Drilling Fluids Can Help Push the Limits of ERD Wells

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Speaker Bio

- Retired from Oxy
- Coal Gasification/Liquefaction, Nuclear Reactor Safety, Oil Well Stimulation (Acidizing, Foamed Fracturing Fluids), Drilling & Completion Fluids
- B.A. & B.S. in Chemistry and Mathematics from Univ of Texas at Austin; M.S. & Ph.D. in Physical Chemistry from New Mexico State University
- Houston, Texas
- Drilling Fluid Specializations
  - Lost Circulation
  - Wellbore Stability
  - Extended Reach Drilling
  - Formation Damage
  - Solids Control & Waste Management
  - Drilling Optimization, esp ROP Enhancement, Lubricity
Schematic of a Horizontal Well

- Steel casing
- Steel drillpipe
- Formation
- Drilling fluid
Drillstring/Wellbore/Casing Friction

Excessive friction → Excessive torque and drag

- Limited displacement
- Limited ROP

Excessive equipment stress
Friction Factor in Torque/Drag Calculations

Friction Factor reflects torque and drag in casing and in open hole but is a complex function of:

- Hole geometry
- Dogleg severity (and in some cases rugosity)
- Solid contaminants, such as cuttings
- Mud properties: viscosity (internal friction), filter cake properties, overbalance
- CoF (Coefficient of Friction) for drill string on casing/wellbore
## Friction Factors in Torque/Drag Models

<table>
<thead>
<tr>
<th></th>
<th>Casing</th>
<th>Open Hole</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aqueous Drilling Fluids</td>
<td>0.25</td>
<td>0.30</td>
</tr>
<tr>
<td>Non-Aqueous Drilling Fluids</td>
<td>0.20</td>
<td>0.25</td>
</tr>
</tbody>
</table>

- Fitted Friction Factor: typically 0.2 to 0.4
Torque & Drag Models used for FF Sensitivity Analysis

Courtesy of Innova Drilling & Intervention

Courtesy of Sysdrill Engineering
Sources of excessive friction and torque & drag

- Overly complex hole geometry
- Excessive rugosity and/or dogleg severity
- Cuttings beds, i.e. poor hole cleaning
- Poor mud properties: excessive viscosity, filtration rate (thick filter cake) and overbalance
- Swelling clays
- Excessive CoF (Coefficient of Friction)
Thinners & Friction Reducers vs Lubricants

- To reduce laminar shear Viscosity ► “Thinner”
- To extend laminar regime and suppress turbulence (thus reducing breadth of transition regime and generating a lower “Darcy friction factor”) ► “Friction or Drag Reducer”
- To reduce torque and drag (friction between drillstring and casing or wellbore, described by CoF) ► “Lubricant”
To reduce the friction factor

- Straighten hole trajectory and smooth hole geometry
- Optimize hole cleaning and mud properties
- Lower CoF
  - Tubulars with lower CoF, e.g. aluminum, coatings, hard-coated connections
  - Tool joints/accessories with low CoF and better wear properties, e.g. hardbanding, rotating and non-rotating drill pipe protectors, subs (bearing-based and roller tools)
  - Drilling fluid lubricants
    - Liquids...long-chain NAFs & alcohols; fatty acids/esters; polymers; encapsulated liquids
    - Solids...very long-chain co-polymers; graphite; composites
Lab Measurements of CoF

- Reproducible
- Consistent with field values, i.e. relative lab values of CoF trend the same way as field values of Friction Factor
- There are dozens of devices that may be suitable, but few simulate field conditions very well
EP Fann & High-Angle Lubricity Testers

The Standard: EP Fann Lubricity Tester
ambient temp/press, but suitable for Lab and Field

High-temperature Lubricity Tester (HLT)
only for Lab use
Stickance Tester

CoF of steel on filter cake at HTHP
Lab and Field use
Lubricity Evaluation Monitor (LEM)

CoF of steel on steel or rock, with or without filter cake, HTHP with option to replenish lubricant

Only lab use
Factors that affect performance of lubricants

- **Materials:** Steel/Steel, Steel/Rock, Steel/Filter Cake
- **Drilling Fluid Composition:** Gel vs Polymer vs Dispersants vs NADFs
- **Lubricant Composition**
  - Liquid Lubricants
    - Compatibility with drilling fluid: Water vs NAF, polymers, surfactants, solids – must disperse (but not form tight emulsion or interact strongly with mud components)
    - Wettability of friction surfaces and film strength
    - Compatibility with hardware, e.g. MWD tools
  - Solid Lubricants
    - Particle Density, Size, Shape, Resilience
- **Conditions:** Temperature and Pressure
Typical LEM Test Run: 4140 Steel on Berea Sandstone at 150°F
LEM Test Results: Gel/Water vs PAC Muds

- Change in Coefficient of Friction (%)

- PAC
- Gel/water
Field Tests of Three Lubricants in PAC Mud
Reduction in Torque (%) LEM vs Field
Encapsulation enables liquid lubricants to be available when and where they are needed.

- Curve: 9,000 to 10,000 ft MD
- Lateral: 10,000 to 15,400+ MD

**Total Time for Curve & Lateral**

- Well #1: 184 hr
- Well #2, with lubricant: 121 hr

Encapsulated Lubricant Conc.: 15 ppb (3% v/v oil), maintained with 1,100 lb/1000 ft
Granular and fibrous Lost Circulation Materials can have a profound impact on torque, especially in ERD wells (SPE-95430).

Plastic spheres and cylinders may perform even better.

Compatible with most mud chemistries (SPE-48939).

Environmentally friendly.

