

Specialized Fluid Design Increases Drilling Efficiency in Deepwater Gulf of Mexico

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Abstract

A major operator in deepwater Gulf of Mexico recently drilled a very successful riserless section using an ultra-supersaturated drilling fluid, in conjunction with a polymer injection system. The fluid and the polymer injection provide outstanding rate of penetration (ROP), proper hole cleaning and a gauged wellbore in sediment and salt.

There were also cost and storage savings because of the ability to dilute the riserless drilling fluid system to lower densities than traditionally used while maintaining desirable salinity and viscosity. The operation includes drilling a 26-in. vertical hole using a 10 to 12 lb/gal density riserless drilling fluid necessary for wellbore stability and mitigating shallow hazards while keeping the riserless fluid near salt saturation.

The excess suspended salt fluid design delivers high salinity, even at high seawater dilution rates, keeping the wellbore in gauge, a critical factor for directional control. Furthermore, the system enables the operator to perform a very successful 22-in. casing run and cement job. In the past, excess salt fluids resulted in severe salt agglomeration and settling in liquid mud plants and boat transport tanks.

A new anti-agglomerant technology was employed into the fluid design to prevent severe salt agglomeration. The fluid is stored for prolonged periods in the mud plant and boat transport tanks with little or no salt settlement. The benefits saved the operator significant time and money.

Introduction

Throughout the Gulf of Mexico, drilling operators face the challenge of drilling deepwater wells with a riserless drilling fluid system. Traditionally, these types of fluid systems were developed to mitigate the hazards of shallow water flows or shallow gas, and provide a deeper surface casing point to optimize wellbore design. Large wellbores, high pump rates in excess of 1,000 gpm and slow ROP contribute to the need for operators to mobilize large quantities of a heavy “spike” fluid. The fluid is blended with a less dense fluid (generally seawater) to control the bottomhole pressure¹. The ability to blend the two fluids on the fly enables the operator to make quick changes to the density of the fluid to keep the wellbore stable. As Turner and Morales explain, some areas of the Gulf of Mexico are infamous for shallow water flows that can be easiest controlled using a heavier fluid than seawater. When

shallow flows occur, a heavier “kill mud” is necessary to raise bottom-hole pressures and stop the flow. The use of riserless drilling fluids has greatly improved drilling efficiency and success rates for running and cementing surface casing.²

Operators are exploring and developing areas of the Gulf of Mexico comprised of shallow salt formations. The Louann salt is an evaporate that spreads across the Gulf of Mexico and was formed during the Jurassic period.³ The formation exhibits creeping and deforming because the salt does not increase in density with the depth of where it is laid down. When the density of the overlying overburden equals the density of the salt, the salt begins to flow.³ The plastic-type salt body tends to overturn sediments and situates itself at shallower depths than the formations that precede it. The salt moves depending on the depth at which it is buried, the geothermal temperature, mineralogy, content of water and where differential stresses are applied to the salt body.

Salt formations throughout the Gulf of Mexico comprise salt domes, sheets, canopies and nappes. The salt formation is formed from the evaporation of enclosed salt water bodies. Halite makes up the majority of the salt in the Gulf of Mexico, however, potassium salts such as potassium chloride, carnalite and polyhalite exist as well. The salt also comprises sulphates such as gypsum and anhydrite as well as other lesser known salt varieties.⁴

As drilling operations begin to target sub-salt reservoirs, they must drill around salt diapirs or the welds. Therefore, wells are being drilled through massive salt bodies such as domal overhangs. When the bodies stretch near the mud-line, conventional riserless drilling with seawater or freshwater pump-and-dump fluids becomes very challenging because of salt erosion.

According to Akers, the supersaturated fluid is a successful and proven design to drill shallow salt while pumping-and-dumping. A saturated NaCl brine is used as a base fluid and excess undissolved salt is suspended in the fluid.¹ The fluid is sent out as the spike and blended with seawater. As the two fluids blend, the excess salt dissolves into solution because the seawater is far from saturation. By raising the final fluids' salinity to achieve saturation, the level of salt erosion is greatly diminished.¹ By minimizing the erosion and/or leaching (wash-out), operators can expect to have better cement jobs and a more solid foundation for surface casing.

