DEVEX 2016

Smart EOR Screening Workflow connecting Analytical and Numerical Evaluations

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Outline

Industry context

Understanding the role and complexity of EOR

EOR screening tool & benefits

Case Study

Conclusion
Enhanced oil recovery (EOR) processes include all methods that use external sources of energy and/or materials to recover oil that cannot be produced economically by conventional means.
SLB’s Vision for EOR

Goal: Developing and implementing technologies and services to help increase recovery factors in oil fields.

- EOR is the most integrated activity of the O&G Industry;
- Each activity (yellow boxes) has to take place in a well synchronized manner for incremental oil to be realized at the stock tank. If one of them fails there will be no additional recovery realized;
- In the past, EOR projects were designed with focus mainly on reservoir engineering and laboratory experiments;
- EOR success in the field requires collaborative integration from all disciplines (Geoscience-Engineering-Economics)

Synchronised integration of the enablers will bring the incremental reserves
EOR Project: “Concept to Field Implementation”

- Improve Design & Accelerate Implementation
- Improve Execution

[Diagram showing the workflow of EOR project from idea/concept to field implementation, highlighting stages such as screening studies, physical models lab, field modeling, etc.]
Technology Relevance – Measurement Scale
Oil Recovery Stages

IOR methods improve RF after the natural depletion phase
• Reservoir management (automation, smart wells)
• Reservoir stimulation (fracture, acid)
• Secondary recovery (water-flood, gas-injection)
• EOR

EOR comprises
1. Defining strategic injection points in the reservoir
2. Injecting heat, chemicals or gas in optimal quantities
3. Mobilizing otherwise unrecoverable oil
Objectives
1. Increase the mobility of hydrocarbons
2. Increase micro (CO2) & macro (polymer) sweep efficiency

Means employed
• Modification of phase viscosities and capillary pressures
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EOR processes

Conventional Secondary Recovery Pressure Maintenance
- Water Injection
- Gas Injection (Combination WAG)

Current Methods of Enhanced Recovery
- Thermal Recovery Methods
  - In-situ Combustion
    - Forward
    - Reverse
  - Hot-fluid Injection
    - Steam Injection
    - Hot water injection
- Improved Fluid-Injection Methods
  - Immiscible Displacement
    - Polymer
    - Surfactant
  - Miscible Displacement
    - Micro emulsion & micellar flooding
      - CO2, N2, LPG, alcohol HP enriched gas drives

Future Trends Developments Possible EOR
- Foam & complex Gas, oil, water mixtures
- Explosives, Hypersonic etc.

Still in R&D phase

Current Practice

Needs technology application
Waterflooding

<table>
<thead>
<tr>
<th>EOR Method</th>
<th>Pressure Support</th>
<th>Sweep Improvement</th>
<th>IFT Reduction</th>
<th>Wettability Alteration</th>
<th>Viscosity Reduction</th>
<th>Oil Swelling</th>
<th>Hydrocarbon Single Phase</th>
<th>Compositional Change</th>
<th>Incremental Recovery Factor</th>
</tr>
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<tbody>
<tr>
<td>Waterflooding</td>
<td>Waterflooding</td>
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IFT = interfacial tension
WAG = water-alternating-gas
ASP = alkali-surfactant-polymer

2. Waterflooding provides the base case for comparison of other methods.
3. Oil stripping occurs as miscibility develops.

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Thermal Recovery

<table>
<thead>
<tr>
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<th>Viscosity Reduction</th>
<th>Oil Swelling</th>
<th>Hydrocarbon Single Phaze</th>
<th>Compositional Change(^1)</th>
<th>Incremental Recovery Factor</th>
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Chemical Recovery

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## Miscible recovery

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<th>Incremental Recovery Factor</th>
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<tr>
<td>Gasflood miscible</td>
<td>Hydrocarbon</td>
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<td>Hydrocarbon WAG</td>
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<td>High</td>
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<tr>
<td>CO₂ WAG</td>
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<td>Highest</td>
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</tbody>
</table>

Recovery methods in this category include both hydrocarbon and non-hydrocarbon miscible flooding. These methods involve the injection of gases (carbon dioxide, nitrogen, flue gases, etc.) that either are or become miscible (mixable) with oil under reservoir conditions. This reaction lowers the resistance of oil to flow through a reservoir, making it more easily produced, either by water drive or injected gas pressure.

