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Torque Management Optimization in Qatar Offshore ERD Wells Using Wellbore Shielding Additives

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Abstract

Al Shaheen, one of the world's largest offshore oil fields, is located 80 km north of Ras Laffan in Qatari waters. With over 500 ultra-extended reach drilling (ERD) wells drilled—many exceeding 25,000 ft in horizontal length—the field presents unique technical challenges. These include complex well trajectories, narrow carbonate reservoirs, and high-rate drilling practices, all of which contribute to elevated torque and drag, stick-slip, and wellbore instability.

Extended-reach drilling (ERD) operations often encounter elevated torque and drag, particularly in high-angle, shallow true vertical depth wells (TVD) with complex three dimensions (3D) trajectories. This paper presents a novel approach to mitigating these challenges through the integration of a wellbore shielding additive into high-performance water-based mud systems. Applied at concentrations of 4–8 lb/bbl, the additive improves wellbore stability, reduces torque and drag, and minimizes stick-slip occurrences. Field applications across multiple wells demonstrated significant improvements in filter cake quality, friction factor reduction from 0.3–0.4 to 0.15–0.25, and increased rate of penetration. These enhancements enabled drilling beyond previous torque limitations by 4,500 to 5,000 feet, accessing deeper production zones. The additive's dual functionality—pressure shielding and friction reduction—proved effective in maintaining structural integrity under high overbalance conditions.

The system's success was contingent on prior treatment with a liquid lubricant, typically ester-based at 3% by volume. The synergy between the lubricant and the shielding additive was critical in reducing mechanical stresses and improving torque response in long-lateral sections. Additionally, improvements in tripping times and reduced stick-slip severity contributed to enhanced operational efficiency.

The findings underscore the importance of optimizing drilling fluid compositions in complex ERD environments to improve operational efficiency, safety, and hydrocarbon recovery. This paper contributes new insights into torque and drag mitigation in ultra-ERD environments, emphasizing the importance of fluid design and additive synergy. The results are broadly applicable to other high-angle, long-lateral wells in carbonate reservoirs, offering practical value to drilling engineers seeking to improve performance in technically demanding offshore fields.

Introduction

Extended Reach Drilling (ERD) has become a cornerstone of offshore development, enabling operators to access remote reservoir targets from centralized platforms while maximizing reservoir contact and minimizing surface infrastructure, cost, and environmental footprint. However, ERD wells present severe technical and operational challenges, particularly in mature carbonate fields such as Al Shaheen, located approximately 80 km north of Ras Laffan in Qatari waters. Discovered in 1982, Al Shaheen is one of the world's largest offshore oil fields, with more than 500 ERD wells drilled to date. Many wells exceed 30,000 ft measured depth, with horizontal sections often surpassing 25,000 ft, establishing the field as a global benchmark for ultra-ERD operations. At such extended reaches, challenges are amplified by:

- complex well trajectories requiring aggressive build turn sections, narrow carbonate reservoirs prone to instability under high overbalance.
- elevated torque and drag associated with long laterals and tortuous well paths.
- High-RPM drilling practices required for effective hole cleaning frequently introduce stick-slip and vibration issues.

Traditional torque-mitigation approaches, including high lubricant concentrations and drill-pipe size reduction, have proven inadequate for these ultra-ERD conditions, often resulting in diminishing returns, compromised hydraulics, and increased operational cost. Consequently, a step-change in drilling-fluid design became necessary to enable safe, efficient drilling beyond previous torque limits

Challenges in ERD Wells

The complexity of ERD wells stems from their geometry and operational demands:

- Long Horizontal Sections: Extended laterals increase frictional resistance, resulting in elevated torque and drag. This limits weight transfer to the bit, reducing drilling efficiency and directional control.

- Complex Trajectories: Wells often require aggressive build and turn sections to navigate thin pay zones, introducing tortuosity and high dogleg severity.
- Narrow Carbonate Reservoirs: These formations are prone to instability under high overbalance conditions, leading to sloughing, washouts, and differential sticking.
- High-Rate Drilling Practices: To maintain hole cleaning in long horizontals, operators employ high RPM (>120) and high ROP (100–600 ft/hr), which exacerbate torque and stick-slip phenomena.

These conditions frequently result in surface torque exceeding 40,000 ft-lbs, stick-slip vibrations, and increased drag during tripping and casing runs. In extreme cases, torque limitations force premature TD calls, compromising reservoir exposure and production objectives.

Historical Mitigation Strategies

Traditionally, torque management in Al Shaheen relied on:

- Lubricant Additions: Up to 3% by volume of ester-based lubricants were incorporated into drilling fluids. While effective in reducing friction factor initially, their performance diminished in ultra-long laterals due to dilution and thermal degradation.
- Drill Pipe Size Reduction: Switching from 5" to 4" drill pipe lowered torque but negatively impacted hydraulic efficiency and hole cleaning.
- ROP Reduction: Slowing drilling rates improved torque control but increased well-delivery time and cost.
- Premature TD Decisions: In cases where torque became unmanageable, wells were terminated early, sacrificing reservoir coverage.

These approaches provided incremental improvements but failed to deliver sustainable torque control in ultra-ERD environments. The limitations highlighted the need for innovative fluid design strategies that address both mechanical and formation-related challenges.

Role of Filter Cake in Drill String Friction

Torque and drag in drilling operations originate from frictional resistance between the drill string and the wellbore wall. Frictional force can be expressed as:

$$F_f = \mu N$$

where F_f is the friction force, μ is the coefficient of friction, and N is the normal force pressing the drill string against the wellbore.

In extended reach wells, the normal force N is dominated by gravity induced side forces, well trajectory, tortuosity, horizontal length and differential pressure effects. This results in elevated torque which contributes to poor weight transfer to the bit, increased vibration and stick-slip, requiring higher RPM to deliver effective WOB and sustain ROP.

Since N is largely insensitive to operational adjustments and is controlled by geometry and gravity, the friction coefficient (μ) remains the only practical lever for torque reduction. As a result, lowering μ becomes the primary focus of torque-mitigation practices.

The coefficient of friction is an emergent property of the contact interface (filter cake) between the drill string and the wellbore wall. Consequently, the frictional response is governed not by steel rock contact, but by steel-filter cake interaction. The mechanical and physicochemical properties of this filter cake play a major role in torque and drag behavior.