Furthermore, if the drilling assembly contains a rotary steerable-type system, a saturated fluid can provide a gauge borehole, resulting in superior directional control (by keeping the rotary pads engaged with the wellbore). Losing directional control while drilling surface salt can result in undesired inclination in which the surface casing must be set at an angle. This early on inclination in the surface casing leads to numerous other problems, possibly requiring re-drilling the riserless section.

During riserless drilling operations that utilize blending multiple density fluids, high seawater cut-back rates can reduce the fluids' density while also sacrificing the fluids' carrying capacity. In some cases, it takes two or three barrels of seawater to cut one barrel of spike fluid to reach the desired density. When this occurs, nearly all of the fluid viscosity is lost and the ability to clean the hole and the conductor pipe becomes very challenging. A mix of high viscosity or weighted sweeps are generally used to assist with hole cleaning to reduce the chances of packing off.² An alternate and innovative method such as injecting liquid bio-polymer at a controlled rate is a safer and more efficient method for providing sufficient viscosity to the final blended fluid.

In 2013, an exploration well was drilled in deepwater Gulf of Mexico that met nearly all of the aforementioned challenges. Offset wells showed that a shallow salt dome in the riserless section was a significant challenge because of logistics, slow ROP, directional control problems, poor cement jobs and formation integrity tests. An ultra-supersaturated fluid, in conjunction with a newly designed polymer injection system, was the optimal fluid design. The operator witnessed significant savings in rig time and successfully drilled its first interval with significant efficiency.

Deepwater Drilling Fluids – Gulf of Mexico

Initial Gulf of Mexico deepwater wells were successfully drilled with high salt/polymer water-based drilling fluids starting in the early 1980s. Typically, the pre-riser surface hole is drilled with fresh or drill water-based bentonite drilling fluids, and subsequently, a high salt/polymer fluid design is used from post-riser to TD. The high-performance, water-based fluid design utilized at least 20% by weight NaCl up to saturation for shale inhibition and gas hydrate inhibition. The overall design also includes partially hydrolyzed polyacrylamide, lower system pH, xanthan gum for viscosity and limited commercial bentonite additions.⁵ As water depths increased, the use of glycol-based gas hydrate inhibitors were also included in the deep- water drilling fluid design.⁶ With the advent of synthetic- based drilling fluids in the late 1980s and early 1990s, the increased drilling efficiencies achieved with the fluid designs cemented their position as the fluid design of choice for Gulf of Mexico deepwater drilling . As water depth increases, formation fracture gradients become weaker.⁷⁻¹⁰

The fracture gradient typically defines the pressure (or mud weight) required to fracture the formation or rock versus depth. Fracture gradients must be taken into account by

drilling engineers for drilling a successful well. Improper fracture gradient design can result in expensive and potential consequences such as multiple casing strings and lost circulation. Well design becomes even more complicated in deepwater applications because of the potential for gas hydrate formation and the lower fracture gradients encountered.

Fracture pressures on land are a function of the overburden pressure exerted by the formation. In offshore applications, the overburden pressure exerted by seawater is less than that exerted by sand-shale formations. Therefore, the overburden pressure in psi/ft or apparent fracture gradient in the offshore well is less than in the land well. The overburden pressure must be offset by setting additional casing strings or carrying lower mud densities. In deepwater drilling, a substantial amount of hole must be drilled riserless with returns going to the sea floor before a suitable casing shoe can be established for the drilling fluid to be pumped from the bottom of the hole to the rig floor 80 to 120 ft above sea level. As operators move into deeper water depths, drilling fluid design must take into account the lower fracture gradients.

One of the unique operating areas of deepwater drilling is the "riserless" section which involves drilling the surface section of the wellbore with mud returns to the sea floor rather than back to the rig; sometimes the process is also known as "pump and dump." The process helps operators mitigate the lower fracture gradient inherent in deep water and drill deeper before setting the surface casing (usually 26-in or 28-in).

