Polymer project in OffShore Brazil: from Screening to Pilot Planning

Repsol E&P Technology Center & Repsol - Sinopec Brasil BU

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Chemical EOR Workshop - Key Success Factors
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Outline

- Introduction
- Repsol EOR Methodology approach
- EOR Technology Pre-Screening
- Experimental evaluation and Scale up from lab to field
- Next steps
- Conclusions
Introduction

Main EOR Characteristics

- IOR/EOR Definition
  - Secondary Recovery
    - Water Injection
    - Pressure Maintenance
  - Tertiary Recovery (EOR)
    - Oil Recovery employing fluids not present in the reservoir

- Main EOR Processes
  - Gas Injection (CO₂, N₂, Natural Gas)
  - Chemicals (Polymers, Surfactants & Alkaline and Combinations)
  - Thermal Processes

- Critical reservoir parameters that define EOR Technology Selection
  - Depth (P&T), Thickness
  - Permeability, Formation Water Salinity
  - Oil Viscosity @ Reservoir Temperature
  - Type of Sand (Sandstone, Carbonate)
Introduction
Chemical EOR begins to emerge as an important recovery strategy

- Worldwide average recovery factor (RF) of light and medium crude oil deposits is around 30% - 35%
- Worldwide annual production decline in conventional oil fields is around 5.5% and 14% in offshore deep water.
- Each increase of 1% in the RF adds between 55 and 70 billion barrels to worldwide estimated reserves.
- Changes in the market and improvements to the chemical EOR process have allowed projects once considered uneconomical to now be viable.

Past: Experience
- Cost-prohibitive chemical costs
- Low oil prices (<$40 per barrel)
- Poor understanding of chemical behavior in reservoirs
- Uncertain recovery factors

Present: Commercialization
- Improved polymer, surfactant, and alkaline chemicals available at lower cost
- Higher oil prices (> $60 per barrel)
- More effective laboratory techniques to design cost-effective projects
- Large database of failed and successful projects
Phases to follow for EOR Technology Selection.

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<td>• Injectivity &amp; Tracer Test</td>
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<td>• Scale up to field Model</td>
<td>• Impact on existing Facilities</td>
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<td></td>
<td>• Operational risk assessment</td>
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Repsol Work Flow for Pre-Screening of Recovery Processes

1. Analogous Reservoir Identification
   - What have been done in similar reservoirs?

2. Pre-screening using average properties
   - How much the target reservoir is similar to other reservoirs with successful recovery processes?

3. Pre-screening using reservoir distribution of properties
   - ¿Where, in the field, you can apply EOR?; What is the EOR impact in the field?

4. Ranking of technologies
   - Oil recovery, Success factor, and Costs & Environmental impacts

Pre-screening & Ranking

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Screening of EOR processes to Repsol Business Units

**Spain**; 2010; Offshore; Carbonates, Light oil

**Venezuela**; 1 Fields Onshore; Sandstones; Extra-heavy Oil (In progress)
   - 1 field Offshore; Sandstone; Heavy Oil

**Brazil**; 1 Field Offshore; Sandstones; Medium Oil (In Progress)

**Ecuador**; 1 Field Onshore; Sandstones; Medium - Heavy Oil (In progress)

**Trinidad**, 3 Fields Offshore; Sandstone; Light Oil

**Russia**, 1 field Heavy Oil; Carbonates & Sandstone; Heavy Oil (In progress)

**USA**; 1 field; Onshore; Carbonates; Medium Oil (In progress)
Field Characteristics and EOR pre-screening using average properties

- The reservoir is a Turbidite
- Permeability range between 1 D and 5,0D (Avrg. 2500mD)
- Porosity between 27% and 31%
- Water table around 1500m and a Reservoir depth 2300m
- Pressure of 183 bar (2650psi), 54°C
- Very high salinity production water (60000-80000ppm NaCl, 300-1500ppm Ca++, 200-750ppm Mg++)
- De-sulfide sea water as injection water
- The crude oil is medium heavy with 16°API to 22°API, viscosity between 7cP and 22cP at reservoir conditions

