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Application of High Performance Water-Based Mud in Woodbine Horizontal Wells

Tyler Langford and Lance Blanchard, Halcón Resources; Shannon Comeaux and Harry Dearing, Newpark Drilling Fluids

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Abstract

The Woodbine formation of southeast Texas represents one of North America's newest and most prospective oil plays. As with many emerging areas that have been drilled extensively with vertical wellbores, the Woodbine presents challenges when drilled horizontally. Shale instability and lost circulation are but two of the issues that pose relatively minor problems in vertical wellbores, but become major obstacles to the successful drilling, evaluation and casing of a horizontal well.

This paper describes the design and application of a high performance water-based drilling fluid that has proven effective in mitigating the historical horizontal drilling problems in the Woodbine sandstone. An examination of the formations to be drilled and designing a fluid specifically tailored to deliver a stable and usable wellbore provided a basis to begin execution. The initial work resulted in guidelines for inhibitor types and concentration. Prior experience in a number of horizontal areas with over a thousand applications of the high performance water- based drilling fluid provided sufficient data to set lubricity targets. Using these design parameters, fluid formulations and drilling fluid programs were integrated into comprehensive well plans.

The authors will discuss the successful drilling of a number of Woodbine horizontal wells that has since led to an ongoing program to deliver wells as required by the resource development plan. Continuous improvement during the drilling campaign resulted in enhancements that further reduced the time and costs of subsequent wells. Among the operational improvements were simplified well plans with reduced hole sizes and fewer casing strings. A total of eight wells in Madison and Leon counties will be reviewed with particular emphasis on the continual progress in improving design and execution, which will be illustrated in detailed analysis of well trajectory, hole sizes, casing depths and day curves.

Introduction

The Woodbine formation consists of a Cretaceous-aged series of sandstone and siltstone rocks, located at about 6,400-9,600-ft depths across several East Texas counties (Fig.1). The Woodbine resides within the prolific Eagle Ford source rock and is generally described as being between the overlying Austin Chalk formation and the underlying Buda formation.[1] Studies and log data of the normally pressured and organic- rich sandstone indicate a hydrocarbon bearing formation with high resistivity (oil saturated) and decent porosity (storage capacity).

The subject zones have been produced conventionally for decades, but more recently horizontal drilling and multistage hydraulic fracing are allowing operators to redevelop this conventional asset. Consequently, the play has emerged as a highly prospective resource opportunity in East Texas. A Tudor Pickering Holt (TPH) examination of Woodbine horizontal wells completed in 2010-2011 showed that since it has produced conventionally, rates of return typically are higher than other unconventional resources.[2] At that time, the estimated ultimate recovery (EUR) of Woodbine wells was listed at 250 mboe with initial production (IP) rates of 650 boepd.

Halcón Resources holds approximately 150,000 net acres in East Texas, much of which are prospective for the Woodbine formation. During the fourth quarter of 2012, Halcón was operating up to four rigs in the play.

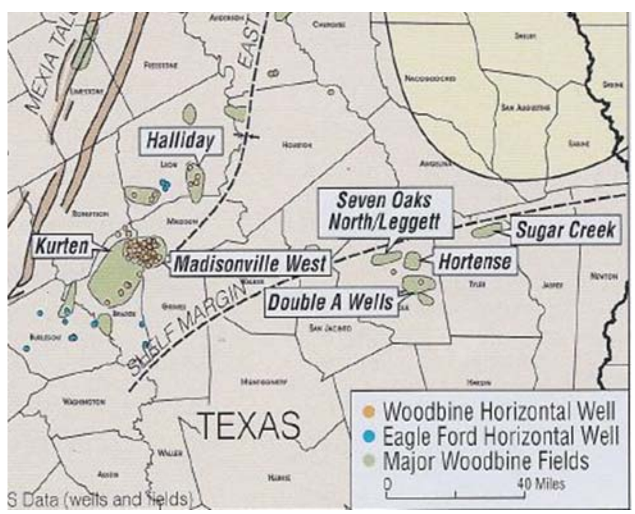

Fig. 1: Woodbine play delineated boundaries (Source: IHS Data)

Overall Well Summaries

The eight wells of this study represent wells drilled from four drilling locations with five wells in Leon County, TX and three wells in Madison County, TX. The five Leon County wells were drilled with two wells each on two pads with the fifth well a single well location. Conversely, the three Madison County wells were drilled on a single pad. Table 1 presents a thumbnail summary of all eight wells.

Table 1: Summary of well depths, days and number of casing strings

Well Name	MD, ft	TVD, ft	Days	Csg
Leon County, TX				
Mamie Wakefield 3H	12,654	6,600	24	3
Mamie Wakefield 3A2 4H	12,525	6,643	16	2
Zach Wakefield 2 1H	14,265	7,066	21	2
Zach Wakefield 2 2H	15,080	7,105	17	2
Champion Ranch B1H	13,765	6,847	17	2
Madison County TX				
Samantha Rizzo 1H (with pilot hole)	15,899	8,739	42	3
Samantha Rizzo 2H	15,893	8,771	28	3
Samantha Rizzo 3H	16,330	8,768	25	3

The wells in this study provide a representative cross section of the measured and total vertical depths and the geometries of the horizontal wellbores drilled in the Woodbine formation. All the examined wells were spudded in the fourth quarter of 2012.

Offset Review

From an historical perspective, drilling horizontal wells in the Woodbine formation has proven to be much more difficult than would be expected given the numerous vertical wells that have been constructed in the area over many years. Typical vertical well plans into the Woodbine set a surface string at approximately 2,000-ft MD/TVD and, depending on the depth of the Woodbine, drill to total depth of 7,000 to 9,000-ft MD/TVD.

Usually, the drilling fluid of choice is a low-solids non-dispersed system with minimal treatment at a density of 10-lb/gal or less. In some areas where shale stability is a concern, sulfonated asphalt is used to drill the reactive Midway shale zone. For these wells, remediating lost circulation issues in the weaker zones simply requires spotting lost circulation material (LCM) and reducing mud weight.

Adhering to this casing program and using a similar mud system has proved to be problematic for Woodbine horizontal wells for a number of reasons:

- Exposure time of the troublesome Midway more than doubles from three to five days to 10 to 14 days
- Build sections in the low-strength zones require higher density fluids to maintain wellbore stability[3] due to stress changes from wellbore orientation
- Because of the higher mud weight requirement, severe lost circulation is more likely
- Some areas of the Woodbine sand are pressure depleted from production

Considerable experience in the area has confirmed that a different approach is required to successfully drill long lateral Woodbine horizontal wells. A critical first step in this new approach required a detailed shale analysis coupled with an experimentally proven drilling fluid design that would serve as a starting point for a successful well.

Shale Analysis

Cuttings from offset wells in Madison County were analyzed. A summary of the analysis from the primary offset well is shown in the appendix in Table A1. Composite samples from the depths of interest included 6,700-7,300-ft, 7,390-7,840-ft, and 8,020-8,500-ft. The complete results for the composite sample from 8,020-8,500-ft are given in Fig. A1 as an example of a complete X-ray diffraction/X-ray fluorescence analysis using proven procedures[4].