The riserless section is typically drilled with the dual gradient approach using a 16 lb/gal or "spike" fluid that is diluted or "cut back" at the rigsite with seawater, NaCl, or in some cases, CaCl₂ brine to the required fluid density. The riserless drilling fluid systems are designed to resolve several problems associated with conventional riserless drilling operations. The benefits of using the riserless mud drilling procedure include:

- Maximize hole stability and maintain formation integrity
- Maximize the 26/28-in casing shoe depth
- Eliminate unnecessary casing strings
- Reduce logistics to eliminate rig down time
- Prevent shallow gas/water flows
- Increase ROP

The riserless fluid process blends specially formulated 16.0 lb/gal drilling fluid with seawater, sodium chloride and/or calcium chloride to generate a fluid with a predetermined density and rheology. The procedure is executed using specialized proprietary equipment and techniques. Extensive pre-planning is required to determine the mud weight and the necessary fluid volume. A rig survey ensures that all the necessary components for a successful riserless fluid process are present or identified for modification. Prior to the job execution, the fluid manifold unit, which comprises a shearing device and flow control equipment, is set up on-site. The unit

must be rigged up, and a diverse group of logistic issues immediately addressed for the procedure to be effective.

Specialized Fluid Design: Surface Salt

When drilling massive surface salt sections without a riser, it is critical that the drilling fluid system does not cause excessive hole washout. High washout rates can prevent proper directional control that is critical for maintaining an inclination of less than one degree before running surface casing. High washout rates can also contribute to poor cement jobs and can lead to excessive fluids to keep the hole filled. For minimum washout while drilling the salt, it is necessary to keep the fluid as close to saturation as possible. The amount of washout can be controlled to a degree by the amount the drilling fluid is saturated or under saturated with salt.¹¹ The chart below shows calculated washout while drilling a 26 in hole through salt at 50 ft/hr while pumping at 1,200 gpm. From the bit depth, this chart displays calculated washout using fluids with varying degrees of sodium chloride solutions over a 1,000 ft interval of salt. For example, if using a fluid with 51,331 mg/L of chlorides, you can expect the hole to be washed out up to 11 in (26 in to 37 in) at 1,000 ft above the bit

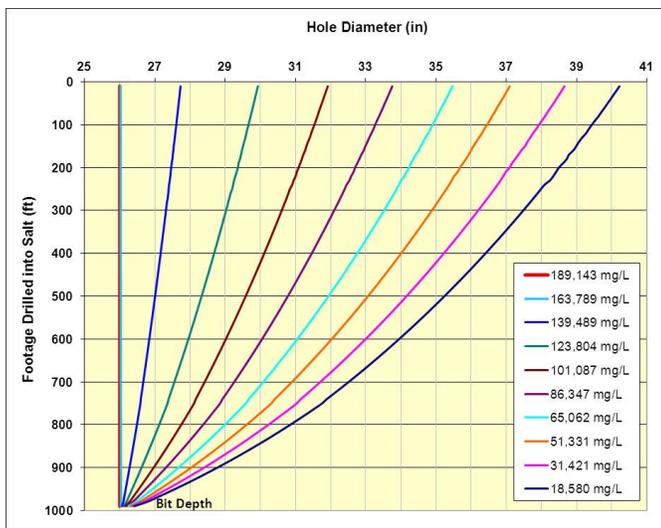


Fig. 1. Hole washout in salt 1,000 ft above bit while drilling 50 ft/hr and pumping at 1,200 gpm. NaCl Solution Chlorides (CF mg/L)¹¹

The salinity of the final riserless fluid pumped downhole is a function of the excess salt in the 16 lb/gal spike fluid and the salinity of the dilution fluid, which is normally seawater. The amount of excess salt in the riserless mud formulation is dependent on the desired final density after dilution, the final salinity desired and the salinity of the dilution-based fluid utilized.

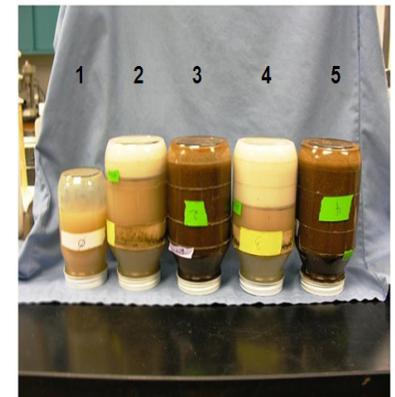
There are a number of fluid design and operational issues when using super-saturated fluids for the riserless salt sections. One of the biggest challenges is suspending the excess salt and preventing it from agglomerating and settling

out in storage tanks, on boats or on the rig. Laboratory testing and previous jobs show that the salt tends to agglomerate over time and create giant slabs or chunks that eventually settle and compact inside the tanks. Losing the salt in tanks causes excessive time for loading boats, cleaning and chances that the fluid does not have the salt to reach the chloride content necessary. To prevent the settling, the ultra-super-saturated riserless fluid is designed with an anti-agglomerant agent that retards and nearly prevents the occurrence of salt agglomeration and subsequent settlement. The illustration below shows super-saturated solutions (110 and 220 lb/bbl excess salt) that contain no anti-agglomerant additive compared to those that do. The differences in settling rates show the anti-agglomerant samples staying suspended for more than six months.

