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Pushing the Limits of Riserless Deepwater Drilling

Paul Scott, Marathon Oil Co., Sam Ledbetter, Rick Chester, Drilling Specialties Co., and Don Powell, M-I SWACO

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Abstract

Pushing the limits of riserless deepwater drilling with sacrificial weighted mud requires special supervision, processes, fluids, products and equipment. Although it is a common practice in deepwater operations, many factors limit its use to efficiently set large diameter surface casing at increased depths in formations with higher formation pressures and reactive shale. This technique when properly executed can provide significant savings in the time and money required to drill deepwater wells.

The requirements of performing large volume riserless operations with fluids that provide significantly improved properties is described below. Properly designed riserless drilling operations can provide large volumes of “on the fly” mixed and pumped high-density fluids with good inhibition, high and stable viscosity, and good filtration control. These properties can easily be made to match or exceed what is often used on shallow water operations where circulation is maintained to the surface.

A case history is presented where these principals are applied to a deepwater well offshore Nova Scotia. Also the authors describe the accelerated development and production of a unique liquid additive product that was critical to the success of the operation.

Introduction

Riserless deepwater drilling with weighted mud has become standard practice on many operations.[1-8] When done properly this dual-gradient method will balance subsurface pressures to contain shallow hazards and improve wellbore stability so that the first casing string can be set much deeper than with conventional drilling techniques. The method, which is the subject of this paper, is the open-ended circulating arrangement where the sacrificial weighted drilling fluid is discharged at the seafloor and is often referred to as “pump and dump”.

The advantages of being able to control subsurface pressures and set the first casing string at a deeper depth are:

- Controls shallow hazards such as shallow water flow (SWF) or shallow gas
- Delivers a stable wellbore so the hole stays open and casing can be run
- Dual gradient hydrostatics more closely matches the shallow formation pressures as compared to a full column of weighted fluid being circulated back to the floating drilling rig
- Extends casing depths, thus requiring fewer strings of casing
- Provides for larger diameter wellbores at increased depth, improving the probability of reaching total depth (TD) on difficult deep wells
- Reduces the total number of days to depth for the shallow intervals
- Reduces total well cost which in potentially problematic and high measured depth deepwater wells, typically reduces the overall well cost by $1 to $4 million.

While a number of different fluids and fluid blends have been used, the two most common riserless weighted fluid techniques used today are; 1) a two-way blend of seawater and high-weight (usually 16-lb/gal) water-based mud (WBM) and 2) a three-way blend which incorporates calcium chloride brine into the fluids used in the two-way blend. Blending the high-weight WBM with seawater and $CaCl_2$ brine greatly extends the volume of fluid available to perform these operations. However, the resulting blends may not have acceptable rheology, fluid loss control, or stability. Calcium chloride is used to improve shale inhibition and help prevent bit and stabilizer balling which would reduce ROPs and potentially cause pressure surges and/or swabbing. While a fairly wide range of $CaCl_2$ concentration has been used, 20% by volume of 11.6-lb/gal $CaCl_2$ brine in the final blend seems to be sufficient to provide shale inhibition and prevent balling.

The basic process is to designate one surface pit as the suction pit with a mixing manifold installed on top so all of the fluids being blended and any mud additives are mixed at the mixing manifold then discharged into the suction pit. During the entire riserless drilling operation, the concept is to keep the designated suction pit partially full of blended mud so that the residence time and mixing in this suction pit will average out any changes in mud weight and allow additional mixing for the multiple fluids and any mud additives.

Due to the soft shallow formations and large diameter bits, the flowrate needed to clean the hole and make connections are quite high. Consequently, the volume of weighted mud needed is quite large, on the order of tens of thousands of barrels. In addition, due to the higher rates of penetration (usually >150 ft/hr) in these shallow intervals, most of these riserless drilling operations are completed within a relatively short period, meaning the time available to re-supply the drilling rig is short and problematic. With these two conditions, developing a fool-proof plan of action to mix, pump, and treat tens of thousands of barrels of weighted mud in 12 to 24 hours requires significant planning and oversight.

Key to executing an aggressive riserless drilling operation with weighted mud is to have a detailed plan of how to transfer the high-weight WBM from the various storage locations to a surface pit where it can be subsequently metered into the mixing manifold. All of the fluids being mixed need to have accurate metering devices with a manual check on the final density and volumes being delivered as the operation progresses. This includes any mud additives with a manual check that the desired mud properties are being achieved.

