A Neuro-Fuzzy Approach to Screening Mature Fields for EOR Processes

By

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Presented by: Geraldo Ramos
At the time of first production in August 1983, Sanha LPG FPSO (Block 0 - Angola) the first floating facility to combine all LPG processing and export functions onboard the same unit.
Background & Motivation

- In Angola the term oil is vanishing

- Production by primary and secondary recovery
  - Approximately 60 – 70% of recoverable HC still remain in the reservoir

A: Onshore; Offshore: Water depth - B) 0 – 300 m; C) 300 – 1,500 m; D) >1,500 m

Capex, Opex, Risk, Uncertainties increase with increasing water depth
Background & Motivation

Well C6Y19

Pressure (Psia)

01-Jun-08 22-Jan-10 14-Sep-11 06-May-13

17-Feb-05 10-Oct-06

3550 3600 3650 3700 3750 3800 3850

Time (Days)
Background & Motivation

Well C6Y19

Time (Days)

BBL/D

0 5000 10000 15000 20000 25000

Background & Motivation

- Increasing energy demand due to population growth;
- Difficulties in discovering new fields as alternatives to the current oilfields;
- Only one Angola EOR case to date;¹
- All of these together with decreasing oil prices, have necessitated the need to improve the current techniques.

Background & Motivation

- EOR implementation can improve recovery in mature fields;

- **Primary Recovery**
  - Natural Flow
  - Artificial Lift

- **Secondary Recovery**
  - Waterflooding
  - Pressure Maintenance

- **Tertiary Recovery**
  - Thermal
    - Steam
    - Hot Water
    - Combustion
  - Gas Injection
    - \( \text{CO}_2 \)
    - Hydrocarbon
    - Nitrogen/Flue
  - Chemical
    - Alkali
    - Surfactant
    - Polymer
  - Other
    - Microbial
    - Acoustic
    - Electromagnetic

- **Oil Recovery**
  - Generally Less Than 30%
  - 30%–50%
  - >50% and Up to 80+%

School of Engineering

www.abdn.ac.uk/engineering
EOR planning

What’s the best time?

The best time! ...during FDP

Disadvantages: lack of production data

The second time is Now!
Design and implementation takes time
Production response does not occur immediately

Adapted from: Paul L. Bondor SPE Distinguished Lecturer Program www.spe.org/dl
<table>
<thead>
<tr>
<th>Methods</th>
<th>Variables</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical</td>
<td>Adsorption, chemical degradation, dispersion, stability at high salinity, rheological properties, IFT, emulsion stability</td>
<td>Suitable solution, cheap, and stable in higher reservoir temperature; lowering IFT, phase separation</td>
</tr>
<tr>
<td>Miscible and immiscible gas</td>
<td>Viscous fingering, capillary effect, gas-assisted gravity drainage, stability, override, supply</td>
<td>Fingering effect and GAGD (gas assisted gravity drainage) application</td>
</tr>
<tr>
<td>Thermal</td>
<td>Adverse mobility ratio, heat loss, IFT, steam override, channelling effect, pollution, corrosion, etc</td>
<td>Surfactant formulation stable to generate foam at high temperature; ability of foam to persist for Extended period of time</td>
</tr>
</tbody>
</table>
EOR Strategic and cultural challenges

- **Strategic challenges**
  - In Angola, the term “easy oil” is vanishing
  - Short term production investments vs. longer term reserves replacement
  - Uneconomic projects at very lower oil prices
  - EOR is new in Angola - Corporate readiness (knowledge and experience)
  - Opposition due to new unknown technologies

- **Cultural challenges**
  - There is significant oil in current fields that can be recovered
  - Risk aversion
  - Lack of commitment from operations (and some management)
  - Lack of knowledge from field operators
Data source and collection

- **Worldwide EOR projects**
  - 365 Projects
  - 10 EOR techniques
  - 6 parameters
  - 16 Countries

Reservoir rock-fluid parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Number of Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>352</td>
</tr>
<tr>
<td>Porosity</td>
<td>351</td>
</tr>
<tr>
<td>Permeability</td>
<td>338</td>
</tr>
<tr>
<td>API Gravity</td>
<td>353</td>
</tr>
<tr>
<td>Viscosity</td>
<td>342</td>
</tr>
<tr>
<td>Saturation</td>
<td>312</td>
</tr>
</tbody>
</table>