•Samples 2 & 4 have NO anti-agglomerate. Salt is settled and compacted

•Samples 3 & 5 have anti-agglomerate. Salt is still in suspension and has not compacted

•Samples were tested on shakers and slow speed stirrers to represent boat-rides



Sample bottles inverted for photograph to display settling

Fig. 2. Salt settlement, anti-agglomerant vs. no anti-agglomerant. Sample 1 is pure anti-agglomerant

Liquid Polymer Injection System

Because of the high dilution rates required to cut back the 16 lb/gal ultra-super-saturated riserless mud system, a liquid polymer injection system was designed for fast viscosity development. Rapid chemical treatment and yield to build fluid viscosity is critical for efficient hole cleaning and wellbore stability while drilling riserless. The dilution with seawater ranged from 4:1 to 3:1; therefore, additional viscosity was obtained by injecting liquid bio-polymer into the cut back leg on the riserless mud blending manifold. The bio-polymer yielded instantly, providing increased viscosity as the riserless mud is pumped downhole from the suction pit. The injection rate for the polymer pump ranges from 1 to 8 gpm.

Case History

A major Gulf of Mexico operator planned a deep water drilling operation in approximately 7,400 ft of water with a massive section of salt in the riserless portion of the operation. The objectives for the riserless section included:

- Anti-settling of the fluid in storage and boat transport

- Near gauge 26-in hole section for directional control and optimized cementing
- Excellent ROP and successful landing and cementing of 22-in casing

Preventing excessive washout in the surface section is imperative. The high washout rates can prevent proper pad engagement for the rotary steerable system, which is detrimental to maintaining an inclination of less than one degree before running surface casing. High washout rates can also contribute to poor cement jobs and can lead to an excess of fluid to keep the hole filled.

A 16 lb/gal ultra-super-saturated base fluid was the spike fluid to save on mud volume and improve logistics. The higher the density of the spike fluid, the more blended volume can be created with seawater dilution. While examining traditional super-saturated riserless fluid systems (110 lb/bbl Excess NaCl), the chloride content was determined to be too low (when using seawater to dilute it to the necessary 10 lb/gal fluid for pumping downhole). The goal comprised keeping the fluid as close as possible to saturation because lower chloride content results in higher washout rates.



Fig. 3. Hole washout 100 ft above bit, while drilling 50 ft/hr and pumping at 1,200 gpm. NaCl Solution Chlorides (Cl⁻ mg/L) ¹¹

The operator focused on the rotary steerable system and approximately 100 ft behind the bit for rotary steerable pad engagement and directional control. The hole washout chart above shows that at NaCl saturation (189,143 mg/L Cl or 26% by wt NaCl), a gauge hole can be maintained. The operation required that the 26-in hole not wash out more than 1 in, therefore, the fluid must remain over 101,087 mg/L Cl or 15.6% by wt NaCl.

Table 1. Blend table: Base Fluid Diluted with Seawater

	NaCl Solution Chlorides (Cl ⁻ mg/L)				Yields	% 16 ppg Spike	% Seawater
	NaCl Saturated (mg/L)	110 ppb Excess NaCl (mg/L)	220 ppb Excess NaCl (mg/L)	SW to cut 16.0 ppg			
10.00 ppg blend	47,720.2	81,648.1	115,576.0	4.03	5.03	19.9%	80.1%
10.50 ppg blend	55,680.1	100,993.1	146,306.2	2.76	3.76	26.6%	73.4%
11.00 ppg blend	63,639.9	120,338.1	177,036.4	2.01	3.01	33.2%	66.8%
11.50 ppg blend	71,599.7	139,683.2	207,766.6	1.51	2.51	39.9%	60.1%
12.00 ppg blend	79,559.5	159,028.2	238,496.8	1.15	2.15	46.6%	53.4%
12.50 ppg blend	87,519.3	178,373.2	269,227.0	0.88	1.88	53.3%	46.7%
13.00 ppg blend	95,479.1	197,718.2	299,957.2	0.67	1.67	59.9%	40.1%
13.50 ppg blend	103,438.9	217,063.2	330,687.5	0.50	1.50	66.6%	33.4%
14.00 ppg blend	111,398.7	236,408.2	361,417.7	0.36	1.36	73.3%	26.7%
14.50 ppg blend	119,358.6	255,753.2	392,147.9	0.25	1.25	80.0%	20.0%
15.00 ppg blend	127,318.4	275,098.2	422,878.1	0.15	1.15	86.6%	13.4%
15.50 ppg blend	135,278.2	294,443.2	453,608.3	0.07	1.07	93.3%	6.7%

