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Field Implementation and Lessons Learned Regarding Biopolymer-free Water-based Reservoir Drilling Fluid in the Gulf of Mexico

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Abstract

A unique, high density, low solids, water-based reservoir drilling fluid (RDF) has been qualified and utilized for a multi-well development campaign in the Gulf of Mexico. The fluid design was required to address challenging drilling conditions; Deepwater environment, elevated bottom hole temperatures and pressures, etc., while also maintaining low formation damage potential. As observed during field operations, the reservoir drilling fluid exhibited stable rheological properties which required minimal maintenance treatment to achieve the density target. To maintain wellbore stability and balance pore pressure, a high-density divalent brine was required as the base fluid. Fluid design and use considered environmental aspects for offshore operations.

Introduction

An operator has successfully drilled and open-hole gravel pack completed a series of deepwater wells by using a biopolymer-free water-based RDF system. For every well, the reservoir section drilled averaged 1,000 feet (305m), with bottom hole temperature (BHT) of 265 degF (129 degC). Fluid systems and a breaker were chosen based on more than five years of laboratory testing and scaled up liquid mud plant pilot mixes.

Conventional biopolymer systems have poor compatibility with divalent brines, which needed to be used as base fluid due to density requirement, and format brines could not be utilized due to excessive cost of the fluids needed. The calcium bromide-based RDF used for the drilling campaign allowed for achieving high density (>15.3 lbm/gal or 1.84 s.g.) while minimizing solid weighting material. Additionally, it required simple engineering and exhibited high tolerance to drilled solids and cement contamination.

This paper discusses lessons learned, acquired during drilling the first wells, which were successfully converted into operating procedures for subsequent wells, ensuring fluid quality was maintained between wells, and drilling/completion performance was optimized. In addition, details regarding key development milestones of the fluid, acquired via extensive laboratory qualification testing, and small-scale field mixes, are provided.

Laboratory Design

The steps below were followed in the design and optimization of reservoir drill-in fluid and screen running fluid systems:

- Select the base brines for each system based on density and TCT (True crystallization Temperature)
- Design the bridging package and optimize the fluid loss for the RDF.
- Optimize fluids rheological properties and use same to model the drilling hydraulic.
- Determine the fluids stability over time at reservoir temperature.
- Assess RDF filtercake clean-up with breaker
- Perform return permeability testing

Reservoir Drill-in Fluid (RDF) Design

During design and evaluation stages of the biopolymer-free water-based RDF system several factors needed to be considered: high pressure and high temperature stability; rheological profile, suitable for drilling with reduced equivalent circulating density (ECD); minimized formation damage; and effectiveness of the filter cake removal during wellbore cleanout.

First, the base brine was selected based on the final density and the required TCT (<32degF at mudline). The selected base brine density allowed for the RDF systems to be formulated with minimum bridging solids content and with enough free water to provide an optimum yielding of the modified starch. These benefits are important for an optimal hydraulic and filtration (minimal plastic viscosity, pressure loss, equivalent circulating density (ECD), thin filter cake, filtrate and short invasion radius).

The main objective of the RDF system is to minimize formation damage while drilling. The effective way to achieve this objective is to control the quality of the filter cake built on the wall of the formation as the result of filtration due to the overbalance state of the well. The filter cake must quickly and effectively seal the formation pores to minimize any further drilling fluids filtration while drilling and be easily removed before starting to produce or inject into the reservoir. The quality of the filter cake depends on the type, the size, the form and the quantity of the solids present in the drilling-in fluid.

The bridging package was selected based on the reservoir properties and was optimized to achieved excellent filtration properties and high filtercake quality. The designed RDF formulation and its properties are shown in respectively in Tables 1 and 2:

Table 1 – Formulation of a biopolymer-free RDF

Product	Loading	Function
Base brine	0.878 bbl/bbl	Base fluid
Modified starch	5-6 lbm/bbl	Fluid loss control, viscosity
Highly reactive magnesium oxide	0.5-1 lbm/bbl	Viscosity
Specialty additive	1-2 lbm/bbl	HT rheology
Carbonates	As needed	Bridging, density

Table 2 – Rheological properties of a biopolymer-free RDF

	Properties @ 120degF	
Readings, rpm	Initial	After hot roll
600	112	114
300	73	77
200	58	63
100	41	45
6	13	18
3	12	16
Plastic Viscosity, cP	39	37
Yield Point, lbf/100 sqft	34	40
pH	6.8	6.4

To assess the stability of the designed RDF at reservoir conditions, static aging tests were performed at reservoir temperature for up to 88 hours. The static aging tests results, shown in Table 3, proved that the RDF can be left in the open-hole section for up to 88 hours without undergoing substantial thermal degradation.

