The Impact of Well Features on CT Reach

Presented by Patrick Kelleher

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The Impact of Well Features on CT Reach

- CT is commonly used to mill frack plugs prior to bringing new unconventional wells online.
- Without adequate planning CT may not reach all of the plugs in some completions.
- This CT forces study quantifies several parameters to consider during well design and completion.
What Well Features Affect Reach and Weight on Bit?

(Tubing Forces)

- Survey
  - Build Up Rates
  - Lateral Inclinations (Toe Up/Down)
  - Borehole Tortuosity
  - Turns in the Lateral

- CT - Completion factors
  - Radial Clearance
  - Friction Coefficient

Less is More!
Determining Feature Ranges to Compare

- 11 Challenging wells from North America selected for survey analysis
  - Extended Reach
  - ~ 5,000 to 7,000 ft TVD

- Estimated survey parameters for each well and assembled them as statistics: min, max, average
## Survey Parameter Analysis

<table>
<thead>
<tr>
<th>Well Feature</th>
<th>Units</th>
<th>Minimum</th>
<th>Average</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build Up Rate</td>
<td>deg/100 ft</td>
<td>2.2</td>
<td>5.9</td>
<td>8.5</td>
</tr>
<tr>
<td>Tortuosity in Lateral</td>
<td>deg/100 ft</td>
<td>0.6</td>
<td>1.1</td>
<td>1.7</td>
</tr>
<tr>
<td>Turn in Lateral (3 Wells)</td>
<td>deg/100 ft</td>
<td>0.9</td>
<td>2.7</td>
<td>3.9</td>
</tr>
<tr>
<td>Highest DLS</td>
<td>deg/100 ft</td>
<td>5.6</td>
<td>13.4</td>
<td>19.1</td>
</tr>
<tr>
<td>Turn While Building</td>
<td>deg/100 ft</td>
<td>0.1</td>
<td>1.0</td>
<td>3.2</td>
</tr>
<tr>
<td>Toe Inclination</td>
<td>deg</td>
<td>89.7</td>
<td>90.2</td>
<td>91.2</td>
</tr>
<tr>
<td>Lateral Length</td>
<td>ft</td>
<td>6669</td>
<td>7831</td>
<td>9103</td>
</tr>
<tr>
<td>TVD</td>
<td>ft</td>
<td>5345</td>
<td>6441</td>
<td>7161</td>
</tr>
</tbody>
</table>
Theoretical Base Well for Feature Comparison

- Simple ‘Base’ well designed using these parameters
  - Build Rate: 5 deg / 100 ft
  - Friction: 0.30
  - 5 ½” 17 lb/ft casing
  - TVD: 6150 ft
  - Water inside tubing and annulus
  - No lateral turning or tortuosity
Comparison Wells

- Variations applied to obtain comparison wells
  - Build Rates: 3 and 8 deg / 100 ft with fixed TVD
  - Toe Up: 91 and 92 deg Inclination
  - Toe Down: 89 and 88 deg Inclination
  - Tortuosity in lateral: 0.7 and 1.4 deg / 100 ft
  - Turns in lateral: 1.5 and 3 deg / 100 ft over 1500 ft
  - Friction Coefficients: 0.25 and 0.28
  - Casing sizes 5 ½ x 20 lb and 5 ½ x 23 lb
CT String Selection

- 100 kpsi yield, 2 3/8”, 0.156 to .236 Wall
- Custom Multi Taper Design
  - Optimized for extended reach and yield stress for the base well
    - Reduces weight along the lateral
    - Increases stiffness in the vertical
  - Commonly used in extended reach applications
Cerberus Extended Reach CT Design Software
CT String Designed for Base Well

- 2 3/8” OD
- 0.156 to .236 Wall
- GT–100

<table>
<thead>
<tr>
<th>Wall Thickness (in)</th>
<th>Section Length (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.156</td>
<td>6114</td>
</tr>
<tr>
<td>0.190</td>
<td>699</td>
</tr>
<tr>
<td>0.204</td>
<td>675</td>
</tr>
<tr>
<td>0.236</td>
<td>12512</td>
</tr>
</tbody>
</table>

* This string used in all comparisons
Using Forces Modeling to Quantify Impacts

- **Friction Lock-Up Depth**
  - Theoretical Max CT Reach
  - Lateral Reach = $D_{\text{lockup}} - D_{\text{end of build}}$

- **Wall Contact Force (WCF)**
  - How forces are distributed

- **Force Transfer Factor (FTF):**
  - Slope of $WOB$ with respect to Surface Force
  - Force Transfer Loss(section) = FTF(top to surface) – FTF(bottom to surface)
Base Case Results

- Lockup at 15,167 ft with 500 lbf WOB:
  - Lateral reach of 8,367 ft
  - No buckling in the lateral due to tapered design
  - Most WCF in vertical section
  - 98% Incremental force loss in vertical section
- Increasing BUR from 5 to 8 reduced lateral reach by 9%
- Reducing BUR from 5 to 3 increased lateral reach by 3%
Toe Up / Down
(degree)

- 1 Degree Toe Up reduced lateral reach by 11%
  - Onset of buckling in the lateral

- 1 Degree Toe Down increased lateral reach by 5%
Lateral Tortuosity
(deg / 100 ft)

- 0.7 deg/100 ft tortuosity reduced lateral reach by 8%

- 1.4 deg/100 ft tortuosity reduced lateral reach by 18%
Lateral Turns
(deg / 100 ft over 1500 ft)

- 1.5 deg/100 ft turn reduced lateral reach by only 2%
- 3 deg/100 ft turn reduced lateral reach by 7%
Coefficient of Friction (Cf)

- Reducing Cf from 0.30 to 0.28 increased later reach by 7%.