Limitations

Limitations for riserless deepwater drilling with weighted mud are:

- Required density
- Volume of high-weight WBM which can be stored and re-supplied
- Logistics of re-supplying high-weight WBM volumes from reserve tanks and supply boats
- Physical and chemical properties of final blended fluids
- Mixing capacity and efficiency for chemical additives to provide satisfactory mud properties

As the required density increases, so too does the quantity of high-weight WBM, while the length that can be drilled with this method decreases.

The volume of high-weight WBM is the most limiting factor of using this technique. The volume of mud that can be stored varies greatly from rig to rig. The required volume increases as a function of increasing hole size due to the flowrate needed for hole cleaning; increases with the required density as stated above; increases with decreasing rates of penetration (ROP) and increases with an increase in the length of the riserless interval to be drilled with weighted mud. While 16 lb/gal is the most common high-weight WBM used for riserless drilling, 19 lb/gal has been used to reduce the ratio of WBM needed to achieve a given density and increase the quantity of blended mud which can be achieved for a given situation. However, not all pit and rig mud transfer equipment is rated for 19 lb/gal fluids.

The volume of mud needed to drill riserless is generally calculated from the desired TD of the casing, the anticipated flowrate, and some estimate of the rate of penetration plus 25-50% (based on field experience). The other approach is to determine how mud high-weight WBM and brine can be logistically supplied to the rig during a 12-24 hour period and back calculating what length hole might be able to be achieved. In addition to the drill-ahead mud volume, kill mud is needed at TD. This volume of kill mud is often calculated and added to four times the gauge hole volume, which will compensate for any washout or circulation that might be needed during the short trip and while running casing.

Using calcium chloride helps with additional volume as most deepwater rigs have dedicated brine storage of 2,500 to 12,000 bbl.

Other innovative ideas used in the past have been to store fully formulated mud in pontoon storage tanks on semi-submersible rigs.[3] Obviously any method to increase the available volume of weighted mud to perform this operation will increase the section length that can be drilled with the technique.

The pump capacity and flexibility of the rig surface mud system for pit-to-pit transfers may not be capable of transferring the volumes required to perform riserless drilling on an uninterrupted basis. Re-supply from supply boats is also problematic and limited by boat pump capacity and transfer piping flexibility, rig bunkering locations, safety rules, weather, and transit time to the shore-based mud plant. In addition, in many parts of the world outside the flourishing deepwater theaters, the mud plant mixing capacity and storage volumes may not allow for an adequate re-supply of high-weight WBM.

The properties of the final blended fluid may not provide for a quality drilling fluid, depending on the ratios of the various fluids used, the formulation for the high-weight WBM, and whether any additives are used. Often the blended fluids end up being quite thin with uncontrolled fluid loss. For the fluid that will be spotted in the hole during the short trip and for running casing, it is important to use additives which provide high and stable viscosity and lower fluid loss.

The API has established fluid specifications for these fluids when used in SWF areas in API RP 65.[9] These specifications are API FL <15 mL/30 min and 10 sec, 10 min, and 30 min gels <25 lb/100 ft^2.

Because the fluid to be spotted in the hole on the short trip and for running casing is quite large and needed immediately after drilling and or circulating the hole clean, it is often not possible to prepare this fluid ahead of time or in a surface mud pit. While some operators send this out in a separate boat and transfer it when needed, it is also possible to blend a fluid with satisfactory properties "on the fly" by adding the required mud product additives prior to the blending manifold. This can be done by using two common additives which are usually supplied as a dry powder or by a using a "fit for purpose" liquid additive tailored to achieve the desired mud properties in the specific blend being used. The authors of this paper believe this is the best method to use in this situation where everything has to happen quickly and at a controlled metered rate.

While riserless drilling with weight mud may seem simple to accomplish, using the technique effectively requires a significant amount of planning and skillful execution. The authors recommend developing a detailed plan of action which utilizes additional experienced on-site supervision, specialized fit-for-purpose blending and pumping equipment, detailed rig-practical processes with contingencies and redundancy, special fit-for-purpose fluids, and special fit-for-purpose products. In each of these areas it is important to try and engineer the total system to be as simple and straight forward as possible, making the final process as fool proof as possible.

Riserless Drilling Experience

The industry's experience with riserless drilling with weighted mud now encompasses hundreds of wells, but no comprehensive industry-wide data is available. Marathon has utilized the technique on a number of wells in the past six years as detailed in **Table 1**.

An example of the hydrostatic pressure achieved by using the riserless drilling technique with weighted WBM is shown in **Fig. 1**. This example is Well 2 in Table 1 and clearly shows the dual gradient nature of the hydrostatic column and the actual measured pressure while drilling data from the well.

