

New Water-Based Fluid for Increased Onshore Drilling Performance

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This paper was prepared for presentation at the 2008 AADE Fluids Conference and Exhibition held at the Wyndam Greenspoint Hotel, Houston, Texas, April 8-9, 2008. This conference was sponsored by the Houston Chapter of the American Association of Drilling Engineers. The information presented in this paper does not reflect any position, claim or endorsement made or implied by the American Association of Drilling Engineers, their officers or members. Questions concerning the content of this paper should be directed to the individuals listed as authors of this work.

Abstract

A new water-based mud system for onshore environments has been successfully introduced to provide increased drilling performance as compared to conventional water-based mud (WBM) systems. As onshore wells become more challenging, conventional water-based mud systems do not provide the technical aptitude required to drill these wells efficiently. As a result, operators choose to use oil-based mud systems (OBM) to reach their drilling objectives. Despite their technical merits, OBMs are often a costly solution with regard to waste disposal and lost circulation.

A new high-performance water-based mud system has been designed to fill the technical performance gap between conventional WBM and OBM for onshore and inland water drilling. The system has undergone extensive field testing in a variety of onshore wells. This paper presents results from a three-well campaign in a South Texas field where differential sticking, losses, twist offs and catastrophic wellbore stability problems were experienced with conventional WBM and OBM. The paper provides a detailed technical overview of the system, the advantages of using the system as compared to conventional WBM and presents case histories from the South Texas drilling campaign.

Introduction

As fields mature and operators continue their search for oil and gas, well complexity is ever-increasing. Not only are operators conducting more advanced drilling operations, such as extended reach, horizontal, and HP-HT drilling, they are also expanding globally into difficult and hard-to-reach locations. Because of the technical difficulty associated with these wells and the remote areas in which they are drilled, exploration and development has become increasingly risky.

Conventional WBM systems have given way to OBM due to the technical benefits and ease of use associated with OBM systems. These inherent advantages provided by OBM are, however, being offset by regulations, disposal costs and concerns over the environmental impact associated with the system. Operators are constantly challenged to balance performance requirements with environmental, waste disposal, economic and logistical drivers.

In recent years, high performance water-based muds (HPWBM) have been introduced. These systems provide performance characteristics approaching that of OBM with reduced environmental impact. A downside of these HPWBM is that they are considered to be costly as compared to conventional WBM and many times approach the costs of an OBM. However, if the HPWBM performs similar to an OBM, the benefits can justify the cost when considering disposal costs and lost circulation events commonly associated with OBM.

This paper presents a new onshore HPWBM that balances superior performance and environmental compliance while still maintaining cost competitiveness as compared to conventional WBM systems.

HPWBM Attributes

Water-based drilling fluids that are designed to emulate the performance attributes of OBMs are referred to as "high performance water-based systems." The key attributes that make OBM effective in difficult wells are:

- shale stability through a reduction of pore pressure transmission
- control of reactive clays
- control differential sticking tendencies
- high rate of penetration (ROP)
- lubricity to minimize torque and drag
- ease of engineering

HPWBM are designed to provide all of these characteristics collectively. Many times, however, not all of the attributes are necessary for a given well or for a particular interval. A new HPWBM has been developed that can be custom fit to a particular field that has a proven superior performance record and is competitive in cost to a conventional WBM.

Shale Stability

Roughly 75% of the formations drilled contain reactive shale, and over 90% of the well-bore stability problems are related to the drilling fluid's inability to control the reactive shale. The most important variable in maintaining shale stability is preventing pore pressure invasion into the shale matrix^{1,2,3,4}. Pressure invasion alters the near wellbore stress state and can induce failure. Shale stability is achieved

when pressure invasion is reduced and differential pressure support is maintained.

The HPWBM incorporates a micronized deformable sealing polymer (MDSP) to mechanically bridge shale micropores, micro-fractures and bedding planes, creating an effective barrier that prevents destabilizing pressure transmission into the shale (Figure 1).

