SPE DISTINGUISHED LECTURER SERIES
is funded principally through a grant of the
SPE FOUNDATION

The Society gratefully acknowledges those companies that support the program by allowing their professionals to participate as Lecturers.

And special thanks to The American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME) for their contribution to the program.
BP EXPLORATION

Wellbore Quality Characterization for Drilling and Casing Running in Challenging Wells

Dr. Colin Mason
Senior Drilling Specialist
Sunbury-on-Thames
United Kingdom

Telephone: +44 1932 739518
Email: masoncj@bp.com
Lecture Overview

- Introduction
- Definition
- Measuring wellbore quality
- Managing wellbore quality
- Field case studies
- Conclusions
Introduction

- "Wellbore quality" common oilfield concept
- Often associated with directional drilling
- Often linked with performance improvements
- Diverse interpretations for each discipline
- No unique definition exists
- No proven method of measurement exist
- **Context:** Drilling and Completions
## Wellbore Quality Parameters

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Influenced by</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tortuosity</td>
<td>Directional driller</td>
</tr>
<tr>
<td>Wellbore spiralling</td>
<td>Directional drilling BHA</td>
</tr>
<tr>
<td>Cuttings bed</td>
<td>Drilling practices</td>
</tr>
<tr>
<td>Ledging</td>
<td>Drilling practices / environment</td>
</tr>
<tr>
<td>Lost circulation</td>
<td>Drilling practices / environment</td>
</tr>
<tr>
<td>Wellbore breakout</td>
<td>Mud weight / exposure time</td>
</tr>
<tr>
<td>Formation damage</td>
<td>Mud type / mud properties</td>
</tr>
<tr>
<td>Target hole size</td>
<td>Planning / Learning</td>
</tr>
<tr>
<td>Measurable</td>
<td>Chosen methodology</td>
</tr>
</tbody>
</table>
Definition – Quality Wellbore

- **Straight wellbore** – minimal tortuosity and minimal hole spiralling (micro-tortuosity)
- **Round gauge hole** – minimal wellbore break-out, no wash-outs and hole not undergogauge
- **Smooth wellbore** – minimal ledging
- **Clean hole** – minimal residual cuttings bed
- **Integrity** – no leakage, no formation damage
- **Fit for purpose** – casing or logs will run to depth
Benefits – Quality Wellbore

- Improved weight transfer – better ROP
- Good hole cleaning – gauge hole
- Lower vibration – constant drilling parameters
- Trouble-free trips & casing runs – gauge hole
- Better log quality – gauge, non-spiralled hole
- Competent cement bond – gauge hole
- Reduced torque and drag – low tortuosity
Influences: Subsurface Environment

Geology influences wellbore quality

- Pore Pressure / Fracture Gradient
- Geothermal Gradient
- Formation Types
- Rock Strength
- Stress Orientation
- Fractures / Faulting
- Life of field issues – depletion
Influences: Wellbore Placement

- Wellpath selection
- Tortuosity (planned versus actual)
Influences: Mud System

In this application an OBM is needed to stabilise a shale.
Influences: Directional Drilling Tools

- Rotary Steerable Tool
  - Long gauge PDC bit
- Steerable Motor
- Tricone Bit
Hole Spiralling – Introduction

- Hole spiralling exists in most wells
- Pitch, amplitude, drift, gauge – key parameters
- Negatively impacts drilling and completion operations
- Usually can be detected from logs
- Effects more pronounced in horizontal / ERD wells
- Long gauge bits – tend to help reduce spiralling
Hole Spiralling – Imaging
Hole Spiralling – Image Log

Example: Average hole size PDM, 9.5-10” with local washouts
Average hole size RSS - 8.7”

Image Log shows
Spiral Hole from
PDM and RSS
(Cannot be seen in Survey)
MWD survey tool crosses the trough or valley of a spiral hole. Inclination and direction of the *drift* is being measured. This effect is called “micro-tortuosity”
Problems associated with a Spiralled Hole

Reduced Drift
- Higher friction forces, higher T&D
- Lower ROP, poor weight transfer
- Casing hangs up
- Ambiguous log response

Cuttings Bed Traps
- Poor hole cleaning
- Backreaming and short trips
- Stuck pipe
- Poor cement job

Unstable bit
- Higher vibration
- More tool failures
- Shortened bit life
- More trips
Spiralling results from Unstable Bit

Confined by high-side troughs

Confined by low-side peaks

How Spiralling is Created
Measuring Wellbore Quality

- **Explicit methods** – physical measurements
  - individual measures possible
  - difficult to interpret in terms of wellbore quality
  - specific examples illustrated