One recent case history involves using the riserless dual gradient technique on a deepwater offshore exploration well off the east coast of Nova Scotia. For this well, the technique was chosen as an lower cost option to achieve a 8½-in. hole size at TD as compared to either using a large diameter wellhead system or to having a contingency expandable liner.

Some of the challenges of this project included the shore-based mud plant and supply vessels, which were severely limited so that both the initial supply of the WBM and any re-supply would be difficult. In the final analysis, the Deepwater Pathfinder drill ship was chosen to drill the project. This selection was partially due to its large mud capacity and the option of converting one of the ballast tanks to store even more high-weight WBM for the riserless section. The Pathfinder would be mobilized from the Gulf of Mexico and could be loaded with the required high-weight WBM and WBM products needed for the riserless drilling interval prior to the transit to Nova Scotia.

For the kill mud, the volume needed for the short trip and for running casing was so large that premixing it in the surface pits was not possible. This kill mud would need to have high and stable viscosity and low fluid loss to assure that the casing could be run to bottom. It was decided that the best solution to this situation was to develop a system that would allow the kill mud to be mixed and pumped "on the fly".

Mixing and pumping the kill mud "on the fly", would require that large volumes of powdered products or liquid additives to be mixed into the blended fluids just prior to being pumped downhole. After investigating bulk addition systems, it was decided that the best method would be to use a single liquid additive developed to provide the desired rheology and fluid loss.

Riserless Drilling Fluid Additive Development

The goal of the fluid additive selection project was to develop a liquid product that could provide both fluid-loss control and viscosity and meet Canadian environmental regulations for offshore use. In previous applications of riserless drilling, readily available liquid products were used but those products were not satisfactory because two different products were needed to provide both fluid-loss control and viscosity properties to meet the API RP 65 Drilling Fluid Specifications.

In previous riserless drilling wells, there had been problems with bit balling and cuttings build-up around the bottom hole assembly. For this reason, it was decided to use 20-25% calcium chloride brine in the three-way blended fluid. The concentration of calcium chloride brine used for cutting's inhibition was in the 20-25% by volume range.

Testing of the liquid polymer was done using a blend of 20-25% by volume 11.6-lb/gal calcium chloride brine, seawater and a heavy-weight freshwater drilling fluid. Two freshwater drilling fluids of different weights - a 16 lb/gal and 19 lb/gal - were used in initial drilling fluid development. It was decided to use the 19-lb/gal drilling fluid in the final blend and product development was continued using the 19-lb/gal freshwater system.

The base fluid used to build the new product was a "green" base liquid xanthan gum polymer suspension. There were two reasons for this choice. First xantham gum would give the needed rheological properties necessary to meet the API 65 specifications and, secondly, the "green" base liquid xanthan had a "gold" rating for use in the North Sea. Canadian offshore environmental regulations are patterned after North Sea regulations, making this an environmentally good choice for Nova Scotia.

Other liquid polymer suspensions were examined, including liquid PAC (polyanionic cellulose) and guar suspensions, but they did not work in this application. Initial testing of the liquid polymer suspension was done with standard mineral oil/polymer suspension technology that would have been followed by their "green" versions, had they shown promise.

The addition of the liquid guar caused the blended system to flocculate. Because of the system flocculation, the liquid guar was no longer considered for use in the system as the fluids were not stable and had high fluid loss.

The liquid PAC and xanthan systems formed a smooth, stable drilling fluid system. By themselves, neither the liquid PAC nor the liquid xanthan gave the required properties. Initial test results are shown in **Table 2-4**.

Several choices of fluid-loss-control polymers were evaluated in conjunction with the xanthan, including PAC, guar, HEC (hydoxyethylcellulose), poly-saccharides, and synthetic polymers. Synthetic polymers were considered due to the calcium chloride content of the fluid, but were rejected because of cost as well as performance. After several different formulations using various types of fluid-loss-control additives were evaluated, it was decided to use a polysaccharide for fluid-loss control.

One of the challenges of finding the right blend of rheological modifiers and fluid-loss-control agents was maintaining a performance balance between the two types of polymers. It was important to maintain good solids suspension characteristics in the blend to prevent settling from occurring and the rheological properties needed to be easily controlled so the system would maintain the proper flow properties while drilling. By using the polysaccharide for fluid-loss control in the final polymer suspension, rheological properties of the fluid were controlled by the xanthan gum while the fluid loss was controlled by the polysaccharide.

Once the drilling fluid system was developed, a loading for the liquid polymer suspension could be determined. Based on laboratory testing, the concentration of polymer suspension need to obtain the desired fluid properties was 8 lb/bbl. Properties of the fluid at various liquid polymer loadings are given in **Table 5**.