In addition to the mechanical bridging provided by the MDSP, an aluminum complex is utilized that precipitates out in the pore throats of shale matrix upon lowering of pH or contact with multivalent cations. The aluminum complex forms a semi-permeable membrane, which provides an additional barrier to pore pressure transmission. An independent study of pore pressure transmission and membrane efficiency in shale concluded that aluminates and silicates equally provide the highest membrane efficiencies in WBMs⁵.

Clay Swelling

The inability to suppress hydration in reactive clays leads to complications such as bit balling, accretion, poor solids removal efficiency, high dilution rates, filtration control and control of rheological properties. Reactive clay swelling, along with pore pressure transmission, is a leading cause of shale instability.

Clay hydration occurs from surface hydration, bonding of water molecules to oxygen on the surface of the clay, and ionic hydration, which is the hydration of interlayer cations with surrounding shells of water molecules⁵. Surface and osmotic absorption leads to two distinctly different problems: swelling, which is the expansion of the clays due to water uptake; and dispersion, which is the disintegration of the clay fabric after hydration.

Clay inhibition is more difficult to achieve with water-based systems due to the similarity of the wetting characteristics between the drilling fluid and the formation. The new HPWBM uses an environmentally acceptable water-soluble clay hydration suppressant to stabilize highly reactive clays through a cation exchange mechanism. The suppressant effectively inhibits reactive clays from hydrating, thus controlling problems associated with reactive shales.

Wellbore Strengthening/Differential Sticking

Stuck pipe due to differential pressures in depleted zones is problematic with WBM and OBM. The MDSP developed for the new HPWBM, utilized with the proper selection of lost-circulation-material (LCM), has proven to reduce differential sticking tendencies when drilling depleted zones. The MDSP will bridge at the borehole interface of low permeability formations, such as tight gas sands. This bridging creates an external as well as an internal filter cake, which effectively controls differential sticking tendencies.

Additionally, the internal filter cake enhances the effective rock strength, thereby increasing the formation fracture resistance. This increase in rock strength allows depleted sands to be drilled with the appropriate mud weight required to control pressured shales and/or pressured production sands

while reducing mud losses to the depleted formation⁶.

Maximizing ROP/Minimizing Torque and Drag

Conventional WBM often exhibit low rates-of-penetration (ROP) as compared to those delivered when drilling with OBM. The drilling of soft, reactive formations often presents issues with regard to bit balling and, consequently, a reduction in ROP. Bit balling is due to reactive clay accretion on the water-wet bit and bottom-hole-assembly (BHA), which effectively prevents the bit from contacting the formation. The new HPWBM contains an ROP enhancer that preferentially "oil wets" the bit, drill string and other metal components with environmentally friendly base fluids and surfactants. The ROP enhancer renders the metal surfaces hydrophobic, reducing the tendency of reactive clays to adhere to the bit and BHA surfaces.

A proprietary method of addition is employed to inject the ROP enhancer so that a continuous, non-emulsified stream of additive is contacting the bit during drilling. This provides a step change in performance by minimizing mechanical emulsification and reducing concentrations of the product needed to deliver performance.

A secondary function of the ROP enhancing additive is a reduction in frictional forces arising from contact between the drilling assembly, tubulars and the open hole. Friction factors are representatives of the true friction coefficient of a drilling fluid. Based on torque and drag observations from field data, the new HPWBM has been shown to exhibit friction factor values approaching those of OBM.⁷

Environmental Compliance

Unlike previously developed HPWBM when drilling onshore, the new HPWBM system is designed to provide wellbore stability in a freshwater or low salinity environment. This presents a considerable advantage for waste treatment in land environments, particularly where discharge of chlorides is restricted. In a multi-well campaign, the system can be recycled and re-used on subsequent wells, thus saving the operator valuable mixing and rig time. In addition, mud reclamation reduces the total amount of fluid required, ultimately lowering the overall environmental impact of the drilling operations.

Based upon field data, the new HPWBM has also been shown to exhibit reduced dilution rates as compared to conventional water-based systems. Field studies have demonstrated that the HPWBM averages dilution rates less than 0.7 bbl/ft, whereas typical WBM systems average over 1 bbl/ft.⁷ This reduction in dilution rate translates into not only lowered waste disposal costs but also reduced chemical usage.