As such, the new generation high-performance water-based mud (HPWBM) was selected for the horizontal drilling campaign due to its consistently low coefficient of friction (CoF) and proven performance in over 1,000 horizontal wells throughout North America. The shale analysis identified the need for a high degree of inhibition from the system and a number of candidate shale inhibitors (Table 2) were considered. A careful review of the analytical results suggested that potassium compounds would provide the needed performance.

The reasons that potassium compounds were selected as the most promising and effective inhibitors is due to the types of clay present in the Madison County shale samples. Potassium ions have proven to be effective shale inhibitors in illitic and mixed layer clay dominated shale[5]. The clay content of the shale samples show that these formations contained illite and mixed layer clays. The cation exchange capacity (CEC) was also relatively high at 20 to 22 meq/100g. Sulfonated asphalt and glycol based additives were found to have been used without much success in offsets so they were eliminated from consideration. Also, the polymers present in the HPWBM serve to provide a similar coating action to these additives.

Additional inhibitors may have application in future wells due to changing conditions within the play. In particular, in areas where mud densities higher than 10 lb/gal can be required, a sodium chloride brine system using a concentration of 15 wt% to 26 wt% salt may prove to be cost effective. Recent experience with field brine based HPWBM in the Eagle Ford suggests this may be an alternative to the potassium compounds chosen for application when higher mud densities are required in the Woodbine. Use of brine can complicate cuttings and fluid disposal, so all aspects of its use should be examined prior to selecting it as a drilling fluid.

Table 2: Inhibitors considered for use in Woodbine wells

Inhibitor	Concentrations, lb/bbl
Potassium acetate	1 to 4 lb/bbl
Potassium silicate	2 to 8 lb/bbl
Potassium carbonate	1 to 6 lb/bbl
Potassium chloride	5 to 15 lb/bbl
Amine compounds	0.5 vol% to 3 vol%
Glycol based additives	0.5 vol% to 3 vol%
Sodium chloride	10 to 26 wt% (saturation)
Asphaltic materials	2 to 8 lb/bbl

Drilling Fluid Design

First developed to reduce costs and improve performance in the Haynesville shale[6] tight gas resource area, the high performance fluid comprises a thermally stable synthetic viscosifier, a performance enhancing additive that consistently reduces the drilling fluid coefficient of friction (CoF), a high-temperature low-end rheology modifier, and a water-wetting surfactant conditioner that prevents solids from become oil-wet. In areas with bottom hole temperatures lower than 275°F, the high-temperature rheology modifier is not required.

Table 3 presents a typical mud formulation with the rheological properties maintained for the study wells. In addition to the products specific to the high-performance fluid and inhibitors, additives for supplemental filtration control and secondary viscosity provide the necessary filtration control and low-end rheology. One key property of the HPWBM is the coefficient of friction (CoF) value, which is measured using a lubricity tester (Fig. A1). Although most often used in a laboratory setting, this key value is measured with each check of the fluid properties at the rig site. Accordingly, the lubricity is one of the most crucial properties of the HPWBM mud and is measured frequently and can be adjusted to meet specific target values.

Table 3: High performance fluid formulation in fresh water

Additive	Concentration
Potassium source	As required
Synthetic viscosifier liquid	2 lb/bbl
Xanthan gum	¼ to ½ lb/bbl
Polyanionic cellulose	½ to 1 lb/bbl
Performance enhancer	3 vol%
Conditioner	¼ to ½ lb/bbl
Barite	as required
Potassium hydroxide	for pH
Properties	
Density	9.0 to 10.0 lb/gal
Plastic viscosity	10 to 15 cPs
Yield point	15 to 20 lb/100 ft^2
API Filtrate	less than 6 cm^3/30 min
pH	9.5 to 10.5
Coefficient of friction (CoF)	0.06 to 0.08

Drilling Fluids Program

Along with maintaining effectual hole cleaning properties in the upper and lateral sections, one of the principal requirements of the drilling fluid program was to maximize wellbore stability in the highly reactive shale sections of the intermediate interval. From a wellbore stability perspective, of primary concern was the historically problematic Midway Shale immediately underlying the 10-3/4-in surface casing. The potassium source provides the required wellbore stability.

The initial wells both in Madison and Leon County for the Woodbine program were programmed with three casing strings to compensate for the expected wellbore stability challenges. However, owing to the effectiveness of the new HPWBM in inhibiting the reactive clays and maintaining a stable wellbore, the intermediate string was eliminated for the remaining four Leon County wells.

The three-string casing program for the four wells using it comprised:

Surface casing
Hole size/depth: 14-3/4-in to 3,400-4,000-ft MD/TVD
Casing size: 10-3/4-in

Intermediate casing
Hole size/depth: 9-7/8-in to kick off point (KOP) at 6,050-ft MD/TVD
8-3/4-in to landing point at 6,960-ft MD / 6,650-ft TVD
Casing size: 7-5/8-in or 7-5/8-in X 7-in

Production casing
Hole size/depth: 6-3/4 in or 6-1/8 in to 12,500-ft MD
Casing size: 5-1/2-in and 4-1/2-in

For these wells, the 14-¾-in surface hole would be drilled to the 10-¾-in casing point at 3,400-4,000-ft using a lightly treated water-based mud with high-viscosity bentonite sweeps every 45 feet to optimize hole cleaning. For the first Madison County well, the WBM used in the upper hole would be treated with a purified carboxymethylated starch filtration control agent to reduce fluid loss below 7 cc/30 min just prior to entering the Wilcox.

The mud program calls for displacement with the new HPWBM to drill the 9-7/8-in pilot hole, 8-¾-in curve and the 6-¾-in lateral production interval. For these sections, plastic viscosity (PV) would be maintained at between 10-15 cPs with less than 8% low-gravity solids (LGS). The yield point (YP) would be maintained from between 15 and 24 lb/100ft^2 to the production string. In Madison County, an elevated mud density was required to help stabilize the shale section just above the Woodbine.

After landing the curve and setting intermediate casing, the mud weight was to be reduced from a high of 10.2 lb/gal to between 8.9 and 9.2 lb/gal to drill the lateral section. For the production hole, the mud was treated with a performance enhancing additive at 3 to 5 vol% to keep the CoF within the programmed range of 0.05 to 0.09. The performance enhancing additive reduces torque and drag and increases penetration rates by improving weight transfer to the bit and reducing cuttings adhesion to bit surfaces.

Owing to the impressive wellbore stability observed in the first two wells, the decision was made to eliminate the intermediate casing string in the subsequent wells in Leon County.

The new representative casing program was:

Surface casing
Hole size/depth: 12-1/4- in to 4,700-ft MD/TVD
Casing size: 9-5/8-in

Production casing
Hole size/depth: 8-3/4-in to 14,100-ft MD
Casing size: 5-1/2-in

As with the preceding mud programs, the surface hole would be drilled with a lightly treated WBM with high-viscosity bentonite sweeps every 45 to 90 feet to maintain adequate hole cleaning.