Table 3 – Rheological properties of a biopolymer-free RDF after static aging

	Properties @ 120degF	
Readings, rpm	Initial	After static @250degF 88 hours
600	117	96
300	78	63
200	63	50
100	45	36
6	18	13
3	16	10
Plastic Viscosity, cP	39	33
Yield Point, lbf/100 ft2	39	30
pH	6.5	6.1

Solids Free Screen Running Fluid (SF SRF) Design and Evaluation

To successfully run the production screens, a biopolymer-free water-based Solids Free (SF) system was designed and tested. Testing revealed that SF exhibited the same performance in terms of formation and formation fluids compatibility as the RDF but without a risk of plugging production screens. Production screen tests were performed before the fluid was pumped downhole.

SF SRF formulation and properties are presented in Table 4 and Table 5 below:

Table 4 – Formulation of a solids-free SRF

Product	Loading	Function
Base brine	0.930 bbl/bbl	Base fluid
Specialty starch	9 lbm/bbl	Fluid loss control, viscosity
Highly reactive magnesium oxide	4 lbm/bbl	Viscosity
Specialty additive	3-4 lbm/bbl	HT rheology
Thermal stabilizer	8 lbm/bbl	Thermal stability

Table 5 – Rheological Properties of a solids-free SRF

	Properties @ 120degF	
Readings, rpm	Initial	After sieves
600	175	162
300	115	103
200	90	80
100	61	53
6	18	13
3	14	10
Plastic Viscosity, cP	60	59
Yield Point, lbf/100sqft	55	44
pH	5.8	5.8

Specific requirements for density (>15.3 lbm/gal), high temperature rheology, and low fluid loss while drilling resulted in a formulation that used calcium bromide divalent brine as a base fluid, special modified starch and magnesium oxide with increased chemical reactivity as rheology modifiers and fluid loss control agents.

Breaker Test

It was determined that a filtercake removal chemistry was required to remove carbonate-based bridging materials before producing these wells through open hole gravel pack lower completions

One of the qualities of the filtercake is its ability to be easily removed (dispersed or dissolved) before production from or injection into the reservoir. Since the RDF filtercake consists of modified starch component and acid soluble sized calcium carbonates, a breaker primarily consisting of chelant and acid precursor components, was selected to provide adequate delay and effectively dissolve the RDF filtercake after lower completion was installed (post-gravel pack operation). The selected breaker formulation is shown in Table 6:

Table 6 – Selected Breaker formulation

Product	Loading, % vol.	Function
Base brine	70	Base fluid
Chelant	10	Carbonate removal
Acid precursor	19	Carbonate removal
Specialty additive	0.1	Corrosion inhibitor
Surfactant	0.9	Dispersant

Breaker system results could be visualized with the pictures below (Figure 1), showing results of carbonates dissolution and starches breakdown:

Figure 1 – Results of the breaker system action of carbonates dissolution and starches breakdown using aloxite disks: without gravel pack (left) and with gravel pack (right) demonstrating almost complete filtercake removal

Return Permeability Test

The return permeability tests were performed by soaking the core samples with the breaker system for predetermined amount of time and then measuring the flow initiation pressure and a flow in the production direction. The results of a return permeability and a flow initiation pressure are presented in the Table 7:

Table 7 – Return permeability test results for RDF

	Return Permeability – Production, %	Flow Initiation Pressure, psi
Test 1	103.5	0.77
Test 2	98.9	0.75
Test 3	100	0.85

After the return permeability testing the core samples were examined for filtercake removal effectiveness and fluid invasion. Figure 2 below demonstrates clean core with minimal filtercake residue:

Figure 2 – Results of return permeability tests performed with core samples from the field

Deepwater Drilling Application

Before proceeding with drilling the open hole interval with biopolymer-free water-based RDF, fluid properties were verified and confirmed as per quality control procedure. Previous experience and analyses of the offset wells suggested using a two-pit system that separated the suction pit and a returns pit. These pits were equalized at the bottom and contained most of active surface volume. RDF was pretreated with defoamer to mitigate surface foaming and drive entrained air out during circulation. Only, small amount of new treatment was required. As a precaution rig floor personnel treated RDF with defoamer at the trip tanks and the diverter box on the rig floor. Agitation of the active pits was kept to a minimum, just enough to assist in dispersing foam, resulting from entrained air escaping drill-in fluid.