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2. Waterfolding provides the base case for comparison of other methods.
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EOR methods by lithology (Alvarado et al. ‘10)

Based on a total of 1507 projects
Quick screening criteria per EOR process
Optimal oil gravity API (Taber, Martin & Seright ‘96)

Relative production (boe/day) is shown by size of EOR method
EOR Database: EOR project history in clastic reservoirs

- Thermal methods have been consistently active through the 1990s period of low oil prices
- Whereas immiscible hydrocarbon projects have constantly decreased
- Miscibles CO2 projects of interest are starting to be more prolific
- Similar trend can be observed in the carbonate reservoirs where CO2 and hydrocarbon miscible are dominant
EOR Database: Viscosity distribution

- Dependence of thermal/chemical projects for the higher end viscosity
- Dependence of miscible/immiscible for the lower viscosity projects
EOR Database: API gravity vs. Viscosity
EOR Database: API gravity vs. Viscosity

Again the same color scheme for the 4 EOR methods. Bubble size indicates the temperature.

Most of the Miscible treatments (brown) can be found within areas containing oils of high gravities and low viscosities.

Thermal methods for fields with high viscosity, low gravity oils within low temperature areas.
What is EORt?

Basically it’s an expert system which aims at helping the user to identify the potential of different EOR processes based on a worldwide database of successful EOR projects.

Goal: identify best EOR technique for given field conditions
The Solution - Workflows

Provide a standard workflow for analyzing by screening EOR opportunities and suggest best suited EOR methods with minimum user interactions.
EOR Screening Tool

EORt Qualitative Screening:
- Compares industry experience and reservoir characteristics to substantiate the EOR method selection
- Estimates pore level recovery with analytical methods
- Provides analog fields from an industry wide database

EORt Quantitative Screening:
- Systematically takes reservoir model and identifies appropriate sectors for EOR studies
- Uses numerical simulation to quantify recovery and rank the best EOR alternatives
- Provides forecasts of all streams for economic screening
Data Flow
Data Flow

![Diagram showing data flow process involving industry guidance, polymer foam, and a Bayesian network.]

- Industry EOR database
- Bayesian network
- Industry guidance
- Polymer
- Foam
- Screen and ranking result
Data Flow

Sector modeling

EOR method 1 settings
EOR method 2 settings
- Import Eclipse Model.
- Import Fluid Model.
- Importing Scale Data.
- Reservoir Temperature & Water Salinity.
Analytical Screening: Data Analysis
Analytical Screening

The image shows a software interface for Analytical Screening, which is used for evaluating Enhanced Oil Recovery (EOR) potential. The interface allows selecting EOR potential formation, and there are three areas labeled Area1, Area2, and Area3. Each area contains a table with columns for EOR agent (Foam, Hydrocarbon gas (miscible), N2 (immiscible), CO2 (immiscible), VAG (miscible), ASP), Industry guidance, Compatibility, Macro scale flooding, and Pore scale ranking. The interface provides a visual comparison of these factors across different EOR agents.
### Analytical Screening

**INDUSTRY GUIDANCE (This Criterion ranks method applicability):** PORO, PERM, TEMP, DEPTH, API, VISC, GAS CAP
- based on Bayesian network generated from EOR database
- The Rank value goes from 0-1.

**DATABASE WITH SIMILAR FIELDS:** 3000 PROJECTS
- **GREEN:** FIELDS IN DATABASE THAT APPLY THE SELECTED AGENT
- **ORANGE:** FIELDS IN DATABASE THAT DON’T APPLY THE SELECTED AGENT
- **GRAY:** NO RECORD OF EOR METHOD IN THE DATABASE

<table>
<thead>
<tr>
<th>EOR agent</th>
<th>Industry guidance</th>
<th>Compatibility</th>
<th>Macro scale filtering</th>
<th>Pore scale ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foam</td>
<td></td>
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<tr>
<td>Miscible</td>
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<tr>
<td>Foam</td>
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<tr>
<td>Miscible</td>
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<td>N2</td>
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<tr>
<td>Miscible</td>
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<td>CO2</td>
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<td>Miscible</td>
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<td>ASP</td>
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<tr>
<td>AS</td>
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<tr>
<td>Polymer</td>
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</tr>
</tbody>
</table>

Schlumberger-Private
Analytical Screening

COMPATIBILITY; this Criterion evaluates
- Model temperature and Salinity compatibility with chemical method.
- Depth, Viscosity, formation thickness and Oil Saturation compatibility with thermal methods.
- Industry data base guidance compatibility with all methods.

