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New Records of Drilling & Environmental Performance Achieved in Delaware Basin Wolfcamp Horizontals Utilizing a Novel High-Performance Water-Based Fluid

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Abstract

With increasing determination to improve drilling economics, efficiencies, and a growing focus on environmental stewardship, an engineered approach to deliver high-performance drilling and environmental excellence was recently implemented on a series of Wolfcamp horizontal wells utilizing a novel high-performance water-based mud (HPWBM).

The Wolfcamp formation is found throughout the Permian basin. Oil and gas developments and crude production from the Wolfcamp have increased over the past decade and now drive nearly one-third of total production in the Permian. The industry's movement towards clean, sustainable well-site practices coupled with longer lateral intervals, along with a demand to deliver wells faster and more economical, has created compelling challenges for drilling fluids used in well construction. The challenges of drilling extended reach Wolfcamp shale laterals demand a fluid that provides a high level of torque and drag reduction (lubricity), hole cleaning, along with a stable wellbore. As a result, the selection process for drilling fluids is critical to project success.

This paper will present advancements made in HPWBM design through a side-by-side, in-field comparison of twelve (12) wells drilled with the HPWBM, versus offset wells drilled with non-aqueous fluids (NAF). Use of HPWBM resulted in improved well economics, a reduction in environmental impact and records set in drilling performance, including footage per day, days to drill the lateral sections and a record well from spud to total depth.

Introduction

Oil and gas developments in the Wolfcamp have driven increased production over the past decade. In the past, development wells were drilled with vertical trajectories, and have since transitioned to aggressive horizontal profiles. The significant increase in crude production from the Wolfcamp is an outcome resulting from this transition towards horizontal drilling, coupled with increased lateral lengths and optimized completions. Horizontal lateral lengths in the Delaware have increased from roughly 2,500 feet in 2005 to more than 9,500 in 2021. The changed trajectory towards horizontal well profiles, coupled with increased distances drilled in the laterals creates compelling challenges for drilling fluids used in well construction.

In the Delaware Basin, shallower formations, such as the Salado, include halite and anhydrite layers followed by weaker formations in the Delaware Sands. A surface casing string is required to protect fresh zones and typically set at roughly1,350 feet. The Salado (Halite) formation is covered by the first intermediate casing string set just below the salt in the Lamar Limestone at roughly 5,000 feet. A second intermediate string is used to case off the Delaware Mountain group (Bell Canyon, Cherry Canyon and Brushy Canyon) as well as the Bone Springs zones, which have known hazards of water flows, H_2S gas, seepage, and severe lost circulation. Typically, the casing shoe is set at approximately 10,800 feet in the base of the 3rd Bone Springs or top of the Wolfcamp Shale. This strategy is designed to isolate the production interval from these issues that often result in non-productive time (NPT) in Wolfcamp horizontal wells.

Non-aqueous drilling fluids (NAF) have become the fluid-of-choice for drilling Wolfcamp horizontal wells due to perceived performance related to increased rates of penetration and reduced torque and drag. (Connell et al., 2018) However, the increase amount of gas influxes, frequency and severity of lost circulation events and water flows in the Wolfcamp have increased the risks associated with use of NAF.

In a departure from conventional practices, the operator utilized an engineered approach to deliver high-performance drilling, coupled with environmental excellence, in Wolfcamp horizontal wells through use of a new HPWBM. Use of the HPWBM resulted in improved well economics and records set in drilling performance, including footage per day and days to drill the lateral sections. This paper presents an operational history of a series of Wolfcamp wells over an approximate one-year period in the Delaware Basin. Comparisons between the performance of conventional NAF and the new HPWBM on these wells will be presented as well.