Additional Considerations

Other positive attributes associated with the new HPWBM include:

- Image log quality
- Efficient cementing operations
- Logistics and HS&E concerns

- Barite sag reduction
- Early detection of gas kicks
- Gauge wellbore
- Flexibility to meet specific performance objectives

Field Challenge

Production in gas wells in South Texas has been ongoing for half a century, resulting in severe reservoir depletion.⁸ The level and presence of depletion is difficult to determine due to production commingling, complex geology and the low permeability of the formations. The inability to accurately predict reservoir pressures led some operators to redesign well programs. In the early 1990s, operators changed casing programs from the standard 13-3/8"x9-5/8"x7-5/8" to a more conservative 16"x11 3/4"x9-5/8" with a 7-5/8" contingency liner to set before drilling into a potential depleted zone.⁹ Beginning in 2000-2001, some operators chose a new method, underbalanced drilling with casing (UBDWC) to avoid associated problems with depleted zones. While UBDWC did improve well economics on re-entry wells, there are some drawbacks on new drills, such as open hole logging. The challenge then for new drills is to optimize drilling efficiency without compromising the ability to log the open hole.

Although some operators are using UBDWC, many still attempt to drill with standard casing programs and rely on the drilling fluid to provide a means to control severe losses. The case histories below highlight a three-well campaign by an independent operator drilling with the new HPWBM. These three case histories are compared to wells drilled earlier with conventional WBM and OBM in the same field by this operator.

Offset wells

In Brooks County, offset wells are typically drilled to total depths (TD) between 11,700' and 14,200', at bottom hole temperatures ranging from 270 to 320 °F. Typical wells set surface pipe at 2,000' and intermediate pipe between 9,500' and 11,000', near or just below the top of the Vicksburg formation. The Vicksburg sands are encountered just below intermediate casing point and can extend for hundreds of feet in multiple sand packages. The laminated character of the Vicksburg typically consists of shale/sand sequences with productive intervals varying in permeability from 0.01 milliDarcy (mD) to 10 milliDarcy.

Since 1998, twenty nine (29) wells have been drilled by the operator in the area, twenty four (24) using WBM and five (5) using OBM. Over 50% of the wells drilled by the operator experienced one or more of the following problems: Lost circulation, stuck pipe, CO₂ contamination, poor cement jobs or excessive gas influx. Six of the wells using WBM experienced problems where the wells had to be either sidetracked or abandoned. The average mud weight used to drill the offset wells was 17.5 – 18.5 ppg, and the average number of days for each well was 35 – 40 days. Losses on the offset wells exceeded hundreds of barrels of fluid while

utilizing WBM and thousands of barrels using OBM. The small differential between pore pressure and fracture initiation pressure, along with the fracturing nature of oil-based fluids, led the operator to use conventional WBM.

The problems associated with drilling the Vicksburg with conventional WBM are low ROPs and excessive hole enlargement. Partial or total casing collapses have been documented in a number of wells, and it is believed that excessive washout may contribute to inadequate primary cementing. In early 2007, the operator made the decision to apply the new HPWBM in hopes of minimizing the issues encountered when drilling with WBM, while increasing drilling performance.

Fluid Formulation

Based upon the formations encountered and the problems on offset wells, the HPWBM was customized to balance fluid costs and performance. The HPWBM consisted of the micronized deformable sealing polymer, aluminum complexand an ROP enhancer. Table 1 lists the fluid formulation proposed for drilling the first well.

The combination of these products was designed to reduce pore pressure transmission and subsequent fluid invasion into the lower pressure sand zones. The micronized deformable sealing polymer (MSDP) was also selected because its particle size distribution is ideal to seal and bridge the tight permeabilities found in the Vicksburg sand sections.

Case History #1

The first well utilizing the new HPWBM was a vertical hole with a TD of 13,600'. Conventional WBM was used to drill the 17-1/2" hole section to 2,000'. 13-3/8" casing was then set and a 12-1/4" hole was drilled using conventional WBM to 10,250'. 9-5/8" casing was set at 10,250'. The new HPWBM was then used to drill the 8-1/2" production interval from 10,250' to 13,600'. This section is difficult to manage due to highly depleted sands, a pressure transition requiring mud weights between 15-17 lb/gal within the first one hundred and fifty feet (150 ft) and a BHT of approximately 320° F. The mud weight at TD for the 8-1/2" interval was 18.3 ppg.

