Unlocking Tight Chalk Potential Through Effective Acid Fracturing

Abdel Doghmi, 18th May 2016
Agenda

• Setting the scene:
  – Mungo oil field, CNS - Development strategy.

• Revisiting Mungo chalk potential.
  – Revisiting limited data set.
  – Looking for evidences for economic development.

• Intervention challenges.
  – Low cost approach: shut in wells.
  – Technology in service of efficiency and cost reduction.

• Conclusions & key lessons learnt.
The Mungo Field is a mature medium-sized oil field with a primary gas cap located in the Central North Sea. NUI platform with 13 km tie back to ETAP Central Processing Facility (CPF), brought online early 2000s. Four-way dip closure against Mungo salt diapir. (very similar to nearby chalk filed Machar) - Paleocene sand are primary target ~ 250 mmbls. **30 - 300 mm.bbls STOIIP** locked in tight chalk: Ekofisk, Tor and Hod Chalk Formations. UNLIKE Machar: - Little sign of natural fracture network. - Minimal mud losses observed. - Sub-seismic faults / fractures. Under-appraised: 1 chalk appraisal + acid stim: “failure” in 2001 but several penetrations with existing wells.
**Early 2000s - Chalk Appraisal Well: W173**

**W173 Mud Losses**

<table>
<thead>
<tr>
<th>Well</th>
<th>mMD</th>
<th>MUDLOSSES</th>
<th>TYPE</th>
<th>Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>22_20-A13</td>
<td>2775.5</td>
<td>1</td>
<td>Spurt losses</td>
<td>Tor</td>
</tr>
<tr>
<td>22_20-A13</td>
<td>2778.5</td>
<td>2</td>
<td>Spurt losses</td>
<td>Tor</td>
</tr>
<tr>
<td>22_20-A13</td>
<td>2817</td>
<td>1</td>
<td>Spurt losses</td>
<td>Tor</td>
</tr>
<tr>
<td>22_20-A13</td>
<td>2835.7</td>
<td>1.5</td>
<td>Spurt losses</td>
<td>Tor</td>
</tr>
<tr>
<td>22_20-A13</td>
<td>2883</td>
<td>1</td>
<td>Spurt losses</td>
<td>Tor</td>
</tr>
<tr>
<td>22_20-A13</td>
<td>2894.5</td>
<td>1</td>
<td>Spurt losses</td>
<td>Tor</td>
</tr>
<tr>
<td>22_20-A13</td>
<td>2898</td>
<td>2</td>
<td>Spurt losses</td>
<td>Tor</td>
</tr>
<tr>
<td>22_20-A13</td>
<td>2902</td>
<td>1</td>
<td>Spurt losses</td>
<td>Tor</td>
</tr>
<tr>
<td>22_20-A13</td>
<td>2916</td>
<td>1</td>
<td>Spurt losses</td>
<td>Tor</td>
</tr>
<tr>
<td>22_20-A13</td>
<td>2924</td>
<td>1</td>
<td>Spurt losses</td>
<td>Tor</td>
</tr>
<tr>
<td>22_20-A13</td>
<td>2958</td>
<td>1</td>
<td>Spurt losses</td>
<td>Tor</td>
</tr>
<tr>
<td>22_20-A13</td>
<td>3052</td>
<td>1</td>
<td>Spurt losses</td>
<td>Tor</td>
</tr>
<tr>
<td>22_20-A13</td>
<td>3071</td>
<td>1.5</td>
<td>Spurt losses</td>
<td>Tor</td>
</tr>
<tr>
<td>22_20-A13</td>
<td>3097</td>
<td>1</td>
<td>Spurt losses</td>
<td>Tor</td>
</tr>
<tr>
<td>22_20-A13</td>
<td>3145.5</td>
<td>1</td>
<td>Spurt losses</td>
<td>Tor</td>
</tr>
<tr>
<td>22_20-A13</td>
<td>3147</td>
<td>1</td>
<td>Spurt losses</td>
<td>Tor</td>
</tr>
<tr>
<td>22_20-A13</td>
<td>3171</td>
<td>1</td>
<td>Spurt losses</td>
<td>Tor</td>
</tr>
<tr>
<td>22_20-A13</td>
<td>3172</td>
<td>1</td>
<td>Spurt losses</td>
<td>Tor</td>
</tr>
<tr>
<td>22_20-A13</td>
<td>3175</td>
<td>1</td>
<td>Spurt losses</td>
<td>Tor</td>
</tr>
<tr>
<td>22_20-A13</td>
<td>3177</td>
<td>1</td>
<td>Spurt losses</td>
<td>Tor</td>
</tr>
<tr>
<td>22_20-A13</td>
<td>3193</td>
<td>1.5</td>
<td>Spurt losses</td>
<td>Tor</td>
</tr>
<tr>
<td>22_20-A13</td>
<td>3233</td>
<td>1</td>
<td>Spurt losses</td>
<td>Tor</td>
</tr>
<tr>
<td>22_20-A13</td>
<td>3235</td>
<td>1</td>
<td>Spurt losses</td>
<td>Tor</td>
</tr>
</tbody>
</table>

