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Use of Innovative Second-Generation Flat Rheology Fluid Ensures Successful Delivery of Narrow Margin, Directional Wells.

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Abstract

The service intensity of drilling campaigns of oil & gas wells continues to increase as well have progressed in complexity from vertical to horizontal wells. Non-aqueous fluids (NAF) are the fluids-of-choice in these complex wells as they provide excellent wellbore stability and low frequency of stuck pipe events. However, equivalent circulating density (ECD), pressures required to break circulation, and surge pressures present challenges with NAF in high-overbalance, narrow margin, directional wells. The objective of this paper is to compare the successful flat rheology NAF (FR-NAF) behavior in different challenging conditions in the studied area. Studied are exhibit different conditions and challenges. A purpose-built flat rheology fluid was recently developed to meet the operational conditions on studied areas in terms of pressures from low density to high density to maintain well control and temperatures. The fluid constituents were carefully selected to exhibit a flat rheology profile to aid in trouble-free drilling of these different complex wells. The FR-NAF was expanded from vertical wells to horizontal wells having high overbalance and narrow margin window environments. Performance efficiency gains include reductions in fluids-related non-productive time (NPT), downhole losses, stuck pipe events, with improved hole cleaning and barite sag management. The paper details the comparison of FR-NAF utilized to successfully drill in totally different challenging conditions as narrow margin and high overbalance pressures in the studied area. Engineered guidelines are presented to characterize the system, to include tightened specifications of rheological properties and key performance indicators (KPI's).

Introduction

As the drilling environment continues to evolve, more challenging well profiles are being drilled in continually more challenging geographies. Well profiles that were previously not considered due to narrow ECD windows are now being drilled with the same expectation of production as previously completed wells. Additionally, the efficiency of a modern drilling operation can no longer afford fluids-related NPT due to re-conditioning of fluid, differentially stuck pipe, pressure-induced losses due to excessive ECD, or formation breakdown due to excess surge and swab pressures. Furthermore, a common fluid must be able to be configured both as a standard drilling fluid as well as a Reservoir Drill-In Fluid (RDIF) without a significant new allocation of products. As such, the prior generation of NAF became ill-suited to these new challenges.

A new generation of drilling fluids first applied in deep-water environments were selected and engineered to perform in the unique operational landscape. This fluid was chosen due to the consistent rheological profile across all possible temperatures and pressures, as well as the robust nature of the fluid and the resistance to common contaminants both onshore and offshore. Additionally, the fluid was chosen to be tolerant of several different types of weight material to allow for the construction of RDIF as well as more conventional systems such as those using barite.

To display and evaluate the consistent rheological behavior of the fluid, select measurements are taken at a series of temperatures and pressures when available to observe the fluid's condition. From these measurements, a set of flat rheology criteria are established:

Less than 30% deviation of LSYP, YP, and Gel Strengths at lowest temperature and highest temperature (60°F and 150°F)

- 10 min gel < 1.7 times 10-second gel
- 30 min gel < 1.3 times 10-minute gel
- PV at 60F < 2.5 times PV at 150F

The criteria established here serve, along with monitoring of wellsite pressure and other operational data, to provide the fluid provider and operator with the insight to know that the FR-NAF is being administered correctly. After a successful trial of the 2nd generation FR-NAF in an onshore environment, a second trial in an offshore environment was specified and intended to be carried out using the same chemistry..

Experimental Evaluation

This section highlights the development of the latest generation of FR-NAF designed for use in challenging and complex, narrow margin wells. The 2nd generation fluid exhibits a rheological profile nearly independent of the temperature and pressure conditions typically encountered in pressure margin operations. The fluid's unique rheological profile translates to a significant reduction in surge pressures, ECD, downhole losses and barite sag, while also improving hole cleaning efficiency when drilling at high rates of penetration (ROP). Key design parameters included rheological properties (gel strengths, plastic viscosity (PV), yield point (YP) and 6/3 rpm readings, resistance to barite sag and ECD management. The design team used novel and proprietary chemistry, evaluated individual components, as well as combinations of components, to achieve the design objectives. The project data showed that both the type and quantity of organophilic clay used affected the performance of the system. This observation led to the identification and use of a low-dose, high performance organophilic clay (LD-HPOC) designed to balance flat rheology, and barite sag management objectives. Another key attribute of the system was the application of a unique temperature-activating polymeric viscosifier designed specifically for use with the organophilic clay and filtration control additives. To demonstrate the capability of the fluid, the development team designed formulations over a wide range of operationally feasible temperatures, oil-water ratios, and densities. Successful formulations were tested at densities of 11.4 – 19.3 lbm/gal (1.36 – 2.3 sg) and at temperatures up 350 °F (177°C).