The table above illustrates that the 220 ppb ultra-super-saturated riserless fluid system provides more than 101,087 mg/L Cl⁻ necessary to minimize washout while blending to 10 lb/gal. A strategy included using high dilution rates of 4 barrels of seawater to cut 1 barrel of 16 lb/gal base fluid. The excess 220 lb/bbl of undissolved sodium chloride salt in suspension mixes with the seawater and solubilizes, therefore raising the chloride content of the fluid system to the required concentration. The fluid system enables the operator to maintain higher chloride levels while using a lower density blended fluid. In turn, the operator reduces the amount of 16 lb/gal base fluid necessary for mobilization.

Upon selection of the 220 lb/bbl ultra-super-saturated fluid, preparations are made for mixing and storing the base fluid prior to shipment to the rig. Mixing and storage tanks are inspected and cleaned as well as all lines prior to mixing.



Fig. 4. Mixing ultra-super-saturated riserless fluid at LMP

31,000 bbls of 16 lb/gal ultra-super-saturated riserless mud containing 220 lb/bbl excess NaCl was created for the operation.

Boat Transport

3 vessels were used to transport the riserless 16 lb/gal base mud to the rig. Mud was stored on one vessel up to 4 weeks with no appreciable settling.

Table 2. Density measurements of vessel 1 tanks

	Density				
	4/27/2013	5/1/2013	5/6/2013	5/10/2013	5/14/2013
13 Port	16	15.9	15.8	15.8	16
13 S/B	16	16	15.9	15.9	15.95
Tank 12 Port	16	15.9	15.85	15.8	15.95
12 S/B	16	16	15.9	15.9	16
11 Port	16	16.1	16.2	16.1	16
11 S/B	16	16.3	16.4	16.4	16

Table 3. Density measurements of vessel 2 tanks

	Density		
	5/2/2013	5/6/2013	5/16/2013
13 Port	16	16	16.2
13 S/B	16	15.9	16
Tank 12 Port	16	16.1	15.9
12 S/B	16	16	15.95

Drilling

While drilling the shallow salt, the ultra-super-saturated riserless fluid was blended to an initial mud weight of 10 lb/gal; at 9,634 ft the mud weight was increased to 11 lb/gal. The operator was able to maintain ROP higher than expected while pumping in excess of 1,200 gpm. Sufficient delivery rates from the boat and rapid blending rates allowed for the rig to achieve the aforementioned drilling parameters. The chlorides did not drop below 111,000 mg/L on the 10 lb/gal blend and did not drop below 180,000 mg/L on the 11 lb/gal blend:

Table 4. Flow Properties for Sweeps, Active Mud and Pad Mud

Sample	Sweep	Active	Active	Active	Active	Pad
Mud Weight	8.9	10.05	10.0	11.0	11.0	12.0
Viscosity	300+	40	41	43	42	43
PV	*	5	4	7	8	13
YP	*	15	16	14	15	16
Gels	*	5/6/8	4/6/8	7/8/10	7/9/11	5/6/6
API Filtrate	10.2	31.4	25.0	29.6	28.1	8.8
Chlorides	400	118,000	111,000	183,000	181,000	184,500
Hardness	60	2040	1960	1840	1800	1880

22-in Cement Job

Cement spacer lag time calculations correlated to a 5% washout for an almost perfect gauge hole. The cement company over calculated the required cement, resulting in excess cement at the surface. The cement job was further confirmed successful with a higher than expected formation integrity test on the surface casing.

Rate of Penetration

The rate of penetration while drilling a 26 in hole riserless through the salt section set a record compared to offsets in the area. The sediment portion of the riserless section was also drilled at a much improved rate of penetration. The average ROP in the sediment was approximately 123 ft/hr and approximately 57 ft/hr in the salt.