No losses, well control events, sticking or stuck pipe were encountered drilling the interval. A 7" contingency liner was also planned while drilling the 8-1/2" hole section, in preparation of severe problems when attempting to drill this section, such as seepage, loss of circulation, well control and stuck pipe. The Upper Vicksburg Sand and Lower Vicksburg Sands are severely depleted or highly pressured with a pore pressure of 17.5 ppg to 18.5 ppg. Utilizing the HPWBM in the 8-1/2" section resulted in successful drilling to a TD of 13,600', thereby eliminating the liner.

The well was drilled to TD in 26 days, compared to the estimated programmed days of 35 days. The nine days of rigtime saved netted the operator an estimated \$500,000 USD in savings to the cost of the well. At the end of the well, the mud was treated with a biocide and stored for use on the next well. Retaining the mud not only lowered fluids-related costs but also eliminated the need to mix new mud on the rig,

thereby saving valuable rig time.

An after-action-review (AAR) was conducted upon completion of the well to evaluate the fluid's performance. A committed effort was made by the operator and the fluids company to fully and objectively use the AAR to drive improvements for the Sullivan drilling campaign. Key elements of the AAR process included: 1) What was planned, 2) What was achieved, 3) Highlights, 4) Areas of improvement, 5) Lessons learned, 6) Recommendations. Findings of the AAR process included:

Highlights

- No mechanical or differential stuck pipe events
- No downhole losses
- Completion of the well with less mud weight
- Elimination of the 7" contingency liner

Areas of Improvement

- Reduce fluid costs
- Hole enlargement due to washout
- Lower than desired ROP

Lessons Learned

- Fluid formulation was over-engineered
- ROP enhancer was effective at high concentrations
- HPWBM was effective at bridging depleted formations and preventing losses and stuck pipe

Recommendations

- Adjust fluid formulation to reduce costs
- Use mineral oil in place of ROP enhancer
- Evaluate and optimize bit hydraulics for improved ROP and reduced washout

Case History #2 (Offset to Case History #1)

Well #2 was a vertical hole with a TD of 13,811'. Conventional WBM was used to drill the 17-1/2" hole section to 2,030'. 13-3/8" casing was set and a 12-1/4" hole was drilled using conventional WBM to 10,680', followed by setting 9-5/8" casing at 10,680'. The HPWBM was used to drill the 8-1/2" production interval from 10,680' to 13,811' with recommendations from the AAR.

The mud from the previous well was brought to the rig, cut back to 16.0 ppg and used for the interval. The ending mud weight for the 8-1/2" interval was 17.8 ppg with no losses, seepage, sticking or stuck pipe, which eliminated the need for the 7" contingency liner.

The well was drilled to TD in 24 days, compared to the estimated programmed 35 days. The 11 days of reduced rigtime resulted in \$600,000 in cost savings to the operator. Improvements implemented after the AAR reduced the drilling time by two days as compared to Well #1. Similar to the previous well, the mud was treated and stored for use on yet a third well.

Once again, an AAR was conducted to further improve the performance of the mud system. Excessive hole enlargement was again noted on Well #2, despite modifying the bit hydraulics. The main recommendation resulting from the second AAR was the use of potassium hydroxide instead of caustic soda for pH control. The potassium hydroxide would

provide additional shale inhibition to the mud system to prevent washout.

Case History #3 (Offset to Case History #1 and #2)

The third and final well in the Brooks County campaign was a vertical hole with a TD of 13,600'. Conventional WBM was used to drill the 17-1/2" hole section to 2,011'. Surface casing was set, and a 12-1/4" hole was drilled using conventional WBM to 10,833'. 9-5/8" casing was set, and HPWBM was used to drill the 8-1/2" production interval from 10,833' to 13,600'. The bottom hole temperature was approximately 310° F.

The use of potassium hydroxide in place of caustic soda helped reduce the washout observed in Well #1 and Well #2 (Table 2), which led to better primary cement jobs on the wells.