- **Implicit methods** – indirect measurements
  - measure responses to wellbore quality
  - Illustrated by analogy and applications
Measuring Wellbore Quality

Explicit Methods

- Drift – caliper logs
- Surface finish – inferred from image logs
- Micro-tortuosity / spiralling – pitch, amplitude
- Tortuosity / doglegs – statistical analysis
- Pseudo measure – directional difficulty index
Caliper Logs – Drilling vs. Trip-Out

- Colville HRZ
- Kuparuk
- Kuparuk C
- Miluveach
- Kingak

12
11.5
11
10.5
10
9.5
9
9.5
8.5
8
7.5
7
6,000
16,500
17,000
17,500
18,000
18,500
19,000

Measured Depth (ft)

- Caliper during Drilling
- Caliper during Trip-Out
Measuring Wellbore Quality

Implicit Methods

- Require a methodology / philosophy
- Identify appropriate response variable
- Information to characterize responses
- Analysis and interpretation
- Scoring / ranking process
Head Trauma Injury Assessment

Scenario

- Patient arrives at Emergency Room
- Apparent Head Injury
- Immediate assessment of brain function needed
- No immediate visual assessment possible
  - no useful explicit measure
- How does the physician carry out the evaluation?
- Responses to stimuli are carried out
  - implicit measures
### Head Trauma Injury Assessment

Three responses determine overall severity of head trauma.

<table>
<thead>
<tr>
<th>Glasgow coma scale</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Eye opening</strong></td>
<td></td>
</tr>
<tr>
<td>spontaneously</td>
<td>4</td>
</tr>
<tr>
<td>to speech</td>
<td>3</td>
</tr>
<tr>
<td>to pain</td>
<td>2</td>
</tr>
<tr>
<td>none</td>
<td>1</td>
</tr>
<tr>
<td><strong>Verbal response</strong></td>
<td></td>
</tr>
<tr>
<td>orientated</td>
<td>5</td>
</tr>
<tr>
<td>confused</td>
<td>4</td>
</tr>
<tr>
<td>inappropriate</td>
<td>3</td>
</tr>
<tr>
<td>incomprehensible</td>
<td>2</td>
</tr>
<tr>
<td>none</td>
<td>1</td>
</tr>
<tr>
<td><strong>Motor response</strong></td>
<td></td>
</tr>
<tr>
<td>obeys commands</td>
<td>6</td>
</tr>
<tr>
<td>localises to pain</td>
<td>5</td>
</tr>
<tr>
<td>withdraws from pain</td>
<td>4</td>
</tr>
<tr>
<td>flexion to pain</td>
<td>3</td>
</tr>
<tr>
<td>extension to pain</td>
<td>2</td>
</tr>
<tr>
<td>none</td>
<td>1</td>
</tr>
<tr>
<td><strong>Maximum score</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
</tr>
</tbody>
</table>

GCS = Glasgow Coma Scale

- **GCS ≥ 13** Mild Brain Injury
- **9 ≤ GCS ≤ 12** Moderate Brain Injury
- **3 ≤ GCS ≤ 8** Severe Brain Injury
The Wellbore Quality Scorecard (WQS)

Methodology

- Technique based on head trauma assessment
- Wellbore quality inferred from response variables
  - drilling, tripping-out and casing running
- Primary response variables are T&D parameters
- Surface logging data used to characterize responses
- Trend analysis principal evaluation tool
- Extent and intensity of data variations evaluated
Example – Torque Trend Data

Very low open hole friction factor indicative of good drilling practices also OBM used so good lubricity hole quality considered excellent

Narrow bandwidth

Torque (kft.lb)

Measured Depth (m)

FF = 0.17/0.11
Surface Torque
Bit Torque
### Wellbore Quality Scorecard – Guidelines

