CT Extended Reach
Can We Reach Farther?

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Canadian ICoTA Conference

October 2013
How can we reach farther?
(Force and Friction)

- Apply force to downhole end
  - Tractor
  - Pump down annulus
- Reduce friction
  - Vibration
  - Lubrication
  - Rollers
  - Rotate CT
  - Increase buoyancy (decrease WCF)
Downhole Pulsation of CT
(Agitator™)

Power Section

High Speed Power Section

Rotor

Stator

Nutation
Nutation

Time / Rotation / Nutation

Relative positions of Valve Plates

Valve & Bearing Section
Field Example: Downhole Pulsation Tool

- 5.5” casing to 6,500’
- 4.5” liner to 14,000’
- Purpose of Intervention
  - Logging

Wellbore Trajectory
Downhole Pulsation Tool
(CT Lockup 11,697’ w/o pulsation // 12,652’ w/pulsation)
Benefits of Rotating CT

- Reduce friction
  - Increase WOB
  - Extend reach
- BHA orientation
- Reduced risk of sticking
- Improved hole cleaning
- For RIH rotational speed needs to be similar to RIH speed
Rotating CT Unit
(Concept of Canister)
How can we reach farther?
(Reduce Helical WCF)

- Increase CT Stiffness (EI)
  - Increase OD and/or wall thickness
  - Use material with higher modulus of elasticity
- Decrease radial clearance
  - Smaller Hole ID
  - Larger OD CT
- Reduce the residual bend
  - Straightener
- Combined JP/CT string
  - Hybrid CT/JP System
Tubing Straightener
(Mounted on Top of Injector)

Self-aligning guidance rollers

Accumulator

Straightening roller
Straightener
Tubing Straightener

Without  With
Hybrid CT/JP System

Key Components

- Gooseneck
- Tower
- HWO Rig Assist Unit
- Reel Trailer
Hybrid CT/JP System
What Does it Do?

- Hydraulic Workover (HWO) unit runs jointed pipe and CT
  - CT injector not used
- Rigless operation
- Well control package – no wireline

Potential Benefits

- Eliminate CT Transportation Weight Constraint Issues
- Use of larger CT sizes
  - Deeper penetration before CT lockup
  - Increased pull/push capacity
  - Enables higher pumping rates
Basic Theory
(buckling)

\[
SBL = 2 \sqrt{\frac{EIW_b \sin \theta}{r_c}}
\]

\[
HBL = 2 \sqrt{\frac{2EIW_b \sin \theta}{r_c}} = \sqrt{2} SBL
\]

- Straight wellbore with inclination \( \theta \)
- Simplified equations, friction ignored
- Straight CT (no residual bending)
Basic Theory
(post buckling)

- Once buckled, friction increases as the square of the effective axial force

\[ F_f = \beta F_e^2 dL \]

- Force Transfer Factor (FTF) = \( \frac{dF_b}{dF_t} \)
- Lockup defined as 1% FTF
- For a horizontal, straight well section:

\[ \frac{dF_b}{dF_t} = \frac{1}{(1 - F_t\beta L)^2} \]
Typical L Shaped Well

- Vertical to 8,000 ft KOP
  - HBL nearly 0 in vertical section
  - Unbuckled CT in upper portion
  - Buckled CT in lower portion
- Build up to 90 deg in 1,000 ft
  - HBL increased in curve – no buckling
  - Buckled CT can be pushed into the curve
- Horizontal
  - Buckled section
  - Unbuckled section
Base Case

- 2” X 0.204” 90 Grade straight wall CT
- 9 5/8” (8.921”) csg entire well
- KOP 8000 ft, BUR 9 deg/100
- Reaches horizontal at 9,000 ft
- Horizontal as long as needed
- Friction coeff 0.25
- Water throughout the CT and the well
- -1,000 lb force on end (WOB)
Base Case
Base Case
## Well Parametric Analysis