The mud program for the two-string wells called for displacement with the new HPWBM in the 8-3/4 -in hole and continuing to TD of approximately 14,000-ft MD. As per the program, PV would be maintained at between 8-18 cPs for the entirety of the well and LGS to be held at less than 6% throughout.

The yield point (YP) would be maintained from 6 to 12 lb/100 ft^2 in the 12-1/4-in surface hole, increasing to between 8 to 18 lb/100 ft^2 for the remainder of the well.

The mud weight would be maintained at 9.0 lb/gal for the KOP and increase slightly to 9.5 lb/gal for the curve and lateral zones to 9.5 to 10.0 lb/gal. Again, for the production hole, the mud was programmed to be treated with a performance enhancing additive at 3 to 5 vol% to keep the CoF within the programmed range of 0.05 to 0.09.

Individual Well Summaries

An examination of eight wells drilled in Madison and Leon counties with two different rigs documents the sequential performance improvements in Halcón Resources' horizontal Woodbine campaign.

Samantha Rizzo #1H (H&P 249), Madison County
Spud: 9/09/2012

The Samantha Rizzo #1H represents the first well to be drilled in the Madison County area. The well was programmed to 16,200-ft MD/8,710-ft TVD with a 9 7/8-in pilot hole drilled to around 9,400-ft MD into the Buda formation. The wellbore was to be plugged back to 8,000-ft with the curve for the 6-¾-in lateral section built at a rate of 10°/100-ft to 90°, landing out to approximately 8,900-ft MD.

The drilling fluids program called for displacement with a 9.0 lb/gal HPWBM in the 9-7/8-in pilot hole, following high-viscosity sweeps in the surface interval. The primary fluid-related challenges identified for this initial well were hole cleaning in both the upper and lateral sections, seepage losses, highly reactive clays and unstable shale sections in the intermediate hole.

The spud mud was displaced to HPWBM at 4,240-ft after drilling out surface casing. The 9-7/8-in pilot hole was drilled to 9,340-ft MD interval depth. A full suite of logs were run to total depth and the hole was found to be essentially in gauge (see the caliper log in Fig. A3).

After setting an open hole whipstock, the well was sidetracked at 8,100-ft MD. Some seepage losses were observed after increasing the mud density to 10.5 lb/gal. They were mitigated by the addition of LCM compatible with the directional tools. The curve was built and landed at 9,258-ft with a final mud weight of 10.5 lb/gal. The 5,009-ft pilot and build section was drilled in 15 days with the 7-5/8-in casing successfully ran and cemented.

The 6,641-ft lateral section experienced partial lost returns at 10,953-ft and after a 13 lb/bbl LCM sweep, the density of the HPWBM was cut back from 9.0 lb/gal to 8.7 lb/gal. The production interval continued to sustain considerable losses until reaching target depth of 15,899-ft in 24 days including running production casing. One possible reason for the losses could have been from depletion due to offset vertical well production. Approximately 650 bbl were lost downhole until the production casing was cemented successfully.

As in many horizontal wells, there were instances of well flow and gas with some time circulating with the well shut in. The field personnel did an excellent job in maintaining well control with minimal mud lost downhole and lost time.

The depth vs. days and depth vs. mud density curves for all the wells drilled in Madison County are presented in Fig. A4 and Fig. A5 in the appendix. The other two wells shown on the curves will be discussed later.

Lessons learned:

- The HPWBM provided the needed wellbore stability that allowed the pilot hole to be drilled, evaluated and sidetracked to horizontal
- Increasing the density while building the curve prevented the problems seen with offsets with wellbore stability
- Setting the intermediate casing allowed for the mud density to be reduced while drilling the lateral
- LCM additions and reducing mud density can reduce losses, but will not eliminate them entirely
- Rate of penetration for building the curve with a 9-7/8-in directional assembly is slower than using an 8-3/4-in assembly.

Mamie Wakefield 3H (H&P 226), Leon County
Spud: 9/11/2012

The second well spudded was the first one drilled in Leon County. It was programmed to 11,600-ft MD with 7-5/8-in intermediate casing. Surface hole was drilled to 3,450-ft and 10-3/4-in casing set. The well was displaced with an 8.4 lb/gal HPWBM after drilling out the surface casing. A 9-7/8-in hole was drilled to the kick-off point (KOP) at 6,025-ft MD. An 8-3/4-in curve building assembly was picked up and the curve was built to 80° inclination at 7,113-ft and the well was logged and 7-5/8-in casing ran to total depth. The mud density at the section total depth was 9.6 lb/gal. The density was increased as hole conditions dictated.

After drilling out intermediate casing and following a successful formation integrity test (FIT) with an equivalent mud weight (EMW) of 10.0 lb/gal, drilling of the lateral continued trouble free to target depth of 12,645-ft MD / 6,600-ft TVD. Mud density was maintained at 9.5 lb/gal for the lateral.

The depth vs. days and depth vs. mud density curves for all the wells drilled in Leon County are shown in Fig. A6 and Fig. A7 in the appendix. The other four wells shown on the curves will be discussed later.

Lessons learned:

- Many of the issues encountered in the Madison County well were not seen on this well
- A high density of 10.5 lb/gal was not required to successfully build the curve
- No lost circulation was experienced
- On the basis of this performance, the next well was programmed without the intermediate casing string
- Minimal risk of wellbore instability occurred due to the use of the HPWBM

Mamie Wakefield 3A2 4H (H&P 226), Leon County
Spud 10/06/2012

After drilling surface hole to 4,100-ft., 9-5/8-in surface casing was set. The 8-3/4-in section was drilled to 12,525-ft MD/6,643-ft TVD in 15 days. The HPWBM displaced the spud mud after drilling out the surface casing. The mud from the previous well was used to displace, which reduced the waste volume and maximized the value that the HPWBM delivered. Upon encountering a tight spot at 10,650-ft while reaming to bottom after a trip, the hole was shut in when it began to pack off and was observed to be flowing. Accordingly, the density was increased to 10 lb/gal and the gas circulated out of the wellbore. Afterwards, drilling continued to the 12,525-ft MD/6,643-ft TVD with the 5-½-in casing string run and cemented successfully. The casing run was modeled using industry standard torque and drag software[7] and it was found that the friction factor for the casing run was 0.20 (Fig. A8). The depth vs. days and depth vs. mud density curves for all the wells drilled in Leon County are in Fig. A6 and Fig. A7 in the appendix.

Lessons learned:

- Intermediate casing can be eliminated successfully in this area with minimal risk
- Mud density in the lateral may need to be increased to reduce reaming and possibility of well control issues

Samantha Rizzo #2H (H&P 249), Madison County
Spud 10/25/2012

The second well from the Samantha Rizzo pad was planned as a conventional three-string well without a pilot hole. The 14-3/4-in surface hole was drilled to 4,230-ft. without incident and 10-3/4-in casing set. After testing and drilling out surface casing, a formation integrity test was made. The spud mud was displaced with the HPWBM used on the previous Samantha Rizzo well. The reuse of the HPWBM in pad drilling operation saved the cost of replacement and disposal, while enhancing the environmental profile. A 9-7/8-in hole was drilled to the KOP at 8,000-ft MD / 7,954-ft TVD. One wellbore pack-off incident occurred at 7,038-ft MD. After working the drill string free, it was pulled to 6,645-ft MD where circulation was re-established.

