Physics Based Drilling Engineering
Speaker Information

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K&M Technology Group

- >25 Year of Global Horizontal/ERD Expertise
- Extensive experience in every US Unconventional Basin
- Acquired by Schlumberger in 2008
- Provide Engineering, Training, Wellsite Services, and Software
- History of in-house software development since 1990
- Launch of of next-gen ERA software in 2015

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The role of a drilling engineer
- What it used to be
- What it is today
- What it should be

Examples of using physics to
- Drill faster
- Run and cement casing
- Prevent drill string failure

A proposition
Drake’s Well
Cable Tool Rigs
Spindletop
Rotary Rigs
Oil Based Mud
Tricone Bits
PDC Bits
ERD
RSS
Wired Pipe

Lubinski and the Golden Age
• BHA Tendency
• Buckling
• Deflection
• Whirl
• Geomechanics
• Torque and Drag
“Engineering” or Project Management?

- Cost estimate / AFE
- AFE supplement
- Risk assessment
- Procurement
- Permits
- SPCCP
- Meetings, meetings, meetings
What “Engineering” Should Be

- Casing design
- Torque and drag
- Hydraulics
- Geomechanics
- Drillstring design
- BHA design
- Vibration
- System redesign for performance
  - (aka “optimization”, but not really the same thing)
The Four Method Approach

- Herrick outlined 4 methods that humans use to approach a problem


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<th>Method</th>
<th>Data</th>
<th>Model</th>
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<td>Politics (self interest)</td>
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- Each method is present in daily life
- Each have their place in society with varying degrees of usefulness
- Science leads to a deeper understanding of reality
- The laws of physics were derived from the scientific process
Example 1: Using Physics to Drill Faster

- Haynesville, North Louisiana
- Production hole challenges
  - HPHT environment
    - >10,000 psi BHP
    - >320 °F BHT
  - Weak, water-sensitive shale
  - Slow ROP
  - Poor directional response
Mechanical Specific Energy (MSE)

What is MSE?
- Measure of energy used to destroy rock
- For a known rock strength, efficiency can be inferred

$MSE = \frac{WOB}{A_B} + \frac{120 \times \pi \times RPM \times T}{A_B \times ROP}$

Origins?
- Developed by Teale in 1965 (Int. J. Rock Mech. Mining Sci. Vo.2)
- Evolved and validated by Pessier in the 1992 (SPE 24584)
- Applied by Waughman in 2002 (SPE 74520)
- Popularized by Dupriest in the 2005 (SPE 92194)

Why use MSE?
- **While Drilling:** Optimize parameters for maximum performance
- **While Planning:** Identify performance bottlenecks
Why is MSE Important?

Rock Compressive Strength
MSE analysis revealed that the bit was balling

Causes
- Improper bit design
- Insufficient bit hydraulics
- Slow bit RPM

Effects
- Slow ROP
- Plugged jets
- Unable to steer effectively

Conventional wisdom perceived the issue to be “hard rock”
- Heavy set bits
- Low speed and high torque motors
- High WOB
- Little emphasis on hydraulics
- Disbelief that a bit could ball in oil-base mud
Solutions: Bit and Motor Selection

Designed bits for reduced balling tendency
- Change from 7 blade to 5 blade bit design
- Minimize cutter back rake and bevel
- Improved bit hydraulics
- Limit WOB to reduce DOC

More Appropriate Motor Selection
- 4:5 Even-Wall vs. 7:8 Standard Elastomer
Solutions: BHA Design

- Stabilized BHA for better directional response
- Reduced bend setting from 2.38° slick to 1.5° stabilized
- Proper stabilizer design to prevent jamming while sliding
Results: 5xROP Improvement
Results: Dramatic Impact on Economics

Cumulative savings >400 days and >USD 30MM
Example 2: Using Physics to Install Casing

- Haynesville, North Louisiana
- Operator plans to extend laterals
  - Typical lateral length of 5,000’
  - New wells to exceed 11,000’
- Historical casing program
  - 10½” surface
  - 7⅝” intermediate
  - 5½” x 4½” production

Can the long laterals be cased and cemented?
5½” x 4½” Cementing ECD (7⅝” Intermediate)
5½”x5” Cementing ECD (9½” Intermediate)

5” x 5½” Casing: ECD Snapshot - End of Cement Job
Sensitivity to Flow Rate

Well: Well Field: Haynesville
Operator Location: Location

- Sitting Profile (Length, Component):
  13000 ft, 5½” x 5 ft Q=125, Wedge 163
  9100 ft, 5½” x 18 bpm Q=125, Wedge 521

- Hole Profile (Depth, OD, ID):
  11160 ft, 9½” in Casing, 8.755 in
  23310 ft, 8½” in Hole

- Run Speed: 0 ft/min
- RPM: 30
- Flow Rate: 4.9 bpm
- Mud Weight: 15.3 ppg
- Rheology: 90/90/90/90/90/90

- Fluid Volume (Volume, Density, Weight, Rheology):
  69 bbl, Spacer 1, 10.0 ppg, 92/90/41/29/11/8
  90 bbl, Base MWD, 8.4 ppg, 6/10/3/0/0
  80 bbl, Base MWD, 8.4 ppg, 6/10/3/0/0

- 12500 ft
- 25000 ft

- ECD (ppg)
  - Low Risk Collapse
  - Pore Pressure
  - 6.0 bpm ECD
  - Med Risk Collapse
  - 2.0 bpm ECD
  - ESD
  - High Risk Collapse
  - 3.0 bpm ECD
  - Sh Min
  - 4.0 bpm ECD
  - Breakdown
  - 5.0 bpm ECD

- Maximum ECD: 21.0 ppg

- Minimum ECD: 10.0 ppg

- Critical ECD: 15.0 ppg
5½”x5” Casing T&D (Conventional)
5½”x5” Casing T&D (Reaming)
5½” x 5” Casing T&D (Actual vs. Model)
Example 3: Using Physics to Prevent Failure

- Cotton Valley, East Texas
- 6 1/8" hole
- 4" drill pipe
- Water-base mud

*This was a missed opportunity to prevent string failure*
Root Cause of Drill String Failure

Rotary drilling with excessively buckled drill pipe

- The hole was significantly over gauge
- WOB far exceeded the buckling resistance of the drill string
- Bending stress resulting from buckling exceeded the fatigue endurance limit of the pipe
- Fatigue ultimately led to drill pipe failure

This could have easily been prevented with realtime monitoring!
On Bottom Torque

- Measured surface torque while drilling
- Calculated drill string generated torque (using T&D)
- Difference is “perceived” bit torque (using T&D)
- Bit torque calculated from motor $\Delta P$ does not agree with T&D calculated bit torque below ~14,500’
- This suggests that something other than bit torque was causing the drill string to experience such high torque
On Bottom Torque

- \( \Delta P \) vs. T&D calculated bit TQ—gauge hole
- \( \Delta P \) vs. T&D calculated bit TQ—20” enlargement in shale
Consequences of Hole Enlargement

- 20” hole results in significantly lower buckling resistance, much higher torque and bending stress
- Excessive bending stress eventually led to fatigue failure
- A twistoff, fishing job and sidetrack ($2MM total) could have been avoided
A Proposition: to Managers

Managers:
- Don’t hire degreed Engineers to fill out paperwork – expect and enable them to engineer
- Equip Engineers with the software and training they need to do their job

Educators:
- Start teaching holistic well design - vertical wells and duplex pumps are a thing of the past

Engineers:
- Take ownership of the well design process
- Don’t rely on services companies to solve complex well design issues
Thank You