Challenge in IOR from heterogeneous carbonate reservoirs of deep offshore Pre-Salt fields in Brazil

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Outline

» LRAP history

» The EOR scenario in offshore Brazil

» Overview of research projects
How LRAP (EOR Lab) began...

» Two projects funded by BG Group were approved by ANP in 2013:
  – Developing Experimental Enhanced Oil Recovery Capabilities in Brazil (Infrastructure)
  – Understanding Brazilian Pre-Salt Reservoirs: A BG Fellowship Training Programme (HR training)

» Cooperation with Heriot-Watt University, UK
  – Expertise developed in the past 20 years of R&D

» Shell acquired BG Group in 2016

» One RD&I project funded by Petrobras at the end of 2016: SCAL

» Two RD&I projects funded by Shell were approved by ANP in 2017:
  – WAGEX & CFC
Interdisciplinary Group of Fluid Dynamics - NIDF
During the last years, Brazil’s Oil and Gas Industry has been preparing for dramatic changes.

Source: ANP, “A Retormada do setor de Petróleo e Gás”. Presented at the XII SPETRO, UFRJ, Oct. 2017
Why EOR is important in Brazil?

- Brazilian Pre-Salt reservoirs are gigantic assets which are game-changers for the Brazilian Oil and Gas Industry.

Industry Challenges

» Recovery Factor in Brazil is still very low – 21%.

» Carbonate Pre-Salt reservoirs represent a significant part of the overall portfolio in Brazil – over 50% production from the Pre-Salt in 2018.

» Complex rock-fluids interactions. Need for research!

» Existent reservoir models still not able to represent the Pre-Salt scenario.
The Pre-Salt Scenario

- High production potential: 30,000 STB/day per well (average)
- High quality, but very complex, reservoirs
- Very large structures
- Light oil
- Average daily pre salt production in Jan 2019:
  - 1.84 million BOE/day (54.9% of total production)
The Pre-Salt Scenario

- **Challenges**
  - Heterogeneous carbonate rocks.
  - High-salinity brines.
  - Ultra-deep waters.
  - Salt layer of over 2 km.
  - Over 20% CO₂ in produced gas.

Sources:
Pizarro, J. O. D. S. et al. SPE 155665-MS.
Costa Fraga, C. T. et al. SPE 21-8084 WPC.
ANP: “It is necessary to properly allocate RD&I resources to foster exploration and production in Brazil”

1% of additional recovery leads to:

- USD 11 billion in Royalties
- 2.2 Bboe increase in reserves
- USD 18 billions in new investments
- *Libra Field: increase of 1% in the RF over the worst recovery estimative*
  
  → *Increase of USD 5.3 billion in the consortium gross income*
Overview of some research projects
Initial wettability

- Wettability of pure minerals

<table>
<thead>
<tr>
<th>Mineral</th>
<th>1-15 Field B</th>
<th>1-30 Field B</th>
<th>1-15 Field D</th>
<th>1-30 Field D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>72 ± 4</td>
<td>65 ± 4</td>
<td>61 ± 4</td>
<td>64 ± 4</td>
</tr>
<tr>
<td>Dolomite</td>
<td>65 ± 4</td>
<td>66 ± 4</td>
<td>61 ± 4</td>
<td>61 ± 4</td>
</tr>
<tr>
<td>Calcite</td>
<td>119 ± 4</td>
<td>111 ± 4</td>
<td>145 ± 4</td>
<td>167 ± 4</td>
</tr>
</tbody>
</table>

T = 60 °C; P = 1000 psi; Fields B and D

Calcite is the only mineral with wettability shift through aging
Initial wettability

Shorter aging times for shifting on outcrops. After 30 days all rocks strongly oil-wet.
Core flood tests – CO₂ flooding

Additional 25% oil recovery by carbonated brine injection
Core sample

Before the test:

After the test:
Micro-CT images: wormhole
Tracer test

C/Co x PV

After the test
Interpore 2018 – 10th International Conference on Porous Media

Objective: Develop a well-defined workflow involving Basic and digital petrophysics for Brazilian pre-salt reservoir rocks evaluation, using experimental data, geological information, 3D modelling, and numerical simulation;

Use of different techniques: permeameter/porosimeter, SEM-EDS and XRD measurements, μCT with different pixel sizes, centrifuge method for two-phase fluid flow, and numerical simulation;

Colaboration with Universiteit Utrecht.
Primary drainage – An experimental and computational study with Brazilian pre-salt analogue carbonate rocks

- Objective: Evaluate primary drainage simulations based on PNM and comparison with measurements from centrifuge method;
- We generated calibrated Pore Network Models (PNM) from Brazilian pre-salt analogue carbonate rocks μCT images, using experimental techniques such as NMR, DRX, SEM/EDS and DSA to evaluate the pore and rock structures, rock-fluid and fluid-fluid interactions for two-phase flow modelling;
- Collaboration with Universiteit Utrecht.
Objective: This study analyzes the representative elementary volume (REV) in a region of interest (ROI) of a highly heterogeneous carbonate rock sample; Porosity and absolute permeability are estimated in different subvolumes of the sample based on digital petrophysics; All necessary steps for reconstruction and segmentation of the complex pore system of the sample, as well as numerical simulations of fluid flow, are presented and discussed; The results are promising for reservoir evaluation because the workflow can be applied for any type of highly heterogeneous carbonate reservoir rocks.
THANK YOU!

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