Wolfcamp Drilling Fluids Progression

In the past, these wells were drilled with conventional NAF, often encountering operational challenges such as waterflows, natural gas influxes and lost circulation. During the modern development of unconventional plays across US land operations, NAF gradually became the default choice of fluids systems. For many drilling engineers, there are perceived benefits to using non-aqueous fluids (NAF). These include:

- Faster rates of penetration (ROP)
- Reduced torque and drag (lubricity)
- Improved formation stability
- Higher temperature stability
- Ease in running casing and liners

NAF drilling fluids have numerous potential deficiencies when compared to water-based drilling fluids:

- Increased occurrence of lost circulation
- Higher mud weight/equivalent circulating density (ECD)
- Reduced flow rates
- Potential formation damage
- Complicates cementing
- Increased environmental and health impacts

The operator recognized and embraced important concepts of Environmental, Social and Governance (ESG), which led to a decision to move toward use of HPWBM in place of NAF. Environmental, social, and governance (ESG) criteria are a set of standards for a company's operations that are used to evaluate programs and performance in meeting sustainability commitments. Environmental criteria consider how a company performs as a steward of nature. Social criteria examine how it manages relationships with employees, suppliers, customers, and the communities where it operates. Governance deals with a company's leadership, executive pay, audits, internal controls, and shareholder rights. (Smith et al., 2022). Major reductions in product consumption on HPWBM led to an average decrease of 16.12 truckloads per well compared to NAF (Barite, Diesel, Products, Liquid OBM and Trash Haul-Off). Average reduction of days on well by 7.59 days and decrease in truck loads resulted in a significant impact on CO2 emissions.

HPWBM provide a higher level of performance than is currently attainable using conventional water-based muds and are an environmentally compliant alternative to non-aqueous fluid (NAF). The HPWBM utilizes a small footprint both on location and on the environment, improving ESG rating of the operator. Recent advancements in polymer chemistry have proven renewed relevance in the use of water-based drilling fluids to deliver wells faster and with lower cost.

Well Performance Analyses

A baseline for well delivery performance was established and then used to compare the operational performance of use of NAF and HPWBM in Wolfcamp wells. All the wells in the program were drilled to similar depth and targeted the same Wolfcamp production zone.

When using NAF, the operator was averaging 20.3 days from spud to release of the rig on a typical Wolfcamp horizontal well, averaging 1,061.2 feet/day overall, and 787.3 feet/day in the lateral section. These well metrics were comparable to offset wells drilling similar lateral lengths and production targets in the surrounding Lea County.

NAF fluid cost per well in the field (for all operators), without waterflows, gas influx or lost circulation were in the range of $80,000 -$90,000. The average NAF cost per well (for all operators) increased to the range of $150,000 -$300,000 when water-flows or lost circulation events were encountered.

A comparison of high gravity solids (HGS) concentrations on these wells reveals an additional performance hinderance of NAF. The increased HGS (Figure 1) needed in NAF to achieve the same fluid density results in higher Plastic Viscosity (PV), equivalent circulating density (ECD) and wear on motors. The higher solids content results in increased frictional loss, flow rates, decreased penetration rates and higher friction factors.

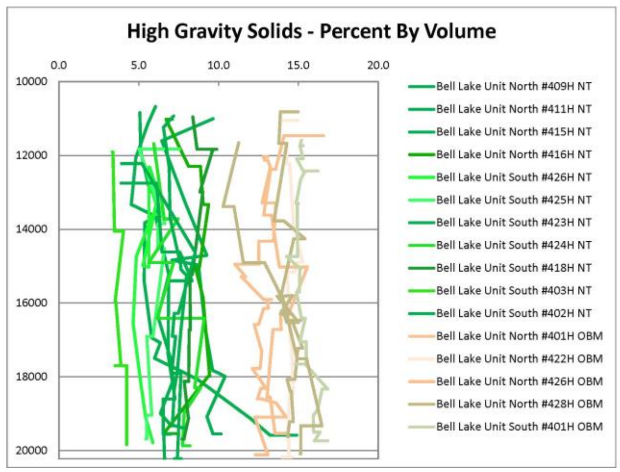

Figure 1- HGS comparison showing the difference between the HPWBM and NAF systems

Torque and Friction Factors

Torque limitation was a major concern when discussing the switch from NAF to HPWBM. The success and performance from previous wells gave a historical prospective, proof that 2-mile laterals are possible. The following chart (Figure 2) displays the real time and laboratory friction factors of different fluid systems. The friction factors calculated in wells using HPWBM were 0.17-0.19 while the wells using NAF were 0.15-0.20 respectively.

