Development of a Bespoke Enhanced Oil Recovery (EOR) Technology: A Future for Angolan Oilfield Production

By

Geraldo Ramos, Lateef Akanji (PhD, DIC) & Waheed Afzal (PhD)

Presented by: Geraldo Ramos
Outline

- Introduction
  - An overview of Angolan oil production: challenges and opportunities
- Screening outcome and discussion
- EOR: development of a bespoke technology
- Conclusions
Introduction

- The Angolan oil and gas industry became the centre of attraction for a wide range of businesses and opportunities since 1955

- However, sustainable management of current production, require more services, potential investors and new technologies

- Hence, investing in current fields is more profitable compared to development of green fields or remote areas which require additional economic and technical efforts

- Therefore, application of EOR in Angola is critical to extracting the remaining oil left beyond the conventional oil recovery
Factors dictating the Angolan production

- Management of resources and reserves
- Compliance with contractual obligations
- Respecting the mutual dictates of OPEC
- Protecting the Angolan sustainable development
- Respecting the HSE standards (including zero flaring and discharge)
- Oil price
Challenges and opportunities

- Technical and economical
  - Asset integrity management (AIM)
  - Reduced in known players (reservoirs and infrastructures)
  - Pre-salt development
  - Mature fields development
    - Enhanced oil recovery (EOR)

At the time of first production in August 2004 (Block 15 – Angola), the FPSO (Floating Production Storage And Offloading) was the world’s largest. Storage capacity 2.2 million barrels.
Challenges and opportunities

- Alignment between shareholders
- Reduced the approval cycle
- Development of “marginal fields”
  - Angolan content capacity
  - Logistic support
  - Engineering and management
  - Fabrication
  - Goods and services
  - Know-how transfer
  - Training and specialization
## EOR: methods, problems & challenges

<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 & 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
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.
Why EOR in Angola?

- In Angola, the term “easy oil” is vanishing: production moving from onshore to ultra-deepwater
- Pressure and production decline in mature fields
- Difficulties in discovering green fields as alternatives to the current oilfields;
- There is significant oil in current fields that can be recovered;
- Only one Angola EOR case to date;
- EOR implementation can improve recovery in mature fields

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
EOR roadmap in Angola

Data management → Screening studies → Laboratory work → Simulation study → Project feasibility

Initiation and planning phases

Monitoring the performance → Full Field development & implementation → Pilot execution phase

Adapted from: SPE Papers 163124; 143287; 92006
Data source and collection

- Worldwide EOR projects\(^1\)
  - 365 Projects
  - 10 EOR techniques
  - 6 parameters
  - 16 Countries

Data analysis
Data analysis – box plots &

**Number of projects or data set**

- Miscible HC Gas (#37)
- Miscible CO2 (#132)
- Polymer (#24)
- Steam (#145)
- Combustion (#16)
- Block T (#210)

**Number of projects or datasets**

- Miscible HC Gas (#37)
- Miscible CO2 (#132)
- Polymer (#24)
- Steam (#145)
- Combustion (#16)
- Block T (#125)

1. Adasani and Bai, 2011; Chauhan, 2014; Saleh et al., 2014b; 2. Ramos and Akanji, 2017

**Saturation, %**

- Frequency

**Depth, ft**

- Frequency
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.
  - NNs are low-level computational structures.
  - NNs can learn (supervised and unsupervised).
  - Caveat - Neural networks are opaque to the user.

- FL deals with reasoning on a higher level.
  - FL uses linguistic information acquired from domain experts.
  - FLs lack the ability to learn and cannot adjust themselves to a new environment.
Model development: Neuro-Fuzzy

Layer 5
Defuzzification

Layer 4
Fuzzy inference
Or operation

Layer 3
And operation

Layer 2
Fuzzification

Layer 1
Input

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

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

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
Testing process (Steam)

- 4 statistical values were determined: Mean, STD, RMSE, NDEI
- Degree of suitability was quantified using NDEI;
## EOR Screening Results – Block C

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Area 1</th>
<th>Area 2</th>
<th>Area 3</th>
<th>Area 4</th>
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</thead>
<tbody>
<tr>
<td><strong>Area</strong></td>
<td>Steam</td>
<td>Misc. Gas</td>
<td>CO2</td>
<td>Polymer</td>
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<tr>
<td><strong>20 &lt; NDEI ≤ 30%</strong></td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>10 &lt; NDEI ≤ 20%</strong></td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
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<tr>
<td><strong>NDEI ≤ 10%</strong></td>
<td>×</td>
<td>✓</td>
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<td>×</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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</tbody>
</table>

✓ = Suitable; × = Not Suitable

- This is not a binary decision operation;
- Hence, the engineering expertise and knowledge is needed for final decision.
Integrated multipurpose lab scale EOR

- 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.
- The NF model employed in this study, shows that Misc. gas, polymer and combustion are the EOR techniques that will likely be technically successful.
- A special integrated multipurpose lab scale EOR rig has been developed to screen a wide range of EOR techniques.
- For full investigation, simulation, lab and pilot tests are needed.
- Angola needs a highly-skilled, professional, technical and multi-cultural workforce capable to sustain and overcome the challenges of current fields.
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Thank You
Questions?