Afterwards, the interval was drilled to the KOP at 8,000-ft MD and swept clean without further incident. While POOH to change the directional assembly, the hole pulled tight in the sands under the surface casing shoe from 5,190-ft MD to 4,300-ft MD. Based on the lessons learned from the Samantha Rizzo #1 well, an 8-3/4-in directional assembly was used to build the curve.

The mud density was increased to 10.3 lb/gal at 8,800-ft MD and an LCM pill was run after encountering some 110 bbl of losses. Drilling then resumed and the curve successfully landed at 9,118-ft MD/8,659-ft TVD. At that time, the mud was weighted up to 11.1 lb/gal and additional losses occurred. After treatment with a 40-bbl LCM pill, the string was POOH trouble-free with tight spots observed. The intermediate 7-5/8-in casing string became stuck between 8,000 and 8,750-ft MD/8,605-ft TVD in the 8-3/4-in hole. After working the casing free and establishing full returns, the casing was reamed to total depth and cemented.

The production interval was drilled using a 6-3/4-in. directional assembly with 8.8 to 9.0 lb/gal fluid density. Moderate losses, at least two tight spots, and an MWD tool failure were encountered while drilling the 6,775-ft 6-3/4-in production interval. Nevertheless, the interval was drilled from 9,118-ft MD to the actual 15,893-ft TD in a total of 15 days with the production casing run to bottom and cemented successfully. The well was drilled to completion in 28 days. See Fig. A4 and Fig. A5 for day and mud density curves.

Lessons learned:

- The 7-5/8-in casing lacks sufficient clearance to easily go to bottom in an 8-3/4-in build section
- The shallow zones below surface casing and the Woodbine sand cannot hold 11.1 lb/gal fluid without lost returns

Zach Wakefield 2 #1H (H&P 226), Leon County
Spud 10/29/2012

The third Leon County well was drilled from a new pad location near the Mamie Wakefield pad. After moving the rig, surface hole was drilled to 4,735-ft. MD/TVD. This was more than 600 feet deeper than the two wells drilled previously. The additional surface casing was set since the formations were 400 to 600-ft down dip from the previous wells. Also, it was anticipated that this would reduce the likelihood of shallow lost circulation. Prior to running 9-5/8-in surface casing, an LCM pill was spotted and surface casing was run and successfully cemented with cement returns to surface.

The surface mud was displaced to the HPWBM prior to testing and drilling out surface casing. A FIT of 11.0 lb/gal equivalent was made. As in the past, the mud was reused from the previous well with cost and environmental benefits.

After drilling to 7,169-ft MD, the 8-3/4-in, the BHA was changed to increase the curve build rate to 15°/100-ft for this well as required by a target change. The curve was successfully landed at 7,511-ft MD. After a BHA change, drilling proceeded to 12,539-ft MD where a motor failure occurred. After pulling out and finding part of the motor and bit left in the hole. An attempt to fish was unsuccessful due to the unavailability of an overshot extension and an open hole sidetrack made at 11,053-ft MD. A total depth of 14,265-ft MD was reached and casing ran to total depth. Approximately four days were lost due to the loss of the motor and bit in the hole and required open hole sidetrack. The days on well vs MD and mud weight vs MD for the five Leon County wells are presented in Fig.A6 and A7.

Lessons learned:

- Typical fishing assemblies cannot pass through high dogleg build sections, when it was found that the needed tool was not available, sidetracking became the preferred option
- The HPWBM provides good drill rates even at high build rates

Zach Wakefield 2 #2H (H&P 226), Leon County
Spud 11/22/2012

The fourth Leon County well was spudded after skidding the rig from the first well on the pad. Surface hole was drilled to 4,705-ft. MD directionally and logged. After running 9-5/8-in surface casing and drilling out, the well was displaced to the HPWBM. Drilling proceeded to 15,080-ft MD. No issues with mud losses were experienced and the density was maintained at 9.5 to 10.0 lb/gal. The well was drilled in 17 days with the casing run and cemented successfully.

Lesson learned:

- Implementing previous lessons learned and working according to plan results in a successful well

Samantha Rizzo #3H (H&P 249), Madison County
Spud 11/23/2012

The deepest of the wells in this study, the Samantha Rizzo #3H was drilled to 16,330-ft MD in 26 days. The well was drilled to total depth in 19 days and a horizontal logging run required and additional three days. Implementing the lessons learned from the previous two wells drilled on the pad, along with lessons from other drilling operations, resulted in a smoothly executed drilling plan.

After drilling and setting 10-3/4-in surface casing at 4,230-ft MD, the well was displaced to the HPWBM after testing casing and drilling out. A 9-7/8-in hole was drilled to the KOP at 8,007-ft MD. An 8-3/4-in directional assembly was used to build the curve to 9,104-ft MD. Utilizing a combination casing string with 7-in casing in the 8-3/4-in hole and 7-5/8-in casing in the 9-7/8-in hole, intermediate casing was run without incident and cemented with full returns. The mud density at casing point was 10.8 lb/gal.

Drilling/sliding in the lateral proceeded using a 6-1/8-in. directional assembly with no downhole issues to the 16,330-ft TD. The production string was run and cemented successfully after the aforementioned logging run on drill pipe using rotary tools. The mud density was controlled in the 8.9 to 9.0 lb/gal range with minimal downhole losses. The days on well vs. MD and mud weight vs. MD are presented in Fig. A4 and A5.

Lessons learned:

- A combination 7-5/8-in by 7-in casing string eliminated issues of running 7-5/8-in casing in the 8-3/4-in build section
- The 6-1/8-in hole drilled at least as efficiently as the previous 6-3/4-in sections on the previous two wells using the same 4-in drill pipe

Champion Ranch B1H (H&P 249), Leon County
Spud 12/23/2012

The final subject well in this study delivered exceptional results similar to the previous several wells, reaching a total depth of 13,765-ft MD in an impressive 17 days.

The 9-5/8-in. surface casing was run to 3,710-ft. After drilling out and displacing with the HPWBM, a single 8-3/4-in directional bit run was utilized to drill to KOP, build the curve and drill the lateral to 11,716-ft MD. Another bit run reached total depth of 13,765-ft. MD. Some minor mud losses occurred with the 10.0 lb/gal density used. Casing was run to total depth and cemented without issue.

Lesson learned:

- Using the typical 10°/100 ft build rate allows a single assembly to be used from drill-out to TD.

Conclusions

Most operators expect to see rapid improvement in performance when beginning operations in an area. These wells demonstrate that the rate of improvement can be very rapid. One common denominator of all the subject wells is they utilized a well-designed HPWBM mud system with high performance field implementation. Other conclusions apparent from the results of these wells include:

- The HPWBM provided the required wellbore stability for successful drilling operations
- The HPWBM with the performance enhancing additives can be used to drill long lateral horizontal wells in a challenging geological area
- Responding appropriately to challenges results in rapidly improving performance
- Innovative drilling engineering in an environment that encourages experimentation and continuous improvement results in lower cost wells

It is imprecise to determine the exact cost savings and performance improvements over the course of drilling a number of wells in the same area. For these wells a number of cost saving results are apparent:

- Elimination of the 7-5/8-in casing string on the Leon County wells reduced tangible and intangible costs substantially with approximately six days saved per well.
- Reducing the lateral drilling time over three wells from 17 days to seven days in Madison County lowered intangible drilling costs
- Minimizing downhole losses by managing mud densities, hole cleaning practices, and LCM application both reduced time and mud costs

As with any ongoing drilling program additional performance improvement in the future is expected. Improving rig operations, tools and drilling fluid products can be expected to further enhance savings on wells in the future.