Drilling Fluid	Open Hole Friction Factor	Steel on Steel Coefficient of Friction (COF)
Air	0.40 - 0.60	
Foam Water-Based	0.35 - 0.55	
Lignosulfonate Water-Based	0.20 - 0.30	0.20 - 0.28
Polymer Water-Based	0.20 - 0.30	0.20 -0.28
OBM	0.15 - 0.20	0.07 - 0.12
HPWBM	0.17 - 0.19	0 .05 - 0.09

Figure 2, Friction Factors of various fluids systems

Torque was tracked and monitored and compared to the historical clay-free NAF wells. Dog leg severity (DLS) played a major factor on the first to wells, as it does on all horizontal wells. The BLUS #402H well had an 11° and 13° dog legs approximately 500' apart midway through the lateral. The BLUS #402H well had several major dog legs throughout the lateral. The decision was made to change from a 5" motor to a 5-3/4" motor and the DLS was greatly reduced, and torque normalized with historical NAF averages (Figure 3).

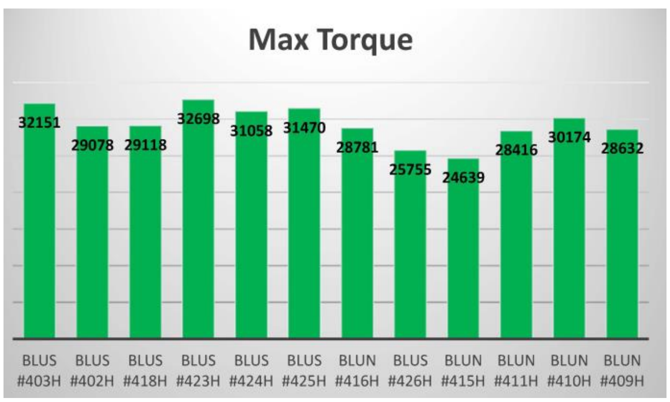

Figure 3, Maximum torque of subject wells.

While torque increased to 34,000± on the BLUS #403H well and the BLUS 402H well compared to 23,500± average on traditional NAF wells, ROP (Figure 4), Days on Well (Figure 4) and overall economics (Figure 5) improved significantly.

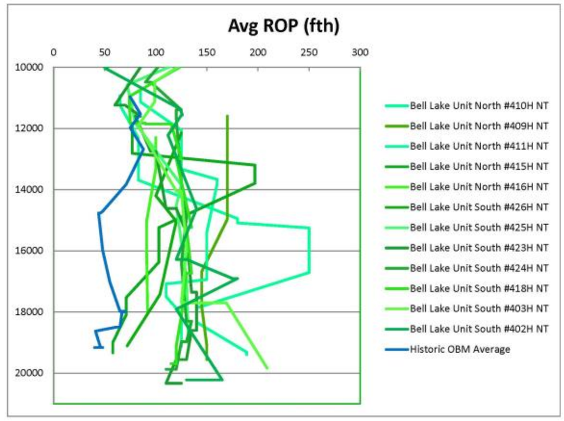

Figure 4, Average ROP of subject wells vs historic OBM average

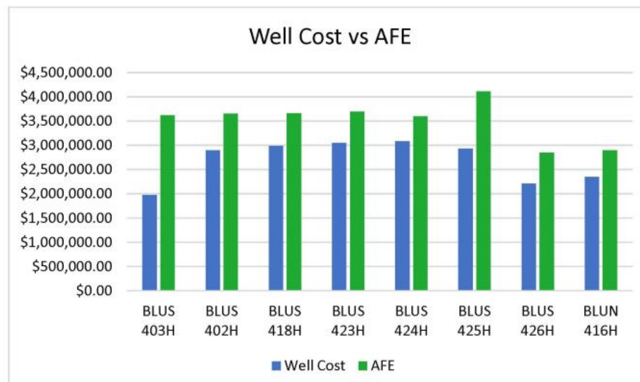

Figure 5, AFE of subject wells vs historic NAF average

An interesting development noticed during the swap from NAF to HPWBM was a reduction in fluid density (Figure 6) needed for well bore stability, for both tectonic stability and well control.