<table>
<thead>
<tr>
<th>Change from Base Case</th>
<th>Lockup Depth (ft)</th>
<th>Horiz. Length (ft)</th>
<th>Force Transfer Factor</th>
<th>Max von Mises</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vertical (%)</td>
<td>Curve (%)</td>
<td>Horiz (%)</td>
<td>RIH (%)</td>
</tr>
<tr>
<td>Base case</td>
<td>12,073</td>
<td>3,073</td>
<td>5.3%</td>
<td>66.8%</td>
</tr>
<tr>
<td>Friction coefficients = 0.30</td>
<td>11,415</td>
<td>2,415</td>
<td>3.7%</td>
<td>62.0%</td>
</tr>
<tr>
<td>Friction coefficients = 0.35</td>
<td>10,673</td>
<td>1,673</td>
<td>1.8%</td>
<td>57.0%</td>
</tr>
<tr>
<td>HBL without curvature</td>
<td>11,817</td>
<td>2,817</td>
<td>4.8%</td>
<td>23.4%</td>
</tr>
<tr>
<td>HBL set to 0</td>
<td>11,265</td>
<td>2,265</td>
<td>10.2%</td>
<td>24.1%</td>
</tr>
<tr>
<td>3.8&quot; ID tubing to end of curve</td>
<td>12,579</td>
<td>3,579</td>
<td>13.7%</td>
<td>67.3%</td>
</tr>
<tr>
<td>6.25&quot; ID casing entire well</td>
<td>13,130</td>
<td>4,130</td>
<td>4.7%</td>
<td>67.3%</td>
</tr>
<tr>
<td>Kickoff at 15,000 ft</td>
<td>19,073</td>
<td>3,073</td>
<td>5.3%</td>
<td>66.8%</td>
</tr>
<tr>
<td>0 density fluid in well</td>
<td>11,797</td>
<td>2,797</td>
<td>6.5%</td>
<td>64.2%</td>
</tr>
<tr>
<td>4.5 deg build from 7,000 ft to 9,000 ft (slower build)</td>
<td>12,033</td>
<td>3,033</td>
<td>74.8%</td>
<td>67.1%</td>
</tr>
</tbody>
</table>
## String Parametric Analysis

<table>
<thead>
<tr>
<th>Change from Base Case</th>
<th>Lockup Depth (ft)</th>
<th>Horiz. Length (ft)</th>
<th>Force Transfer Factor</th>
<th>Max von Mises</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Base case - 15,000 ft kick-off</em></td>
<td>19.073</td>
<td>3.073</td>
<td>5.3%</td>
<td>66.4%</td>
</tr>
<tr>
<td><em>HBL = 0</em></td>
<td>18.265</td>
<td>2.265</td>
<td>10.2%</td>
<td>67.2%</td>
</tr>
<tr>
<td><em>2 3/8&quot; X .204&quot; CT</em></td>
<td>20.215</td>
<td>4.215</td>
<td>1.9%</td>
<td>71.0%</td>
</tr>
<tr>
<td><em>2 7/8&quot; X .250&quot; CT</em></td>
<td>21.849</td>
<td>5.849</td>
<td>5.4%</td>
<td>81.2%</td>
</tr>
<tr>
<td><em>2 3/8&quot; X .204&quot; CT - HBL = 0</em></td>
<td>19.355</td>
<td>3.355</td>
<td>7.6%</td>
<td>72.8%</td>
</tr>
<tr>
<td><em>2 7/8&quot; X .250&quot; CT - HBL = 0</em></td>
<td>20.820</td>
<td>4.820</td>
<td>5.4%</td>
<td>70.3%</td>
</tr>
<tr>
<td><em>Tapered 2&quot; 125 grade string</em></td>
<td>20.793</td>
<td>4.793</td>
<td>5.4%</td>
<td>40.6%</td>
</tr>
<tr>
<td><em>Tapered 2&quot; string - HBL = 0</em></td>
<td>17.964</td>
<td>1.964</td>
<td>21.4%</td>
<td>51.3%</td>
</tr>
<tr>
<td><em>Tapered HBL without curvature</em></td>
<td>20.522</td>
<td>4.522</td>
<td>4.5%</td>
<td>54.0%</td>
</tr>
</tbody>
</table>
Modeling Conclusions

- Whether or not residual bend exacerbates the onset of helical buckling is a major issue that needs to be understood.
- If the HBL is understood, a tapered string may be designed which significantly extends the reach.
- Picking up and setting down may remove buckling in the curve, allowing further reach.
- Increasing the yield strength increases the residual bending.
Tubing Forces Lab
Tubing Forces Lab
Tubing Forces Lab

- 1” ID, 16 ft L clear ‘Casing’
- ¼” OD, 17 ft L ‘Test Samples’
- Dual screw tailstock
- Force input and output load cells
- Depth string potentiometer
Test Samples
Dry Run
With Vibration
Lubricated
Lubricated, Alternate $\mu$
Initial Conclusions from Testing

- Residual curvature causes premature buckling and increased wall contact forces
- Residual curvature and residual torsion is even worse
- Residual torsion alone has little effect