In building any polymer suspension, many hurdles need to overcome and building this product was no exception. Stability of the polymer suspension was an initial concern during the project. It is easy to build a suspension that will be stable for a few days, but this product would require long-term stability both in dynamic and static conditions. The suspended polymer(s) would need to be stable for a period of time while waiting at the dock to be shipped, but also while being transported from the Gulf of Mexico to offshore Nova Scotia.

One of the benefits of using current suspension technology as the base to build the new product from is the inherent long-term stability of the current polymer suspension. Liquid polymer suspensions built using current polymer suspension technology have been stable for as long as a year or more. By using the current suspension, development time of the product was greatly reduced. This was critical in the development of the product because of the short lead-time between the first initial ideas of building the product to the final production of the material. Although there were some bumps along the way in getting the stability of the polymer suspension correct, the final product was a stable suspension and no problems were experienced with polymer settling prior to the material being used on location.

The size of the liquid totes used for the project was 270 gal. Twenty-two totes were made up for a total of 122,000 lb of liquid polymer suspension. The density of the liquid suspension was 9.23 lb/gal. Two totes a day of liquid suspension were made, taking eleven days over a month time period to manufacture the liquid polymer suspension. The totes were then sent to the dock at Port Fourchon, Louisiana.

Prejob Modifications and Planning

As part of the rig selection process, it was determined if a ballast tank was converted to extra mud storage capacity on the Deepwater Pathfinder, 100% of the required high-weight WBM needed for the riserless section could be loaded on the drill ship in the Gulf of Mexico prior to the transit to Nova Scotia. Accordingly, engineering studies were undertaken and the conversion was performed. Modifying ballast tank No. 1C allowed an additional 9,000 bbl of 16.0-lb/gal WBM mud to be stored. This was in addition to the existing 9,300 bbl of 16.0-lb/gal reserve WBM which could be stored in the adjacent two hull tanks, for a total of 18,300 bbl in reserve tank storage.

ABS approved the use of the Ballast Tank No. 1C as a drilling mud tank. The space was evaluated for loading 9,300 bbl of 16.0-lb/gal drilling mud. The existing ballast suction from the tank was isolated with a spectacle blind and all ballast valves that normally fill the tank with ballast water were closed. The suction from the tank was then tied into the existing mud transfer pumps so the transfer pumps could roll the mud in the ballast tank; thus reducing solids settlement. A mud return line was installed and split in two so that mud can be delivered to both the forward and aft end of the tank. This was done to increase agitation of the mud in the ballast tank. Following transfer of 16.0-lb/gal mud into Ballast Tank No. 1C was completed, the mud in the tank was re-circulated periodically to prevent barite from falling out.

A normally closed pneumatically actuated valve was installed on the main leg of the return line and this valve was tied into the pressure transducer for the tank and would shut if the pressure transducer registered an equivalent hydrostatic equal to 9,114 bbl of 16.0-lb/gal mud in the tank.

The plan was to build and pump 12.5-lb/gal “kill mud” on the fly at a rate of 1,200 gal/min. Pilot tests indicated that 19.0-lb/gal WBM mud was the best choice to blend into the 12.5-lb/gal kill mud. Two separate yard tests were conducted to check on the feasibility of injecting a liquid polymer into the blending unit to build a “kill mud” on the fly.

The first test was at a mud plant at Pelican Island in Galveston, Texas. Four fluids were blended using the following ratios in order to get a final fluid weighing 12.5 lb/gal:

1) 19.0-lb/gal water base mud = 31.6%
2) 11.2-lb/gal $CaCl_2$ brine = 25.3 %
3) sea water = 43.1 %
4) Liquid polymer pumped at 8 lb/bbl

Three prehydration tanks with pumps pumped the three fluids to a blending unit. A meter system was used to pump and measure the liquid polymer to the blending unit. This system has an adjustable volume control which allows from 1 to 50 gal/min to be pumped and measured. The vane-type meter liquid meter system was plugged with solids from the liquid polymer and the test was unable to continue. So it was decided this kind of meter was not appropriate for products containing solids.

The second test was conducted at the yard in Maurice, Louisiana. This test was conducted to find a meter and pump that could pump the liquid polymer at the rate required. Seven pumps and two different types of meters were tested before finding the correct combination that would meet the requirements. A diaphragm pump and a 1-in Coriolois type meter were found to be the best combination to meet the requirements.