This biopolymer-free water-based RDF possesses high tolerance to water hardness and cement contamination; therefore, on multiple wells remaining cement in the casing was drilled out with the RDF. The amount of cement drilled was minimized to reduce acid insoluble drilled solids (AIS) content in the drill-in fluid.

To maintain good low-end rheology of the RDF and a low fluid loss, a treatment plan was developed to proactively treat the circulating system. Pills were made with drill-in fluid segregated from an active system into the pill pits. These pills contained additional loading of specialty modified starch for fluid loss and rheology and extra amount of highly active magnesium oxide for rheology improvement.

Treatments were incorporated into the active system by pumping treatment pills of 50 bbls volume, when boost pumps were slowed down and the pill was pumped into the drill string. That eliminated possibility of treatment chemicals to be picked up by boost pump returns and separated at the mudline – which would allow unyielded starch to be stripped at the shaker. After drilling approximately 300 ft (91m) treatment pills were pumped every hour whenever operations allowed to do so. During drilling biopolymer-free water-based RDF maintained good properties almost all the way to the end of the interval as evidenced by data in the Figure 3:

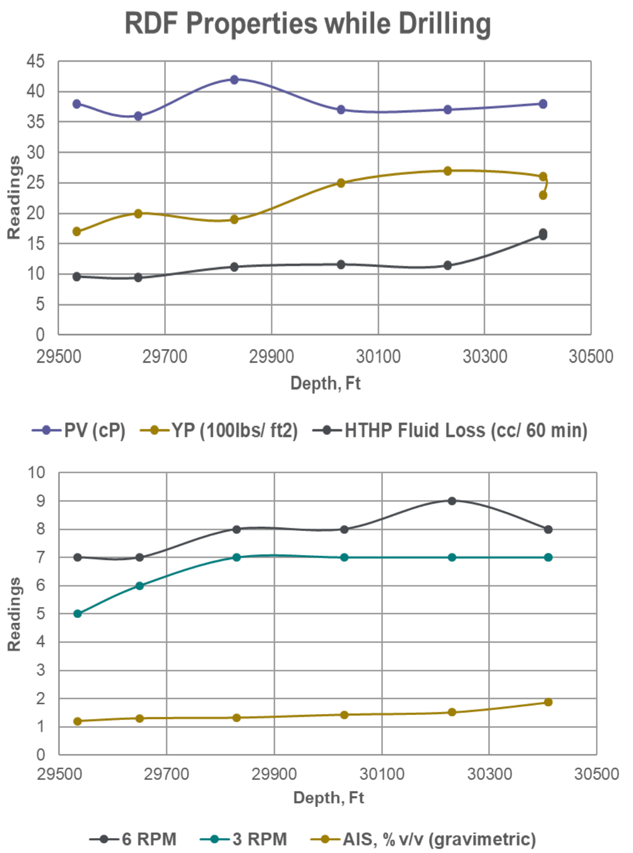

Figure 3 – Rheological properties, fluid loss, and drilled solids loading of the RDF while drilling the interval

There was an increase in HTHP fluid loss as the end of the reservoir section was approaching. Pictures below (Figure 4) show incorporation of drilled solids into filtercakes, which can be seen as darkening. However, the amount was small enough not to cause accessive thickening of the filtercake, and it was in correlation with measured AIS during drilling (small increase from 1.2% to 1.9%). Despite drilled solids incorporation inot the filtercake its integrity and malleability was maintained.

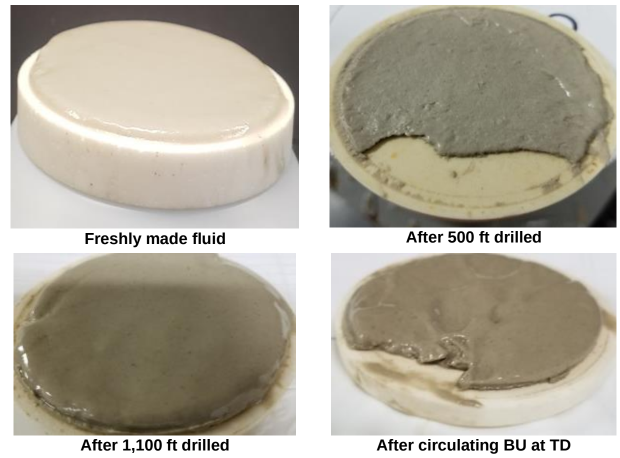

Figure 4 – Biopolymer-free water-based RDF filtercake evolution during interval drilling and after circulating bottoms-up after reaching total depth drilled