Additionally, a series of contamination and treatment response testing took place to determine system response to contaminants both commonly encountered during all drilling operations as well as those specific to offshore drilling and the region. Table 1 presents laboratory data of the FR-SBF and shows the near-independence of temperature and pressure effects on the flow properties and gel strengths of the fluid. HPHT Rheology measurements were made of the same candidate FR-NAF to accurately approximate the hydraulics seen while drilling.

Table 1 - FR-NAF Laboratory Development Testing Results

Temp (F)	60	80	100	120	150
600	143	101	82	72	63
300	80	56	47	42	38
200	58	41	35	32	30
100	35	25	22	21	20
6	9	8	8	9	9
3	8	7	7	8	8
LSYP	7	6	6	7	7
PV	63	45	35	30	25
YP	17	11	12	12	13
10s Gel	12	10	11	11	13
10m Gel	24	22	23	25	27
30m Gel	25	24	25	27	31
ES					323
Alkalinity (ml H_2SO_4/ ml Fluid)	2.45				
Excess Lime (lbm/bbl)	3.16				
HTHP Temperature (F)	210				
HTHP Filtrate (mL/30min)	1.0				
Water in Filtrate	0.0				
Filter Cake Thickness (1/32")	2				
Oil Separation/Syneresis/Top Oil (mL)	0				
Top Density (g/ml)	1.444				
Bottom Density (g/ml)	1.47				
Sag Factor	**0.504**				

Table 3 displays the results of the HPHT Rheology measurement on the candidate fluid. As can be seen, the fluid maintains a stable rheological profile up to the maximum expected temperature and pressure of the well. One specific challenge seen in the deployment of FR-NAF in environments using low kinematic viscosity base oils such as Low-Toxicity Mineral Oil (LTMO), is that a greater concentration of viscosifying products will be required to maintain the desired rheological profile as compared to the concentrations needed when building FR-NAF with a higher kinematic viscosity base oil, such as would be used in deep-water Gulf of Mexico.

Table 3. FR-NAF Laboratory Development Testing, Grace M7500 HPHT Rheology

Temp ˚F	PSIG	PV	YP	LSYP	Gel10s	Gel10m
60	0	61	20	12	13	20
100	0	35	15	8	10	18
100	1500	39	15	9	10	19
150	0	23	17	9	11	23
150	1500	28	18	10	13	26
150	3500	36	17	11	14	27
180	1500	26	16	11	15	27
180	3500	31	19	12	17	29
180	6500	40	20	14	18	33
220	1500	19	23	15	18	25
220	3500	26	22	15	22	31
220	6500	33	23	16	24	34

This is seen acutely in Table 2, where the maximum variance in the laboratory-prepared fluid reaches the limits of the target specification, with yield point slightly exceeding..

Table 2. Observed vs. Maximum Variance in selected readings for laboratory-built fluid.

	Variance	Maximum Variance
LSYP	16.67%	30%
PV	152.00%	250%
YP	54.55%	30%
10s Gel	30.00%	30%
10m Gel	22.73%	30%
30m Gel	29.17%	30%

Field Evaluation

After the completion of the onshore field trial with the candidate FR-NAF, the selection process for a suitable offshore well commenced. After evaluation of submitted FR-NAF formulations, a 12 ¼" Intermediate interval was selected, with a projected bottom-hole static temperature of 220° F and overbalance pressure of approximately 1000 psi.

An unweighted pre-mix was constructed at a shore base and then transported to the offshore location where the volume would be weighted up to the desired density and a bridging package added. Construction of the unweighted FR-NAF premix at the shore base is necessary, as space and personnel limitations on offshore installations restrict the amount of fluid that can be mixed on location. As a result, approximately 2,500 bbl (398 m³) of unweighted FR-NAF premix was built and subsequently shipped to the offshore installation as space became available. The premix, after receipt at the rig site, was conditioned to mitigate seawater contamination in transit and then weighted up with barite.