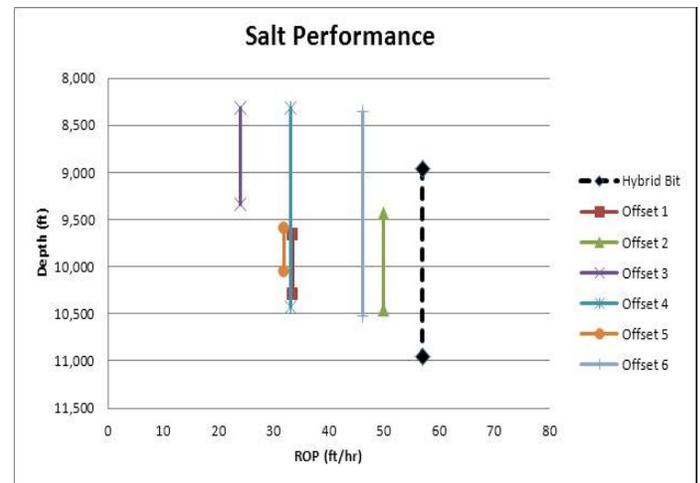
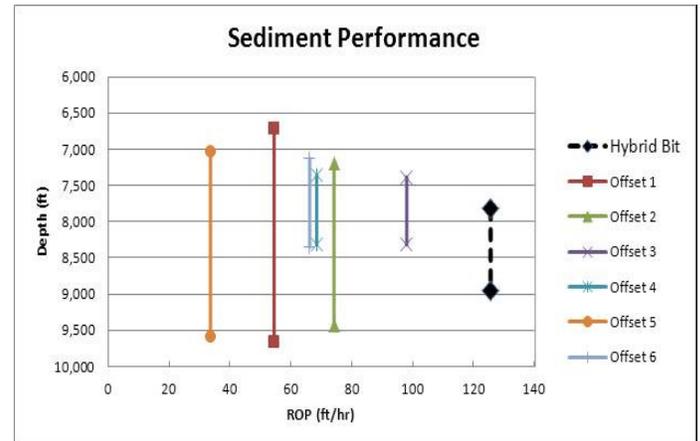


Fig. 5. “Hybrid Bit” displays subject well that used the ultra-super-saturated riserless fluid with 220 lb/bbl excess NaCl. Other wells shown are offsets in same area.

Pit Cleanout

After pumping the last of the extra (~2,800 bbls) ultra-super-saturated riserless fluid back to the boat for return, the rig began cleaning the pits. Upon inspection, there were not any notable settled solids in any of the pits that stored the 16 lb/gal fluid. There were minimal solids in the pit that was utilized for blending the spike fluid with seawater, resulting in the active 10 lb/gal and 11 lb/gal mud.

The rig washed out all of the pits by accessing them from the topside (through a 12in by 12in sampling hatch) with a 1-in water hose for all but the blending pit. The blending pit

was cleaned utilizing a fire hose for expediency. The ability to clean with such ease eliminated the need for a man in the pit, saving considerable time, eliminating permit requirements and making the clean-up job safer.

Boat Cleaning

The anti-agglomerant technology works well with boat tanks free of sediment (barite and salt). All three boats exhibit similar tank conditions.



Fig. 6. Boat tanks prior to pit cleaning, no sediment

Tables

Table 1. Blend table: Base Fluid Diluted with Seawater

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Table 3. Density measurements of vessel 2 tanks

Table 4. Flow Properties for Sweeps, Active Mud and Pad Mud

Figures

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Conclusions

- Record ROP drilling salt and sediment in deepwater Gulf of Mexico.
- Gauge hole resulted in excellent directional control and successful cementing of 22-in casing with excess cement returns to the sea floor.
- Successful formation integrity test indicates excellent cement job.
- Inclination of surface casing is less than 1° using the ultra-super-saturated riserless fluid.
- Operator set 22-in surface casing 500 ft. deeper than planned because of higher than expected ROP and excess available fluid.
- Polymer injection system rapidly increases blended fluid viscosity.
- No settling of barite or salt in LMP, boats or rig using anti-agglomerant technology.
- No salt agglomeration; can lengthen time between full circulation on transport boats.

Nomenclature

GPM = Gallons per minute (gal/min)

PPG = Pounds per gallon (lb/gal)

LMP = Liquid mud plant

PPB = Pounds per barrel (lb/bbl)

ROP = Rate of penetration

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