CASE STUDY 2 - Reservoir Drainage Strategy for the Mariner & Bressay Heavy Oil Fields: Possible use of EOR and IOR – Wednesday 20th October

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Petroleum Technology Manager,
UK Heavy Oil (Bressay and Mariner), Statoil
Summary

- Mariner and Bressay are 2 large heavy oil discoveries in the UK section of the northern North Sea. A fields are currently in a Concept selection phase with tentative production start in late 2015.

- The oil is heavy with API of 11-14 and reservoir oil viscosities of 65-540 cp. The reservoirs are at 1000-1500 m reservoir depth with excellent reservoir quality (Darcy range sand).

- The main challenges are related to water coning (Bressay and Mariner Maureen) and limited ability to map individual sands in Mariner Heimdal.

- The reservoir drainage strategy are produced water reinjection, a use of high well density and high liquid handling capacity compared to normal North Sea light oil fields. Special measures and equipment are to be used to actively regulate water inflow along wells. Geosteering using state of the art equipment is to be an important part of the well planning.

- Several EOR techniques have been screened. Polymer has been identified as a possible means to increase oil recovery. Challenges in the implementation of this are discussed.
Content

• Introduction
• Reservoir characterization and performance
• Complex well design and well integrity considerations
• Choice of recovery method
• Production and artificial lift difficulties
• Fluid processing difficulties
Statoil UK Heavy Oil portfolio
Mariner & Bressay

Introduction
# Mariner / Bressay Petroleum Technology - Benchmarking

<table>
<thead>
<tr>
<th></th>
<th>Grane*</th>
<th>Captain</th>
<th>Peregrino*</th>
<th>Mariner* Maureen</th>
<th>Mariner* Heimdal</th>
<th>Bressay*</th>
<th>Orinoco** Heavy oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil API</td>
<td>19</td>
<td>19</td>
<td>14</td>
<td>14</td>
<td>12</td>
<td>11</td>
<td>8-10</td>
</tr>
<tr>
<td>Depth m</td>
<td>1500</td>
<td>884</td>
<td>2200</td>
<td>1400</td>
<td>1200</td>
<td>1000</td>
<td>600</td>
</tr>
<tr>
<td>H m</td>
<td>40</td>
<td>40</td>
<td>30-100</td>
<td>40</td>
<td>10-40</td>
<td>80</td>
<td>20-30 m +</td>
</tr>
<tr>
<td>Viscosity @ reservoir conditions cp</td>
<td>10</td>
<td>50-150</td>
<td>163</td>
<td>65</td>
<td>540</td>
<td>550</td>
<td>1 000-10 000</td>
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<tr>
<td>Reservoir temperature °C</td>
<td>77</td>
<td>31</td>
<td>80</td>
<td>46</td>
<td>38</td>
<td>37</td>
<td>37</td>
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<tr>
<td>Water depth mMSL</td>
<td>128</td>
<td>113</td>
<td>106</td>
<td>105</td>
<td>105</td>
<td>105</td>
<td>0</td>
</tr>
<tr>
<td>Porosity %</td>
<td>31</td>
<td>32</td>
<td>30</td>
<td>32%</td>
<td>30</td>
<td>30%</td>
<td>31%</td>
</tr>
<tr>
<td>Permeability Darcy</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>2.5</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

* Statoil operated  
** StatoilHydro partner

Introduction
Mariner & Bressay Stand Alone Field Development
Reference cases as presented at DG1

- Reference Case Characteristics
  - 100 m Water Depth
  - Stand-alone developments
  - High level of reservoir penetration (ML wells)
  - Dry trees
  - Many long horizontal GP wells (ML) with ESP pumps
  - Many ESPs
  - High liquid handling capacity and PWRI

- Process Challenges with heavy Oil: Solution: Diluent Injection

<table>
<thead>
<tr>
<th>Planning phase</th>
<th>Bressay</th>
<th>Mariner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slots</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>Oil rate design (Sm³/d)</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>Water rate processing and re-injection (Sm³/d)</td>
<td>220</td>
<td>300</td>
</tr>
</tbody>
</table>
Comparison Water vs Oil Process Capacities

Water to Oil Process Capacity vs Oil Viscosity

Challenge:
Reduce W/O:
Water shut in?
Polymer?