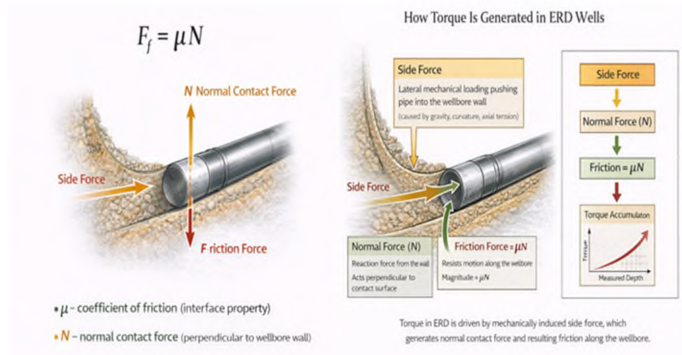

Figure 1—Conceptual illustration of torque generation in ERD wells, showing how normal contact forces imposed by well geometry translate into frictional resistance (μN), emphasizing the role of friction coefficient in torque buildup

At the microscale, neither the drill string surface nor the filter cake surface is smooth. Contact occurs at microscopic high points, commonly referred to as surface asperities (J.A Greenwood; J.B.P, Williamson, 1966). During sliding or rotation, these asperities mechanically interlock, and require deformation, fracture, or plowing for relative motion to occur (Bowden, F.P, 1950). This localized interaction increases interfacial shear resistance, as the drill string must effectively climb over, deform, or break asperity contacts within the filter cake structure, thereby contributing to elevated torque and drag.

From a mechanical standpoint, frictional resistance is controlled by the shear strength of the material that undergoes deformation during rotation or sliding. In poorly conditioned wellbores, shear occurs through rigid solids and exposed formation grains within the filter cake, resulting in unstable frictional behavior.

Friction Mechanism in Conventional Filter Cakes

In conventional drilling fluids systems, the filter cake formed on the wellbore wall is continuous but typically heterogeneous in structure. It consists of a mixture of weighting agents, drilled solids, and polymers, often containing micro-voids and mechanically weak zones.

When the drill string contacts this type of filter cake, the applied normal force is transmitted through discrete load-bearing solids clusters rather than uniformly across the interface. As the drill string moves, shear resistance is generated through

- Deformation and crushing of rigid particles such as Calcium carbonate
- Breaking of particle-particle contacts
- Plowing and rearrangement of solids clusters within the cake.

These mechanisms are referred to as solid-dominated shear. Because rigid mineral solids exhibit relatively high shear strength, resistance to motion is significant, leading to elevated friction factors, torque and drag even in cases where filtration control is acceptable, the mechanical response of a heterogeneous cake under shear remains a major contributor to frictional resistance.

Mechanical Modification of the Filter Cake by PSP

The introduction of PSP does not create a filter cake where none existed previously; rather, it fundamentally alters the mechanical structure and functionality of the existing filter cake. Engineered with a fine and broad particle size distribution, PSP efficiently fills voids between coarser solids and seals micro-fractures and pore throats at the wellbore wall.

PSP is a composite wellbore-shielding material comprising engineered cellulosic fibers combined with fine granular components. This composite architecture enables simultaneous void filling and mechanical interlocking within the developing filter cake, distinguishing its behavior from single-mode particulate or polymeric additives. The fine particle fraction promotes dense packing and micro-void elimination, while the fibrous component reinforces the internal cake structure and resists shear-induced erosion. Importantly, the particle–fiber blend remains stably suspended in the circulating drilling fluid, minimizing segregation and ensuring continuous participation in filter-cake formation throughout extended lateral sections

This results in a denser, more uniform, and mechanically coherent filter cake. From a contact-mechanics perspective, the improved particle packing reduces surface roughness at the drill string–cake interface and promotes a more uniform distribution of the applied normal force, thereby lowering localized stress concentrations and reducing resistance during sliding or rotation.

Importantly, these same improvements in filter-cake structure govern pressure transmission into the formation and directly influence wellbore stability, particularly in depleted or mechanically weak intervals. In conventional systems, pressure can be transmitted through a poorly packed, heterogeneous cake, leading to wellbore enlargement, poor hole cleaning, and increased friction. An effective solution must therefore simultaneously strengthen the wellbore, enhance lubricity, and minimize formation damage. This paper presents a torque-management approach that combines Pressure Shielding Polymer (PSP) with low-PSD cellulosic fiber (Super Fine) and ester-based lubricants. The resulting synergy improves filter-cake integrity, limits pressure invasion, reduces friction factor, and stabilizes the wellbore—enabling operators to drill 4,500–5,000 ft beyond previous torque limits while significantly expanding drainage area and production potential.

<u>Wellbore Shielding Concept</u>

The breakthrough came with the introduction of Wellbore Shielding technology, which focuses on creating a thin, impermeable barrier on the wellbore wall to:

- Prevent pressure transmission into the formation.
- Minimize filtrate invasion and formation damage.
- Stabilize mechanically weak zones under high differential pressures.

This barrier acts like a skin on the wellbore, reducing spurt loss and maintaining structural integrity even under dynamic drilling conditions. Unlike conventional lost circulation materials (LCM), which often fail in microfractured formations, Wellbore Shielding additives are engineered to deform and interlock under pressure, forming a flexible and resilient seal.

<u>Pressure Shielding Polymer (PSP)</u>

PSP is the cornerstone of this technology. It is a proprietary blend of modified polymers and engineered solids designed to seal microfractures and pore throats up to 150 µm, form an ultra-low-permeability filter cake resistant to erosion under high shear, maintain stability at elevated temperatures (>400 °F), and deliver non-damaging performance with return permeability exceeding 75% in independent testing. The composite particle size distribution of PSP enables effective sealing of pore throats and microfractures up to approximately 150 µm. This progressive sealing mechanism limits pressure transmission into the formation while avoiding the development of thick or brittle filter cakes. By restricting pressure invasion at the wellbore wall, the system reduces effective normal forces acting on the drill string, thereby contributing to lower torque and drag in high-angle and horizontal sections. The effectiveness of PSP is rooted in its carefully engineered particle-size distribution (PSD) (Dv10 ≈ 14.2 µm, Dv50 ≈ 72.2 µm, Dv90 ≈ 235.7 µm; Span ≈ 3.07), which enables progressive bridging across a wide range of fracture apertures. This PSD allows PSP to rapidly bridge and seal microfractures while simultaneously filling voids within the developing filter cake, creating a dense, impermeable barrier that minimizes fluid invasion and pressure transmission.

