Optimization of A Water Alternating Gas Injection

Compositional fluid flow simulation with Water Alternating Gas Injection optimization on the up-scaled synthetic reservoir CERENA-1

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Motivation

• The synthetic reservoir modelled to replicate the reservoir in the Brazilian Pre-salt geological play, the Jupiter field to be precise, a reservoir with considerable amount of oil, and huge amount of gas that contains large CO$_2$ concentrations.

• Continuation on the work done by Pedro Pinto on CERENA-I.

Main Objectives

• Find a production strategy to improve oil production, and reduce the quantity of CO$_2$.

• Further optimization of the selected production strategy to maximize oil recovery and minimize gas production.
Introduction

Motivation

• The synthetic reservoir modelled to replicate the reservoir in the Brazilian Pre-salt geological play, the Jupiter field to be precise, a reservoir with considerable amount of oil, and huge amount of gas that contains large CO₂ concentrations.

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State of the art and theoretical background

• **Water Alternating Gas Injection Scheme**: is one of the numerous enhanced recovery process. WAG injection involves drainage (D) and imbibition (I) taking place simultaneously or in cyclic alternation in the reservoir.

• **SWAG** – Simultaneous Water Alternating Gas Injection
State of the art and theoretical background

Particle Swarm Optimization

- The selected optimization technique chosen for this study is the Particle Swarm Optimization technique.

- It's a co-operative, population-based global search swarm intelligence metaheuristics.

- Bird = a particle, Food = a solution
- pbest = the best solution(fitness) a particle has achieved so far.
- gbest = the global best solution of all particles within the swarm

An individual gains knowledge from other members in the swarm (population)
Particle Swarm Optimization

For each particle
    initialize particle
End For

Do
    For each particle
        calculate fitness value
        if the fitness value is better than the best fitness value (pBest) in history
            set current value as the new pBest
    End

choose the particle with the best fitness value of all the particles as the gBest

For each particle
    calculate particle velocity according to previous equations
    update particle position according to previous equations
End

While maximum iterations or minimum error criteria is not attained

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Introduction to CERENA-I

Dataset Description

- A Model based on the Jupiter field in Brazil
- Top at 5000m
- GOC at 5370m, OWC at 5435m
- 90m thick oil zone with 18ºAPI
- Oil with 55% CO₂ (molar)
- Reservoir rocks: Stromatolites and Microbiolites
- 16km²
- 7 million cells
Introduction to CERENA-I

Fluid System

<table>
<thead>
<tr>
<th>Component</th>
<th>Molar %</th>
<th>Mol. weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>N₂</td>
<td>0.16</td>
<td>28.013</td>
</tr>
<tr>
<td>CO₂</td>
<td>0.91</td>
<td>44.01</td>
</tr>
<tr>
<td>C₁</td>
<td>36.47</td>
<td>16.043</td>
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<tr>
<td>C₂</td>
<td>9.67</td>
<td>30.07</td>
</tr>
<tr>
<td>C₃</td>
<td>6.95</td>
<td>44.097</td>
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<tr>
<td>NC₄</td>
<td>3.93</td>
<td>58.124</td>
</tr>
<tr>
<td>IC₄</td>
<td>1.44</td>
<td>58.124</td>
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<tr>
<td>NC₅</td>
<td>1.41</td>
<td>72.151</td>
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<tr>
<td>IC₅</td>
<td>1.44</td>
<td>72.151</td>
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<tr>
<td>C₆</td>
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<td>84</td>
</tr>
<tr>
<td>C₇⁺</td>
<td>33.29</td>
<td>218</td>
</tr>
</tbody>
</table>

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**Estimated observations**

<table>
<thead>
<tr>
<th>Bubble point (bar)</th>
<th>Dew point (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>493</td>
<td>400</td>
</tr>
</tbody>
</table>

