**OVERVIEW**

AGR were assigned by the International Petroleum Associates Norway (IPAN) to perform the technical studies and training, concentrating on best methodology for the Enhanced Oil Recovery of Heglig oilfield in Sudan. The EOR activity in Sudan was administered by the Norwegian Petroleum Directorate (NPD) on behalf of the Oil for Development (OfD) programme which provides foreign assistance focusing on petroleum policy including legal and institutional framework, resource and HSE management.

Heglig oilfield is situated within the north-west to south-east trending Muglad Basin in south-west Sudan, part of the Central African Rift System. Three phases of rifting occurred between the Cretaceous and the Tertiary, resulting in deposition of a thick sequence of sediments over a long time span in the basin. Commercial hydrocarbons are sourced from the Aradeiba Main, Bentiu 1, Bentiu 2 and Bentiu 3 Formations.

Heglig boasts much of Sudan’s proven oil reserves. The oilfield was first developed in 1996 by Arakis Energy and is today operated by the Greater Nile Petroleum Operating Company, GNPOC. Production reportedly peaked in 2006. The field is connected to Khartoum and Port Sudan via the Greater Nile Oil Pipeline.

**APPROACH**

**Scenarios of EOR strategies**

Based on sector model screening, it was decided that there were two EOR actions to be incorporated to the full field model: horizontal producers in Aradeiba F/Bentiu 1 Formation; and polymer injection in Aradeiba Main and Aradeiba F/Bentiu 1.

The Reference Case used pertains to a full field model with existing drilling and production plans for the oilfield without any EOR actions.

An analysis of the results of inputting these strategies into the model follows:

**Horizontal Producer Wells**

It was found that new infill wells within the Aradeiba F/Bentiu 1 reservoirs require a specific length to obtain an adequate initial productivity and sufficient reservoir contact. Simulations including inflow control device completion gave a small increase to the overall recovery. Horizontal wells will also reduce the water coming from the underlying aquifer. The main risks pertaining to horizontal drilling were a combination of more directional well placement and associated expenses when compared to vertical wells. This will require more thorough planning.

**Polymer Injection**

This method is expected to enhance oil recovery by improving the unfavourable mobility ratio for water displacement. The EOR potential is dependent on the polymer viscosity; 12 cp based on lab data is considered a highly optimistic case, whilst 1cp is considered to be the most realistic case due to polymer break down and degradation.

- **Overview and results from EOR measures applied to the full field model of Heglig**

<table>
<thead>
<tr>
<th>Case</th>
<th>Injectors, Aradeiba Main</th>
<th>Injectors, Bentiu 1</th>
<th>Horizontal producers, Bentiu 1</th>
<th>RF (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>2 New</td>
<td>None</td>
<td>None</td>
<td>35</td>
</tr>
<tr>
<td>Horizontal producers</td>
<td>2 New</td>
<td>None</td>
<td>11 wells</td>
<td>35.9</td>
</tr>
<tr>
<td>Polymer Injection</td>
<td>4 New, 5 new, 7 converted</td>
<td>None</td>
<td></td>
<td>36.5</td>
</tr>
<tr>
<td>Combined case</td>
<td>4 New</td>
<td>5 new, 7 converted</td>
<td>11 wells</td>
<td>37.4</td>
</tr>
</tbody>
</table>
Polymers are sensitive to high temperature and high salt concentration. The temperature and connate (fluid trapped in the pores of sedimentary rocks during deposition) water, which proved to be fresh, should not be problematic for the shallowest reservoirs of Heglig reservoirs.

Surfactants were also considered as a combination with polymer injection. The aim of surfactants is to reduce the residual oil saturation in water swept zones, thus the premise for surfactant injection is high residual oil saturation. The residual oil saturation in the water swept zones of Heglig is unknown. A program for in-situ measurement is recommended.

Risks with chemical injection include back production in the aspects of facilities, water handling, and polymer degradation during injection that may decrease the desired viscosity.

A Combination of Horizontal Wells and Polymer Injection

All cases were constrained by a stepwise decline in total field liquid rate which was similar in all simulation cases and based on the reference case. In the plan for Heglig developed in 2014, two new water injectors in Aradeiba Main were planned for pressure maintenance.

As in figure (top right), the applied EOR actions generate extra oil compared to the Reference Case. Evidently, horizontal wells increase the cumulative production instantly after application, whilst it is some time until the effect of the polymer injection is seen in the recovered volumes.

SOLUTION

These assignments resulted in a recommendation for further planning of the selected pilot(s). The recommended work prior to the Front-End Engineering Design (FEED) phase evolved from the study covered a number of areas:

In the G & G disciplines, it was suggested that seismic should be re-processed to improve frequency content, and shallow events studied and interpreted to see if they can explain features at depth. In addition, G&G and petrophysical work should be implemented in the field static model so a detailed geological analysis of the pilot areas could be made, and geosciences input should also be included in history matching.

In the field of reservoir engineering, the recommendations included collection of additional fluid samples to confirm oil viscosity and asphaltene content, consider ways to measure in-situ residual oil saturation, and update the simulation models with data from ongoing core experiments on chemical flooding.

Well planning should be a multidisciplinary effort that involves a detailed geological evaluation of the selected area, a well design and borehole stability study, and risk and contingency planning. It was also recommended that there should be detailed planning at the pilot stage, including front-end engineering design, the infrastructure and logistics, and impact assessments covering the production facilities and environmental issues.

ADDED VALUE

The Heglig oilfield EOR study was challenging on many levels, particularly due to the lack of availability of a complete data set and field history. Multidisciplinary interaction proved critical to the overall study through the integration of knowledge and information so the three main scenarios could be investigated, from the Reference Case of the existing plan, to the action of drilling infill horizontal wells and to more advanced chemical EOR by polymer injection, and combination of the two.

The Heglig oilfield study also conveyed the importance of providing knowledge transfer by training the Sudanese geoscientists and engineers to enable future sustainability of the much-needed Sudanese petroleum industry.