Beyond sealing and pressure isolation, this same PSD-driven packing mechanism directly governs the mechanical and tribological behavior of the filter cake at the drill string interface. By filling voids and eliminating solid heterogeneity, PSP produces a denser, more uniform and mechanically continuous cake with reduced surface roughness. The smoother interface reduces solid asperities and mechanical interlocking (Bowden, F.P, 1950) between the drill string and the wellbore wall. The applied nominal load is distributed more uniformly across the contact area, (J.A Greenwood; J.B.P, Williamson, 1966) lowering localized solids concentrations and reducing resistance to sliding or rotation.

In addition to these mechanical effects, PSP contains modified polymeric components that adsorb onto mineral and filter-cake surfaces, establishing a hydrated interfacial layer whose properties are governed by polymer–water interactions

At the molecular level, the surface of PSP particles contains hydrophilic functional groups, including hydroxyl (–OH) moieties, which exhibit strong affinity for water through hydrogen bonding. When PSP particles are dispersed in the drilling fluid, water molecules associate with these functional groups and become adsorbed at the particle surface, forming a tightly bound hydration shell. This hydration shell consists of structured water molecules that are constrained by hydrogen bonding and therefore behave differently from bulk water, exhibiting gel-like characteristics under confinement (Klein, 2013; Raviv & Klein, 2002)

The polymeric components of PSP hydrate in the aqueous phase, forming a thin, water-rich interfacial layer that is immobilized within the filter cake. During drill string motion, shear is preferentially accommodated within this hydrated polymer layer rather than through direct solid–solid contact between the steel pipe and rigid filter-cake particles Because this hydrated layer has a lower shear strength than mineral solids, the effective shear resistance at the drill string–filter cake interface is reduced, resulting in a lower coefficient of friction (Klein, 2013; Raviv & Klein, 2002)

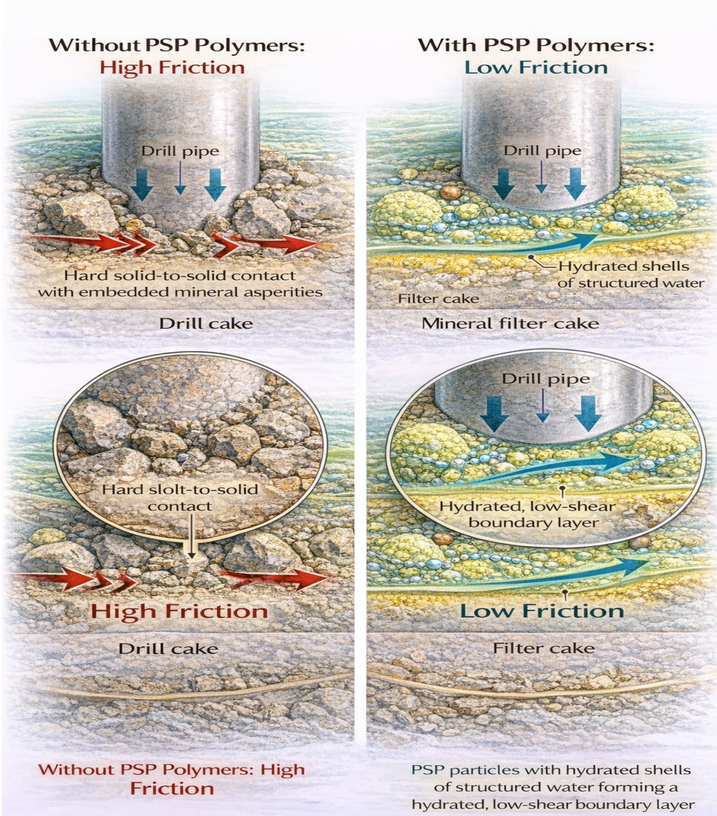

Figure 2—Conceptual schematic illustrating the lubrication mechanism of PSP polymers at the drill string–filter cake interface. Hydrated polymer shells form a low-shear, water-rich boundary layer that reduces solid–solid contact and friction.

At the contact interface, the hydrated polymers associated with PSP retain bound and structured water, which remains confined at the surface of the filter-cake particles. As the drill string is pressed against the wellbore wall, this bound water layer resists being fully squeezed out under normal load, providing a degree of load support at the interface. At the same time, the hydrated layer shears easily during sliding or rotation, creating a lubricious contact condition often described as hydration-mediated boundary lubrication. This combination of resistance to compression and ease of shear enables low-friction sliding while maintaining mechanical stability under high contact forces (Klein, 2013)

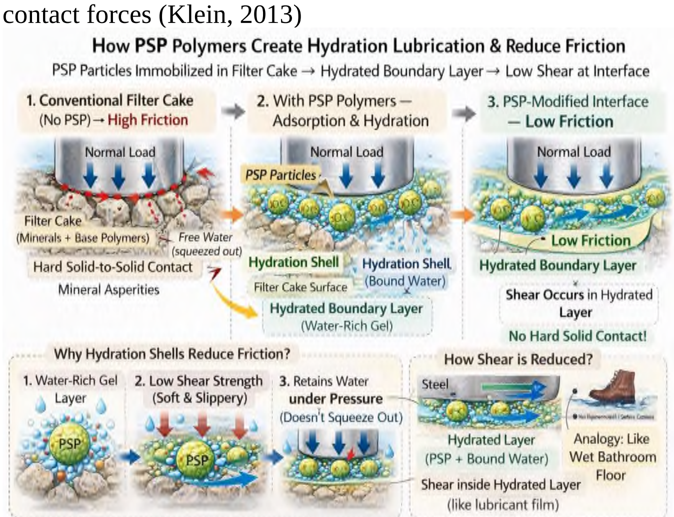

Figure 3—Conceptual schematic illustrating hydration-mediated boundary lubrication induced by PSP polymers. Adsorption and hydration of PSP particles within the filter cake form a water-rich, low-shear boundary layer that supports normal load while accommodating shear, thereby reducing friction at the drill string–filter cake interface

The effectiveness of this boundary lubrication mechanism is strongly dependent on the mechanical integrity of the filter cake. The smooth, erosion resistant cake formed by PSP protects the polymeric interfacial layer from abrasion and removal, enabling stable frictional behavior under high normal loads and dynamic drilling conditions.