**Fingerprint Plot: Sample 20**

<table>
<thead>
<tr>
<th>Component</th>
<th>Molar %</th>
<th>Mol. weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>55.00</td>
<td>44.01</td>
</tr>
<tr>
<td>C₁</td>
<td>16.56</td>
<td>16.043</td>
</tr>
<tr>
<td>C₂</td>
<td>4.46</td>
<td>30.037</td>
</tr>
<tr>
<td>C₃</td>
<td>3.15</td>
<td>44.097</td>
</tr>
<tr>
<td>C₄⁻⁵</td>
<td>5.69</td>
<td>70.237</td>
</tr>
<tr>
<td>C₇⁺</td>
<td>15.11</td>
<td>218</td>
</tr>
</tbody>
</table>

**Calculated observations**

<table>
<thead>
<tr>
<th>Bubble point (bar)</th>
<th>Dew point (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>492.9964</td>
<td>399.9967</td>
</tr>
</tbody>
</table>
Dynamic Simulation of CERENA-I

Sectorial Model

- 1km²
- 280,000 active cells
- Use of sectorial model, due to computational constraints

Permeability models:
- x and y to the left;
- z to the right.
Dynamic Simulation of CERENA-I

Upscaling of CERENA-I
Dynamic Simulation of CERENA-I

Production scheme for CERENA-I
Dynamic Simulation of CERENA-I
Optimization Results

Production wells Bottom-hole Pressure:
- Same BHP or Different BHP

Same Bottom-hole Pressure:
Dynamic Simulation of CERENA-I
Optimization Results

Same Bottom-hole Pressure:
Dynamic Simulation of the CERENA-I

Optimization Results

Different Bottom-hole Pressure:

1. $\$j$ vs $\$k$
2. $\$j$ vs $\$m$
3. $\$j$ vs $\$n$
4. $\$k$ vs $\$m$

5. $\$k$ vs $\$n$
6. $\$m$ vs $\$n$

FOPT ranges from 0 to 5,000,000.
Dynamic Simulation of CERENA-I

Optimization Results

Different Bottom-hole Pressure:

![Graph showing different bottom-hole pressures with Pareto front and remainder]

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**Injection rate and WAG ratio**: j and k are fractions for portions of water and gas injected respectively which could be from 0.01 to 0.99.

**WAG ratio** = Volume of water injected: Volume of Gas injected

≡ Water injection rate : Gas injection rate

≡ Water injection rate : (Water injection rate x k/j)

≡ j : k

1570sm³/day
Dynamic Simulation of CERENA-I

Optimization Results

- Some selected WAG ratio

1570sm³/day
Dynamic Simulation of CERENA-I

Optimization Results

5570sm³/day
Dynamic Simulation of CERENA-I

Optimization Results

7570 sm$^3$/day
From the results obtained, we observed the following:

- Inverse relation between the injection fluids

- An optimal trend line is observable

- As we increased the injection rates, the optimal trend line becomes visible.

- The optimal trend line is between the same range in the 3 injection rates tested.
The selected WAG ratio in this work was the ratio 2:3, and the results obtained are shown below.

40,214 m$^3$/day
Well Position: The reservoir was divided into 4 parts, with one well in each compartment. Each well is supposed to move just within its own compartment and the total oil and gas produced observed together.
Dynamic Simulation of CERENA-I

Optimization Results

Average vertical reservoir Porosity map of the reservoir overlapped over the production results
Conclusion and Future works

- This shows the importance of the parameters we discussed in improving oil recovery.

- We can also the effect of tertiary recovery mechanisms on our reservoir.

- Recreating this work on the original reservoir would be of great interest.

- Plans have started to study the WAG system both microscopically and macroscopically for improved optimization.

- Plans to use other possible production schemes and compare the results are in the pipeline.
References

- Pedro Pinto (2013). Dynamic simulation on the synthetic reservoir CERENA I; Compositional fluid flow simulation with 4D seismic mitoring on a reservoir with a large content of CO₂.