Industry does not possess a standard method or apparatus for testing solid lubricants.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Density</th>
<th>Min. Dimen.</th>
<th>Aspect ratio</th>
<th>Shape</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>gm/cc</td>
<td>mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>1.27</td>
<td>-</td>
<td>-</td>
<td>Granular</td>
<td>Irregular</td>
</tr>
<tr>
<td>S2</td>
<td>1.25</td>
<td>1.66</td>
<td>1.99</td>
<td>Cylindrical</td>
<td>Uniform</td>
</tr>
<tr>
<td>S3</td>
<td>1.07</td>
<td>0.4</td>
<td>1</td>
<td>Spherical</td>
<td>Uniform</td>
</tr>
<tr>
<td>S4</td>
<td>1.01</td>
<td>0.2</td>
<td>1</td>
<td>Spherical</td>
<td>Uniform</td>
</tr>
<tr>
<td>S5</td>
<td>1.14</td>
<td>0.37</td>
<td>-</td>
<td>Granular</td>
<td>Irregular</td>
</tr>
</tbody>
</table>
Drag Lubricity Tester

Fluid: 1.25 ppb PAC in fresh water
Temp/Press: Ambient

Graph showing coefficient of friction vs. % concentration for different samples labeled S1 to S5 and a base case.
Torque Lubricity Tester

Fluid: 1.25 ppb PAC in fresh water
Temp/Press: Ambient

Note: The Stickance Tester shows similar trends to the D & T Lubricity Testers
Conclusions – Liquid Lubricants

- Lubricants can reduce CoF and friction factor, but they can also increase ROP and reduce potential for differential sticking and bit-balling.

- Performance of low-toxicity liquid lubricants depends on mud system:
  
  Gel WBM > Polymer WBM > Non-Dispersed WBM > NADFs

  For WBM – hydrocarbons (especially olefins), fatty acid esters, high-molecular-weight polyglycols;
  For NADF – very few work, but some success with fatty acid esters

- Nature of the contact surfaces also affects lubricant performance: usually performance is better on Steel/Steel than on Steel/Rock or Steel/Filter Cake, and trends on one type of surface do not correlate well with trends on other surfaces.
Conclusions – Liquid Lubricants (cont’d)

- Generally 1 to 3 vol% liquid lubricant in a mud is enough, but emulsification and depletion on solids requires continuous additions and maybe higher initial dosage.

- Lubricant sweeps are usually more economical than treatment of the whole mud system, but for long horizontal wells, whole mud treatment may be necessary.

- The performance of liquid lubricants can be described by the change in wettability that accompanies lubricant adsorption on the contact surfaces: simple wettability test can be a useful screening tool for potential lubricants.
Conclusions – Solid Lubricants

- Solid lubricants or encapsulated liquid lubricants generally perform better than liquid lubricants in horizontal wells, but dosage requirements may be different.

- Spherical particles 0.04 to 4 mm in diameter and density similar to the mud appear to perform best and are generally better than cylindrical, granular or fibrous particles:
  Examples: co-polymer beads, graphite, coated graphite (e.g. with polydimethylsiloxane), fine mica.

- Solid lubricants are generally inert (compatible with all mud systems) and are unaffected by temperature and pressure.
Planning

- Ensure that the recommended drilling fluid has a sufficiently low CoF that the well can reach the objective using available tubulars and pumping capacity.
- Choose a fluid type that inherently yields an acceptable CoF.

<table>
<thead>
<tr>
<th>Fluid (unweighted)</th>
<th>Steel/Steel CoF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>0.36</td>
</tr>
<tr>
<td>NaCl Brine (9 and 10 ppg)</td>
<td>0.30, 0.26</td>
</tr>
<tr>
<td>CaCl₂ Brine (10.4 and 11.6 ppg)</td>
<td>0.19, 0.13</td>
</tr>
<tr>
<td>Polymer and Silicate WBMs</td>
<td>0.4</td>
</tr>
<tr>
<td>Gel (Bentonite) WBM</td>
<td>0.44</td>
</tr>
<tr>
<td>Dispersed (lignosulfonate) WBM</td>
<td>0.23</td>
</tr>
<tr>
<td>80/20 NADF (synthetic, mineral, diesel)</td>
<td>0.10 to 0.20</td>
</tr>
</tbody>
</table>

- Treatment with solid (preferred) or liquid lubricants is a second choice.
For potential liquid lubricants, run comparative lab performance tests, preferably at downhole temp/press, using 3 vol% lubricant:

- Drill pipe/Casing ➔ Steel/Steel (LEM)
- Drill pipe/Open hole ➔ Steel/Rock (LEM) or Steel/filter cake (Stickance)

For potential solid lubricants, run Stickance, Drag or Torque Lubricity Tester.

Run compatibility tests of potential liquid lubricant with the drilling fluid:
- Emulsification (Cheesing) – incompatibility with surface active materials
- Greasing (Barite Greasing) – incompatibility with divalent ions, e.g. lime
- Foaming

Ensure compatibility of potential lubricant with downhole tools/motors, especially elastomeric components.
General Guidelines

Field Use

- For liquid lubricants, initially treat with sweeps of pure or dispersed lubricant (5 to 50 vol% in a mud pill). If torque and/or drag is reduced, treat whole mud system with 1 vol% lubricant and increase concentration as needed, usually up to 3 - 5 vol%, but more in highly weighted or dirty drilling fluids. With increasing depth, maintain desired concentration with regular additions of fresh lubricant.

- For solid lubricants, treat whole mud system, typically using 1 to 5 vol%, though more may be required with highly weighted or dirty drilling fluids.

- Monitor circulating system for foaming (have defoamer on hand that works!). Monitor shakers for clumping of solids or other signs of wettability change in the mud. For WBM, hardness (Ca$^{2+}$ and/or Mg$^{2+}$) of make-up water may need to be treated out (with bicarbonate or soda ash) to avoid greasing.
Thank You