Evaluating economic tradeoffs in produced water treatment for CEOR flood development

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Agenda

• Introduction
• Economic Screening Workflow Model
  • Purpose
  • Technical Basis
  • Economic Basis
• Case Study
  • SP Flood
  • ASP Flood
• Summary
• Conclusions
Chemical EOR

- **CEOR**: injection of fluids and chemicals which mobilize trapped oil in reservoirs and improve recovery factors.
CEOR Floods and Water Treatment

**CEOR Flood Types**

- **Examples:**
  - Polymer
  - Surfactant Polymer
  - Alkali Surfactant Polymer
  - Surfactant Gas
  - Gravity Stable Surfactant
  - Alkaline Co-Solvent Polymer
  - Hybrid processes

- **Other Considerations**
  - Advanced CEOR chemicals (temperature, salinity tolerance)

**Water Processes**

- **Examples:**
  - De-oiling
  - Filtration
  - Desalination
  - Softening

- **Other Considerations:**
  - Ionic Customization
  - pH Alteration
  - Produced Water Reinjection
Tradeoffs

**ASP Flood**
- Uses alkali to generate soaps from active oil in order to lower interfacial tension
- Lower surfactant retention
- Lower chemical concentrations
- More complex process

**SP Flood**
- Relies only on surfactants to lower interfacial tension
- Higher surfactant retention
- Higher chemical concentrations
- Less complex process

Water treatment can improve CEOR program economics (Henthorne 2011)
Chemical EOR Challenges

• Complexity
  • Reservoir Uncertainty
  • Water Quality and Quantity
  • Water Treatment Needs
  • Water / Reservoir Compatibility

• Economics
  • CEOR applications are costly
  • Declining oil prices are a hurdle to implementation

How can we enable CEOR to proceed in a challenging economic landscape?
A New Perspective

- CEOR Options are Increasing
  - Reservoir modeling techniques are improving
  - New CEOR chemicals are emerging, e.g. salinity, temperature tolerant
  - CEOR chemical prices are decreasing
  - Water treating technology is improving
  - Water treating costs are declining
  - Complex water sources, particularly produced water, are becoming more accessible for CEOR applications

A unified screening tool merging reservoir simulation with water treatment can enable operators to identify technically sound, cost-effective CEOR strategies
Economic Screening Workflow Model

- **Purpose:** Enable operators to evaluate CEOR decisions on the basis of Net Present Value (NPV)
- **Approach:**
  - Evaluate water treatment decisions in oilfield operations
  - Couple water treatment decisions with reservoir simulation, using UTCHEM to predict oilfield performance & NPV economics
- **Reservoir Performance:**
  - Evaluate performance of range of CEOR flood types in targeted fields
- **Water Treatment:**
  - Input source water, treatment goals; output indicative water treatment strategy, CAPEX and OPEX
- **Economic Evaluation:**
  - Calculate $/bbl of injection fluid based on CAPEX, OPEX, taxation, discounting, escalating costs, revenues and discount rates
- **Compare NPV among options to identify optimal CEOR strategy**
Technical Basis

Reservoir Simulation

- Reservoir Properties:
  - Rock types, Petrophysical Properties
- Fluid Saturations
- Well Spacing
- Injection Schedules
- Project Duration
- Predicted Performance in UTCHEM reservoir simulator

Water Treating

- Water Source:
  - Aquifer, Seawater, Produced Water
- Source Water Quality
  - Oil, Solids, Salinity, Hardness
- Treated Water Quality Goals
  - Oil, Solids, Salinity, Hardness
- Location
  - Onshore, Offshore
- Water Treatment Strategy
  - Range of pretreatment, oil reduction, ion removal, technologies
Economic Basis

Reservoir Mechanistic

- CAPEX
  - Wells
  - Mixing facilities
  - Production treatment
- OPEX
  - Well maintenance
  - CEOR chemicals
- Taxes
- Depreciation
- Inflation

Water Treating

- CAPEX
  - Indicative equipment selection:
    - Oil removal
    - Filtration
    - Desalination
    - Softening
- OPEX
  - Labor
  - Electricity
  - Water treating chemicals
  - Repairs and consumables

Total CAPEX, OPEX, taxation, revenue applied to complete scenarios. Variable inputs allow for sensitivity analysis.
Case Study: Overview

- Region: Middle East (hypothetical scenario)
- Reservoir Type: Sandstone
- Oil Saturation: 50% after primary recovery
- Pattern Economics:
  - Single pattern – assumed in a multi-pattern rollout
  - Assume 2 new wells drilled per pattern for economics
- Max Injection Flow Rate In Pattern: 6,000 bbls/day
- Available Water Supply: Produced water
- Oil Price: $45/bbl
- Temperature ~ 50°C
Reservoir Model

- Initial Pressure:
  - 2,000 psi
- Heterogeneity:
  - 0.65 Dykstra Parsons Coeff.
- Mean Permeability:
  - 200 mD
- Remaining Oil:
  - 1.5 MM bbls
  - 2 cP
- Topside Injector:
  - Max 2,000 bbls/day
  - Max 3,900 psi
- Pattern Spacing 20 Acres
Case Study: Objectives and Details