Proactively treating the circulating system with modified starch and chemically active magnesium oxide pills helped maintain reservoir drill-in properties. Overall, fluid performance during the drilled interval exceeded expectations and ROP was higher than planned (Figure 5), while keeping ECD within acceptable levels (Figure 6):

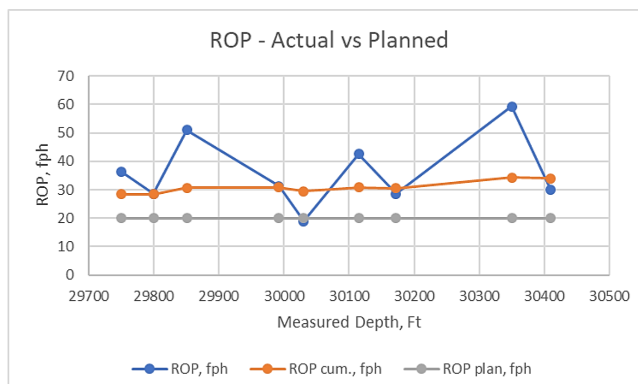

Figure 5 – Rate of penetration while drilling the interval

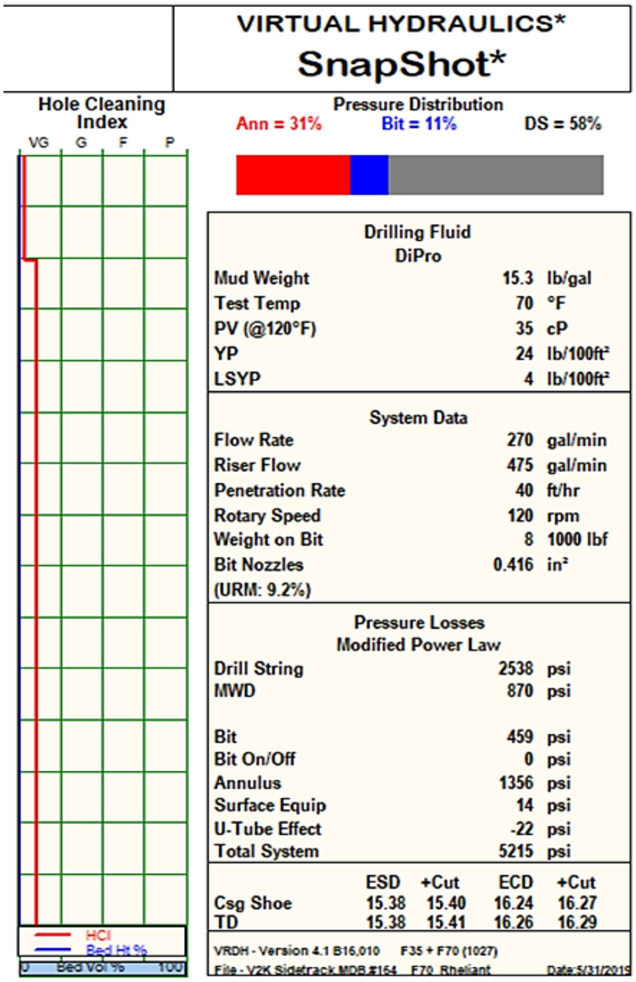

Figure 6 – ECD at the beginning of the open-hole interval and at TD, as simulated with software using actual rheology data

After several bottoms up circulations and a wiper trip the hole was cleaned of debris and solids free screen running fluid was spotted in the open hole and above the casing shoe. Before the solids free screen running fluid was pumped downhole, a final production screen test check was done to confirm that the fluid would not plug production screen. Production screen were run to the bottom with no issues.

After completing the gravel pack operations, after the service tool was shifted and while reverse circulating the excess proppant, the breaker was mixed. Timing was very critical when preparing the breaker and pumping it downhole. Effective communication between mud engineers and the rig floor assured smooth operation for spotting the breaker downhole. Designed delay time was adequate for the completion assembly to be pulled out of the hole before sustained losses and closing of the formation isolation valve.

