EXPLORATION
The ‘Gatwick Gusher’ Fact or Fiction?

GEO TOURISM
A World of Drifting Ice

GEO PHYSICS
OBS: Taking the Plunge

GEO PROFILE
Paul Dailly: Building Kosmos
Following secession in 2011, Sudan’s hydrocarbon production reduced dramatically from approximately 450,000 bpd to 100,000 bpd, changing the country’s production status from that of a substantial oil exporter to being a nation just self-sufficient in petroleum. Sudan is currently producing about 250,000 bpd.

As part of Norway’s commitment to the implementation of the Comprehensive Peace Agreement of 2005, the Oil for Development (OfD) programme provides foreign assistance focusing on petroleum policy, including the legal and institutional framework, and resource and HSE management.

Enhancing Heglig
Enhanced Oil Recovery (EOR) activity in Sudan was administrated by the Norwegian Petroleum Directorate (NPD) on behalf of OfD. International Petroleum Associates Norway (IPAN) were contracted as technical advisors to OfD and NPD, and global oil and gas energy and software company AGR were sub-contracted to IPAN to perform the technical studies and training. AGR’s remit was to concentrate on finding the best methodology for EOR at the Heglig oilfield, which boasts much of Sudan’s proven oil reserves.

Heglig 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 was first developed in 1996 by Arakis Energy (now part of Talisman Energy), and today is operated by the Greater Nile Petroleum Operating Company. Production reportedly peaked in 2006. The field is connected to Khartoum and Port Sudan via the Greater Nile Oil Pipeline.

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 the 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.

Multidisciplinary interaction and local skills development proved critical when analysing scenarios for advanced chemical EOR in a Sudanese field, thus enabling future sustainability for the vital Sudanese petroleum industry.

MARTHE ÅSNES BIRKELAND and GUDMUND OLEN, AGR

Horizontal Producer Wells: It was found that new infill wells within the Aradeiba F/Bentiu 1 reservoirs require a specific length to obtain 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 coning 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, which 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 1 cp is considered the most realistic case due to polymer break down and degradation. 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, so a programme for in-situ measurement was recommended.

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

Combination of Producer 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 illustrated below, the applied EOR actions generate extra oil compared to the reference case. Evidently, horizontal wells increase the cumulative production instantly after

Overview and results from EOR measures applied to the full field model of Heglig. (Combined case: both horizontal producers and polymer injection.)

<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</td>
<td>5 new, 7 converted</td>
<td>None</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>
application, whilst it is some time until the effect of the polymer injection is seen in the recovered volumes.

**Technical Conclusions**

These assignments resulted in a recommendation for further planning of the selected pilot(s). The recommended work prior to the Front-End Engineering Design 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 could 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 can be made, and geoscience input should also be included in history matching.

In the field of reservoir engineering, the recommendations included analysing fluid sample viscosity and asphaltene content, and the updating of the simulation model with an analysis of the final results from core experiments.

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.

**Training for Sustainability**

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

*Training the local workforce was a vital part of the Heglig study.*