Enhanced Oil Recovery in a Multilayer Complex Reservoir Casabe Project Case Study

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Project Background

Discovered in 1941
~1,450 wells drilled by 2015
Active waterflooding
Five Spot patterns
~15 acre spacing
Producing formations: Colorado, Mugrosa, La Paz
Fluvial environment
Layered sand/shale sequence
~ as many as 25 zones/producers
18-25 API oil with ~ 30-80 cp viscosity
Original pressure ~ 1,500 psia,
Current range from 400-1,200 psia
- $k = 50\text{--}300 \text{ mD}$
- $RF \approx 20\%$ pattern WF
Vertical and Horizontal Heterogeneity

VERTICAL HETEROGENEITY DUE TO CHANNEL STACKING
MODIFIED FROM RAMON Y CROSS, 1997

Relative Preservation Of The Channels Sandstones Under Low And High A/S Conditions
Project Background

- Large difference in mobility between oil and water in Casabe ($M_{w,o} \sim 25$)
- Maturity of secondary recovery create several operational problems in the field
  - Increase of the water cut
  - Water influxes
  - Increased volume of produced sand, etc.
- Heterogeneities create irregular water fronts, causing early water breakthrough

\[ E_V = E_A \times E_I \]

Where:
- $E_V =$ Volumetric Efficiency
- $E_A =$ Areal Efficiency
- $E_I =$ Vertical Efficiency

5 Year EOR Cycle Time

- Screening
- Pilot Design
- Lab/Tracer Studies
- Pilot Drilling & Installation
- Pilot Operation & Surveillance
- Pilot Expansion
- Full Field Devt Plan

- No Economic Technique
- Final Costs Uneconomic
- Go-No Go Decisions
- Incremental not Delivered or Proven
- Follow-up Doesn't Deliver
- Full Field Uneconomic

Deliverables
- Technique
- Pilot Areas
- Budget
- Predictions
- Pilot Plan
- AFEs
- Proof of Concept
- Early Cash
- Reserves & FID
EOR Project Implementation Process + Focus Team

- Project Manager
- Reservoir Engineer
- G&G
- Production Technologist
- Well Construction Engineer
- Facilities Engineer
- Production Optimization
- Economic Analyst
- Supply Chain Support
Screening criteria for EOR processes

- Formation type/lithology
- Reservoir geology
- Oil Composition and Oil Viscosity
- Formation Water Salinity and Divalent
- Reservoir Temperature
- Formation Permeability

Operational issues to consider

- Availability of injecting agents (Water, Gas, CO₂, N₂)
- Pattern configuration and well spacing
- Well Completion
- Facilities configuration and constrains
- Energy
- Environmental and Legal Regulations
Conceptual Design

Two Polymer Flooding Pilots for mobility control and \( S_{or} \) Reduction EOR; variation in chemical make up for different K/V shale

– One in Average Rock Quality, swept.
– One in Best Rock Quality, swept

Two layers comprising >30% of OOIP
EOR Experimental Tests

Viscosity modification with HMPA Polymer

Surfactant Phase Behavior

Core Flooding

Digital Rock

Oil and water saturations

Low Polymer concentration

High
Tracer Technology

\[ M_{\text{traz}} = 10 \cdot V_p \cdot LDR \]
InterWell Tracer Irruption observed on both sands A2 (Upper) and A2i (Lower).

InterWell Tracers confirm Sand deposition direction. Irruption on 2nd line production wells confirm complex channeling system.

Base on irruption times severe channeling is observed between CSBE 1222 (INY) and CSBE-1159 (Central Well).
Viscosity reduction test on injection valves

No reduction effect on 9 mm circulation valves. Dramatic viscosity reduction on flow regulation valves.
cEOR Project Design

- Block 6.
  - 4 Polymer Injector Wells
  - 9 Oil Producer Wells
  - 1 Observation Well
  - Comingle Production
  - Selective Polymer Injection
Simulation Cases

- Four (1/4) Injectors
- Four injectors
- Sixteen Injectors

Five Spot Pattern  Four Inverted Five Spot Patterns  Four Inverted Five Spot Pattern
Implementation of the surveillance plan

**Preparation & Baseline**
- Understand actual well behavior.
- Know actual well mechanical conditions.
- Identify prod/inj. enhancement opportunities before the pilot.
- Baseline preparation.

**Monitoring During Pilot**
- Monitoring key variables to make decisions related to changes in injection parameters.
- Ensure wells are operating at optimum conditions.

**Field Challenges**
- Selective injection
- Water flow regulator valves
- Commingled production
- Low Production Rates
- Poor production monitoring
- No real time data for production/injection optimization
- Sand production
- Different type of ALS with rods
- High water cut
- Casing/tubing damage
Surveillance plan

What are we injecting? Is the polymer is under specifications?

Effect on the producer. Increase of oil production?