Drilling Fluids commonly contain polymeric additives for Rheology and filtration control. However, these polymers are primarily present in the bulk fluid phase and are not retained at the drill string-wellbore contact interface under dynamic drilling conditions. As a result, their contribution to friction reduction is limited and transient.

While conventional drilling fluids contain polymers that hydrate and interact with water, these polymers are primarily dispersed in the bulk fluid and are not retained at the drill string–filter cake interface where frictional shear is generated. In contrast, the polymeric components of PSP are physically incorporated into the filter cake through fine particle packing and pore-scale confinement. This immobilization anchors polymer-rich, hydrated regions directly at the contact interface. By retaining these polymers within a dense and erosion-resistant filter cake, PSP enables sustained modification of interfacial shear behavior under load, distinguishing its friction-reduction mechanism from that of conventional drilling fluid systems

The combined mechanical smoothing of the filter cake and reduction in interfacial shear strength directly translate into measurable reductions in friction factors with field results showing friction factor reductions from 0.3-0.4 to 0.15-0.25. These observations are consistent with the proposed physiochemical mechanism, and explain the observed decreases in torque, drag, and stick & slip severity across all drilled sections.

<u>Cellulosic Fiber (Super-Fine)</u>

The low-PSD cellulosic fiber is incorporated to enhance filter-cake mechanical integrity rather than to provide lubrication. Owing to its fibrous morphology, the material interlocks with solids within the filter cake to form a mechanically stable internal network that resists erosion and particle rearrangement under dynamic conditions such as drill string sliding and rotation. Maintaining this integrity prevents continuous removal of the cake and the repeated exposure of fresh rough surfaces, which are known contributors to stick-slip behavior and unstable torque in highly deviated and horizontal wells (Klungtvedt et al., 2023).

By preserving a stable and coherent filter cake, the cellulosic fiber indirectly protects the hydrated polymer layer formed by PSP, allowing low-friction interfacial conditions to persist over extended drilling intervals. Experimental studies on cellulose-based fibrous additives in water-based drilling fluids demonstrate that such fibrous networks significantly improve filtration performance and filter-cake robustness under dynamic loading. Consequently, the combined use of PSP and low-PSD cellulosic fiber promotes continuous wellbore coverage along the wellbore wall, even in high-angle and horizontal sections where mechanical stresses are severe (Tran et al., 2011)

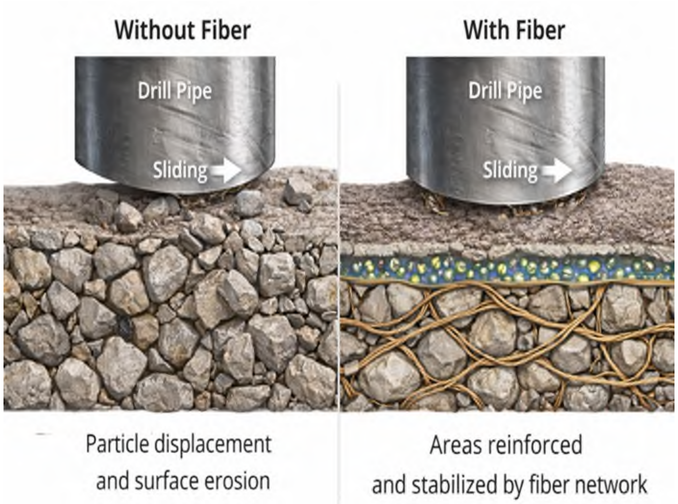

Figure 4—Conceptual illustration of mechanically reinforced filter cake under dynamic contact. Low-PSD cellulosic fiber forms an internal network that limits particle rearrangement and surface erosion during sliding, supporting sustained filter-cake continuity.

Synergy with Ester-Based Lubricants

PSP and low-PSD cellulosic fiber primarily improve the quality and stability of the filter cake, while ester-based lubricants mainly reduce friction, torque, and drag. The lubricants work by forming a thin, lubricious film at the contact point between the drill string and the filter cake. However, for these lubricants to remain effective, this film must stay attached at the contact surface and not be scraped away during drilling.

The smooth and erosion-resistant filter cake created by PSP, and reinforced mechanically by the fibers, provides a stable and uniform surface that allows lubricant films to remain intact. By reducing surface roughness and limiting abrasive damage, the filter cake enables the lubricants to work more efficiently. As a result, metal-to-filter-cake contact is reduced, the friction factor decreases from 0.30–0.40 to 0.15–0.25, and weight transfer to the bit improves.

Together, PSP, Cellulosic Fibers, and ester-based lubricants form a complementary system in which the filter cake is first stabilized and strengthened, and then friction is reduced in a controlled and sustained manner. This combined mechanical and chemical action leads to lower torque and drag, smoother drilling, and higher efficiency, especially in long and high-angle or horizontal well sections

Formation Damage

- Return permeability >75%, ensuring minimal formation damage.
- Compatibility with water-, oil-, and synthetic-based mud systems.
- Thermal stability exceeding 204 °C (400 °F), maintaining filter-cake integrity and stable frictional behavior under high-temperature ERD conditions and extended circulation times.