W173 well was completed in Dec. 2000, as chalk appraisal

- 5 ½” X 4 ½” S13% Cr upper completion.
- 5” S13%Cr liner and perforated with 0.304 EHD.
- 600 m of Tor / Ekofisk / Hod + Acid stim.

**From Drilling Report:**

- “Perforation depths identified from mud losses”
- “High number of perforations required to attempt to access all possible natural fractures”

**Perforation Intervals:**

<table>
<thead>
<tr>
<th>Interval Top (mMD)</th>
<th>Interval Bottom (mMD)</th>
<th>Perf Density (sh/ft)</th>
<th>No. of Perfs</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,145</td>
<td>3,149</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>3,060</td>
<td>3,072</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>3,039</td>
<td>3,043</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>2,983.5</td>
<td>2,986.5</td>
<td>3</td>
<td>20</td>
</tr>
<tr>
<td>2,957.5</td>
<td>2,961.5</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>2,895</td>
<td>2,901</td>
<td>6</td>
<td>39</td>
</tr>
<tr>
<td>2,833</td>
<td>2,837</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>2,777</td>
<td>2,781</td>
<td>4</td>
<td>26</td>
</tr>
<tr>
<td>2,602</td>
<td>2,606</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>205</strong></td>
<td></td>
</tr>
</tbody>
</table>

500 m
W173 – old chalk appraisal - Pumping job
2,000 bbls of MSR + 2,000 bbls of X-linked gel

Mungo Well 22/20-A13 (COA)
Main Acid Fracture Treatment

Increase in WHTP high tubular friction – slug of high viscous fluid

No Water Hammer. High BHP

Pump Trip
REVISITING Mungo Chalk Properties
Limited Data Sets

- Chalk properties from core:

<table>
<thead>
<tr>
<th>Well</th>
<th>Fm</th>
<th>Data Depth (TVDSS)</th>
<th>POROSITY</th>
<th>PERMEABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Top</td>
<td>Bottom</td>
<td>mean</td>
</tr>
<tr>
<td>Chalk 16a-4</td>
<td>Ekofisk</td>
<td>2278.72</td>
<td>2281.00</td>
<td>0.21</td>
</tr>
<tr>
<td>Tor</td>
<td>2337.36</td>
<td>2350.41</td>
<td>0.08</td>
<td>0.07</td>
</tr>
<tr>
<td>A13 Tor</td>
<td>2016.79</td>
<td>2025.72</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>A02 Hod</td>
<td>1758.744</td>
<td>1761.784</td>
<td>0.17</td>
<td>0.16</td>
</tr>
<tr>
<td><strong>AVERAGE CHALK PROPERTIES</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>0.14</strong></td>
</tr>
</tbody>
</table>

- Geo-mechanics:
  - Little evidence of natural fractures.
  - As much as 96% pure limestone.
  - Hard Rock: Modulus 4 and 6 MM psi,
  - UCS between 6,000 and 28,000 psi.

Can such hard rock, in vicinity of salt diapir not be fractured?
How much Permeability do we need?
Evidence for Natural Fractures: PTA

W162: Crestal gas injector 5.9 mD

W173: Early days chalk appraisal well 4.2 mD

Conclusion: Acid stim design should be robust to generate.

1. Sufficient penetration 30 m + for $X_f$.
2. Account for potential natural fractures.
New Chalk appraisal candidate: Shut in W169 – A19


- Horizontal producer, intersecting **220 m chalk interval** 2,980 – 3,175 m MD.
- Landed at 120 m below the original GOC and 700 m above the original OWC.
- Long term shut in (6 months +) due to 85% water cut / high sand production.
Geology Re-interpretation

Image log reprocessed and re-interpreted

Most likely free direction

Geomechanical reservoir model revisited to identify fracture direction

Faults / Conductive and Non-Conductive fractures
Reservoir and Hydraulic Frac. Modelling

3D frac reservoir model used to evaluate production benefits and sensitivity to stimulation treatment

Fracture spacing optimization – demonstrating 2 x 5 fracs optimum
Candidate W169 – A19 Completion


- 1 WSO plug set in 2010
- 13% Cr tubing.
- 90 deg deviation.
- 2 set of cemented casing/liner across.