The ending mud weight for the 8-1/2" interval was 18.4 ppg. The well was drilled to TD with no losses, seepage, sticking or stuck pipe and eliminated the need for the 7" contingency liner.

The well was drilled to TD in 20 days, which the Operator stated was a record well drilled in Brooks County. This well was programmed for 35 days. The 15 days of reduced rig time netted the operator over \$700,000 in cost savings.

Campaign Results

The three-well campaign utilizing the new HPWBM was considered by the operator to be highly successful, as all three wells were completed ahead of schedule; and in the case of Well #3, set a new drilling record for days vs depth in Brooks County. (Figure 2) Figure 3 shows the days vs. depth curve for the three wells drilled with the HPWBM as compared to offset wells drilled with conventional WBM systems. The wells drilled with the HPWBM were completed on average of 23 days faster than those drilled with conventional systems.

All three wells were also drilled to TD with a lower mud weight than the offset wells. The reduction in final mud weight helped eliminate losses and reduce chemical consumption costs. Figure 4 shows the mud weight vs depth for the three wells drilled with the HPWBM as compared to offset wells drilled with conventional WBM systems. The wells drilled with the HPWBM reached TD with an average mud weight of 0.5 lb/gal less than those wells drilled with conventional systems. Table 3 shows the average fluid properties for each of the three wells drilled using the HPWBM.

The record drilling rate, the reduced mud weights and the ability to recycle the mud system from well to well saved the operator an average of \$500,000 per well, for a total savings of \$1.5 million over the three-well campaign.

Conclusions

- A new onshore HPWBM has been developed and successfully trialed in South Texas tight gas wells.
- The HPWBM provided improved operational performance compared to offset wells drilled with

conventional WBM.

- The fluids costs of the HPWBM were comparable to those of a conventional WBM, with significantly improved performance.
- The fluid minimized losses and eliminated stuck pipe events, while reducing the environmental impact of the drilling fluid.
- Minimum washouts were experienced, resulting in good cement bond, and high quality image logs were obtained.
- No formation damage occurred.
- The system has set new performance benchmarks for the area and has become the preferred fluid of choice for the Sullivan Survey.
- The Operator saved a total of \$1.5 million on the three wells by using the new HPWBM.

Acknowledgments

The authors thank Brigham Oil and Gas and Baker Hughes Drilling Fluids (BHDF) for permission to publish this paper. The authors also would like to recognize the contributions of Billy Dye, Chuck Smith, Kathrine Barre, Nels Hansen, Grant Newton, and Cody McDowell (BHDF) for their contributions to this paper.

Nomenclature

Define symbols used in the text here unless they are explained in the body of the text. Use units where appropriate.

<i>BHA</i>	= <i>Bottomhole assembly</i>
<i>BHT</i>	= <i>bottomhole temperature, (°F)</i>
<i>WBM</i>	= <i>Water-based mud</i>
<i>HPWBM</i>	= <i>High-performance water-based mud</i>
<i>LCM</i>	= <i>Lost Circulation Material</i>
<i>OBM</i>	= <i>oil-based mud</i>
<i>Ppg</i>	= <i>pounds per gallon</i>
<i>ROP</i>	= <i>rate of penetration (ft/hr)</i>
<i>TD</i>	= <i>Total Depth (ft)</i>
<i>MSDP</i>	= <i>micronized deformable sealing polymer</i>
<i>AAR</i>	= <i>After-action review</i>

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Table 1: Proposed Fluid Formulation for Brooks County

Product	16.0 ppg	18.0 ppg
Water, bbl	0.6208	0.5424
Bentonite, lb/bbl	5.0	4.0
Filtration Reducer, lb/bbl	1.0	0.5
Sulfonated Asphalt, lb/bbl	5.0	5.0
HTHP Filtration Reducer, lb/bbl	5.0	4.0
Aluminate, lb/bbl	6.0	6.0
MSDP, lb/bbl	2.0	2.0
ROP Enhancer, vol%	1.0	1.0
Barite, lb	411.88	524.85
Sized LCM, lb	7.5	7.5