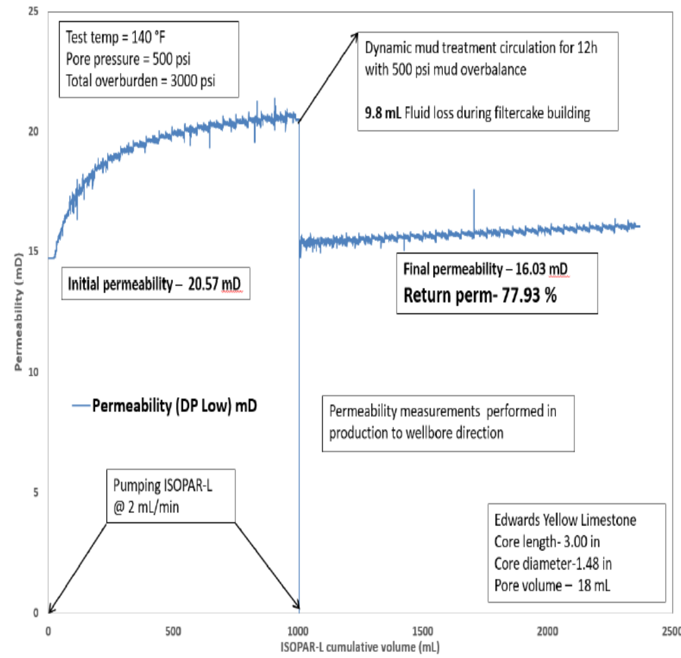

Figure 5—Return permeability test results obtained using a PSP-treated drilling fluid system. The test shows a return permeability of approximately 78% following dynamic mud treatment and filter-cake buildup under representative temperature, pore pressure, and overburden conditions, indicating minimal permeability impairment.

Environmental Safety

PSP and Low-PSD Cellulosic Fiber are designed to be environmentally compliant:

- PLONOR listed for North Sea use.
- HMCS Category P, OCNS Group E.
- Passes North America 96-hour LC50 bioassay for mysid shrimp.

Field Application Results

Across all wells drilled with the integrated system incorporating PSP, low PSD cellulosic fiber and ester-based lubricants, consistent reductions in torque and drag were observed.

The adoption of Wellbore Shielding® technology in Al Shaheen ERD wells has delivered:

- Torque reductions up to 10 kft-lbs in long 8.5" horizontal sections.
- Extended reach by 4,500–5,000 ft, enabling greater reservoir exposure.
- Improved operational efficiency, reducing stick-slip severity and tripping times.
- Economic benefits, including reduced non-productive time (NPT) and enhanced production potential.

The following example illustrates the torque response observed in a well that experienced elevated torque while drilling a turn section. At approximately 8,000 ft MD, the drilling fluid was treated with 4 ppb PSP and 2 ppb cellulosic fibers, resulting in a noticeable reduction in friction factor from 0.50 to 0.30. The treatment concentration was subsequently increased to 6 ppb PSP and 3 ppb Cellulosic Fibers, which stabilized the friction factor at approximately 0.40 and maintained it at this level through the remainder of the section.

At 15,380 ft MD, the mud system was further treated with an ester-based lubricant at 3 vol%, leading to an additional reduction in friction factor from 0.40 to 0.30. This reduced friction level was sustained until section total depth (TD) at approximately 18,000 ft MD (Figure 4)

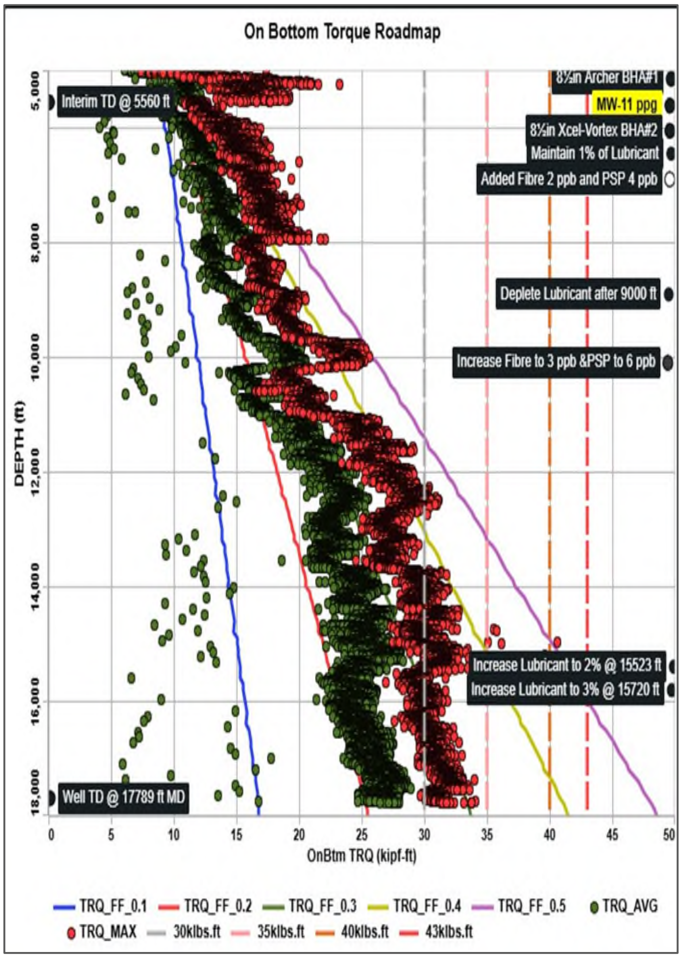

Figure 6—On-bottom torque roadmap illustrating friction factor response with depth during drilling of a turn section. Sequential treatment with PSP and cellulosic fibers reduced and stabilized friction factor, followed by a further reduction after addition of an ester-based lubricant, with improved torque performance maintained to section total depth

Figure 5 illustrates the on-bottom torque response after treating the drilling fluid with 6 ppb PSP and 3 ppb cellulosic fibers. As shown in the figure, the treatment reduced the maximum torque from approximately 40 to 35 kft.lbf and stabilized the average torque in the range of 32–33 kft.lbf.