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6. Breeden, D, Dougan, C., Shank D., and Summers, S.: "Haynesville Performance Review: Unique Clay Free Polymer Drilling Fluid System" AADE-11-NTCE-39, 2011 AADE National Technical Conference, Houston, Texas, April 12-14, 2011.
7. Landmark WELLPLAN™ Torque/Drag Analysis software

Appendix

Table A1 – Summary of Madison County Shale Analysis

<table>
<tr><th></th><th colspan="2">ANA 3327A</th><th colspan="2">ANA 3327B</th><th colspan="2">ANA 3327C</th></tr>
<tr><td>Depth, ft</td><td colspan="2">6,700-7,300</td><td colspan="2">7,390-7,840</td><td colspan="2">8,020-8,500</td></tr>
<tr><td>Main Exchangeable Base</td><td colspan="2">Calcium</td><td colspan="2">Calcium/Sodium</td><td colspan="2">Calcium</td></tr>
<tr><td>Highest Soluble Cation</td><td colspan="2">Sodium</td><td colspan="2">Sodium</td><td colspan="2">Sodium</td></tr>
<tr><td>Highest Soluble Anion</td><td colspan="2">Bicarbonate/Carbonate</td><td colspan="2">Bicarbonate</td><td colspan="2">Carbonate</td></tr>
<tr><td>CEC, meq/100g</td><td colspan="2">20.0</td><td colspan="2">20.7</td><td colspan="2">21.9</td></tr>
<tr><td rowspan="3">Main Clay, % by weight</td><td>Illite</td><td>37</td><td>Illite</td><td>39</td><td>Illite</td><td>29</td></tr>
<tr><td>Mixed-Layer (Illite/Smectite)</td><td>28 (46/54)</td><td>Mixed-Layer (Illite/Smectite)</td><td>27 (45/55)</td><td>Mixed-Layer (Illite/Smectite)</td><td>25 (46/54)</td></tr>
<tr><td>Kaolinite</td><td>24</td><td>Kaolinite</td><td>24</td><td>Kaolinite</td><td>34</td></tr>
<tr><td rowspan="3">Main Components, % by weight</td><td>Total-Clay</td><td>48</td><td>Total-Clay</td><td>52</td><td>Total-Clay</td><td>51</td></tr>
<tr><td>Quartz</td><td>27</td><td>Quartz</td><td>26</td><td>Quartz</td><td>24</td></tr>
<tr><td>Muscovite-Mica</td><td>25</td><td>Muscovite-Mica</td><td>22</td><td>Muscovite-Mica</td><td>23</td></tr>
</table>

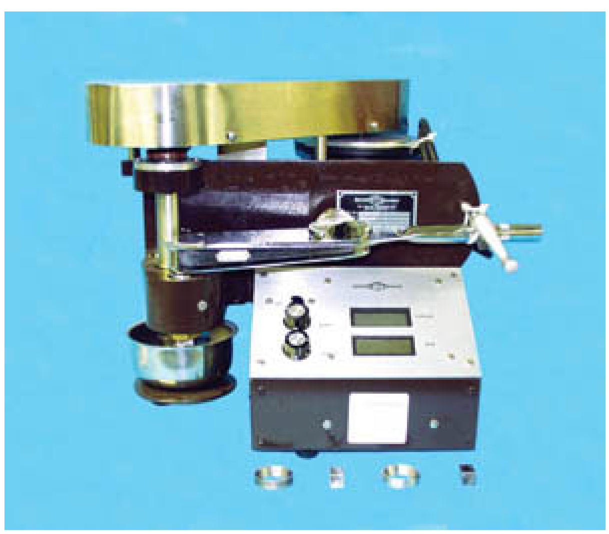
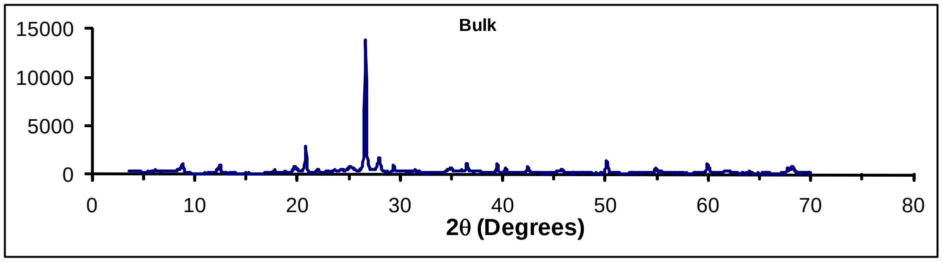


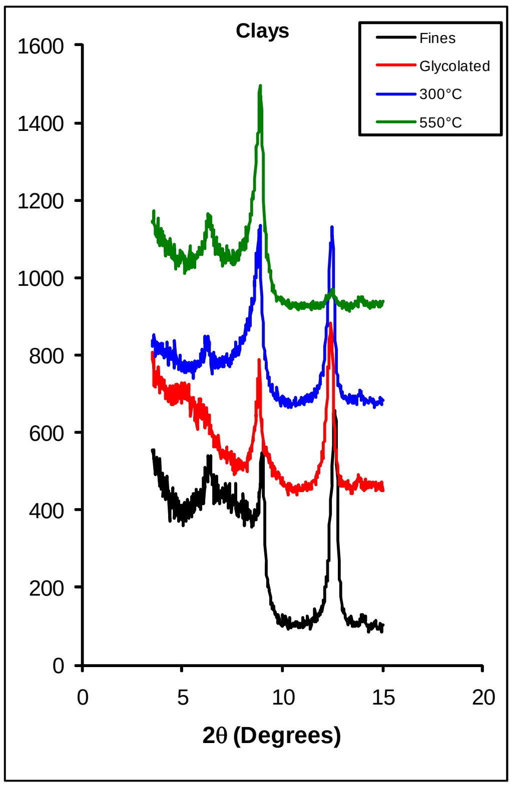
Fig. A1: OFITE Model 111 EP and Lubricity Tester

X-Ray Diffraction Interpretation and Data

Project: ANA 3327 **Sample:** C

Description: 8,020'-8,500'





Soluble Cations and Anions -			meq/100 g
Sodium	6.4	Chloride	0.0
Potassium	0.2	Sulfate	0.0
Magnesium	0.0	Carbonate	5.6
Calcium	0.7	Bicarbonate	4.0

Bulk Composition -	wt%
Total Clay	51
Quartz (SiO2)	24
Muscovite-Mica	23
Calcite (CaCO3)	3