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<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir Type</td>
<td>Turbidite</td>
</tr>
<tr>
<td>Permeability</td>
<td>Range between 1 D and 5,0D (Avrg. 2500mD)</td>
</tr>
<tr>
<td>Porosity</td>
<td>Between 27% and 31%</td>
</tr>
<tr>
<td>Water Table</td>
<td>Around 1500m</td>
</tr>
<tr>
<td>Reservoir Depth</td>
<td>2300m</td>
</tr>
<tr>
<td>Pressure</td>
<td>183 bar (2650psi)</td>
</tr>
<tr>
<td>Temperature</td>
<td>54°C</td>
</tr>
<tr>
<td>Salinity</td>
<td>High</td>
</tr>
<tr>
<td>Crude Oil API</td>
<td>Medium heavy</td>
</tr>
<tr>
<td>Crude Oil Viscosity</td>
<td>7cP to 22cP at reservoir conditions</td>
</tr>
</tbody>
</table>

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### Salinity, ppm

![Salinity ppm graph](chart.png)
EOR experimental program

Rock Samples

<table>
<thead>
<tr>
<th>Stack</th>
<th>Phase</th>
<th>Stack Length (CM)</th>
<th>Pore Volume (CC)</th>
<th>Average Permeability (MD)</th>
<th>Average Porosity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stack 1</td>
<td>Phase 1</td>
<td>17.01</td>
<td>59.21</td>
<td>2516</td>
<td>32.9</td>
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<tr>
<td>Stack 2</td>
<td>Phase 1</td>
<td>19.05</td>
<td>64.17</td>
<td>2582</td>
<td>31.4</td>
</tr>
<tr>
<td>Stack 1</td>
<td>Phase 4</td>
<td>14.70</td>
<td>51.04</td>
<td>5264</td>
<td>31.8</td>
</tr>
<tr>
<td>Stack 4</td>
<td>Phase 4</td>
<td>13.50</td>
<td>56.71</td>
<td>2388</td>
<td>38.0</td>
</tr>
</tbody>
</table>

- EOR laboratory core flood experiments have been conducted.
- Core plugs and oil samples from Field area were provided by the Repsol – Sinopec BU for this study.
- Water and chemical floods have been evaluated to assess the feasibility of increasing the RF of this field.
EOR experimental program

Eight displacement tests to obtain the RF and best suited chemical formulations

Phase 1
Injection Brine + P1 / Injection Brine + P1-S1-P1

Phase 2
Injection Brine + P2 S2+P2 / Injection Brine + P1-S3-P1 + P1-S1-P1

Phase 3
LSW + LSW-P1 / Injection Brine + CLP + LSW

Phase 4
LSW + LSW-P1 / Injection Brine + CLP + LSW
**EOR experimental program**

**Chemicals Characteristics**

**Surfactant Screening Surface Tension (IFT), Dynes/cm**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Conc, wt%</th>
<th>IFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>0.2</td>
<td>0.0076</td>
</tr>
<tr>
<td>S2</td>
<td>0.2</td>
<td>0.02</td>
</tr>
<tr>
<td>S3</td>
<td>0.2</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Polyacrylamide (P1) in Injection brine & LSW

Cross Linked Polymer (CLP)

Polymer Concentration vs Viscosity
Impact Water salinity on Polymer Viscosity @ 8.5 1/s Shear Rate