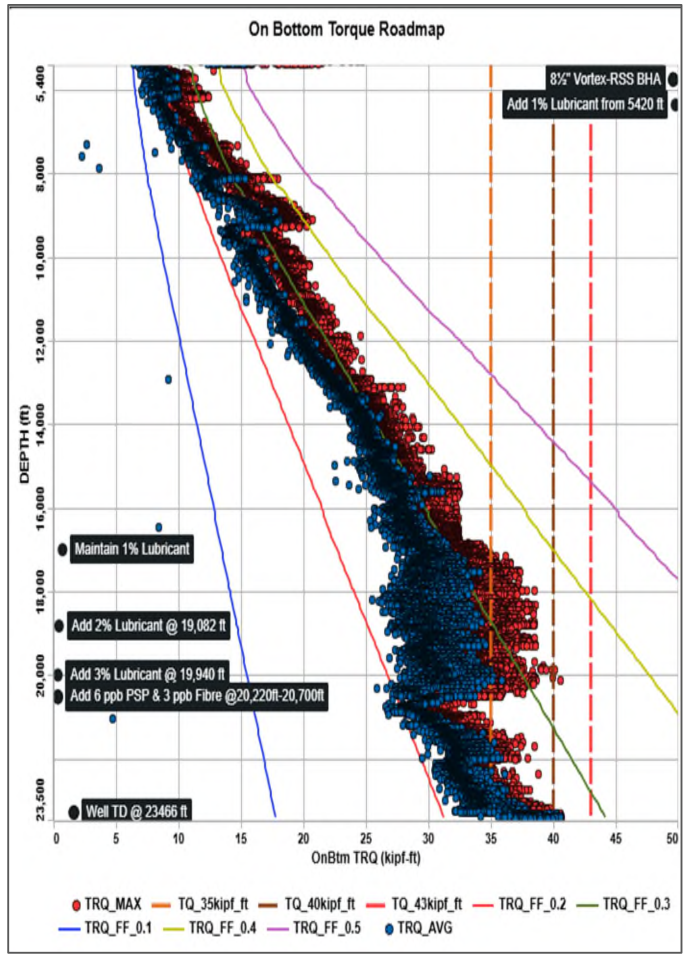

Figure 7—On-bottom torque roadmap illustrating torque response with depth after treatment of the drilling fluid with 6 ppb PSP and 3 ppb cellulosic fibers. The treatment resulted in a reduction of peak torque and stabilization of average torque during drilling of the section.

The above-stated reductions in torque are consistent with the proposed mechanism of reduced surface roughness and lower interfacial shear strength of the drill string-filter cake interface. The repeatability of the response across multiple wells and trajectories supports the interpretations that the observed torque reductions are mechanistic rather than coincidental.

Because PSP modifies the physical structure and shear behavior of the filter cake itself, the resulting reduction in friction factor persists as long as the cake remains intact.

PSP changes the dominant shear mode from solid-dominated to composite layer dominated shear. It should be emphasized that a filter cake is present before and after PSP treatment the observed reduction in friction does not result from the creation of a filter cake, but from a fundamental change in its mechanical structure and shear behavior.

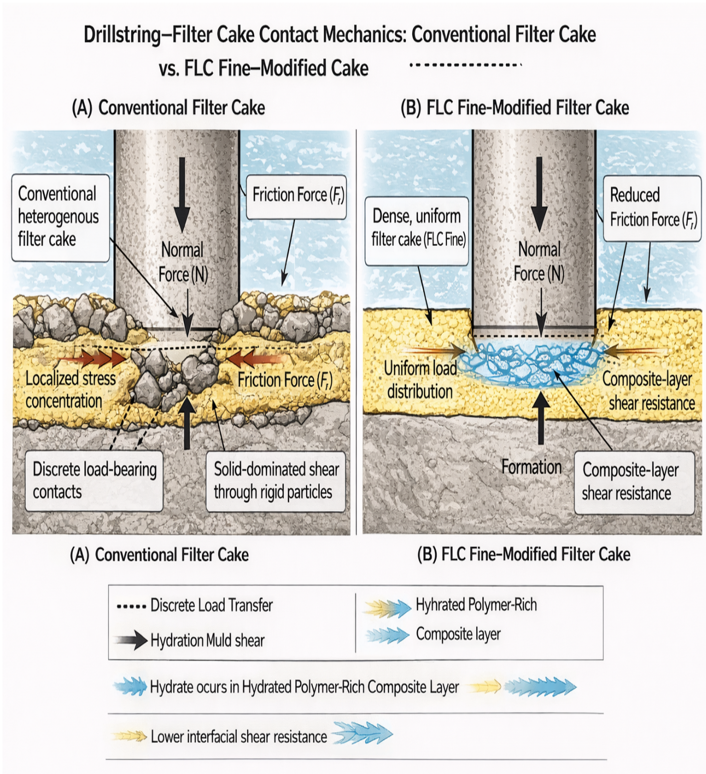

Figure 8—Schematic illustration of drill string–filter cake contact mechanics before and after PSP modification. While a filter cake exists in both cases, PSP treatment changes the mechanical and shear behavior of the cake, leading to reduced interfacial friction

Methodology

The methodology adopted for torque management optimization in Al Shaheen ERD wells was designed to address two critical objectives:

- Enhance wellbore stability under high differential pressures, and
- Reduce friction factor and torque in ultra-long horizontal sections.

This was achieved through a synergistic fluid design incorporating Pressure Shielding Polymer (PSP), low PSD cellulosic fiber (Super Fine), and ester-based lubricants. The approach combined preventive and corrective strategies, validated through laboratory testing and field implementation.

<u>Conceptual Framework</u>

Create a continuous, ultra-low-permeability barrier that:

- Limits pressure transmission,
- Minimizes filtrate invasion, and
- Provides a smooth, lubricious surface for film retention.

<u>Working Mechanism:</u>

- PSP (Pressure Shielding Polymer): A proprietary blend of cellulosic modified polymers and solids engineered to form a sealing layer across microfractures and pores. Its broad PSD (Dv10: 14 µm, Dv50: 72 µm, Dv90: 235 µm) ensures bridging efficiency across a wide fracture aperture range.
- Low-PSD Cellulosic Fiber: Reinforces the filter cake, improving resilience and reducing erosion under dynamic conditions.
- Ester-Based Lubricant: Creates a lubricious film that reduces friction factor and torque, especially in high-angle and horizontal sections.