Introduction
Bressay

- Bressay
  - 288 MMBO Reserves (Wood Mac)
  - 11 API (550 cp), 37 oC
  - 5 exploration wells (6 drains)
  - Multidarcy sands
  - Extensively tested (DST)

- Main Reservoir Drainage strategy
  - Natural Water Drive /Produced Water reinjection
  - Long horizontal producers Dense well spacing (100 m range)
Mariner

- 318 MMBO Reserves (Wood Mac)
- 12-14 o API (65-540 cp), 37-45 oC
- Multi Darcy sand
- 12 exploration wells (19 drains)
- Main Reservoir Drainage strategy
  - M. Maureen/ Bressay)
    - Natural Water Drive /Produced Water reinjection
    - Long horizontal producers
      Dense well spacing (100 m range)
  - M. Heimdal
    - Water Injection
    - Slant Wells
    - Pattern Drive
      (Injector/Producer pattern)
Mariner and Bressay field Geology

- Unconsolidated sands
  - “No” Ø-K relation
  - K (grain size, sorting; Vsh)
  - Shale /Sand has limited seismic visibility (OBC seismic + surface seismic helps)
  - Porosity variation seismic events (foresets)?

Deep to shallow marine ---> HIGH NTG Sands
Mariner and Bressay field Geology (cont.)

- Integrate well data, seismic observations and regional data
- Good pressure communication
- Large aquifer
- Remobilization
- Differential compaction
- Jack-up...

Heimdal Channel/Injectite Complexes

Maureen

Reservoir characterization and performance
Non-Correlation Net Gross vs. Recovery Heavy Oil
Correlation Well Spacing vs. Recovery Heavy Oil

Well Spacing (m) vs Recovery Factor

RF
Correlation Well Spacing vs. Recovery
Heavy Oil

HCPVI/(Uo*Well Spacing)*1E6

Recovery Factor
Field Analogues: Impact of Drive Mechanism on Recovery

**Venezuela- Boscan Field**

- 344 cp
- 500 md
- 1500 m well spacing – no WI (as for Orinoco fields...)

Estimated Upside WI

**China- Bohai Basin (status)**

- 60 cp, 2000 md, 200 m well spacing, WI

Figure 18 – Simulated recoveries from cyclic steam injection, steamflooding, waterflooding, and production by primary drive. The highest recovery after 30 years is forecast at 42% with steam drive, while accelerated recovery is obtained by cyclic steam injection (Kumar et al., 2001).
Heavy Oil Well Flow (Lift) Challenges

Heavy Oil well, 1000 Sm3/d

0 bar
25 bar friction
75 bar gravity
100 bar

Conv Oil well, 1000 Sm3/d

64 bar
2 bar friction
42 bar gravity
108 bar

Reservoir characterization and performance
Typical Well Design Offshore Heavy Oil

- **Conventional**
  - Open Hole Gravel Pack
  - ESP power consumption

- **Challenge**
  - Long wells
  - Down Time
  - Water /Gas
  - Work over /inflow control

- **Upsides**
  - Autonomus Inflow Control Devices (water/gas)
  - Screens?
  - HSP
  - Downhole diluent

Performance Comparison

- No_Diluent, Diluted 30%, Rate
- Diluted 50%, Rate
- No_Diluted, 30%, Power
- Diluted 50%, Power

Complex well design and well integrity

Classification: Internal     2010-10-04
Infill Potential?
Heavy Oil Impact on Reservoir Drainage

Mobility ratio (water - oil)

\[ M_{wo} = \frac{M_w}{M_o} = \frac{k_{rw} \cdot \mu_o}{k_{ro} \cdot \mu_w} \]

\[ k_{rw}' = 0.3, \mu_w = 0.77 \]
\[ k_{ro}' = 1.0, \mu_o = 500 \text{ cp} \]
\[ \Rightarrow M_{wo} = 194 \]

Case 1
11 API

\[ k_{rw}' = 0.3, \mu_w = 0.77 \]
\[ k_{ro}' = 1.0, \mu_o = 9 \text{ cp} \]
\[ \Rightarrow M_{wo} = 5 \]

Case 2
20 API

Typical North Sea Oil
35 API

\[ k_{rw}' = 0.3, \mu_w = 0.77 \]
\[ k_{ro}' = 1.0, \mu_o = 1 \text{ cp} \]
\[ \Rightarrow M_{wo} = 0.5 \]

Polymer?

