Underbalanced Coiled Tubing Drilling Case Study:

Drilling Larger Hole Sizes in Underbalanced Conditions and Ensuring Hole Cleaning

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Well Description

> Well located in the Paris basin, France

> Wells in the field are depleted oil wells in a carbonate reservoir and have to be pumped.

> Wells produce with a high water cut

> Thin payzone

> Barefoot completion
Overall Objective and rational for CTD

> Tap into an un-drained pocket of the reservoir

Why CTD:

> Only drilling method that can offer continuous underbalance

> Higher ROP

> Well fully contained during drilling

> Based on a successful 4-well CTD program in 2007

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Specific Program Objectives

- Perform all work with zero HS&E incidents
- Initiate open hole side-track inside the porous reservoir boundaries, 4m thickness
- Drill at least 300m long drain
- Keep the well underbalanced and drill in one run
- Capture technical learning and best practices
Different Well Geometry

PREVIOUS WELL

7” Casing
4-1/2” Liner
4-1/8” OH

THIS WELL

7” Casing
6” OH
6-1/8” OH
Planning for success

> Tubing Forces
  > Getting weight to bit
  > Hook load

> Hydraulics
  > Bottom Hole circulating pressure (BHCP)
  > Hole cleaning ability
Previous well: 2-3/8” CT, 3” BHA

BHCP vs Injection Rates 2-3/8 CT, 3” CTD BHA

Gas Injection Rate (Ncum/min)

- Formation Pressure
- Target BHCP
- Liquid Phase 223.6 l/min
- Cleanability
- Liquid Phase 260.4 l/min
- Cleanability
- Liquid Phase 297.2 l/min
- Cleanability
- Liquid Phase 334.0 l/min
- Cleanability
- Liquid Phase 370.8 l/min
- Cleanability
- Motor Max Rate 140 USGPM
- Motor Min Rate 60 USGPM

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New well: 2-7/8” CT, 5” BHA
Results
Drilling Results: Plan View

Plan Plot

-1000 -900 -800 -700 -600 -500 -400 -300 -200 -100 0
N-S (m)

-100 -200 -300 -400
E-W (m)

- Original Well Plan
- Existing
- Drilled
- Updated Well Plan

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Drilling Results: Section View

Vertical Section (m)

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Underbalance

Lesson learned: separator capacity needs to match ROP capability
Weight-on-Bit Comparison

Comparison of Predicted Max WOB and Measured WOB
BHCP Comparison

Comparing Predicted & Observed Steady State BHCP for 2-phase Circulation
Liquid rate fixed at 400 l/m, 3 N2 rates

Formation Pressure
Target BHCP
Predicted Steady State BHCP
Observed BHCP (10500 data points)

Liquid Properties:
Diesel
## Objectives vs Results

<table>
<thead>
<tr>
<th>Objective</th>
<th>Result</th>
</tr>
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<tbody>
<tr>
<td>Perform all work with zero HS&amp;E incidents</td>
<td>Achieved</td>
</tr>
<tr>
<td>Initiate open hole side-track inside the porous reservoir boundaries 4m thick</td>
<td>Achieved</td>
</tr>
<tr>
<td>Drill at least 300m long drain</td>
<td>Achieved (438m)</td>
</tr>
<tr>
<td>Keep the well underbalanced and drill in one run.</td>
<td>Not achieved</td>
</tr>
<tr>
<td>Capture technical learning and best practices.</td>
<td>Achieved</td>
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