<u>Laboratory Validation</u>

1. FANN-90 Dynamic Filtration Tests

Dynamic filtration tests were conducted to evaluate the performance of PSP and Low-PSD Cellulosic Fiber under simulated downhole conditions:

- Test Conditions: Temperature: 140°F, Differential Pressure: 500 psi, Shear Rate: 60–120 s^{-1}, Duration: 90 minutes
- Key Parameters Measured:
  - o Fluid Loss: Total filtrate collected during the test.
  - o Filtration Rate: Indicates the rate of fluid invasion.
  - o Cake Deposition Index (CDI): Represents the balance between cake buildup and erosion.
- Desired Results:
  - o Fluid loss reduced to as low as possible (<5 ml)
  - o CDI values between <20 ml/hr², indicating rapid and stable cake formation.
  - o Filtration rate dropped to 0.078–0.121 ml/min, confirming minimal invasion.

Interpretation:

A low CDI signifies that the filter cake is deposited as fast as it is eroded, maintaining a continuous film on the wellbore wall—effectively plastering the wellbore. This minimizes pressure transmission, reduces formation damage, and mitigates stick-slip tendencies in high differential pressure zones.

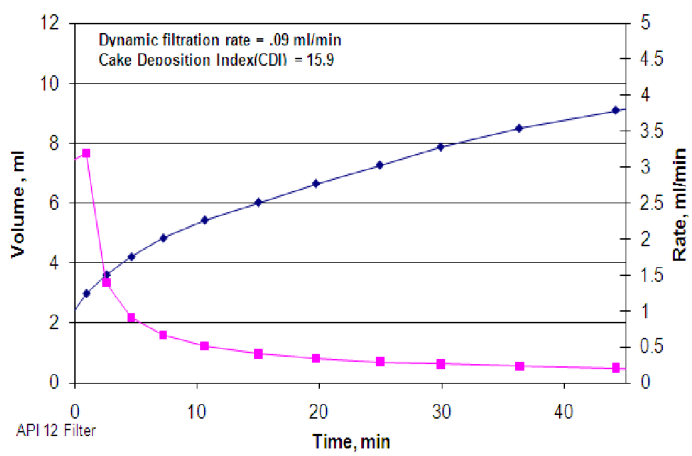

Figure 9—FANN-90 dynamic filtration test results for the PSP and low-PSD cellulosic fiber system under simulated downhole conditions (140 °F, 500 psi differential pressure, shear rate 60–120 s^{-1}). The cumulative filtrate volume (left axis) and instantaneous filtration rate (right axis) are plotted versus time. The rapid decline and stabilization of filtration rate, together with a low Cake Deposition Index (CDI ≈ 15.9), indicate that filter-cake deposition occurs at a rate comparable to erosion, resulting in a stable and continuous filter cake during dynamic flow conditions.

2. Permeability Plugging Test (PPT)

PPT tests validated the sealing capability of PSP and Low-PSD Cellulosic Fiber:

- Test Conditions: Temperature: 140°F, Differential Pressure: 500 psi, Disc size - 10µ for carbonates and 40µ for sandstone reservoir formations, Duration: 30 minutes

- Key Parameters Measured:
  - Spurt Fluid Loss: Total filtrate collected during the test.
  - Total Fluid Loss: Indicates the fluid loss and invasion.
- Desired Results:
  - Spurt loss minimized as low as possible < 2 ml
  - Total Fluid Loss < 15 ml/30min
  - Cake Characteristics – sleek, < 1mm.

3. Sand Bed Tests

Sand Bed tests confirmed bridging efficiency and invasion control:

- Invasion depth <6 cm under 100 psi differential pressure.
- Demonstrated strong wellbore shielding effect.

Field Implementation

- Additive Concentrations
  - PSP: 4 ppb
  - Cellulosic Fiber-SF: 2 ppb
  - Ester-based lubricant: 1–3% by volume, stepped up during high-angle turns (>40°).
- Application Procedure
  - Premix Strategy: High-concentration pill (up to 45 ppb) prepared in reserve pits, Controlled bleed into the active system to maintain target concentrations.
  - Solids Control Optimization: Shaker screens adjusted to API 120 or coarser to minimize product loss, Centrifuge usage restricted to prevent excessive depletion.
  - Monitoring: Real-time torque and friction factor trends tracked using surface sensors and downhole data, Adjustments made ahead of torque-prone intervals (~200 ft before).

Operational Best Practices

- Maintain PSP concentration at 4 ppb throughout the section.
- Monitor rheology and Equivalent Circulating Density (ECD) to prevent losses.
- Adjust Viscosifier levels in premix to avoid excessive rheology increase.
- Use caustic soda to stabilize pH after PSP addition.
- Dilution rates managed to maintain mud weight and additive concentration.

Performance Indicators

- Torque Reduction: Up to 10 kft-lbs observed in long 8.5" horizontal sections.
- Friction Factor Improvement: From 0.3–0.4 down to 0.15–0.25.
- Extended Reach: Additional 4,500–5,000 ft beyond previous torque limits.
- Stick-Slip Mitigation: Significant reduction in severity, improving drilling efficiency.

This methodology ensured a dual benefit: mechanical torque reduction and chemical wellbore stabilization, enabling successful drilling of ultra-long laterals in Al Shaheen ERD wells.

Results

The integration of Pressure Shielding Polymer (PSP), Low-PSD Cellulosic Fiber, and ester-based lubricants in Al Shaheen ERD wells delivered measurable improvements in torque management, friction factor reduction, and overall drilling efficiency. This section presents the field performance data, correlates it with laboratory findings, and discusses the operational and economic implications.

Torque Reduction

Field trials across multiple ERD wells demonstrated significant torque reductions after introducing PSP and Low-PSD Cellulosic Fiber into the active mud system:

- Well-1: Maximum torque reduced from 43 kft-lbs to 33 kft-lbs (≈23% reduction).
- Well-2: Torque dropped from 42 kft-lbs to 31 kft-lbs (≈26% reduction).
- Well-3: Torque decreased from 44 kft-lbs to 35 kft-lbs.
- Well-4: Torque lowered from 36 kft-lbs to 30 kft-lbs.

These reductions were observed in 8.5" horizontal sections exceeding 20,000 ft, where torque previously approached operational limits. The improvement allowed drilling to continue safely without premature TD calls.

Friction Factor Improvement

The synergy between PSP, Low-PSD Cellulosic Fiber, and ester-based lubricants resulted in a substantial decrease in friction factor:

- Initial friction factor: 0.30–0.40.
- Post-treatment friction factor: 0.15–0.25.