Mobility ratio may in principle be reduced by i.e. heat or polymer injection.

Choice of recovery method
Impact of increased Oil viscosity

- Lower rates
- More off plateau on high water cuts
- More wells?

Choice of recovery method
60 Wells 500 cp well layout

Choice of recovery method
9 cp Year 3 Oil Saturation

40 Wells 9CP – after 3 years (1-JAN-2020)

Choice of recovery method
9 cp Year 20 Oil Saturation

- Good sweep
- Limited trapped oil

Choice of recovery method

40 W 9CP – after 20 years (1-JAN-2037)
500cp Year 3 Oil Saturation

60 Wells 500 cp – after 3 years (1-JAN-2020)

Choice of recovery method
500 cp Year 20 Oil Saturation

- Trapped Oil
  - Interbedding high hand low permeable layers
  - Shales
  - Geology critical

- Water Breakthrough
  - Severe Coning
  - Along Faults?

Choice of recovery method
Bressay – Low Polymer Injection simulation model

- 40 slots (70 OP+ 6 WI)
- PWRI
- Alt. 1:
  - 4 WI with polymer, 220 k blwpsd
- Alt 2;)
  - 4 WI with polymer, 60 k blwpsd Injection
  - 2 water disposal well injectors in flanks (160 k blwpsd)

60 000 bl/d Water with Polymer

160 000 bbl Produced Water without polymer

550 cp – after 3 years (1-JAN-2020)

Water/Gas

Polymer flooding for mobility ctrl (P): Water thickener for stable displacement of viscous oils
Conclusions Polymer Flooding

- Max potential > 10% RFU
- Bio Polymers are not feasible
- Polymer must be injected continuously
- Challenge cost of polymer
- **Low Sal** not feasible or proven technology
- **Alternatives**
  - 6 WI (4 Polymer wells + two water disposal wells 160 Kbbl/spd)
  - 4 WI 220 K water with polymer
- Marginal Economy
- Recommended to mature PWRI + Polymer towards DG4

<table>
<thead>
<tr>
<th>Uw pol</th>
<th>PWRI w. Pol</th>
</tr>
</thead>
<tbody>
<tr>
<td>220 K</td>
<td>60 K</td>
</tr>
<tr>
<td>4 cp</td>
<td>Polymer Required t/d</td>
</tr>
<tr>
<td>47</td>
<td>14</td>
</tr>
<tr>
<td>12 cp</td>
<td>107</td>
</tr>
<tr>
<td></td>
<td>25</td>
</tr>
</tbody>
</table>

Layer summation of difference in $S_0$ between polymer flooding and water injection case
Water/Oil Relative Permeability

Wettability | No | Nw | Sor | Krw(Sorw) |
---|---|---|---|---|
"WW" | 1,2 | 4,0 | 0,17 | 0,15 |
"MW" | 1,6 | 2,9 | 0,20 | 0,21 |
"OW" | 3,0 | 2,0 | 0,30 | 0,35 |

Sw | Kr
---|---
0 | 1
0.2 | 0.8
0.4 | 0.6
0.6 | 0.4
0.8 | 0.2
1 | 0

Legend:
- Base
- WW
- OW
Impact of Wettability on Rel. Permeability Heavy Oil

**Recovery Vs "Wettability"**

- "OW" (Oily Wettability)
- "MW" (Mixed Wettability)
- "WW" (Water Wettability)

**Plateau Length Vs "Wettability"**

- "OW" (Oily Wettability)
- "MW" (Mixed Wettability)
- "WW" (Water Wettability)

**Relative Plateau Level Vs "Wettability"**

- "OW" (Oily Wettability)
- "MW" (Mixed Wettability)
- "WW" (Water Wettability)
Krw Field Experience Literature

- Kr’w lab >> Kr’w history match ?
- End Point Water < 0.1 vs >0.3 lab ?
- Question is Krw parameter of Uo??
- Kr’w @ what Sor??
- Krw(Uo)??