• Objective:
  • Evaluate performance and economics of three floods to identify optimized solution:
    • Waterflood
    • SP Flood
    • ASP Floods

• Injection Plan
  • 0.30 PV SP/ASP Slug
  • Polymer drive until NPV stops increasing

• Waterflood
  • De-oil and filter produced brine

• SP
  • 0.75% surfactant
  • 0.28 mg surf /g rock retained
  • De-oil and filter produced brine

• ASP
  • 0.30 % surfactant
  • 0.12 mg surf /g rock retained
  • De-oil, filter, and soften produced brine
Technical Basis: Water

• Source: Produced Water

Water Quality Assumptions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Source Quality</th>
<th>Treated Target</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Source Quality</td>
<td>Waterflood</td>
</tr>
<tr>
<td>Temperature</td>
<td>°C</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Oil</td>
<td>mg/L</td>
<td>100</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Solids</td>
<td>mg/L</td>
<td>20</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Salinity</td>
<td>mg/L</td>
<td>50,000</td>
<td>50,000</td>
</tr>
<tr>
<td>Hardness</td>
<td>mg/L</td>
<td>3,000</td>
<td>3,000</td>
</tr>
</tbody>
</table>

• Location: Onshore
• Total Pattern Injection Rate: Max 6,000 bbls/day
# Water Treating Strategies

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Waterflood De-oil/Filter</th>
<th>SP De-oil/Filter</th>
<th>ASP De-oil/Filter/Soften</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>IGF + Walnut Shell Filtration</td>
<td>IGF + Walnut Shell Filtration</td>
<td>IGF + Walnut Shell Filtration</td>
</tr>
<tr>
<td>Solids</td>
<td>Membrane Filtration</td>
<td>Membrane Filtration</td>
<td>Membrane Filtration</td>
</tr>
<tr>
<td>Desalination</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Softening</td>
<td>-</td>
<td>-</td>
<td>Nanofiltration</td>
</tr>
</tbody>
</table>
## CEOR Chemical Estimates

<table>
<thead>
<tr>
<th>Commodity</th>
<th>ASP Slug Concentration</th>
<th>SP Slug Concentration</th>
<th>Cost per Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>-</td>
<td>-</td>
<td>$0.05/bbl</td>
</tr>
<tr>
<td>Alkali</td>
<td>20,000</td>
<td>-</td>
<td>$0.17/lb</td>
</tr>
<tr>
<td>NaCl</td>
<td>-</td>
<td>20,000</td>
<td>$0.05/lb</td>
</tr>
<tr>
<td>Polymer</td>
<td>2,000</td>
<td>2,000</td>
<td>$1.00/lb</td>
</tr>
<tr>
<td>Surfactant</td>
<td>3,000</td>
<td>7,500</td>
<td>$2.50/lb</td>
</tr>
<tr>
<td>Cosolvent</td>
<td>5,000</td>
<td>5,000</td>
<td>$0.75/lb</td>
</tr>
</tbody>
</table>
## Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Waterflood De-oil/Filter</th>
<th>SP De-oil/Filter</th>
<th>ASP De-oil/Filter/Soften</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CAPEX</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wells</td>
<td>$4 MM</td>
<td>$4 MM</td>
<td>$4 MM</td>
</tr>
<tr>
<td>Polymer Facility</td>
<td>-</td>
<td>$5 MM</td>
<td>$5 MM</td>
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<tr>
<td>Surfactant Facility</td>
<td>-</td>
<td>$3.7 MM</td>
<td>$3.7 MM</td>
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<tr>
<td>Water Treating Facility</td>
<td>$27,000</td>
<td>$27,000</td>
<td>$4.5 MM</td>
</tr>
<tr>
<td><strong>OPEX</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CEOR Chemicals</td>
<td>$0.06 / bbl injected</td>
<td>$10.04 / bbl injected</td>
<td>$5.86 / bbl injected</td>
</tr>
<tr>
<td>Overhead</td>
<td>0.10 * CAPEX</td>
<td>0.10 * CAPEX</td>
<td>0.10 * CAPEX</td>
</tr>
<tr>
<td>Labor, Electricity, etc.</td>
<td>Included in Overhead</td>
<td>Included in Overhead</td>
<td>Included in Overhead</td>
</tr>
</tbody>
</table>
Oil Recovery

Barrels of Oil Produced Thousands

Days

WF
SP
ASP

0 500 1000 1500 2000 2500 3000

THE PRODUCED WATER SOCIETY SEMINAR 2016
NPV for $45/bbl Oil

Net Present Value Millions

Years of Flood Elapsed

ASP

SP

WF

$7.52

$5.09

$3.96

$(-20.00)

$(-15.00)

$(-10.00)

$(-5.00)

$0.00

$5.00

$10.00

$15.00

$20.00

0

1

2

3

4
Summary and Conclusions

• In the current oil price landscape, new strategies are needed to enable operators to evaluate and enable CEOR.

• A model has been developed to leverage advancements in reservoir engineering and water treating technology to improve CEOR program planning.

• A case study was implemented to demonstrate tradeoffs between flood performance and NPV-based economics.

• Results suggest that under certain conditions increased water treatment can allow for use of more cost effective CEOR processes.
THANK YOU

Questions?