mg/l Sulphate
- 5 mg/l Sulphate

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### New Field Development

#### Nitrate Treatment Simulations

<table>
<thead>
<tr>
<th>Injection Water</th>
<th>Nitrate Ion Dose (mg/l)</th>
<th>P90 H₂S Conc. (ppmv)</th>
<th>% Reduction in H₂S Conc. with Nitrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW-PWRI</td>
<td>0</td>
<td>991</td>
<td>0%</td>
</tr>
<tr>
<td>SW-PWRI</td>
<td>100</td>
<td>593</td>
<td>24%</td>
</tr>
<tr>
<td>SRM_20-PWRI</td>
<td>0</td>
<td>146</td>
<td>0%</td>
</tr>
<tr>
<td>SRM_20-PWRI</td>
<td>100</td>
<td>144</td>
<td>1%</td>
</tr>
</tbody>
</table>

- SourSimRL model setup is conservation (pessimistic) with respect to the effectiveness of nitrate treatment
- Very low impact on SRM-PWRI (20 mg/l sulphate) because sulphate is the limiting factor and nitrate treatment acts on carbon availability
New Field Development

Lift Gas H₂S Scavenging

Impact of Gas Lift H₂S Scavenging

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14
Souring simulations evolve with reservoir simulations
Higher injection water breakthrough results in higher souring
Longer field life results in higher predictions of maximum H₂S concentration
New Field Development

H₂S Scavenging Rate

- SW-PWRI
  - Requires process equipment offshore to meet export gas flexible riser requirement
- SRM_25-PWRI
  - H₂S limits can be achieved with liquid scavenger
### Low-Sulphate Waterflood

**Field B Formation / Injection Water**

<table>
<thead>
<tr>
<th></th>
<th>Formation Water</th>
<th>Injection Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphate (mg/l)</td>
<td>11</td>
<td>10-15</td>
</tr>
<tr>
<td>Dissolved Organic Carbon (mg/l)</td>
<td>42</td>
<td>30</td>
</tr>
<tr>
<td>Phosphorus (mg/l)</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Nitrogen (mg/l)</td>
<td>4.1</td>
<td>4.1</td>
</tr>
<tr>
<td>TDS (mg/l)</td>
<td>14,000</td>
<td>26,000</td>
</tr>
<tr>
<td>pH</td>
<td>6.0</td>
<td>6.5</td>
</tr>
<tr>
<td>Temperature (C)</td>
<td>40</td>
<td>35</td>
</tr>
</tbody>
</table>

- Produced water / aquifer water injection
- High permeability, low temperature reservoir
- Entire reservoir is a good environment for bacterial growth

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- $\text{H}_2\text{S(g)}$ increasing, but $\text{H}_2\text{S}$ generation in water phase essentially stable
- Increasing $\text{H}_2\text{S(g)}$ reflects increase in water cut from ~80% to ~90%
Low-Sulphate Waterflood
Field B Sourcing History Match

- History match at reservoir scale
- Injection water with 10 to 15 mg/l sulphate injection water consistent with historical data
Conclusions

- Reservoir souring simulations are key to techno-economic evaluation
- Need to build confidence in souring simulations by validation against historical data
  - High quality / frequent monitoring data
  - Field cases with and without nitrate treatment
- Sourcing simulations need to consider:
  - Gas lift and H₂S scavenging
  - H₂S limits from materials, especially flexible risers
- Update souring simulations as reservoir models evolve
- Low sulphate water injection limits souring development, but doesn’t necessarily prevent it entirely