The drill ship had an existing "master tank" installed to dispense the various liquid additives for the synthetic-based mud. It had separate compartments for a total capacity of 180 bbl. It was decided that using the master tank to hold and dispense 180 bbl of the liquid polymer was preferred rather than using a large number of 270-gal totes. To prevent having to swap hoses during the job, a manifold with six inlets was used to tie in the six tanks on the master tank to a single diaphragm pump.

The one-inch Coriolois meter was used to measure the polymer to the blending unit where the polymer was injected into the seawater leg of the mixing manifold.

Prior to the job, the mixing manifold was completely disassembled and inspected with each of the primary and backup flowmeters serviced with new batteries and calibrated. The project engineer from the mud company developed a detailed "pit transfer plan" which had the specifics about which pit would be used first and the sequence for the mud transfers for the entire job. This was critical to the success of the job as it was used to communicate all of the actions that would be required by about 10 different people during the course of the actual job.

Prior to the transit to Nova Scotia, the drill ship was loaded with 23,264 bbl of high-weight WBM (5,015-bbl, 19-lb/gal and 18,249-bbl, 16.0-lb/gal) plus 6,600 bbl of 11.6-lb/gal $CaCl_2$ brine.

Drilling the Riserless Section

On June 17, 2004, the Deepwater Pathfinder arrived on location. The well was spudded the next day at 18:00 hours. The 36-in casing was picked up and run to the seafloor. It was jetted to 7,182 ft with no problems. High viscosity, unweighted prehydrated gel sweeps were utilized, as needed, while jetting to keep the hole clean. After soaking, the drill-ahead tool was released and drilling initiated. Drilling continued to 8,235 ft with sea water and 100-bbl unweighted viscosified prehydrated sweeps were run every stand drilled down. At 8,235 ft 12.0-lb/gal prehydrated high viscosity sweeps were pumped when every stand of drill pipe was drilled down.

At 9,700 ft on June 20 at 14:45 hours, riserless weighted mud drilling was initiated with a 12.0-lb/gal blend. This was done by blending 16.0-lb/gal high-weight WBM (out of the ballast tank No 1C and the two hull tanks), with a 9.5-lb/gal brine (built by blending 11.6-lb/gal $CaCl_2$ brine with seawater). The remotely operated vehicle's (ROV) cameras indicated that lost circulation occurred temporarily while pumping a 113-bbl, 13.4-lb/gal sweep at 10,053 ft. Therefore, the mud weight being used to drill riserless was cut to 11.0-lb/gal and drilling continued to 10,197 ft with good returns. The blended mud weight was then increased to 11.5-lb/gal. At approximately 10,200 ft, volume accounting indicated that a 9.5-lb/gal brine ratio was not being maintained as determined by gauging the $CaCl_2$ tank. After investigation it was determined that **a 4-in** flowmeter on the blending unit was bad. This bad flowmeter was replaced and the brine ratio was increased to the proper 9.5 lb/gal. At that time the blended mud weight was further increased to 11.8 lb/gal and drilling continued to 10,473 ft where the blended mud weight was increased to 12.0 lb/gal. Drilling continued to 10,820 ft with no trouble. The 13.4-lb/gal sweeps were pumped every stand to help clean the hole.

After 17 hours and 15 minutes of drilling riserless with weighted mud the interval TD of 10,820 ft was reached. At TD, a 200-bbl high viscosity sweep was pumped followed by 3,926 bbl of 12.3-lb/gal kill mud treated with the liquid polymer to achieve the desired high and stable rheology and low fluid loss. The kill mud was built "on the fly" by blending brine (9.5-lb/gal seawater and $CaCl_2$ brine blend) with 19.0-lb/gal WBM while pumping the liquid polymer additive at a metered rate which delivered approximately 8 lb/bbl. The liquid polymer was pumped to lower the API fluid loss from NC to less than 15 mL/30 min and to increase the rheology to a high and stable level such that the hole would stay open.

On the short trip, several tight spots were experienced and the drilling assembly was pumped out while rotating to prevent swabbing. On the cleanout run, the tight spots were washed and reamed and 15 ft of fill was washed through on bottom.

Prior to coming out of the hole to run casing, a 200-bbl high-viscosity sweep was pumped followed by the 12.3-lb/gal kill mud treated with 8 lb/bbl liquid polymer. The volume of kill mud pumped was 1.5 times the hole volume. Afterwards a 50-bbl, 16.0-lb/gal pill of higher density kill mud was spotted on bottom just prior to coming out of the hole. The drillstring was then pulled without tight hole or other problems.