<table>
<thead>
<tr>
<th>Drilling Response (5 points)</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe drilling problems</td>
<td></td>
</tr>
<tr>
<td>- stuck pipe</td>
<td>0</td>
</tr>
<tr>
<td>- near stuck pipe incident</td>
<td>1</td>
</tr>
<tr>
<td>Transient drilling problems</td>
<td></td>
</tr>
<tr>
<td>- poor hole cleaning with high cuttings bed</td>
<td>2</td>
</tr>
<tr>
<td>- severe pack-off</td>
<td>2</td>
</tr>
<tr>
<td>- severe loss circulation</td>
<td>2</td>
</tr>
<tr>
<td>- erratic torque and drag response</td>
<td>3</td>
</tr>
<tr>
<td>Torque and drag response</td>
<td></td>
</tr>
<tr>
<td>- all parameters follow smooth trend</td>
<td>4</td>
</tr>
<tr>
<td>- lower than expected torque and drag</td>
<td>5</td>
</tr>
<tr>
<td>Final Trip-out Response (7 points)</td>
<td></td>
</tr>
<tr>
<td>Stuck pipe</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Casing Running Response (8 points)</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe casing running problems</td>
<td></td>
</tr>
<tr>
<td>- stuck casing</td>
<td>0</td>
</tr>
<tr>
<td>- casing pulled due to downhole problems</td>
<td>0</td>
</tr>
<tr>
<td>Differential sticking environment</td>
<td></td>
</tr>
<tr>
<td>- static friction &gt; 100 klbs on connections</td>
<td>1</td>
</tr>
<tr>
<td>- static friction &gt; 50 klbs on connections</td>
<td>2</td>
</tr>
<tr>
<td>Intervention needed during casing run</td>
<td></td>
</tr>
<tr>
<td>- unplanned rotation needed</td>
<td>3</td>
</tr>
<tr>
<td>- unplanned circulation needed</td>
<td>4</td>
</tr>
<tr>
<td>- joints wiped to reduce drag</td>
<td>5</td>
</tr>
<tr>
<td>Casing run without significant problems</td>
<td></td>
</tr>
<tr>
<td>- elevated but smooth drag levels</td>
<td>6</td>
</tr>
<tr>
<td>- achieved expected drag levels</td>
<td>7</td>
</tr>
<tr>
<td>- better than expected drag levels</td>
<td>8</td>
</tr>
</tbody>
</table>

| Residual cuttings bed / differential sticking       |       |
| - section length with overpulls > 100 klbs         | 1     |
| - section length with overpulls > 50 klbs          | 2     |
| Ledges                                             |       |
| - isolated overpulls > 100 klbs                    | 3     |
| - isolated overpulls > 50 klbs                     | 4     |

| Transient tripping-out problems                    |       |
| - loss circulation                                 | 5     |
| - unplanned circulation                            | 5     |
| - unplanned reaming and back-reaming               | 5     |

| Drag response                                      |       |
| - smooth drag levels measured throughout           | 6     |
| - better than expected drag levels recorded         | 7     |
Wellbore Quality Scores – Interpretation

- WQS is recorded as a response mnemonic
  - D4T5C5 (Drilling 4; Tripping-out 5; Casing Running 5)
- WQS = sum of each response score

<table>
<thead>
<tr>
<th>WQS Range</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 &lt; WQS ≤ 2</td>
<td>stuck pipe or stuck casing</td>
</tr>
<tr>
<td>2 &lt; WQS ≤ 6</td>
<td>low quality wellbore</td>
</tr>
<tr>
<td>6 &lt; WQS ≤ 10</td>
<td>medium wellbore quality</td>
</tr>
<tr>
<td>10 &lt; WQS ≤ 14</td>
<td>high wellbore quality</td>
</tr>
<tr>
<td>14 &lt; WQS &lt; 20</td>
<td>excellent wellbore quality</td>
</tr>
<tr>
<td>WQS = 20</td>
<td>“The Perfect Wellbore!”</td>
</tr>
</tbody>
</table>
Case Study – Horizontal Well Norway

<table>
<thead>
<tr>
<th>Size ins.</th>
<th>Weight ppf</th>
<th>Grade</th>
<th>Connection Type</th>
<th>Top TVD RKB</th>
<th>Bottom TVD RKB</th>
<th>Bottom MD RKB</th>
</tr>
</thead>
<tbody>
<tr>
<td>26&quot;</td>
<td>267</td>
<td>X-65</td>
<td>XLC-S</td>
<td>Surface</td>
<td>478 m</td>
<td>478 m</td>
</tr>
<tr>
<td>13-3/8&quot;</td>
<td>72</td>
<td>P-110</td>
<td>Dino Vam</td>
<td>Surface</td>
<td>1443 m</td>
<td>1521 m</td>
</tr>
<tr>
<td>9-5/8&quot;</td>
<td>53.5</td>
<td>P-110</td>
<td>New Vam</td>
<td>Surface</td>
<td>2654 m</td>
<td>3200 m</td>
</tr>
<tr>
<td>5½&quot;</td>
<td>32.6</td>
<td>Q-125</td>
<td>Vam Top</td>
<td>2554 m MD</td>
<td>2516 m</td>
<td>5398 m</td>
</tr>
</tbody>
</table>