- Lower friction significantly reduces buckling and friction in the vertical section.
5 ½ in Casing Weight (lb / ft)

- Increasing Weight from 17 lb/ft to 23 lb/ft increased lateral reach by 3%
- Same result if only the vertical section is increased in this case
## Parametric Matrix

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Lateral Reach (ft)</th>
<th>Vertical WCF (lbf)</th>
<th>% FTF Loss</th>
<th>Heel WCF (lbf)</th>
<th>% FTF Loss</th>
<th>Toe WCF (lbf)</th>
<th>% FTF Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build 5 deg / 100 ft 0.25 Friction</td>
<td>10,013</td>
<td>54,712</td>
<td>95.0%</td>
<td>22,881</td>
<td>1.6%</td>
<td>36,605</td>
<td>2.2%</td>
</tr>
<tr>
<td>Toe Down 88 deg inclination</td>
<td>9,299</td>
<td>62,931</td>
<td>98.2%</td>
<td>20,701</td>
<td>0.7%</td>
<td>33,792</td>
<td>0.0%</td>
</tr>
<tr>
<td>Build 5 deg / 100 ft 0.28 Friction</td>
<td>8,976</td>
<td>48,239</td>
<td>95.6%</td>
<td>21,698</td>
<td>1.6%</td>
<td>32,160</td>
<td>1.7%</td>
</tr>
<tr>
<td>Toe Down 89 deg inclination</td>
<td>8,806</td>
<td>66,696</td>
<td>98.4%</td>
<td>20,965</td>
<td>0.6%</td>
<td>31,495</td>
<td>0.0%</td>
</tr>
<tr>
<td>Build 3 deg / 100 ft</td>
<td>8,646</td>
<td>34,325</td>
<td>92.4%</td>
<td>23,586</td>
<td>4.0%</td>
<td>32,246</td>
<td>2.4%</td>
</tr>
<tr>
<td>Build 5 deg / 100 ft, 5.5 23 lb casing</td>
<td>8,601</td>
<td>73,007</td>
<td>98.4%</td>
<td>21,835</td>
<td>0.6%</td>
<td>30,548</td>
<td>0.0%</td>
</tr>
<tr>
<td>Build 5 deg / 100 ft, 5.5 20 lb casing</td>
<td>8,478</td>
<td>63,133</td>
<td>98.2%</td>
<td>21,182</td>
<td>0.7%</td>
<td>29,498</td>
<td>0.1%</td>
</tr>
<tr>
<td>Build 5 deg / 100 ft (Base Case)</td>
<td>8,367</td>
<td>66,478</td>
<td>98.4%</td>
<td>21,203</td>
<td>0.6%</td>
<td>29,361</td>
<td>0.0%</td>
</tr>
<tr>
<td>Turn in Lateral 1.5 deg / 100 ft for 1500 ft</td>
<td>8,197</td>
<td>63,133</td>
<td>98.2%</td>
<td>21,182</td>
<td>0.7%</td>
<td>29,498</td>
<td>0.1%</td>
</tr>
<tr>
<td>Turn in Lateral 3.0 deg / 100 ft for 1500 ft</td>
<td>7,802</td>
<td>60,155</td>
<td>98.0%</td>
<td>21,161</td>
<td>0.8%</td>
<td>30,958</td>
<td>0.3%</td>
</tr>
<tr>
<td>Lateral Tortuosity 0.7 deg / 100 ft</td>
<td>7,704</td>
<td>30,908</td>
<td>90.7%</td>
<td>20,565</td>
<td>3.5%</td>
<td>28,577</td>
<td>4.8%</td>
</tr>
<tr>
<td>Build 8 deg / 100 ft</td>
<td>7,644</td>
<td>59,938</td>
<td>98.2%</td>
<td>17,293</td>
<td>0.6%</td>
<td>26,007</td>
<td>0.0%</td>
</tr>
<tr>
<td>Toe Up 91 deg inclination</td>
<td>7,450</td>
<td>26,980</td>
<td>88.1%</td>
<td>21,448</td>
<td>4.7%</td>
<td>26,465</td>
<td>5.9%</td>
</tr>
<tr>
<td>Lateral Tortuosity 1.4 deg / 100 ft</td>
<td>6,898</td>
<td>27,383</td>
<td>88.4%</td>
<td>19,020</td>
<td>4.2%</td>
<td>28,912</td>
<td>6.3%</td>
</tr>
<tr>
<td>Toe Up 92 deg inclination</td>
<td>6,346</td>
<td>22,974</td>
<td>84.7%</td>
<td>20,104</td>
<td>6.0%</td>
<td>24,842</td>
<td>7.9%</td>
</tr>
</tbody>
</table>

- TVD at start of lateral = 6150 ft for all wells
- WOB = -500 lbf for all cases
Force Transfer Loss

- Red shown where the majority of additional set down weight is lost due to wall contact forces.
What Influences these Parameters?

- **Build Rate, Turns, Final Trajectory, Tortuosity**
  - Economics, geography, drilling equipment, and formation characteristics

- **Radial Clearance**
  - Casing, liner and CT Diameter selections

- **Friction coefficient and downhole tools**
  - Fluid Additives
  - BHA vibration tools
Conclusions

- Survey parameters that significantly reduce CT Reach in this case:
  - Toe Up > 0.5 deg
  - Cased hole tortuosity > 0.5 deg /100 ft
  - Build Rates > 6 deg/100 ft
  - Lateral turns > 3 deg/100 ft

- Custom CT string designs reduce buckling in the lateral

- Majority of forces attributed to lock up are in the vertical section (with a custom CT design)
  - Decrease radial clearance if possible
  - Liners add challenges for CT extended reach
The authors would like to acknowledge the following companies for their support throughout this study:

Athena Engineering Services
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NOV CTES

Thank You

Questions?