 4½ / 7” casing shoe tested to 7,500 psi.

- Sand producer.

-> Eline tractoring required for plug & perf.
Acid Selection and Testing

Regained frac conductivity

15% Gelled acid
Stimulation Fluid Testing

- Fluid testing for:
  - Formation compatibility test.
  - Fluid emulsion testing.

- Worked closely with FPS and vendor to optimize fluid utilisation.

- Minimize toxicity (replace 1 / reduce 2 chemicals for eco-friendly version).

- No discharge(s) / No spill(s) recorded during operations.
Corrosion Testing Performed at NPL

- Corrosion testing performed with NPL (National Physics Laboratory experts).
- Detailed corrosion testing performed on completion material and subsea pipeline.
  - HP2 13Cr 95 ksi.
  - P110 1% Cr.
  - Alloy 450.

- Acid recipe: 28% gelled combined with viscoelastic material – latest technology.
- Demonstrated effectiveness of corrosion inhibitor for range of temperature.
- Sampling on ETAP during flowback showed no issues (pH, CO2 or Cl levels.)

HP2 13Cr mass loss coupons.
1% Cr mass loss coupons
Alloy 450 mass loss coupons
Perforation Testing
Challenge: Chalk behind 2 sets of Casing

Recommendations:
- First perform tubing pumping to flush sand/debris to deep perfs.
- 2-7/8” gun 6 spf / 60 deg phasing.
- Increase density with selective fire.
- Narrow/short perforation interval.

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>4-1/2” Casing EHD</th>
<th>7.00” Casing EHD</th>
<th>Target Penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td>2818 XS #1A</td>
<td>0.32” X 0.39”</td>
<td>0.22” X 0.23”</td>
<td>14.00”</td>
</tr>
<tr>
<td>2818 XS #1B</td>
<td>0.36” X 0.38”</td>
<td>0.21” X 0.21”</td>
<td>16.50”</td>
</tr>
<tr>
<td>Average</td>
<td>0.34” X 0.39”</td>
<td>0.22” X 0.22”</td>
<td>15.25”</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>4-1/2” Casing EHD</th>
<th>7.00” Casing EHD</th>
<th>Target Penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td>3123 XS #2A</td>
<td>0.40” X 0.42”</td>
<td>0.30” X 0.31”</td>
<td>25.50”</td>
</tr>
<tr>
<td>3123 XS #2B</td>
<td>0.41” X 0.44”</td>
<td>0.26” X 0.28”</td>
<td>22.50”</td>
</tr>
<tr>
<td>Average</td>
<td>0.41” X 0.43”</td>
<td>0.28” X 0.30”</td>
<td>24.00”</td>
</tr>
</tbody>
</table>
**Primary Objectives:**
- WSO of old deep Paleocene sand perforations.
- Log: Sat / Calliper / Temp / Pressure.
- Perforate and Acid stimulate 220 m tight TOR chalk: **2 stages acid stim.**
- 5 + 5 fracs, with mechanical plug as diversion + ball sealers.
- Limited perforation entry + chemical diversion + perf ball sealers.
- Target min. 30 m half length (assume no conductive natural frac).
- Demonstrate chalk PI > 1 bpd/psi.

**Strategic opportunities:**
- Support *appraisal for Mungo Chalk STOIIP range = 33 – 132 - 287 mm.stb*
- Provide strategic inputs for Mungo phase 3 drilling campaign.

**Consideration**
- Use of hydraulic fracturing technique and new stimulation fluid technology.
- Challenges due to Mungo being NUI – little access / limited POB capability.
- **4 weeks campaign**, e-line tractoring – end Q2 2015 using *Ensco 101 Rig*.
- Use of dedicated Stimulation vessel collaborating with other North Sea operator.
SIMOPS for Efficiency & Cost Reduction

- Intervene from NUI
- Use beds on E101
- Progress workovers
### Technology for Efficiency & Cost Reduction

**Soluble perforation ball sealers**

<table>
<thead>
<tr>
<th>Test ID</th>
<th>Temp (F)</th>
<th>Fluid</th>
<th>Diameter (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0 minutes</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
<td>2% KCl</td>
<td>0.609</td>
</tr>
<tr>
<td>4</td>
<td>200</td>
<td>15% HCl</td>
<td>0.6145</td>
</tr>
</tbody>
</table>