The 20-in casing was run while pumping seawater to keep it full of seawater until the casing entered the wellhead. Once the casing was stabbed into the wellhead, 12.3-lb/gal kill mud was pumped to fill the drill string and casing. The casing was run to 10,777 ft with no problems and the well was circulated with about 1,000 bbl (annular volume) of 12.3-lb/gal kill mud during the cementing operation. The total of all blended mud volume used on this section was 45,442 bbl as shown in **Table 6**.

For the most part the drilling of this riserless section went very smoothly. The three-way blend of WBM,

$CaCl_2$ brine and seawater helped insure the successful drilling of this interval and the setting and cementing of the 20-in casing. The short trip before running casing did require some back reaming. The subsequent trip in the hole to run casing went very smoothly as did the cement job.

Lessons Learned

While drilling this interval, a faulty meter on the brine line of the three-way blender led to not adding the desired concentration of $CaCl_2$ brine into the mud being pumped down the hole. Thus, the fluid being pumped at the start of the weighted mud drilling did not have the desired level of inhibition. Several blending tests were conducted which showed that the meters were working correctly. However, a slightly lighter weight mud being blended with less $CaCl_2$ brine led to correct mud weights being pumped, but not the desired $CaCl_2$ (due to the $CaCl_2$ density being roughly equal to the blend density).

Below are the lesson learned from this well and the problems encountered can be minimized by implementing some important procedures:

- Have a meeting with everyone involved outlining possible problems and what to look for to identify them
- Run the blend tests, but just because the mud weight ends up correct, do not assume the proper quantities of individual fluids are being delivered
- Run individual volume calibration tests on each meter being used, just prior to the job
- As a manual back up to the flow meters, strap each tank periodically throughout the job to insure that the proper amount of fluid is being blended
- Prior to the job calculate and communicate to everyone the proper chloride and calcium concentrations that should be measured on the blended fluid so that the actual mud checks serve as another method to confirm the correct blend is being pumped
- The liquid polymer additive was quite effective, but was more difficult to pump at the cold temperatures (52-55°F) experienced during the actual job as compared to the yard tests. The pump chosen had a larger capacity than the yard tests indicated, which was a good decision. For any future job, an even larger diaphragm pump or different style positive-displacement pump would be recommended.
- The diaphragm pump slowed approximately 8 gal/min between the first and second batch. At the start of the second batch, the diaphragm pump started making a rattling noise that indicated some trash might have been caught in the pump and may have caused the pump volume to slow down between the first and second batches. This demonstrates the need to have a back-up pump on location, if needed to replace the primary pump.
- Because of the location of the master tank and the blending unit, it required approximately 150 ft of 2-in hose which created more back pressure for pumping the liquid polymer than had been anticipated. In the future the hose length should be kept to a minimum or a larger diameter hose should be used.

Summary

Riserless drilling with weighted mud is an effective technique to efficiently set large-diameter surface casing at increased depths in formations with higher formation pressures and reactive shale. This technique has proven on multiple deepwater wells to save time and money.

The limits to using the technique are the required mud weight, the required volume, logistics, required properties at TD, and the equipment needed to mix and pump large volumes of treated mud “on the fly”. Having a good detailed rigsite plan, extra supervision, and a fit for purpose fluid additive is highly recommended.

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Table 1 – Weighted Mud Riserless Drilling Experience

Well	Water Depth (ft)	Hole Size (in)	Start of Weighted Mud Riserless Drilling BML (ft)	Casing Depth BML (ft)	Length Drilled Riserless With Weighted Mud (ft)	Volume High-weight WBM (bbl)	Volume $CaCl_2$ (bbl)	Total Volume Weighted WBM Pumped (bbl)	Density Wt WBM (lb/gal)
13	6,929	16	2,771	3,891	1,120	16,141	4,554	45,442	12.0
12	4,725	26	2,809	3,473	664	7,885	6,047	31,523	11.0
11	8,469	24	1,952	2,852	900	6,354	4,348	22,670	11.5
10	4,159	26	2,302	3,014	712	21,503[2]	5,597	50,103	11.5
9	4,578	24	2,608	3,445	837	9,793	10,246	42,274	11.0
8	3,287	24	937	2,009	1,072	7,720	4,480	25,476	11.5
7	3,287	30	582	937	355	3,905	2,764	13,376	11.5
6	4,489	24	2,024	2,465	441	7,255	2840	25,651	11.0
5	7,729	20	2,611	3,420	809	10,015	6,000	32,792	11.5
4	5,566	24	1,544	2,704	1,160	15,245	1961	35,185	12.1
3	7,202	26	1,851	2,571	720	12,603	1253	38,504	11.0
2	3,319	17	899	1,682	783	8,060	0	19,573	12.0
1	7,210	24	948	2,161	1,213	27,883	0	77,724[1]	11.2/10.6

1. Had stuck casing and MWD logged interval which took additional volume.

2. Including 10,703 bbl of 12.9-lb/gal super-saturated salt mud for drilling into salt, it too was diluted with 16-lb/gal high-weight WBM and seawater to achieve a 11.5-lb/gal saturated salt fluid to prevent salt dissolution.