Clay Composition -	wt%
Kaolinite	34
Chlorite	7
Illite	29
Smectite	4
Mixed-layer	25
Illite/smectite	46 / 54

CEC -	meq/100 g
	21.9

Exchangeable Bases -	meq/100 g
Sodium	7.0
Potassium	1.8
Magnesium	0.5
Calcium	10.9

Specific Gravity -	He Pyc.
	2.67

Oxide	Mass%
SiO2	61.6
Al2O3	17.8
Fe2O3	7.1
K2O	5.9
MgO	2.4
TiO2	1.4
CaO	1.1
SO3	0.9
PbO	0.4
Cr2O3	0.3
ZrO2	0.2
MnO	0.2
P2O5	0.1
SrO	0.1
ZnO	0.1
MoO3	0.1
Br	0.1
BaO	0.1
Co2O3	0.1

Fig. A2 – Complete Shale Analysis Results from Madison County, Texas Well for 8,020-8,500 ft Composite

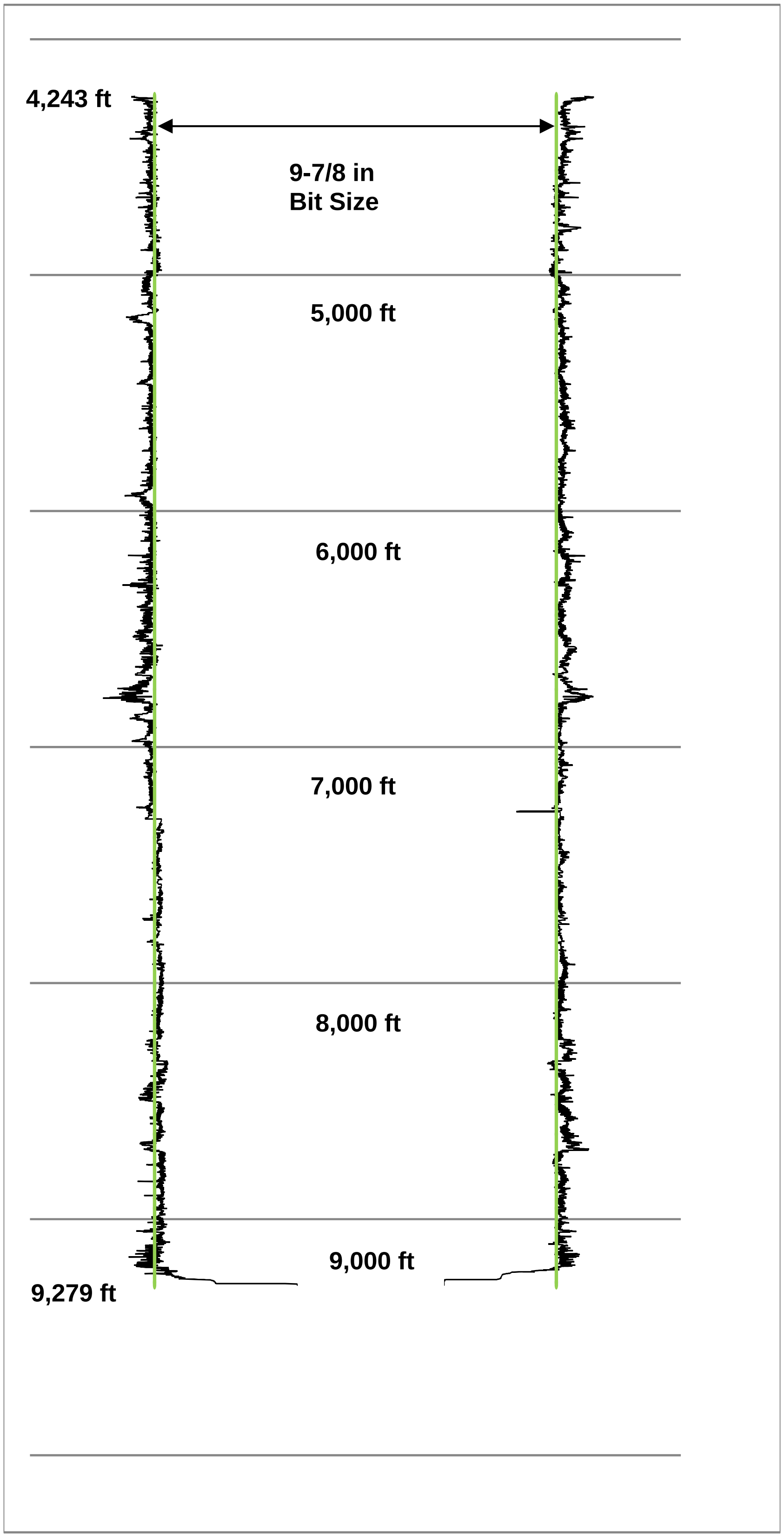


Fig. A3 – Samantha Rizzo 1H Caliper Log

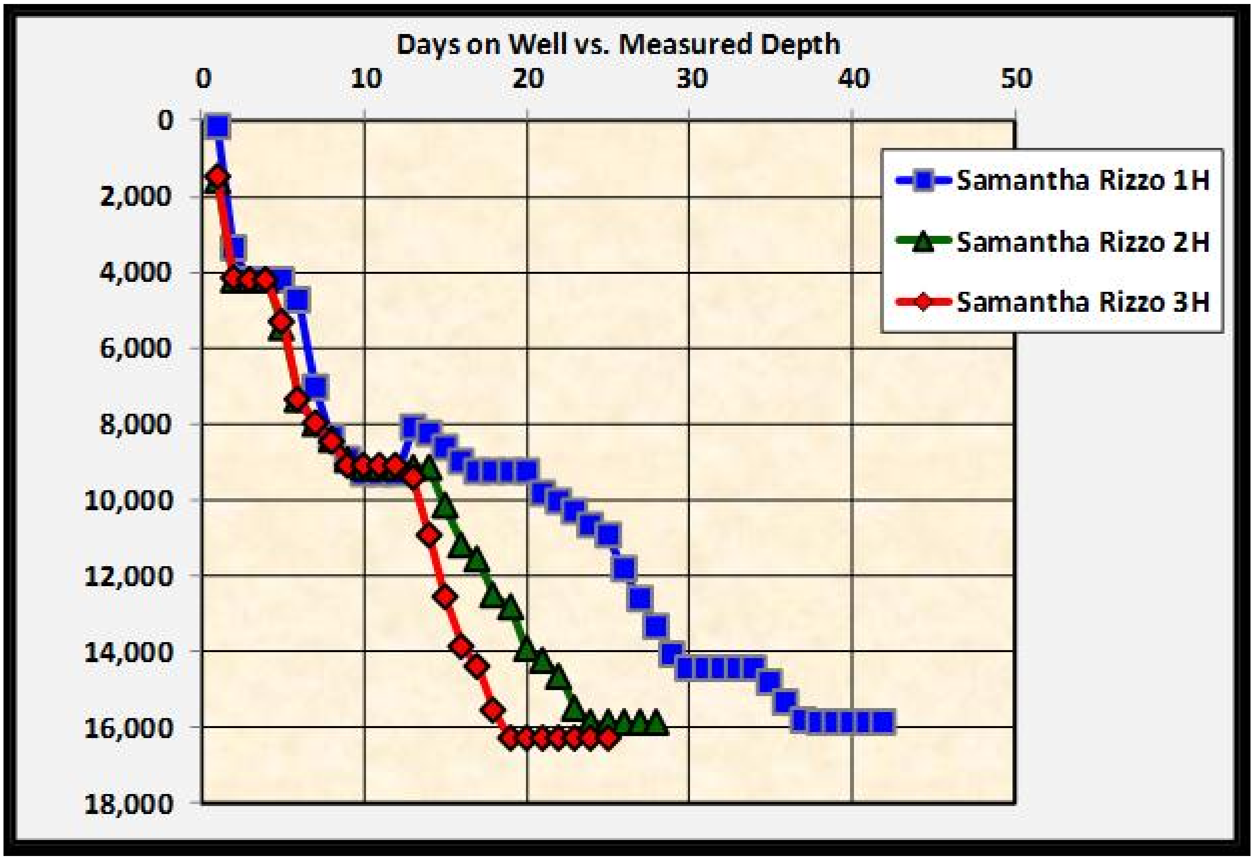


Fig. A4: Days vs MD for the three Madison County wells

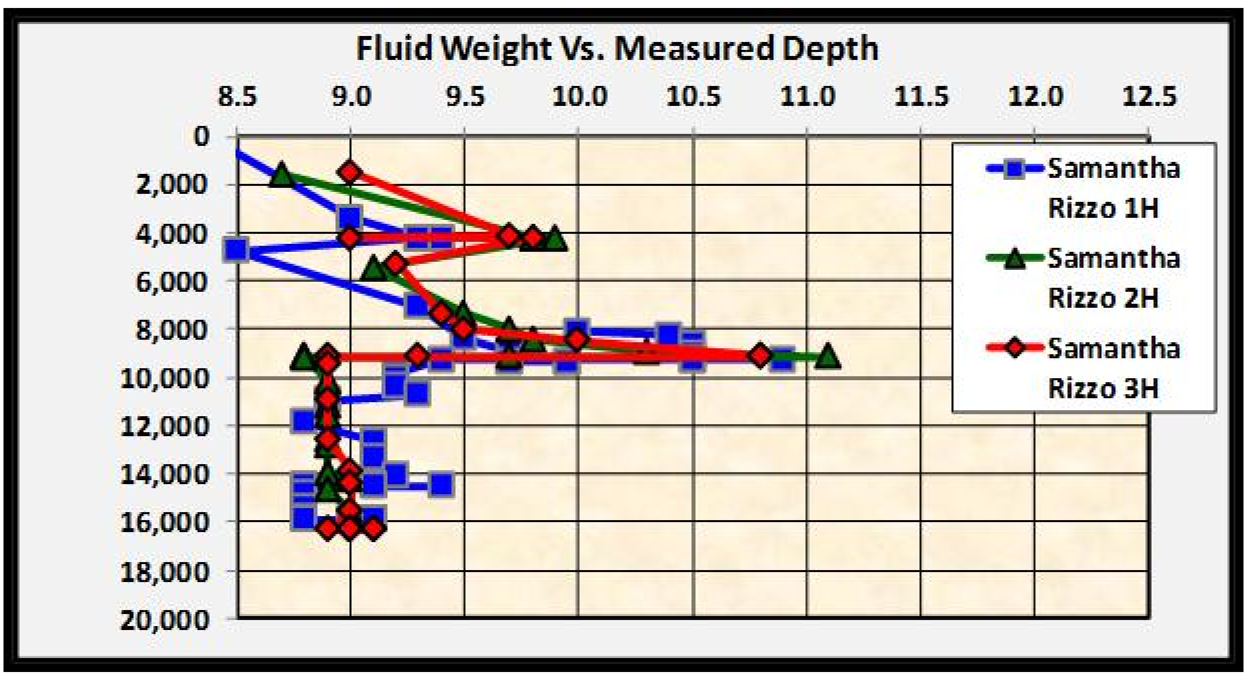