**Diagram:**

- Fluid drag attempting to unseat ball
- Pressure differential holding ball in place
- Need to overcome inertia to get ball to seat
- Interval treated with acid has now been largely sealed by balls. Next acid stage will be diverted.
ZONE 1 – Treatment Plot

- 7,150 bbls of 28% acid
- 4,150 bbls of 50# titanate gel
- 600 bbls of self diverting agent

BP UK Mungo Well W169

Acid Fracturing Treatment Zone 1 - LCA28 and VDA15 at Surface

- Spearhead 28% slick acid
- 300psi friction reduction
- 900psi reduction DHPG
- Formation breakdown
- LCA at perfs 300psi loss
- VDA at perf. 400psi
- Successful balls diversion balls
  - 15 x 5/8 + 150 psi
  - 15 x 5/8 + 300 psi
  - 30 x 5/8 + 250 psi
  - 30 x 5/8 + 300 psi

- 7,150 bbls of 28% acid
- 4,150 bbls of 50# titanate gel
- 600 bbls of self diverting agent

BP Frac & Stim: Abdel Doghmi
ZONE 2 - Treatment Plot

- 7,050 bbls of 28% acid
- 3,350 bbls of 50# titanate gel
- 550 bbls of self diverting agent

BP UK Mungo Well W169
Acid Stages at Perfs Zone 2 - 30th May 2015

Successful ball action
- 15 x 5/8 + 50 psi
- 15 x 5/8 + 1000 psi
- 15 x 5/8 + 150 psi
- 30 x 5/8 + 300 psi
### ACA Results (Pumping Frac PFO analysis)

<table>
<thead>
<tr>
<th>Step</th>
<th>Operation</th>
<th>Stage 1</th>
<th>Stage 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$\text{kh}$ (mDft)</td>
<td>Skin</td>
</tr>
<tr>
<td>1</td>
<td>Breakdown/ACA</td>
<td>49</td>
<td>n/a</td>
</tr>
<tr>
<td>2</td>
<td>SRT 1</td>
<td>380</td>
<td>n/a</td>
</tr>
<tr>
<td>3</td>
<td>Main Frac</td>
<td>7,600</td>
<td>-4.6</td>
</tr>
<tr>
<td>4</td>
<td>SRT 2</td>
<td>7,600</td>
<td>-4.8</td>
</tr>
</tbody>
</table>

* Likely to be balls in perforations awaiting dissolution.

---

**Zone 1**

- **30 x KH increase**

**Zone 2**
Mungo Production Separator
All wells – all rates (as at 26\textsuperscript{th} July 2015)

IPC:  
Yesterday’s Allocated Export:

<table>
<thead>
<tr>
<th></th>
<th>Oil</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>17,500</td>
<td>14.8</td>
</tr>
<tr>
<td></td>
<td>7,066</td>
<td>6.1</td>
</tr>
</tbody>
</table>

**Mungo Cluster**

\[+5.5 \text{ mbd}\]
Revisiting Mungo Fault / Fracture System
Mungo Chalk Appraisal – W169 Acid Stim

Conclusions

• All objectives successfully completed with no accidents, incidents or environmental issues.

• Successful intervention proving chalk potential on Mungo:
  
  − Chalk fraccability:
    ✓ Proved effective perforation and stimulation strategy – limited entry + soluble ball sealers.
    ✓ Suitable acid stimulation recipe tested in lab and proved on field, using latest technology.
    ✓ Clear signs of induced / secondary fractures during fracturing operations.

  − Deliverability: economics rates & Volumes:
    ✓ PI of 18 bpd/psi vs. 1 bpd/psi (target).
    ✓ Proved kh post stim. up to 8,000 mDft observed vs. 300 mDft expected.
    ✓ 7 mmbbls contacted volume in W169. PTA.

Key Lessons:

• Revisit Exploration wells in light of new technology capabilities.

• Use existing penetration or low cost side-track options.

• Exploration bias – do not give up on 1 “failure” W173 - Mungo dedicated chalk?

• Integration with subsurface & intervention teams.
Back Up Slides
W169 Acid Frac
Zone 1 - ACA/Decline Analysis

ACA

SRT 1

Main Frac

SRT 2

Time (hours)

PSI

STB/D
Simple Stress Regime Classification

Normal regime, $\sigma_v$ is $\sigma_1$

Sharp transition zone

Thrust regime, $\sigma_v$ is $\sigma_3$

Strike-slip regime, $\sigma_v$ is $\sigma_2$