The cement was drilled out with WBM due to total losses in the preceding interval. Once the cement shoe was drilled, a displacement to the candidate FR-NAF took place. Once the displacement was completed and fluid properties stabilized, a bridging package was introduced to the system consisting of ground marble, resilient graphite, super-fine fibers and a nanoparticle additive due to the presence of a 1,000 psi overbalance in the trial interval. Drilling continued through the interval without issue. There were no notable lost circulation events, and the filtration properties of the fluid were maintained well within spec both for the HPHT filter press as well as the PPA. (Figure 4). At interval TD, density was increased from 85 lbm/ft³ (11.36 lbm/gal, 1.36 g/ml) to 87 lbm/ft³ (11.63 lbm/gal, 1.39 g/ml) for sufficient static density to maintain wellbore integrity.

The trip out of the wellbore at interval proceeded without issue, on elevators. After a cleanout run and lay-down of directional tools, a logging campaign spanning 22.5 days commenced. Table 4 below displays the length of each static interval, the flow rate when pumping, the maximum transient (spike) pressure encountered as well as the stable circulation pressure seen after the transient. There were no apparent incidences of barite sag, as would be indicated by a difference in expected and actual density of drilling fluid during initial circulation after a static period. Fluid was conditioned after each static interval as operational conditions allowed, generally with standard treatments of emulsifier and wetting agent along with hydrated lime to control and restore alkalinity.

Table 4. Length of Static Interval, Flow rate, Transient and Stable Circulating Pressures.

Static Interval	Hours static	Flow Rate	Maximum Pressure	Stable Circulating Pressure
	Hr	GPM	PSI	PSI
1	100	280	795	700
2	150	280	880	730
3	114	200	571	485
4	48	540	1100	970

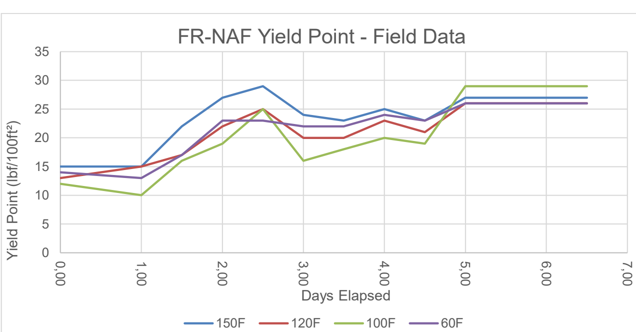

Figure 1. FR-NAF Yield Point, Field Data.

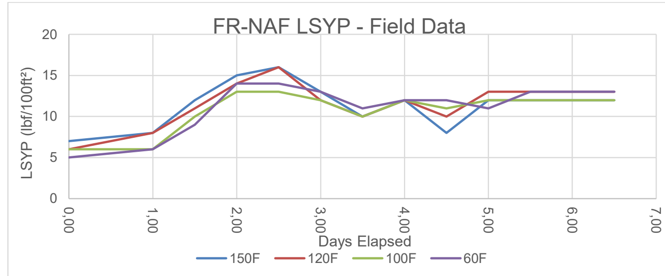

Figure 2. FR-NAF Low-Shear Yield Point, Field Data.

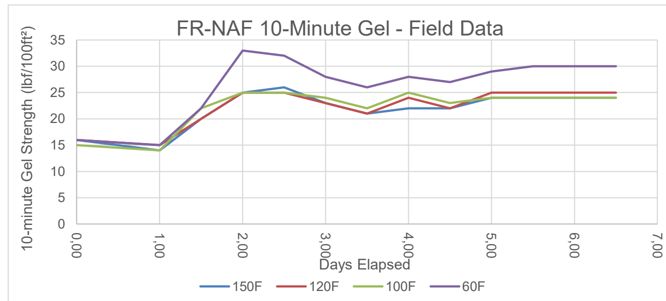

Figure 3. FR-NAF 10-minute Gel Strength, Field Data.