This reduction enhanced weight transfer to the bit, improved directional control, and minimized stick-slip severity during high-RPM drilling.

Extended Reach

One of the most significant outcomes was the ability to drill 4,500–5,000 ft beyond previous torque limits, with some wells achieving up to 10,103 ft additional reach. This extended lateral exposure translates directly into increased drainage area, improved production potential, and optimized reservoir development.

Operational Benefits

- Stick-Slip Mitigation: Downhole vibration logs indicated a marked reduction in stick-slip severity after PSP treatment.
- Improved Tripping Times: Lower drag facilitated faster tripping and casing runs.
- Enhanced Hole Cleaning: Stable wellbore geometry and reduced torque allowed higher RPM without excessive mechanical stress.

Discussion

Synergy of Additives

PSP + fiber provides chemical stabilization (shielding, sealing, cake integrity), while ester-based lubricants provide mechanical friction reduction (boundary films).

PSP’s smooth, erosion-resistant cake retains and protects both lubricant films and the hydrated polymer boundary layer—critical for sustained boundary lubrication under high load/low speed typical of ERD

Comparison with Historical Approaches

Previous strategies—such as high lubricant volumes and drill pipe size reduction—offered limited improvements and introduced operational compromises. In contrast, the integrated approach:

- Delivered consistent torque reduction without sacrificing hydraulics.
- Enabled higher ROP and RPM without excessive mechanical stress.
- Reduced non-productive time (NPT) is associated with premature TD calls and stuck pipe incidents.

Economic Impact

- Extended Reach: Additional 5,000 ft of lateral exposure significantly increases drainage area and production potential.
- Cost Savings: Reduced NPT and fewer trips offset additive costs.
- Operational Efficiency: Faster tripping and casing runs lower overall well delivery time.

Summary of Findings

The application of PSP and Low-PSD Cellulosic Fiber, combined with ester-based lubricants, represents a step-change in torque management for ERD wells. By addressing both chemical and mechanical aspects of wellbore stability, this approach enables safe and efficient drilling of ultra-long laterals, unlocking greater reservoir potential and delivering measurable economic benefits.

Conclusions

The application of Pressure Shielding Polymer (PSP), Low-PSD Cellulosic Fiber, and ester-based lubricants in Al Shaheen ERD wells represents a significant advancement in torque management and wellbore stability for ultra-extended reach drilling operations. The integrated approach delivered measurable improvements in both mechanical and chemical aspects of drilling performance, enabling operators to overcome historical limitations and achieve operational objectives safely and efficiently.

Key Findings

- Torque Reduction and Friction Factor Improvement
- Field trials demonstrated torque reductions of 22–30%, lowering maximum torque from 42–44 kft-lbs to 30–35 kft-lbs in long 8.5" horizontal sections.
- Friction factor decreased from 0.30–0.40 to 0.15–0.25, significantly improving weight transfer to the bit and reducing stick-slip severity.

Extended Reach and Reservoir Exposure

- The optimized fluid system enabled drilling 4,500–5,000 ft beyond previous torque limits, with some wells achieving up to 10,103 ft additional reach.
- This extended lateral exposure translates directly into increased drainage area, improved production potential, and enhanced reservoir development efficiency.

Enhanced Wellbore Stability and Formation Protection

- Laboratory validation confirmed the effectiveness of PSP and Low-PSD Cellulosic Fiber in forming an ultra-low-permeability barrier, reducing fluid invasion and pressure transmission.
- FANN-90 dynamic filtration tests achieved CDI values of 1.48–1.61 ml/hr², indicating rapid and stable cake formation.
- PPT and Sand Bed tests validated bridging efficiency and minimized invasion depth (<6 cm), ensuring minimal formation damage.

Operational Efficiency and Economic Impact

- Reduced torque and drag facilitated faster tripping and casing runs, lowering overall well delivery time.
- Mitigation of stick-slip and improved hole cleaning allowed higher RPM and ROP without excessive mechanical stress.
- Cost savings from reduced non-productive time (NPT) and fewer trips offset additive costs, delivering a favorable economic outcome.

Technical Significance

The success of this integrated approach lies in its dual-action mechanism:

- Chemical Stabilization: PSP and Low-PSD Cellulosic Fiber create a continuous sealing layer that prevents pressure transmission and stabilizes the wellbore under high differential pressures.
- Mechanical Friction Reduction: Ester-based lubricants enhance sliding efficiency, reducing torque and drag in ultra-long laterals.

This synergy addresses the root causes of torque and drag in ERD wells, offering a sustainable solution that outperforms traditional methods such as high lubricant volumes and drill pipe size reduction.

Recommendations for Best Practices

- Maintain PSP concentration at 4 ppb and Low-PSD Cellulosic Fiber at 2 ppb throughout torque-prone intervals.
- Step up ester-based lubricant concentration to 1–3% by volume during high-angle turns (>40°).
- Implement premix strategy for PSP to ensure proper hydration and concentration control.
- Optimize solids control equipment (API 120 or coarser shaker screens) to minimize product loss.
- Monitor rheology and Equivalent Circulating Density (ECD) to prevent losses and maintain system stability.
- Use real-time torque and friction factor monitoring to adjust treatment proactively.

Future Outlook

The demonstrated success of PSP and Low-PSD Cellulosic Fiber in Al Shaheen ERD wells provides a blueprint for torque management in other ultra-ERD environments worldwide. Further research could focus on:

- Advanced rheology control techniques to optimize fluid performance under extreme conditions.
- Integration with digital drilling optimization tools for predictive torque and drag modeling.
- Environmental impact studies to reinforce sustainability credentials of Wellbore Shielding® technology.

In summary, the adoption of Wellbore Shielding® technology through PSP and Low-PSD Cellulosic Fiber, combined with ester-based lubricants, marks a step-change in ERD drilling performance. By enabling safe and efficient drilling of ultra-long laterals, this approach unlocks greater reservoir potential, reduces operational risk, and delivers tangible economic benefits—positioning it as a best-in-class solution for torque management in complex offshore environments.

Acknowledgments

Cite

Nomenclature

ROP – Rate of Penetration
RPM – Rotations Per Minute
NPT – Non-Productive Time
PSP – Pressure Shielding Polymer

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