Onshore Operations

Initial mix of both the biopolymer-free water-based RDF and the biopolymer-free water-based SF system took place at the Completions Fluid Plant after multiple small batch mixes verified mixing procedures and properties. With a large multi-well campaign, it is important to minimize volume growth as operations progress. Keeping this in mind, the biopolymer-free water-based RDF system is transported back to shore between each well to undergo brine reclamation and fluid reconditioning.

Initial mix

Small batch yard mixes were performed during the design phase to verify mixing procedures and properties of the fluid made at a large scale. When both those items were finalized the initial mix began.

Tanks were cleaned to completions standards and inspected prior to use to eliminate the possibility of contamination. The polymer is passed through a sieve attached to the hopper and added at a moderate speed and allowed to yield prior to the addition of all other chemicals. Quality checks are performed, and samples are taken prior to any fluid being sent to storage. The SF fluid is passed over a shaker to remove any debris or particles that would cause a PST failure prior to the quality check and sample collection.

Reconditioning

Following the completion of each well, the biopolymer-free water-based RDF is sent back to the Completions Fluid Plant for storage.

Table 8 – Formula used in reconditioning between wells

Product/Fluid	conc.	unit
Returned RDF from Previous Well	0.225	bbl/bbl
Recovered brine	0.674	bbl/bbl
$CaBr_2$ powder	9.4	ppb
Modified Starch	5.15	ppb
Highly reactive magnesium oxide	0.55	ppb
Specialty additive	1.4	ppb
Carbonates	80.85	ppb

Table 9 –Properties of the biopolymer-free RDF during reconditioning stage

	Before Treatment		After Treatment	
Density (ppg)	15.2		15.3	
Rheology @DegF	70	120	70	120
600	107	72	197	132
300	60	47	121	84
200	47	35	92	65
100	28	21	60	43
6	5	4	16	12
3	4	3	13	10
Plastic Viscosity, cP	47	25	76	48
Yield Point, lb./100sqft	13	22	45	36
10 sec	5	4	13	10
10 min	6	6	14	12
HTHP Fluid Loss, FAO SP, 500 psi, 250 DegF				
Spurt/30min/60 min	1/15/28		3/7.5/9.5	
Acid Insoluble Solids (vol%)	1.5		0.5	

Samples are retrieved from each storage tank and sent to the Houston Laboratory for analysis and reconditioning pilot testing. Samples are checked for density, pH, rheological properties, AIS (Acid Insoluble Solids) content, HTHP filtration, base brine density, and base brine ionic composition.

Using the results of this analysis, pilot tests are performed combining a dilution of the returned RDF with treatment to replenish the polymer content and adjust the bridging package.

Brine Reclamation

To minimize volume growth between wells, while also reducing AIS concentration to less than 1% by volume, the base brine of a portion of the used biopolymer-free water-based RDF is “reclaimed” through several processes at the LMP. This reclaimed brine is then used as the base brine for the reconditioning of the used fluid for the next well.

Used RDF is treated with a concentration of chemicals blend to break down the remaining polymer in the fluid and is then centrifuged. The effluent of the process is then further treated, and then decanted until clear brine is observed. The remaining fluid is then centrifuged again and passed through a Diatomaceous Earth (DE) filter and stored for quality control. Once the brine passes a quality exam at the Houston Lab it is cleared for use in the reconditioning and is used in those operations.

Conclusions

- Biopolymer-free water-based reservoir drill-in fluid has demonstrated superior performance for drilling multiple wells into pay zone at high temperature high pressure conditions.
- Preventive conditioning and regular treatment schedule allowed for stable fluid rheology and low fluid loss throughout the drilling campaign, resulting in 50% increase in ROP and managed ECD.
- Logistics and effective communication were a key in successfully running screens, pumping gravel pack and, completing wells.
- Volume gain can be minimized by reclaiming the brine of used RDF to use as base fluid in the reconditioning process.

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Nomenclature

RDF = *Reservoir Drill-In Fluid*
OHGP = *Open-Hole Gravel Pack*
SF SRF = *Solids Free Screen Running Fluid*
LMP = *Liquid Mud Plant*
BU = *Bottoms-Up Circulation*
TD = *Total Depth*
ROP = *Rate of Penetration*
HTHP = *High Temperature High Pressure*
AIS = *Acid Insoluble Solids*
PST = *Production Screen Tester*
TCT =*True Crystallization Temperature*

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