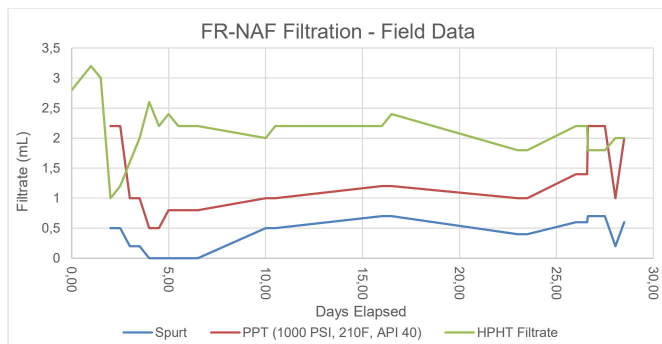

Figure 4. FR-NAF Filtration, Field Data.

Fluid properties were maintained within specifications while drilling both intervals and Figures 5 and 6 detail these properties, measured daily, over the course of drilling operations, compared the upper and lower limits (± 30% variance).

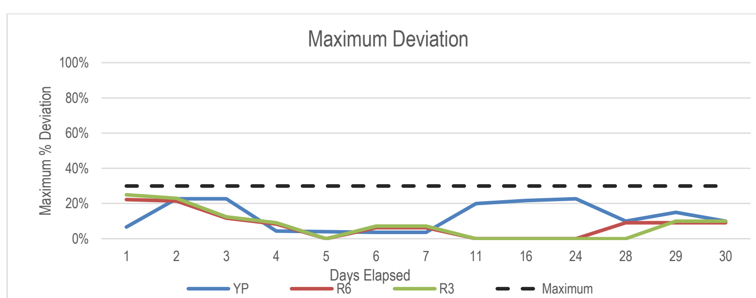

Figure 5. Maximum deviation of selected rheological properties from 60F to 150F.

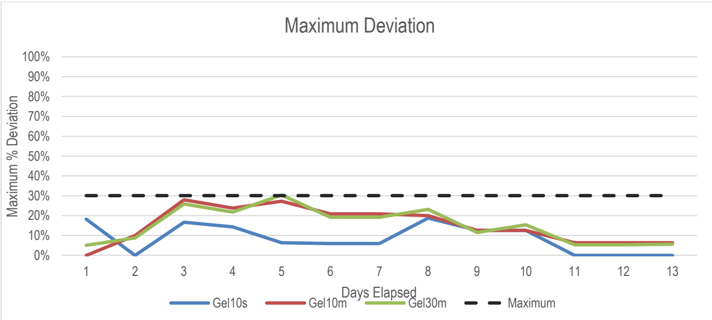

Figure 6. Maximum deviation of gel strengths from 60F to 150F.

Conclusions

- A fit-for-purpose FR-NAF was specified for offshore applications in the target area.
- The system withstood all common contaminants experienced in an offshore environment
- This system is characterized as a 2nd generation FR-NAF with specific applications in high overbalance, narrow margin well designs.
- The interval was drilled successfully without significant operational difficulty.
- Flawless operational execution ensured that 100% of drilling KPIs were achieved and the 2nd generation FR-NAF achieved all performance targets

Nomenclature

ft, m, km – distance (feet, meters, kilometers)
NPT – non-productive time, hours
HP-HT – filtration, high-pressure & high-temperature
F, C – temperature (Fahrenheit, Celsius)
BOP – blowout preventers
TD – total depth
ECD – equivalent circulating density, lbm/gal (sg)
NAF – non-aqueous fluid
ROP – rate-of-penetration
FR-NAF – flat-rheology, non-aqueous fluid
API – American Petroleum Institute
PV – plastic viscosity, cP
YP – yield point, lbf/100 ft²
LSYP – low shear yield point
ES – electrical stability, vols
LD-HPOC – low dose, high performance organo-clay
lbf/100 ft² - pound force per hundred square feet
lbm/gal, ppg – density, pounds of mass per gallon
pcf – density, pounds per cubic feet
LOT – leak-off test
PPA – particle plugging apparatus
RPM – rotations per minute
cP – viscosity, centipoise
rpm – revolutions per minute
psi, psig – pressure, pounds per square inch
bbl – oilfield barrel, 42-gallons

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