Table 2 – Average Hole Sizes for HPWBM wells as compared to offset wells

Well Name	Hole Volume	Start	Stop	Average Hole Size (Caliper)	Bit Size	Hole Diameter Enlargement
Well #3	1,160	10,808	13,523	8.85	8.5	4.1%
Well #2	1,635	10,672	13,490	10.31	8.5	21.3%
Well #1	2,197	10,268	13,621	10.96	8.5	28.9%
Average WBM Offsets	1,664	10,583	13,545	10.04	6.5	18%

Table 3 – Average Mud Properties for the HPWBM Wells

Property	Well #1	Well # 2	Well #3
Mud Weight, lb/gal	17.0	17.0	17.6
PV	28	25	31
YP	25	15	12
API FL, mls	3	3	3
6/3 rpm	14/12	9/10	10/16
10 sec gel	14	9	9
pH	11.2	11.2	11.2
MBT, ppb	15-17.5	20-22	20-22

Figure 1: MDSP seals micro-fractures in shale, reducing pore pressure transmission and promoting wellbore stability

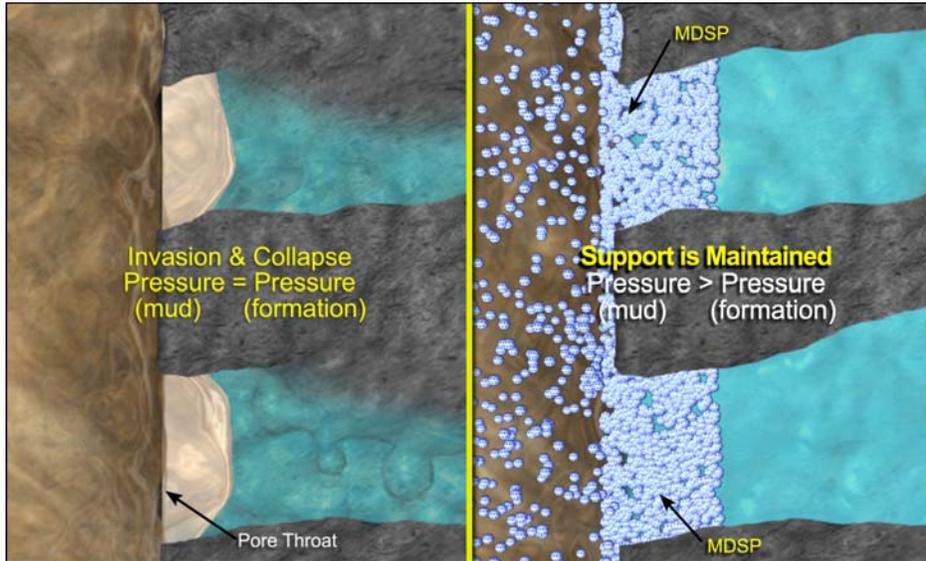


Figure 2 – Planned Days vs. Actual Days Drilled using the new HPWBM

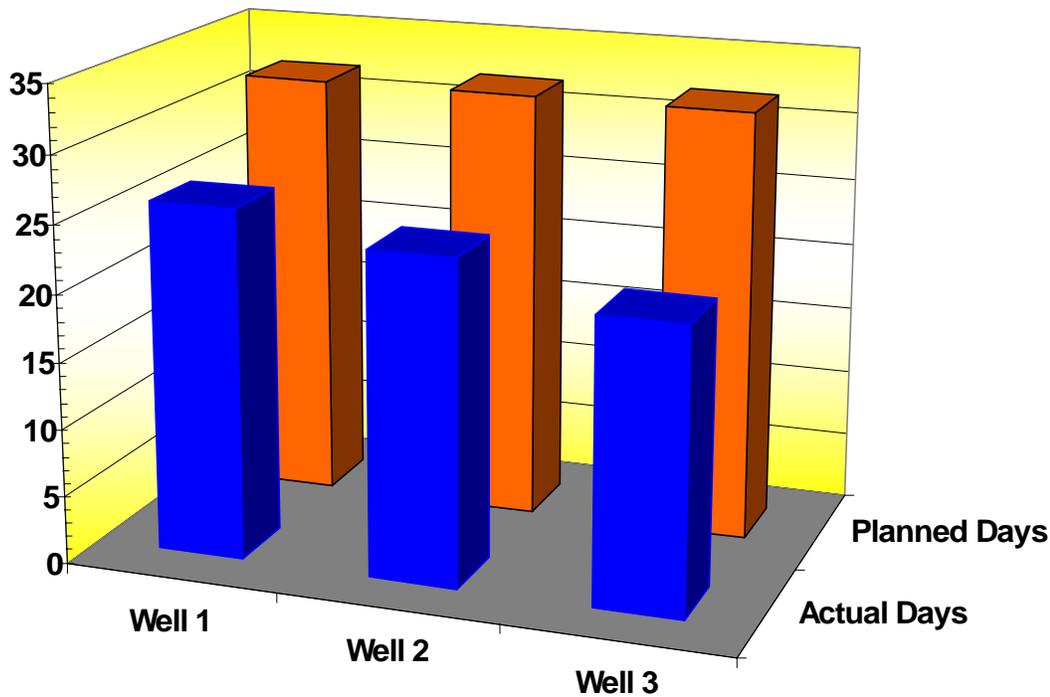


Figure 3 – Days Vs. Depth Comparison of HPWBM Wells with Offsets in Brooks County

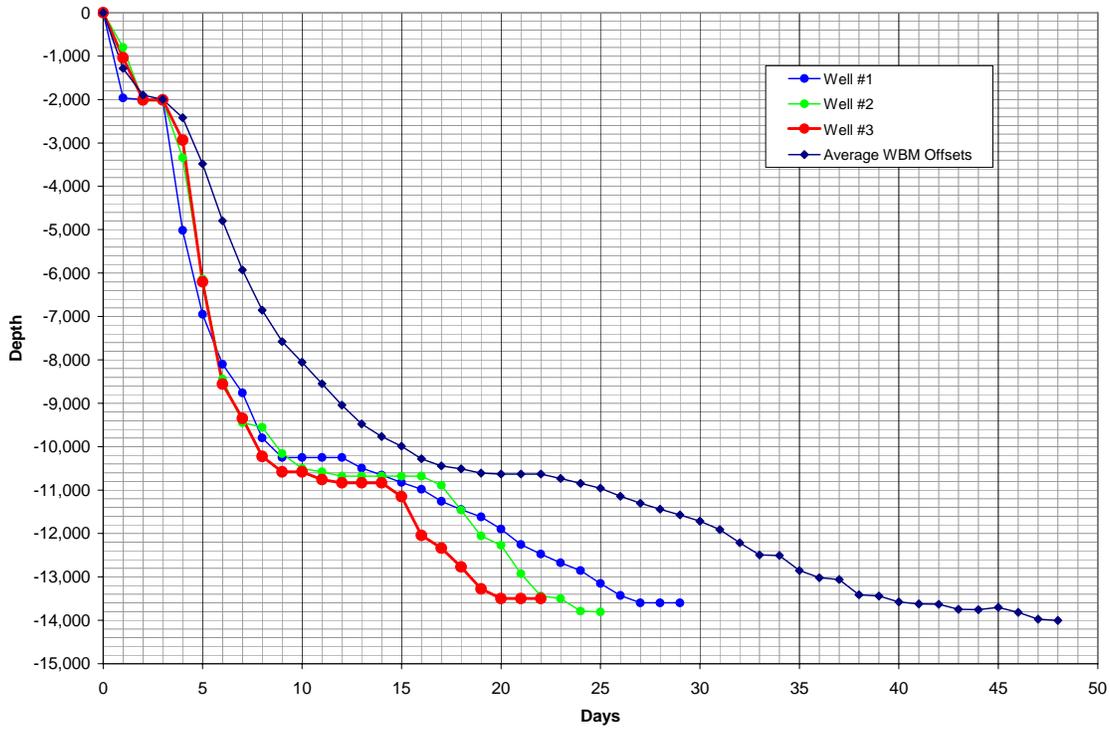


Figure 4 – Mud Weight vs Depth Comparison of HPWBM wells with Offsets in Brooks County