Drill 2,198m 8½” horizontal section
Run 2,844m 5½” thick wall liner
Erratic Torque Response

Vibration problems in chalk reservoir

Case Study – Drilling Response (D3)
Case Study – Tripping-out Response (T2)

**Mud Type:** OBM
- **Weight:** 1.50 SG
- **PV:** 36 cP
- **YP:** 21 lbf/100ft²

**BHA 9:**
- **Hookload**
- **Surface Torque**
- **Pick-Up:** FF=0.15/0.20

**9-5/8” Shoe** @ 3,200m

**TD @ 5,398m**

**Elevated Drag**
- 4,400-4,600m
- 5,200-5,400m

**Reaming/Back-reaming** needed to reduce drag
Case Study – Liner Running Response (C3)

Severe Slip stick effect when running liner

Mud Type: OBM
Weight = 1.50 SG
PV = 35 cP
YP = 19 lbf/100ft²

8 1/4" solid centraliser on 5" casing
8" solid centraliser on 5 1/2" casing
8 1/4" solid centraliser on 7" casing

Surface Torque
Hookload
Slack-Off: FF=0.12/0.45
## Completed Wellbore Quality Scorecard

<table>
<thead>
<tr>
<th>Category</th>
<th>WQS</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Well Offshore Norway</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Drilling Response (max 5 points)</strong></td>
<td>3</td>
<td>Persistent erratic torque response observed. Observation is indicative of vibration problems typically seen in the chalk reservoir. Vibrations are considered a transient problem and should not significantly impact overall wellbore quality. Average rotary friction factors of 0.20/0.15 are typical of field-wide torque behaviour.</td>
</tr>
<tr>
<td><strong>Final Trip-out Of Hole Response (max 7 points)</strong></td>
<td>2</td>
<td>Elevated drag levels in excess of 50kibs are observed from 4,300 to 4,600m and from 5,200 to 5,400m indicating a possible hole cleaning problem. Overpulls also occur at chalk / shale transition zones. A form of slip-stick axial drag is also present when tripping-out through the open hole section. Average pick-up friction factors of 0.15/0.20 are typical of field-wide experience.</td>
</tr>
<tr>
<td><strong>Liner Running Response (max 8 points)</strong></td>
<td>3</td>
<td>Liner running in open hole is far from smooth; significant axial slip-stick events observed which increase in intensity with depth. String has to be worked significantly over last 600m. String also had to be torqued to overcome tight spots / ledges. Slack-off friction factors of 0.12/0.45 are in line with field-wide experience.</td>
</tr>
<tr>
<td><strong>WQS (D3T2C3)</strong></td>
<td>8</td>
<td>A score of 8 corresponds to a medium quality wellbore.</td>
</tr>
</tbody>
</table>
Cost vs. Wellbore Quality Relationship

Field data suggests
Low WQS ⇒ very high D&C costs

Too high WQS ⇒ higher D&C costs

Optimum WQS ⇒ lowest D&C costs
Wellbore Quality Scorecard

Learnings
- A low WQS does not always equate to poor performance
- A low WQS can be due to degree of difficulty of drilling and casing running in that field
- Poorly designed casing run can result in failure
- Implications of scoring wellbore quality need to be understood by operators / service companies
- Wellbore Quality has to be managed at field level
- Need to understand Cost vs. Wellbore Quality relationship
Managing Wellbore Quality

Drilling Practices
- Operating Parameters (WOB, RPM, Flow Rate)
- Connection practices
- Hole cleaning practices
- Mud weight management
- Managing pack-offs
- Vibration management
- ECD management
Managing Wellbore Quality

Tripping / Casing Running Practices

- Surge and Swab Pressure Cycles
  - can result in rock fatigue

- Managing Downhole Problems
  - cuttings bed, ledging, pack-offs, overpulls

- Circulation Losses
  - especially during casing running
Enhancing Wellbore Quality

Emerging Technologies

- Continuous Circulation System
  - reduces swab and surge cycles in well
- ECD Reduction
  - reduces downhole annular pressures
- Fracture Gradient Enhancement
  - strengthens wellbore by forming stress cage
Wellbore Quality Characterization

Conclusions

- Characterization important concept
- Can reflect degree of difficulty
- Most value for horizontal and ERD wells
- Industry standard definition needed
- Measurement protocol biggest challenge
- Wellbore quality scorecard promising technique
- Software needed: efficiency, clarity & consistency
- Wellbore quality enhancing technology exists
Additional Slides
Hole Spiralling – Inferred from Logs