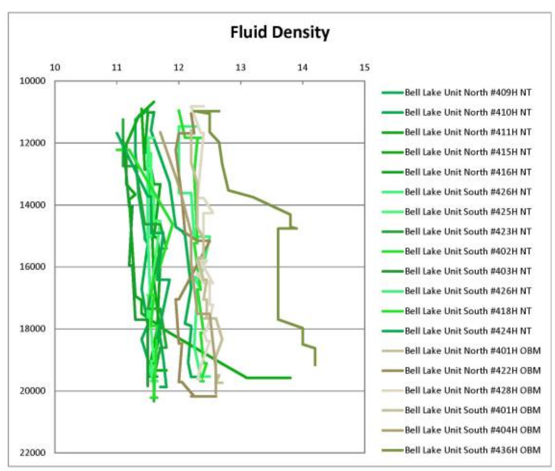

Figure 6, Fluid Densities of HPWBM wells vs NAF Wells.

Advanced Polymer Chemistry

As the industry endeavors for advanced standards for environmental impact, health, and safety, and continually striving for reduce costs and improved efficiencies, advanced polymer chemistry has provided an alternative to the traditional OBM systems. Previous water-based mud (WBM) systems had limitations that prevented their use in certain conditions:

- High Monovalent Salinity
- High Total Hardness (Ca++/Mg++)
- Produced Water
- Divalent salinity

New polymer chemistry overcomes prior limitations, outperforms, and simplifies fluid formulations.

One of the HPWBM key products is a specialized polymer that performs three functions: viscosity, cuttings encapsulation and fluid loss control. This simplification in the number of products required to achieve key fluid properties helps supports safety and ESG initiatives by taking trucks off the road and reducing the number of lifts by rig-site workers to maintain fluid properties. The polymer is innovative and unique in its ability to form a non-invasive, thin pliable filter cake, and shear-thinning rheological properties. The versatile polymer lays down a thin filter cake that is highly lubricous, which reduces the risk of stuck pipe and improves drilling efficiency. The polymer also improves resistance to contamination and minimizes reactivity to calcium or divalent ions. As it develops other components of the new HPWBM, the fluids service provider is advancing its sustainability position by paying close attention to environmental impacts. A tactic of this is through use of plant-based chemistries that do not sacrifice performance and are characterized as renewable resources. The performance of polymers is not affected by high salinity or hardness, and their use in field brines and produced water is possible. Key performance attributes of the new polymer include:

- Multi-functional (filtration, viscosity, encapsulation)
- Plant-based, sustainable chemistry
- Readily dispersible and easy to mix in freshwater or saturated brines
- Provides non-progressive gels
- Chemically stable to contaminants
- Thermally stable to 250°F (121°C) in freshwater

A rheological comparison of new the polymer against traditional polymers shown in Figure 9. Concentrations of 1 lb/bbl of each polymer was utilized in a freshwater base at 9.8 pH. Highly shear thinning characteristics are observed with robust low shear rate viscosity, traditionally prized in the drilling fluids industry. This characteristic serves to provide ideal hole cleaning benefits while contributing minimally to Plastic Viscosity (PV) and resulting pump pressure.