Fig. A5: Fluid density vs MD for the three Madison County wells

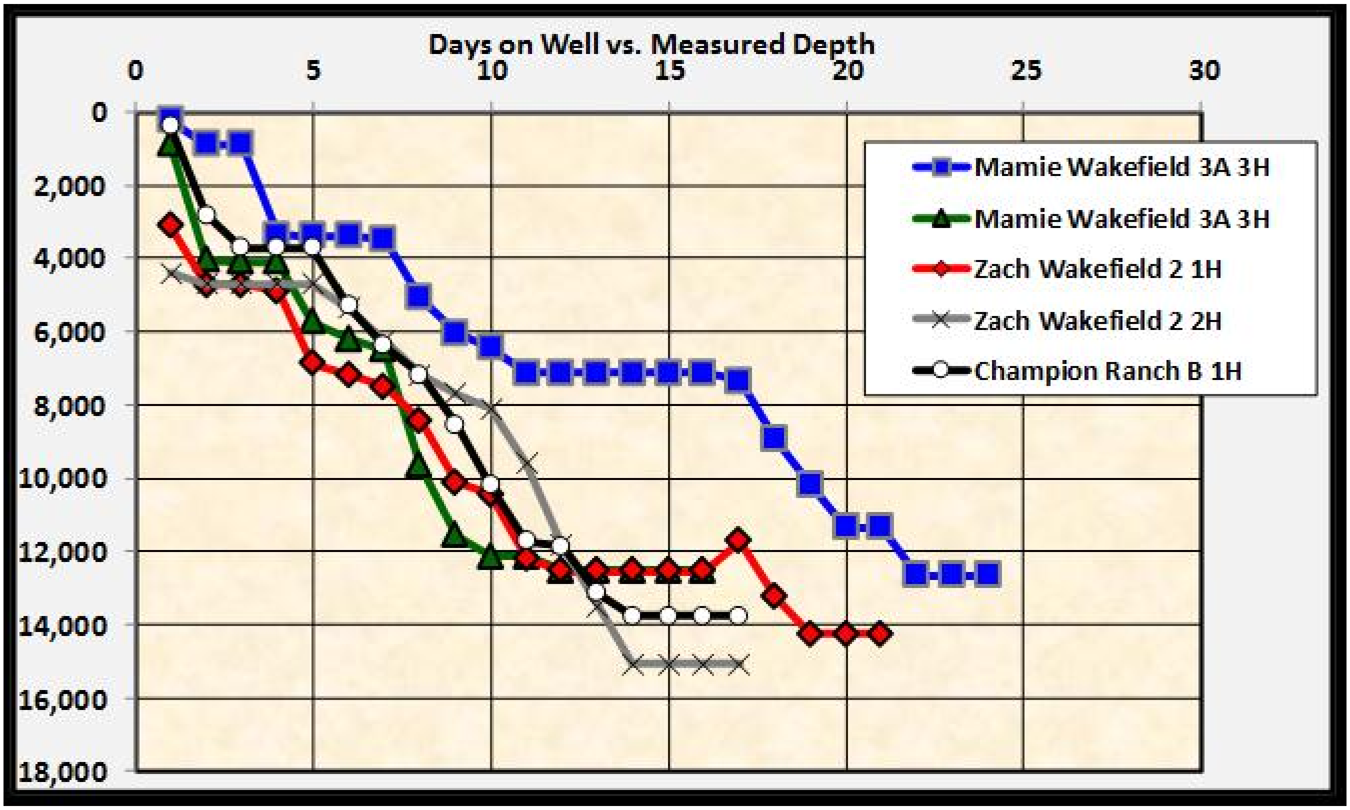


Fig. A6: Days vs. MD for the five Leon County wells

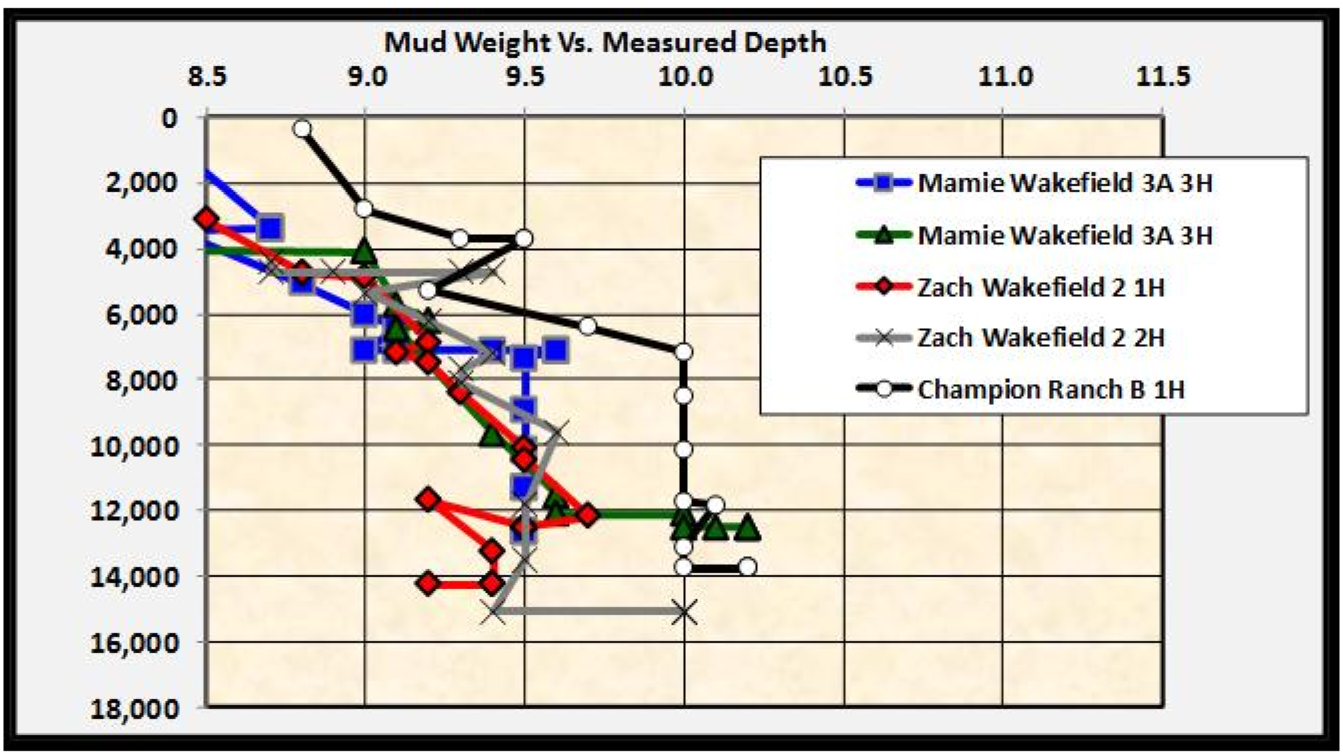


Fig. A7: Fluid density vs. MD for the five Leon County wells

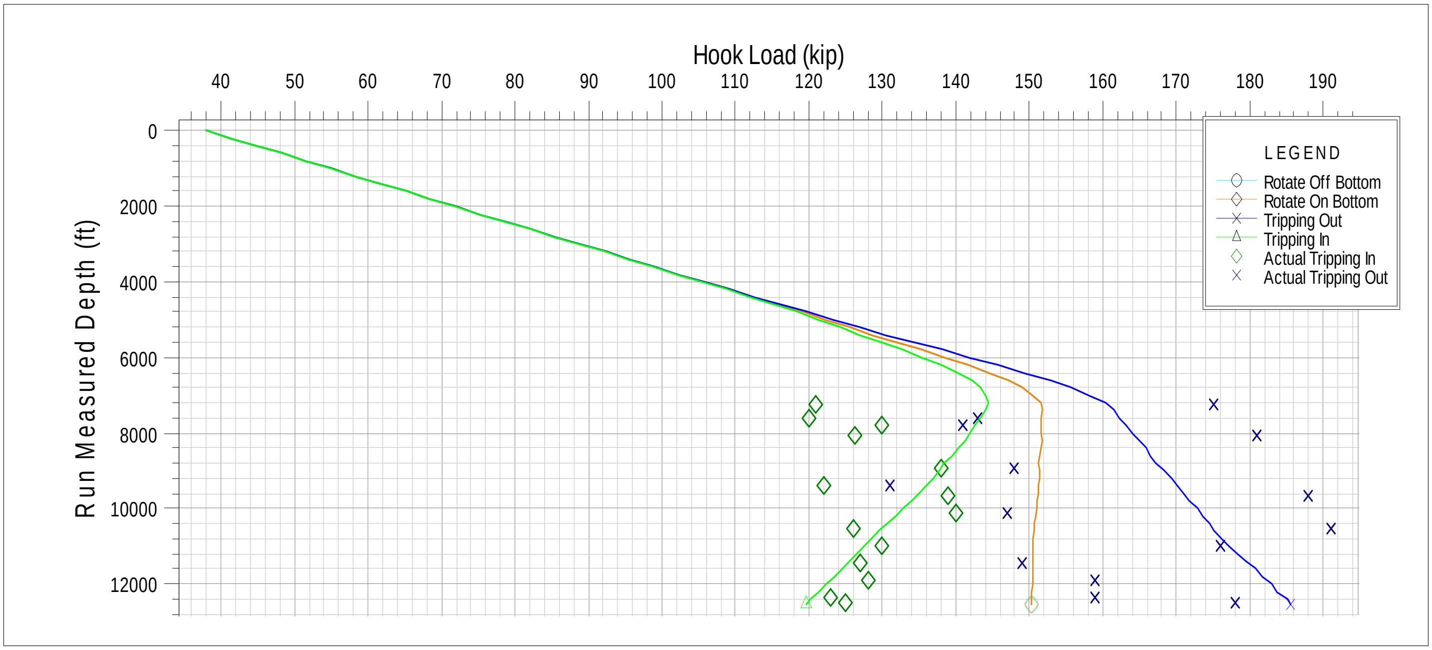


Fig. A8: Casing run model for Mamie Wakefield 3A2 4H