Log Evidence: Caliper vs. Neutron Porosity vs. Sonic DT
Image Log – 8½” Section
Image Logs – 6-1/8” Hole Spiralling
Image Logs – 6-1/8” Hole Spiralling

6 1/8” hole using normal motor

Hole Spiraling
Wellbore Quality vs. Tubing Life

- Slant drilling Canada
- Heavy Oil Reservoir
- Pad Drilling
- 600m TVD
Canada – High DLS Slant Well

Tubing Wear vs. DLS/hole angle for high-DLS well
Well on production for 2½ months before failure
Canada – Low DLS Slant Well

Tubing Wear vs. DLS/hole angle for low-DLS well
Well on production for 21 months before failure
Drilling 12¼” Section – Azerbaijan Well

Mud Type: SOBM
Weight = 1.60 SG
PV = 40 cP
YP = 29 lbf/100ft²

WOB = 20 klbs
Bit Torque = 5 kft.lb
Flow Rate = 1,000 GPM

Surface Torque - BHA 7
Surface Torque - BHA 6
On-Bottom: FF=0.25/0.30
Off-Bottom: FF=0.25/0.30
Surface RPM
Tripping-out 12¼” Hole – Azerbaijan Well

![Graph showing hookload versus measured depth with Pick-Up: FF=0.20/0.20.](image)
Running 9-5/8” Casing – Azerbaijan Well

13-3/8” Shoe
@ 1,560m

12-1/4” TD
@ 4,415m

Hookload
Static Up Drag
Static Down Drag
Pick-Up Trend
Slack-Off Trend
Slack-Off: FF=0.20/0.30
Block Velocity

Mud Type: SOBM
Weight = 1.60 SG
PV = 37 cP
YP = 26 lbf/100ft²

Measured Depth (m)
# WQS – Azerbaijan Well

<table>
<thead>
<tr>
<th>Build and Hold Profile, Azerbaijan</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Drilling Response (max 5 points)</strong></td>
<td></td>
</tr>
<tr>
<td>Persistent erratic torque response observed. This observation is indicative of vibration observed during drilling of the interbedded sand / shale sequence in overburden. Average cased/open hole rotary friction factors of 0.25/0.30 are typical of those in the region.</td>
<td>3</td>
</tr>
<tr>
<td><strong>Final Trip-out Of Hole Response (max 7 points)</strong></td>
<td></td>
</tr>
<tr>
<td>The final trip-out of hole response is smooth and clean. Minor isolated overpulls are observed but are less than 30 klbs. The bandwidth of drag data is fairly narrow which is another indicator of very good hole quality. Average cased/open hole axial friction factors of 0.20/0.20 are similar to those from offset wells in the field. The high response score should provide confidence that casing should run easily to depth.</td>
<td>6</td>
</tr>
<tr>
<td><strong>Casing Running Response (max 8 points)</strong></td>
<td></td>
</tr>
<tr>
<td>Casing running in this region is acknowledged as particularly challenging. Dynamic drag levels in open hole are in line with offset well performance correlating with cased/open friction factors of 0.20/0.30. Static friction forces are in evidence throughout most of the casing run. The highest clusters of static friction occur at the bottom of the Surakhany formation and in the upper Balakhany sands. Excess drag due to static friction exceeds 50 klbs but is less than 100 klbs.</td>
<td>2</td>
</tr>
<tr>
<td><strong>WQS (D3T6C2)</strong></td>
<td></td>
</tr>
<tr>
<td>A score of 11 corresponds to a medium/high quality wellbore. (Maximum possible score 20)</td>
<td>11</td>
</tr>
</tbody>
</table>
WQS: Wytch Farm ERD Wells
Wytch Farm – Torques 12¼” Section

Measured Depth (m)

Surface Torque (kft.lb)
Wytch Farm ERD Wells – WQS Summary

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Drilling Response (Max 5)</th>
<th>Tripping-cut Response* (Max 7)</th>
<th>Casing Running Response (Max ε)</th>
<th>WQS (Max 2ε)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M05</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>M09</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>15</td>
</tr>
<tr>
<td>M11</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>M14</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>18</td>
</tr>
<tr>
<td>M16</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>17</td>
</tr>
</tbody>
</table>

* Estimated values based on casing running response

Comments on high WQS

- Good learning curve
- Continuous ERD drilling program