• Green: COMPATIBLE
• Red: NO COMPATIBLE.

<table>
<thead>
<tr>
<th>METHOD</th>
<th>COMPATIBILITY CRITERIA BY SALINITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>POLYMER</td>
<td>&lt;50000 PPM</td>
</tr>
<tr>
<td>ALKALINE</td>
<td>&lt;46000 PPM</td>
</tr>
<tr>
<td>SURFACTANT</td>
<td>&lt;30000 PPM</td>
</tr>
<tr>
<td>ASP</td>
<td>&lt;30000 PPM</td>
</tr>
</tbody>
</table>
### Analytical Screening

**MACRO SCALE FILTERING** ; this Criterion rank method priority

**METHOD COMPATIBILITY WITH GEOLOGY TYPE DEFINED IN THE DATA ANALYSIS TAB**

- **Green:** COMPATIBLE
- **Red:** NO COMPATIBLE.

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<tbody>
<tr>
<td>Foam</td>
<td></td>
<td></td>
<td></td>
<td>0.687</td>
</tr>
<tr>
<td>VAG (miscible)</td>
<td></td>
<td></td>
<td></td>
<td>0.337</td>
</tr>
<tr>
<td>N2 (inmiscible)</td>
<td></td>
<td></td>
<td></td>
<td>0.332</td>
</tr>
<tr>
<td>Hydrocarbon gas (miscible)</td>
<td></td>
<td></td>
<td></td>
<td>0.332</td>
</tr>
<tr>
<td>CO2 (inmiscible)</td>
<td></td>
<td></td>
<td></td>
<td>0.316</td>
</tr>
<tr>
<td>ASP</td>
<td></td>
<td></td>
<td></td>
<td>0.713</td>
</tr>
<tr>
<td>AS</td>
<td></td>
<td></td>
<td></td>
<td>0.632</td>
</tr>
<tr>
<td>Polymer</td>
<td></td>
<td></td>
<td></td>
<td>0.435</td>
</tr>
</tbody>
</table>
Analytical Screening

PORE SCALE RANKING

- LOCAL DISPLACEMENT EFFICIENCY BASED RANKING (LDE).
- APPLICATION OF FRACTIONAL FLOW THEORY TO EOR.
  SPE 7660
**Analytical Screening**

Choose EOR agents for Numerical Screening.
Numerical Screening

\[
IAP = (S_{oil} EOH - S_{owcr}) \times (PORO / \text{PORO}_{\text{max}}) \times (PERM / \text{PERM}_{\text{max}}) \times NTG \times DZ
\]
Numerical Screening

- Production only Case
- Water Injection Case
- Gas Injection Case
Numerical Screening

- Chemicals
- CO2, Nitrogen, HG
- Water Iny.
- Gas Iny.

- Water Iny.
- Gas Iny.
- Prod. Only

Optimized Parameters

- Optimal slug size (Pf)
- Time: 08/31/2019
- Recovery at time (%): 0.92

Control Name | Opt. value | Boundary
---|---|---
Production rate (STB/d) | 1207.79 | [24.16, 1932.47]
Injection rate [bbl/day] | 483.12 | [24.16, 1932.47]
Alkaline concentration (lbm/STB) | 3.28 | [0.10]
Surfactant concentration (lbm/STB) | 3.28 | [0.10]
Case Study

OSO - EOR SCREENING
OSO Field - Introduction

- Oso field is located in Ecuador’s Orient basin.

- The Hollin reservoir is the deeper reservoir in the Cretaceous Hollin formation.

- It is divided in two reservoirs with different geological and dynamic characteristics:
  - Upper Hollin (product of a braided fluvial environment)
  - Main Hollin (mainly dominated by shore face marine environment)

- Main Hollin reservoir has very good petrophysical properties compared to Upper Hollin, and is supported by an Infinite Aquifer that has kept the pressure at original levels after 9 years of production.

- Most of the wells show an initial high oil rate that declines in few months due to a rising water cut caused mainly due the high vertical transmissibility and strong aquifer support.