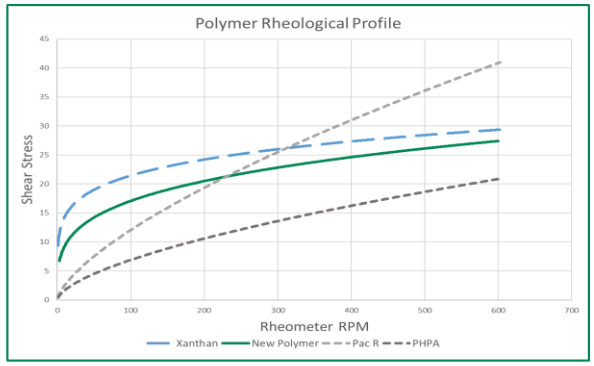

Figure 9, rheological profiles of selected polymers

A unique quality of the polymer is the thin, pliable filter cake produced. (Figures 9 & 10)

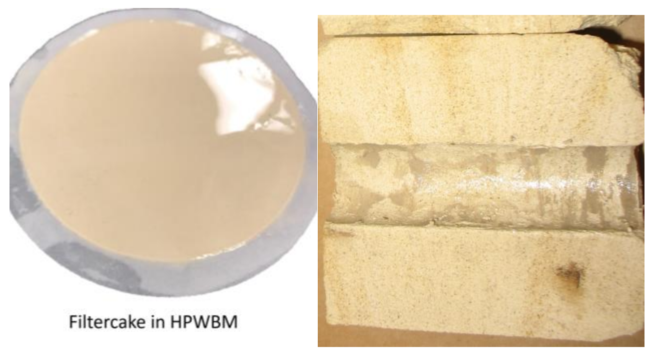

Figure 10, API filter cakes in different fluids

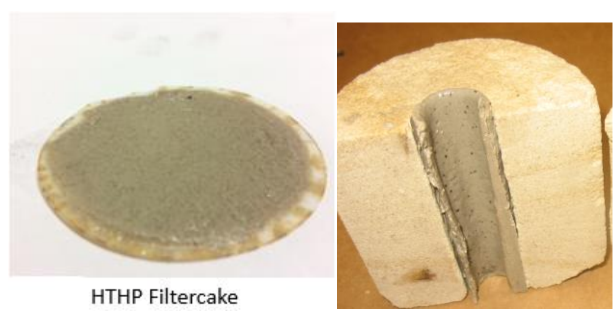

Figure 11, HTHP filter cake, 250F, HPWBM

Field Application

The wells documented in this paper used the new HPWBM from kick of point (KOP) through the total depth (TD) of the lateral production interval. The switch to the HPWBM system for the Wolfcamp horizontal program followed prior success achieved with in the 2nd and 3rd Bone Springs wells (Jones et al., 2020). The system is a rugged, yet simple system that is easy to maintain, and reusable, built on location with a saturated field brine. Figure 12 below highlights the breakthrough in performance, the only change made on the first 2 wells was a switch from NAF to HPWBM. The only other change made was from a 5" motor to a 5-3/4" motor on the last 4 wells.

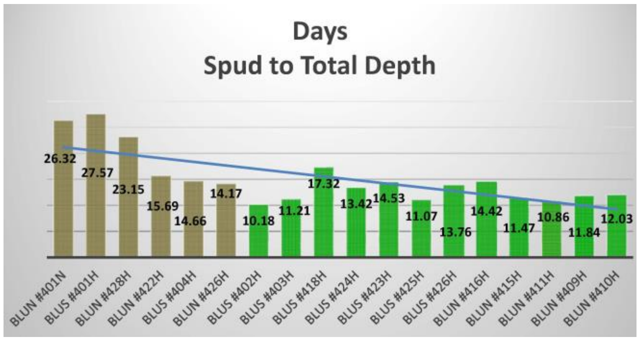

Figure 12, Progressive well performance

Conclusions

The use of HPWBM containing the new polymer chemistry exceeded the operator's expectations in reduction of operational time and expense. Summary of results:

- A 15.29 reduction in cost per foot in the lateral section, from $9.89/per foot to $8.38/per foot. (Figure 13)
- Average drilling day in lateral section (KOP to TD) reduced 58.32% from 13.39 days to 5.58 days. (Figure 13)
- Average fluids cost per foot reduced by 29%, from $8.72 to $6.21 (Figure 13)
- Average total days on well reduced by 37.44% from 20.26 days to 12.68 days. (Figure 13)
- Average Feet/Day increased 32.31% from 1061.21'/Day to 1591.18'/Day from spud to total Depth (Figure 14)
- Average Feet/Day in lateral section (KOP to TD) increased 52.58% from 787.10' to 1,659.88' (Figure 14)
- Average of 7.59 days saved compared to the traditional fluid strategy. Approximate AFE savings of over $546,135 per well based on a daily spread rate of $72,000
- A reduction in fluids costs of 53.18%
- Record well drilled in 10.1 days spud to TD/11.7 days Spud to Rig Release on a 4 string 20,000'± TMD Wolfcamp Horizontal well.
- Reduction in diesel consumption of approximately 33,600 gal/well @ 2.54/gal is a $85,344/well in savings.
- HPWBM does not require a motor realignment like NAF, a savings of $9,000/motor x 2 motors is $18,000 in savings.
- HPWBM is built on location, while NAF is shipped from the mud plant and trucking charges average approximately - 18 loads x 5 hours/load x $125/hr. equals $11,250 in savings.
- Added costs of NAF include NAF cuttings disposal, rig hand bonuses, pit cleaning, and truck washouts.
- HPWBM is designed to be safe for the environment, adhering to government regulations and ESG requirements.
- Multi-functional polymer chemistry provides cuttings encapsulation, filtration control and viscosity.
- Environmentally responsible – smaller footprint on location. Reduced product and barite consumption equate to less trucking impact on cost and the environment.

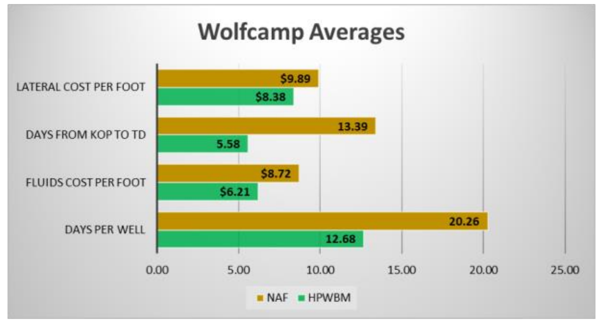

Figure 13, Wolfcamp Averages

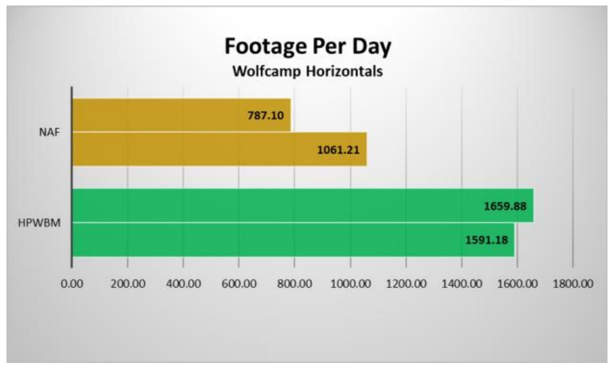

Figure 14, Average Feet per Day in the Lateral

Nomenclature

HPWBM = High-Performance, Water-based Mud
NAF = Non-Aqueous Fluid
H2S = Hydrogen Sulfide
NPT = Non-Productive Time (hours)
ROP = Rate-of-Penetration (feet per hour)
ECD = Equivalent Circulating Density (pounds per gallon)
ESG = Environmental, Social, Governance
HGS = High Gravity Solids
PV = Plastic Viscosity (centipoise)
DLS = Dog Leg Severity
COG = Coefficient of Friction
WBM = Water-based Mud
F/C = Temperature (Fahrenheit/Celsius)
KOP = Kick-Off Point (feet)
TD = Total Depth (feet)

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