Low Salinity water 2000ppm

Injection Water 30000ppm
Lab Coreflooding Experimental results

<table>
<thead>
<tr>
<th></th>
<th>Injection Brine Flood</th>
<th>Chemical Flood 1</th>
<th>Chemical Flood 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stack 1-Phase 1</td>
<td>PV Inj: 9.2</td>
<td>Recov (%): 35.4</td>
<td>Recov (%): 6.8</td>
</tr>
<tr>
<td>Stack 2-Phase 1</td>
<td>PV Inj: 11</td>
<td>Recov (%): 42.4</td>
<td>Recov (%): 16.6</td>
</tr>
<tr>
<td>Stack 1-Phase 2</td>
<td>PV Inj: 4.5</td>
<td>Recov (%): 40.0</td>
<td>Recov (%): 8.0</td>
</tr>
<tr>
<td>Stack 2-Phase 2</td>
<td>PV Inj: 3.5</td>
<td>Recov (%): 38</td>
<td>Recov (%): 5.18</td>
</tr>
<tr>
<td>Stack 1-Phase 3</td>
<td>PV Inj: 0.0</td>
<td>Recov (%): 0.0</td>
<td>Recov (%): 50.9</td>
</tr>
<tr>
<td>Stack 2-Phase 3</td>
<td>PV Inj: 0.0</td>
<td>Recov (%): 0.0</td>
<td>Recov (%): 50.7</td>
</tr>
<tr>
<td>Stack 1-Phase 4</td>
<td>PV Inj: 0.0</td>
<td>Recov (%): 0.0</td>
<td>Recov (%): 48.1</td>
</tr>
<tr>
<td>Stack 2-Phase 4</td>
<td>PV Inj: 0.0</td>
<td>Recov (%): 0.0</td>
<td>Recov (%): 62.3</td>
</tr>
</tbody>
</table>

- Polymer inc. RF 15%
- Around 23% of inc. RF for CLP
- Up to 27% of inc. RF for LSW+P
- Between 6% and 13% inc. RF for Primary LSW
- 1.1-9.6% inc. RF for tertiary LSW
History matching and scaling

Overall good fit was obtained in model and reported parameters

Phase 1 stack 1 fit example

Phase 4 stack 1 fit example
Full field simulation

PILOT AREA

1. $N_x \times N_y \times N_z = 75 \times 23 \times 15 = 25,875$ block (14,588 active block)
2. Average cell size: 100 x 100 x (0.1-1.5 m variable) in x, y and z direction respectively.
3. The average history run time is around 2.0 hours chemical predictions run about 1.5 hours.
4. Model STOIIP = 12.6 MMm³ (79 MMSTB)
5. Oil API = 17, reservoir Temperature = 50 °C
6. Saturation pressure = 231 bar
7. Live oil viscosity = 10.8 Cp at saturation pressure
8. Initial formation water salinity 86000 ppm, Injected water Brine salinity 30000 ppm
## Full Field Simulation Pilot Chemical EOR Summary

<table>
<thead>
<tr>
<th>Chemical System</th>
<th>Pilot Oil Recovery (%)</th>
<th>Cost $/b Incremental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymer</td>
<td>5.5</td>
<td>3.5</td>
</tr>
<tr>
<td>CLP</td>
<td>6.0</td>
<td>2.0</td>
</tr>
<tr>
<td>LSW</td>
<td>4.2</td>
<td></td>
</tr>
</tbody>
</table>

### OIL RATE, M³/DAY

### CUMULATIVE OIL, M³
Next Steps

1.-Polymer injection test in a well in the east of the reservoir. This test will be performed to verify whether the injection would cause any formation damage to the well and to measure parameters to calibrate the model.

2.-The pilot is being considered for 2017, but it is conditional to the injectivity test results as well as the economic analysis.
Conclusions

1. It was developed a road map methodology to select the appropriate EOR technology to improve the RF.

2. It has been applied successfully in several fields: some conventional and some with extreme conditions.

3. Experimental results show that recovery mechanisms with LSW and CLP or Polymer injection are highly dependent on the permeability ranges. While LSW is more preferable for relatively lower permeabilities, the CLP and Polymer acts better in higher permeable media.

4. Field Simulation shows that:
   - LSW has resulted in incremental RF 4.2% without chemicals injected but additional surface facilities in production platform and CAPEX need to be evaluated.
   - CLP and P shows incremental RF of 6% and 5.5% respectively over water flooding and injected chemicals cost of 2.0 and 3.5 US$/bbl incremental oil.

5. The synergy effect of using LSW and Polymer can be quite significant but probably will be limited by economic criteria to be applied in the field.

6. Operator has decided to go ahead with the pilot in the area selected here after Injectivity test results.
Questions?