- PETROAMAZONAS assigned Schlumberger the task of improving the oil recovery factor and perform an EOR Screening process as one of the main targets of PETROAMAZONAS is to implement EOR Agents in the upcoming years.
Validation Process of Geological and Dynamical Models Data

- Geological & Dynamical Models Adjusted
- PVT Data Validation
- SCAL Data Validation
- Operation Conditions
- EOR Agent

- WATERFLOODING
- INMISCIBLE GAS FLOODING
- POLYMERS
- SURFACANT
- ASP
- FOAM
- CO2 MISCEBLE
- N2 MISCEBLE
- HC GAS MISCEBLE
- WAG
- STEAM FLOODING
- CYCLIC STEAM & SAGD
Analysis of Rock Quality Indicator and Movable Oil of Hollin (Upper and Main)

Upper HOLLIN

Main HOLLIN

% Rock Quality Indicator

% Moveable Oil
OSO Field (Hollin Reservoir) - Analytical Screening Results

- **Industry Guidance**: The database shows that there are world areas analogs where EOR agents have been applied.

- **Compatibility**: Due to the low water salinity in Hollin main reservoir all EOR agents are compatible.

- **Macro scale filtering**: The reservoir architecture recommends FOAM and hydrocarbon gas application. However due to volumes necessary for FOAM generation and miscibility uncertainty by injecting C3 - C4 together with the necessary volumes, chemical methods necessary to observe Polymers, AS, ASP.

- **Pore ranking scale**: According to the relative permeability curves of the system, EOR agents having better local displacement efficiency are ASP, FOAM, AS and Polymers.
Numerical Screening – Reservoir Parameters Selection

\[ ERY = (Soil[EOH] - Sower) \times (PORO / PORO_{max}) \times (PERM / PERM_{max}) \times NTG \times DZ \]

- 2 RRE
- 20 ACRES
- RESIDUAL MOVIL ZONE of ACCUMULATION
Numerical Screening Results

Displacement efficiency versus pore volume Injected
## Numerical Screening

### Displacement Efficiency in the Conceptual Area

<table>
<thead>
<tr>
<th>EOR method</th>
<th>RRE1 Displacement efficiency (%)</th>
<th>RRE1 Efficiency Incremental (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASP (slug)</td>
<td>17</td>
<td>8.93</td>
</tr>
<tr>
<td>ASP (mix)</td>
<td>19.7</td>
<td>11.63</td>
</tr>
<tr>
<td>AS</td>
<td>12.8</td>
<td>4.73</td>
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<tr>
<td>Polymer</td>
<td>17.71</td>
<td>9.64</td>
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<tr>
<td>Surfactant</td>
<td>12.81</td>
<td>4.74</td>
</tr>
<tr>
<td>Foam</td>
<td>4.68</td>
<td>0.41</td>
</tr>
<tr>
<td>Hydrocarbon gas (miscible)</td>
<td>4.33</td>
<td>0.06</td>
</tr>
<tr>
<td>WAG (miscible)</td>
<td>7.03</td>
<td>2.76</td>
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<td>Prod. only</td>
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<td>Water flood</td>
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<tr>
<td>Gas flood</td>
<td>4.27</td>
<td>0</td>
</tr>
</tbody>
</table>
Hollin (Main): Pilot area for the EOR evaluation using Polymer Injection as EOR Agent.

Hollin Producer Wells (Black) vs No Producers (Blue)

Sensitivities related to the well spacing, completions intervals and injection rates were carried out to estimate qualitatively the effect of Polymer Injection.
An integrated model was built in order to improve the recovery factor and perform an EOR Screening process.

The EOR Screening process using EORt suggested that Polymer Injection is the most optimum EOR agent to be applied in the reservoir. However, the well spacing and the completions intervals should be refined to overcome the effects of the aquifer.

The project also concluded that EOR laboratory test should be carry out to refine an EOR Screening process.
EOR Screening Workflow (EORt) Value

Technical:
• Comprehensive systematic approach to evaluate EOR potential
• Access to historical data
• Facilitate and speed up the screening process

Strategic:
• Potential to evaluate more fields
• Ability to speed up “what if” scenarios
• Provides technical justification for new data acquisition
Thank you!

QUESTIONS?

PETREL

Data preparation → Data analysis → Screening Estimation → Result interpretation