Number of data set

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Number of Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>API</td>
<td>117</td>
</tr>
<tr>
<td>DEPTH</td>
<td>210</td>
</tr>
<tr>
<td>PERMEABILITY</td>
<td>146</td>
</tr>
<tr>
<td>POROSITY</td>
<td>125</td>
</tr>
<tr>
<td>SATURATION</td>
<td>9</td>
</tr>
<tr>
<td>VISCOSITY</td>
<td>63</td>
</tr>
<tr>
<td>Net Thickness</td>
<td>92</td>
</tr>
<tr>
<td>Temperature</td>
<td>170</td>
</tr>
<tr>
<td>Pressure</td>
<td>0</td>
</tr>
<tr>
<td>F.W. Salinity</td>
<td>0</td>
</tr>
</tbody>
</table>

Worldwide EOR techniques

- Steam: 145
- Miscible CO2: 133
- Miscible HC: 37
- Polymer: 24
- Combustion: 15
- Surfactants: 3
- Nitrates: 2
- Microbial: 3
- Hot Water: 2
- Miscible Acid Gas: 1

Data analysis

1. Oil Saturation (%) vs. Porosity (%)
   - MISCIBLE GAS
   - CO2
   - STEAM
   - POLYMER
   - COMBUSTION
   - Block T

2. Permeability (md) vs. Porosity (%)
   - MISCIBLE GAS
   - CO2
   - STEAM
   - POLYMER
   - COMBUSTION
   - Block T

3. Oil Viscosity (cp) vs. Oil Gravity (°API)
   - MISCIBLE GAS
   - CO2
   - STEAM
   - POLYMER
   - COMBUSTION
   - Block T

4. Reservoir Depth (ft) vs. Oil Gravity (°API)
   - MISCIBLE GAS
   - CO2
   - STEAM
   - POLYMER
   - COMBUSTION
   - Block T
1. Adasani and Bai, 2011; Chaunhan, 2014; Saleh et al., 2014b.
Model development: Neuro-fuzzy

- Fuzzy logic (FL) and neural networks (NNs) are natural complementary tools for intelligent systems.

- NFS can be trained to develop IF-THEN fuzzy rules and determine membership functions for input and output variables of the system.

- NNs rely on parallel data processing focusing on modelling a human brain.

- FL deals with reasoning on a higher level.

Learning capabilities
- NF System
  Explicit knowledge representation
- Fuzzy System
  Neural Network
Model development: Neuro-Fuzzy system

Layer 5
Defuzzification

Layer 4
Fuzzy inference
Or operation

Layer 3
And operation

Layer 2
Fuzzification

Layer 1
Input

\[
RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} [\bar{y}(\bar{x}) - d]^2}
\]

\[
NDEI = \frac{RMSE}{\sigma(d)}
\]

1. Adapted from Akanji and Sandrea, APED, 2016
Training and validation process (depth – steam)

- 80% , training data; 20 % validation (prediction);
- 4 statistical values were determined: Mean, STD, RMSE, NDEI
- Model accuracy quantified by RMSE
○ 4 statistical values were determined: Mean, STD, RMSE, NDEI
○ Degree of suitability was quantified using NDEI ;
**EOR Screening Results – Block T**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Steam</th>
<th>Misc. Gas</th>
<th>CO2</th>
<th>Polymer</th>
<th>Combustion</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 &lt; NDEI ≤ 30%</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>10 &lt; NDEI ≤ 20%</td>
<td>✗</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>NDEI ≤ 10%</td>
<td>✗</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

✗ = not suitable; ✓ = suitable

- This is not a binary decision operation;
- Hence, the engineering expertise and knowledge is needed for final decision
For further investigation a special integrated multipurpose EOR rig has been designed and assembled.

Application:
- Auto-switch between specific methods
  - Gas, steam, chemical, foam generation and injection, hot solvent injection
- Investigation of mechanisms contributing to the identified EOR technique
- Secondary and EOR investigation
- Effluent sequestration and analysis
Conclusions

- Scatter plots, box-plots and histograms provide a quick look for EOR technique suitability;
- The caveat is that the plots do not quantify the uncertainty or consider the weight of each parameter;
- Robust system such as NF is needed for screening reservoir;
- The NF model employed in this study, shows that Misc. gas, polymer and combustion are the EOR techniques that will likely be technically successful;
- For full investigation, laboratory investigation and simulation are needed.
ACKNOWLEDGEMENT

Project Sponsor Company

Sonangol

Academia

ISPTEC

University of Aberdeen

School of Engineering
1. At the time of first production in August 2001 (Block 17 – Angola), the Girassol FPSO was the world's largest. Measuring 984 feet (300 meters) long, 197 feet (60 meters) wide and 102 feet (31 meters) high, the FPSO houses up to 140 people.