Table 2 – Rheology and Fluid Loss of Liquid Guar Polymer Suspension
12.6-lb/gal drilling fluid blend made from seawater, $CaCl_2$ brine and 19-lb/gal WBM

Additive	Concentration (lb/bbl)	Fann 600 (rpm)	Fann 300 (rpm)	Fann 6 (rpm)	Fann 3 (rpm)	Plastic Viscosity (cP)	Yield Point (lb/100 ft^2)	Gel Strengths 10s/10m/30m (lb/100 ft^2)	Room Temperature API Fluid Loss (mL/30 min)
	Room Temperature Properties								
Liquid Guar	1.5	151	116	31	25	35	81	22 / 26 / 28	
Liquid Guar	2.0	125	89	18	20	36	53	22 / 34 / 30	
Liquid Guar	2.5	197	152	55	50	45	107	40 / 50 / 62	80
	Properties @ 120°F								
Liquid Guar	1.5	85	81	20	18	4	77	21 / 20 / 20	----
Liquid Guar	2.0	83	60	19	14	23	37	18 / 40 / 36	----
Liquid Guar	2.5	112	75	22	15	37	38	17 / 28 / 32	----

Table 3 - Rheology and Fluid Loss of Liquid Xanthan Gum Polymer Suspension
12.6-lb/gal drilling fluid blend made from seawater, $CaCl_2$ brine and 19-lb/gal WBM

Additive	Concentration (lb/bbl)	Fann 600 (rpm)	Fann 300 (rpm)	Fann 6 (rpm)	Fann 3 (rpm)	Plastic Viscosity (cP)	Yield Point (lb/100 ft^2)	Gel Strengths 10s/10m/30m (lb/100 ft^2)	Room Temperature API Fluid Loss (mL/30 min)
	Room Temperature Properties								
Liquid xanthan	1.5	77	57	24	24	20	37	21 / 38 / 42	
Liquid xanthan	2.0	104	69	20	20	35	34	19 / 42 / 54	
Liquid xanthan	2.5	110	75	22	23	35	40	21 / 48 / 60	19
	Properties @ 120°F								
Liquid xanthan	1.5	55	45	25	20	10	35	20 / 24 / 30	----
Liquid xanthan	2.0	60	46	28	29	14	32	22 / 55 / 68	----
Liquid xanthan	2.5	90	64	30	30	26	38	24 / 62 / 82	----

Table 4 – Rheology and Fluid Loss of Liquid PAC Polymer Suspension
12.6-lb/gal drilling fluid blend made from seawater, $CaCl_2$ brine and 19-lb/gal WBM

Additive	Concentration (lb/bbl)	Fann 600 (rpm)	Fann 300 (rpm)	Fann 6 (rpm)	Fann 3 (rpm)	Plastic Viscosity (cP)	Yield Point (lb/100 ft^2)	Gel Strengths 10s/10m/30m (lb/100 ft^2)	Room Temperature API Fluid Loss (mL/30 min)
	Room Temperature Properties								
Liquid PAC	1.5	56	44	24	23	12	32	22/24/27	
Liquid PAC	2.0	61	50	29	28	11	39	24/24/23	
Liquid PAC	2.5	73	60	34	31	13	47	27/24/24	75
	Properties @ 120 °F								
Liquid PAC	1.5	48	40	26	23	8	32	18/16/13	----
Liquid PAC	2.0	46	40	27	27	6	34	26/35/40	----
Liquid PAC	2.5	49	43	29	28	6	37	26/22/21	----

Table 5 – Testing Experimental Liquid Polymer Suspension at various concentrations in a 12.6-lb/gal drilling fluid made with Seawater, $CaCl_2$ Brine and 19-lb/gal Freshwater Mud

Additive	Concentration (lb/bbl)	Fann 600 (rpm)	Fann 300 (rpm)	Fann 6 (rpm)	Fann 3 (rpm)	Plastic Viscosity (cP)	Yield Point (lb/100 ft^2)	Gel Strengths 10s/10m/30m (lb/100 ft^2)	Room Temperature API Fluid Loss (mL/30 min)	pH
Base Mud	---	45	37	18	18	8	29	18/18	N/C	8.00
ELPS	4	72	57	27	26	15	42	23/28	21.4	8.00
ELPS	6	100	80	33	33	20	60	30/38	16.6	8.00
ELPS	8	115	93	38	37	22	71	33/45	14.8	8.00