Where we are injecting? All layers are taking polymer?
Initial Evaluation:

**Producers:**
- Casing integrity evaluation
- Initial production distribution
- Production baseline

**Injectors:**
- Initial injection profile
- Injectivity tests
- Sand in annular

**Observation well:**
- Initial oil saturation
- Initial formation pressure

**Reservoir:**
- InterWell tracers

**Schlumberger**
One Stop Shop Concept

- Corrosion and MultiFinger logs
- PLT at different flow rates (SIP analysis)
- Multiphase flow meters

**Injectors:**
- DSL
- WS surface pumps
- RST silicon activation log

**Observation well:**
- RST-C/O
- XPT

**Reservoir:**
- Well connectivity
- Channel size
- Breakthrough times

NT in Casabe
## Schlumberger
### One Stop Shop Concept

### Data Acquisition program:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production monitoring with multiphase flow meters (# of well tests monthly)</td>
<td>2 well test daily</td>
</tr>
<tr>
<td>Wellhead pressure</td>
<td>Real time</td>
</tr>
<tr>
<td>ALS parameters</td>
<td>Real time</td>
</tr>
<tr>
<td>PLT with wireline</td>
<td>Each 6 months</td>
</tr>
<tr>
<td>Downhole pressure gauges</td>
<td># gauges installed</td>
</tr>
<tr>
<td>Polymer injection pressure and rate</td>
<td>Daily</td>
</tr>
<tr>
<td>Viscosity, concentration, filter ratio</td>
<td>Daily</td>
</tr>
<tr>
<td>Polymer stock</td>
<td>Weekly</td>
</tr>
<tr>
<td>Injection profiles</td>
<td>Each 2 weeks</td>
</tr>
<tr>
<td>Oil saturation</td>
<td>Each 6 months</td>
</tr>
<tr>
<td>Formation pressure (PLT and downhole pressure gauges)</td>
<td>As required</td>
</tr>
<tr>
<td>QA/QC (days per month)</td>
<td>Monthly</td>
</tr>
<tr>
<td>QC polymer, polymer breakthrough in producers, water quality, viscosity, filter ratio, concentration</td>
<td></td>
</tr>
</tbody>
</table>

### Polymer specifications

- Viscosity, CP / Concentration, ppm
- Filter Ratio

### Polymer injection process

- Fluids movement in reservoir
- Flowing and Formation

### Prod/Inj Analysis

- NT in Casabe
EOR Pilot Performance Evaluation
Original Oil Saturation
• Shows good Original Oil Saturation
• Not sweep oil

OBSERVATION WELL OBJECTIVES

• Observation well to evaluate increase in sweep efficiency of polymer injection in A2/A2i sands.
• Infill drilling well to evaluate the efficiency of reduction in the injection – production pattern spacing.
B: Oil saturation increase between October 2014 and April 2015
D: Oil saturation decrease between Abril 2015 y October 2015
F: Total Oil Saturation Change entre October 2014 y October 2015
RST Time Lapse. A2i Sand

- **B**: Oil saturation change between October 2014 and April 2015
- **D**: Oil saturation change between Abril 2015 and October 2015
- **F**: Total Oil Saturation Change between October 2014 and October 2015
Flow Behavior

1. **Initial Saturation Condition**: Original So
2. **RST @ 6 months**: So increase, oil front reached observation well.
3. **RST @ 1 year**:
   - Preferential drainage.
   - Channels with So reduction due polymer flood effect, oil is pushed to neighbor wells.
   - Channels with So increase due polymer flood effect, entrapment due to lack of drainage points.
4. **Proof of concept of areal sweep increase.**
CSBE-1222 shows good injectivity both water and polymer.

1. Concentration reduction to 400 ppm
2. Conformance with mother solution at 3000 ppm - A2i
3. Hypochlorite Clean Up - A2
CSBE-1304 shows reduction of injectivity due lack of drainage points.

1. Concentration reduction to 400 ppm
2. Hypochlorite Clean Up - A2. Injection increased.
Prior polymer injection, pattern optimization shows a increase in oil production. Polymer Injection stabilization occurred since January 2015. Dramatic water production decrease after polymer injection. Oil Production Increase after 8-9 months of polymer injection.
Oil production increased after pattern optimization. After polymer injection oil production decrease slightly but water production decrease drastically. After 8-9 month oil increase.
Sweep efficiency increase observed after Water Flooding optimization. Polymer Flood show sweep efficiency over Water flooding. Decrease barrel of water injected by barrel oil produced.
Facilities Installation

Polymer injection started in October 28, 2014, in four polymer injector wells. Total injection capacity is 3,000 B/D of 500 ppm polymer solution at 2,000 psi.

Individual pump for each injector is used to allow individual pressure control.
Conclusions

• Fast Track EOR is feasible and achievable
  With the right integration of Operator and Service Provider(s):
    18 months to pilot online
    36 months to proof of concept
• One Stop Shop to minimized tender, decision and handovers delays
• Successful Implementation of Casabe Pilot Project
• A surveillance plan for any EOR pilot is key to ensure the collection of critical data that will allow a proper evaluation of the pilot.
• The surveillance plan is determined by the characteristics and challenges of each field.
• The implemented plan is far more robust than conventional surveillance used at the field.
• Design, Operation & Surveillance must still be best in class and focus on earliest proof of concept
• A structured Team dedicated to the project is fundamental for success
• Synergy between different players across the organization are crucial to implement a fast track project