Combining State of the Art Perforation Detonation Mechanisms with Improved Perforation Design

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Agenda

- Operational Scenario
- Previous TCP Designs
- Design Challenges
- Perforating Design Requirements
- Case Study
- Perforating Design Solution
- TCP BHA and Procedures
- Results
- Summary
- Way Forward
Operational Scenario

- Multiple target zones on 8.5” Section
- Pore Pressure and Mobility heterogeneity on targets (Pore Pressure @ 65%, and Mobility @ 3x times diff.)
- Target zones spaced by up to 100 meters TVD
- Casing Test Pressure Limitation (Shallow Wells, Low Grade Casing)
- Static Underbalance key for completion quality of wells
- Efficient perforation design required (Hoist schedule/Wells sequence, Operational Costs)
Previous TCP Perforating Designs

• Previous TCP job designs for these fields:

1. Several TCP runs to achieve desired SUB pressures utilizing one mechanical firing head on each run.

2. One TCP run utilizing long gun spacers in between the zones; SUB is also achieved.

3. One TCP run utilizing one mechanical and one/two absolute pressure firing head; SUB is achieved for only the top zone and bottom zones is perforated overbalanced.

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Design Challenges

• **Multi TCP runs:**
  – Increase of HSE exposure (ie. Explosives handling)
  – Increase of Rig/Hoist time (~ 16 hrs for each TCP run)

• **One TCP run with long gun blank spacers:**
  – Increase risk of handling gun spacers trapped pressure
  – Partial gun firing
  – Misuse of blanks (waste of guns)

• **One TCP run with one mechanical and one/two absolute pressure firing heads:**
  – SUB can only be achieved for top zone
  – Casing/Liner integrity can limit this option because of its pressure limitation. (~ 15,000 kPa surface pressure is required to activate the firing head)
Perforating Design Requirements - PDO

• Perforate all zones in underbalanced condition.

• Eliminate long blank gun sections (PDO’s inventory versus planned wells).

• Reduce Hoist/Rig time by perforating in one run to minimize risk and HSE exposure

• Avoid pumping < 5,000 kPa surface pressure through casing (9 5/8” Casing Integrity & 7” Liner top previous SOP pressure test limited at 5kKpa)
Case Study – ABJ-95

- Distance between target zones.
- Differences on Pressure
- Differences on Mobility
Perforating Design Solution

• Displacement of well fluid to Crude Oil to achieve desired static under balance pressures for bottom zones:
  ▪ Common practice for Hoist to use brine. Handling, line-up setup and pumping procedures were considered.
  ▪ 1760psi PP “Low Pore Pressure of upper interval” Crude Oil cushion still @ 230psi overbalance

• Utilization of Novel Electronic Firing Head System:
  ▪ Advantage of very low pressure activation command.
    ▪ Use a pumping unit to achieve required pressure pulses.
    ▪ Use of calibrated pressure gauges.
  ▪ Design Flexibility:
    ▪ Range and accuracy of Delay Time
    ▪ Robust signal minimizes risk of misfire (RIH, Completion setting)
    ▪ Initiation / Cancellation features for activation signal
    ▪ Pressure/Temp data recorded on built-in Gauge
Perforating Design Solution

- Pressure match for additional dynamic underbalance created by selected string configuration
  - Pressure simulation estimates additional 700psi dynamic underbalance created by guns
  - Total expected Underbalance: SUB (Crude Oil Cushion) + DUB
**TCP BHA & Procedures**

1. Displace Well with Crude Oil
2. RIH TCP BHA with Packer on Tubing
3. Fill Tubing string as required to achieve SUB for top zones
4. Apply pressure in annulus to activate the electronic firing head for bottom zones
5. Set the packer and wait for time delay
6. Wait for bottom zone to fire
7. Immediately fire the top zone
8. Continue test/well control plan as per procedures...
Results – Surface Pressure Record

Pumping Unit Chart (Surface)

- Pressure Test surface Lines
- Electronic firing head commands
- Pressure up Annulus
- Firing Indication
Results – Down Hole Pressure Record

Downhole Chart – Electronic Firing Head Fast Gauge

<table>
<thead>
<tr>
<th>Zone</th>
<th>Well Hydrostatic Condition</th>
<th>Static Under Balance</th>
<th>Dynamic Under Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower</td>
<td>SUB</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Upper</td>
<td>OB</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Firing Indication of the electronic firing head

Firing Indication of the mechanical firing head

U-Tube effect: Opening of Prod. Valve *lower gauge

Pressure match with intended cushion weight (Crude Oil)

Pressure Match for Underbalance: SUB + DUB

Upper Zone Formation Pressure

Electronic firing head commands

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Summary

• Nobel Electronic Firing Head has been approved technically by PDO.
• Applicable for similar cases among PDO fields and not only for the initial proposed fields.
• Cost is not the vital issue to select firing mechanism.
• Avoid casing and or top liner seal from possible leaks.
• Evaluation for perforation and integrity among PDO fields.
Way Forward

• Casing and TOL seal pressure will be considered in all future jobs.

• Review the failed casing integrity wells among PDO fields and match with perforation operations history.
Thank You