<table>
<thead>
<tr>
<th>Heavy oil Kr’w analogues</th>
<th>Krw</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPE 93469 W.Cosinga Field</td>
<td>0,1</td>
<td>12-15 API</td>
</tr>
<tr>
<td>SPE 99762 Heavy Oil</td>
<td>&lt; 0,1</td>
<td>400-13000 cp</td>
</tr>
<tr>
<td>SPE 20528</td>
<td>&lt; 0,1</td>
<td>10-18 API</td>
</tr>
<tr>
<td>Emda Canada</td>
<td>0,1</td>
<td>12 API /2000 cp</td>
</tr>
</tbody>
</table>
Field Example – Challenges to interpret SCAL Heavy Oil

Comparing Experimental Data with different Mobility Ratios

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTC Number</td>
<td>7</td>
</tr>
<tr>
<td>Sample Depth, feet</td>
<td>3469.5</td>
</tr>
<tr>
<td>Permeability to Air, md</td>
<td>19960</td>
</tr>
<tr>
<td>Porosity, fraction</td>
<td>27 %</td>
</tr>
<tr>
<td>Initial Water Saturation</td>
<td>31 %</td>
</tr>
<tr>
<td>Effective Permeability</td>
<td>7510</td>
</tr>
<tr>
<td>Koil(Swi)/Kair at Res.</td>
<td>38 %</td>
</tr>
</tbody>
</table>
Field Example - Possible Corrections of Kr data

Action 2008: USS and SS measurements at different Uo to be performed.
Mariner Extended Well Test

- 9/11-8Z: Dec-96-May 97
  - 38 000 bbl water+acid injected
  - Collapsed screen
- 9/11-8Y: Sep- 97-Dec- 97
  - 662 000 Bbbl Oil
  - 742 000 Bbl liquid
  - K=2250 md
  - S=0.5
  - Match Parameters: OWC Steps, Faults, Water Loss 8Y

- 2 PLT’S interpretable??
- Challenges due to collapse of mother bore (8z) with 38 000 Bbls of water + acid lost

PLT/Logs Indicate Formation Water Breakthrough here
Maureen EWT – History Match, January 1998

Match based on Preliminary PLT indicating water breakthrough in a limited area of the well.

Oil/water relative permeability curves - AEA data (Based on 3 USS and 1 SS experiment)
Maureen EWT – “Captain” Curves 2007

Maureen match considered poor due to wrong breakthrough time and shape

Unrealistic “stochastic” barriers in Reservoir Model

<table>
<thead>
<tr>
<th>Maureen (CVX) (MAURELP)</th>
<th>No</th>
<th>Nw</th>
<th>Krw, end</th>
<th>Sor w</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6</td>
<td>3.5</td>
<td>0.3</td>
<td>0.2</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Match

To be weighted zero as this is back produced mud/water

Maureen match considered good
Results are geological reasonable
To be updated in 2010

<table>
<thead>
<tr>
<th></th>
<th>No</th>
<th>Nw</th>
<th>Krw, end</th>
<th>Sorw</th>
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</thead>
<tbody>
<tr>
<td>EWT Match</td>
<td>1.6</td>
<td>1</td>
<td>0.1</td>
<td>0.25</td>
</tr>
</tbody>
</table>
Summary

• Heavy oil offshore leads to:
  — Lower Oftake
  — Higher water cuts
  — Lower recovery factors
  — More wells

• Geological models, wells and dynamic data must be investigated integrated and iteratively

• Challenges in Heimdal due to low seismic visibility

• Old measurements must be validated as i.e. Uo highly impacts reserves and design

• Mitigation actions
  — Increased liquid handling capacities
  — Water shut off techniques
  — EOR (i.e. polymer)

• Drilling more infill wells important
Thank you

Petroleum Technology Team UKI HO

Partners Mariner and Bressay

Offshore Heavy Oil 2010
Thursday 7th October 2010
Le Méridien, Piccadilly, London

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