ELPS= Experimental Liquid Polymer Suspension

Table 6 – Volumes of Blended WBM Riserless Drilling Interval Well 13

Density of blended WBM (lb/gal)	Volume (bbl)
11.0	3,427
11.5	4,209
12.0	20,359
Various sweeps 12.0 to 13.0 lb/gal	1,973
12.3-lb/gal treated kill mud	13,435
10.4-lb/gal mud used to fill casing	2,037
Total mud volume used	**45,442**

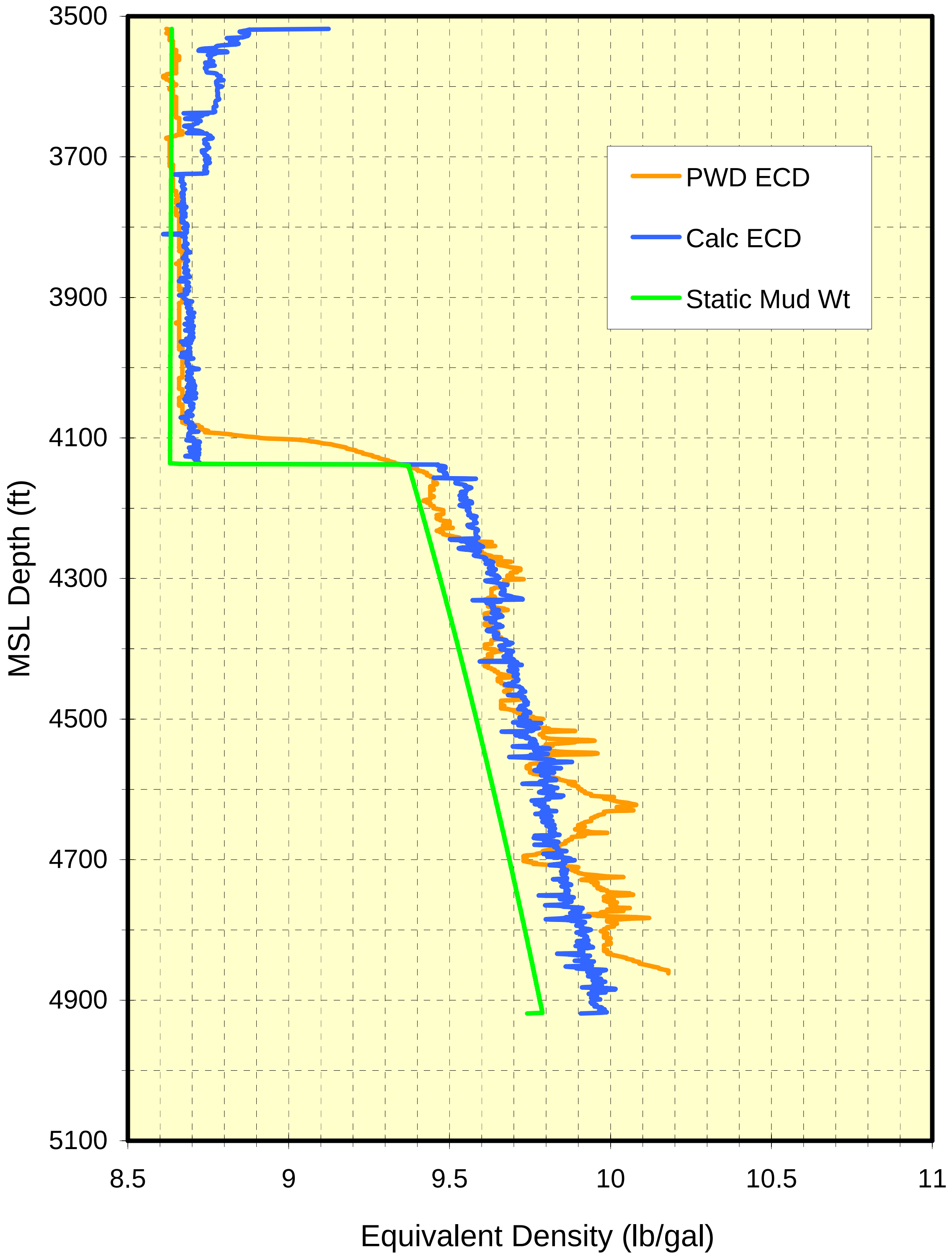

Figure 1 – Example of actual hydrostatics of riserless drilling with weight mud from Well 2, Table1.