AADE-22-FTCE-085

A versatile flat rheology invert emulsion system optimized long horizontal drilling and complex completions

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Abstract

Drilling fluids influence numerous drilling issues, i.e., wellbore instability, differential sticking tendency, downhole losses, and hole cleaning in long extended reach horizontal sections. To achieve good drilling performance and to avoid these types of issues, fit-for-purpose best fluid management practices are required. Supported by accurate engineering of fluid formulation and meticulous control of the fluid properties.

A flat rheology invert emulsion system able to provide excellent hole cleaning while managing adequate equivalent circulating density (ECD), was selected to drill these complex wells. This fluid system uses a novel emulsifier and a rheology modifier for achieving flat rheology independent of temperature and pressure changes. An organo-soluble polymer was also introduced in this system for tighter fluid loss control and to improve filter cake quality.

The solutions were used successfully, and several jobs for (4½" and 5½") completion screen assemblies were run safely to the bottom. This paper will present a comprehensive overview of novel technology, the steps taken from planning to execution, the overall performance-based results, the challenges during implementation, and the troubleshooting steps taken. Based on a lesson learning curve, the engineering approach is enhanced to optimize drilling fluid formulation. Details about how custom fit products were used to meet drilling objectives will also be helpful for similar applications.

Introduction

A non-damaging reservoir drilling fluid with appropriate mud densities is required, in order to stabilize the wellbore. Therefor a proper engineering design is very important to tackle all expected risks associated with the type of reservoirs such as wellbore ballooning, ECD management, break circulation pressure, excessive surge and swab, sagging, hole cleaning and packing off, differential stuck and induced mud losses. Utilizing conventional NAF mud systems in the presence of this risks, mostly lead to a lot of service quality issues which generates a negative economic impact to the project, along with high logistic requirements at different rig sites.

The conventional NAF systems usually lack solids tolerance above 90 lb./ft3 (12 lb./gal), by utilizing Calcium Carbonate as weighting agent, and does require high dilution rates to maintain fluid properties, resulting in extra costs. It was demanded to formulate a drilling fluid able to sustain high solids content while keeping an adequate rheological profile at downhole conditions. Consequently, conventional NAF system components were selected and concentrations optimized such as base oil and salt content, emulsifiers, rheology modifiers, clays, filtration control and wetting agents.

After extensive lab testing to achieve the most economical and technical formulation compared to conventional NAF, a Flat Rheology Oil-based system formulation was selected. Reservoir rocks were characterized, fluid – rock interaction was lab-simulated and fluids behavior verified at different downhole temperatures and pressure conditions, in order to minimize all associated operational risks, where excessive ECDs need to be minimized to prevent ballooning, inducing losses and surge and swab because of the high solids content (300 – 330 pound per barrel of marble sized) for density. Drilling fluids formulations were even contaminated with drilled solids up to 10%. The flatness of the system was successfully achieved by reducing interaction effects between the rheology modifier, drill solids and emulsifier to the minimum for better synergy between all components of the drilling fluid.

What is Flat Rheology Drilling Fluid?

Base oils used to formulate NAFs are chemically inert, but their kinetic viscosity (KV) will decrease with the increasing temperatures. The drilling fluid properties (i.e. Yield Point (YP), 6 and 3 rpm readings, and Gels), will also be affected by downhole temperatures. Usually, the viscosity of a conventional system is inversely proportional to temperature (temperature-thinning effect), it reduces when temperature increases and vice versa (Fig.1).

YP and 6 / 3 rpm readings are the signature parameters that are used to define flat rheology system. These properties are influenced by a combination of physical and chemical interactions occurring inside the formulation and between the different components of the mud system. The gels' structure is also impacted by particle-to-particle chemical interaction; thus, it is also considered as indicator of flatness. The increase in solids content will increase the number of physical interactions which influence the whole rheological profile of the drilling fluid, affecting low shear rate viscosities. Fig. 2 shows the rheology profile of the FR OBM vs temperature.

"Flat Rheology" does include both gel strengths management and low shear rate viscosities management. While proper management of gel strengths does minimize pressure spikes and improves zonal isolation in addition to minimizing swab and surge pressures, the characterization of FROBS also includes viscometer-6 & 3 rpm dial readings or LSYP to maintain a focus on barite sag, hole cleaning, as well as ECD's and overall pressure management. The goal of Flat Rheology systems is to make the viscometer-6 rpm values less temperature dependent. If we can design and engineer Flat Rheology systems to minimize the influence of temperature on the viscometer-6 rpm, it therefore follows that we can also manage the influence on the gel strength. A viscometer-6 rpm dial reading that is less temperature dependent can positively impact barite sag mitigation practices. With the "Flat Rheology" system focus on low shear rheology across a range of temperatures, barite sag management can be improved.

Preparation and Execution

During testing and planning stage many different combinations of emulsifier / rheological modifiers / wetting agent's concentrations at different OWR were formulated and their respective rheological profiles were used to do hydraulic simulations, ECD and hole cleaning prediction. The optimum combination was selected to be applied and trial - tested at site in very similar scenarios where conventional NAF was used before.

The synergy in the system was achieved by tailor-made in the concentration of the emulsifier, wetting agent, rheology modifier, and organophilic clays used to formulate this system. Optimum ratio between both organophilic clays were synthesized differently to complement each other to achieve superior flat rheology were fragile and non-progressive gel structure were achieved by the emulsifier and wetting agent packages

Hydraulic simulations proved that the system would induce minimum pressure fluctuation in the wellbore due to lower ECDs and pressure spikes because of better hole cleaning. Client flexibility to select OWR as per requirements for torque and drag, expected lubricity, and does make the system tolerant to a high solids content by the usage of emulsifier/wetting agent package when this enabled client to go up to 330 – 350 pounds per barrel (ppb) of Calcium Carbonate including bridging particles loading in this application.

Flat rheology system enables drilling fluid engineers to manage same properties on the surface and downhole where they are affected by the temperature and pressure. As rheological parameters of the fluid are stable at any temperature and pressure along drilling the entire section, flat rheology drilling fluid systems provides a great advantage as they help to address these concerns and maintain unchanged parameters (fluctuations) of the system while drilling from surface to bottom. These unique properties of flat rheology systems differentiate the system from other NAF systems, where surface rheology needs to be elevated enough to compensate its decrease because of temperature and pressure increase, and to assure that downhole rheology would be sufficient, combined with good drilling practices.

After offset wells analysis, the main challenges can be listed as per below:

- Running ICD production screens
- Differential stick
- Wellbore instability
- Surge and Swab
- Ballooning effect
- Downhole losses
- High Torque and Drag
- Hole Cleaning

A very good hole cleaning and low ECD were maintained in this small-diameter hole section by applying precise engineering of drilling fluid properties and high expertise for planning and execution. It was decided by the operator to replace the conventional OBM system with the flat rheology oil-based system, where marble was used as weighting material. Hydraulics simulations were run to identify a precise range of target properties as per application conditions. A fluids proposal was submitted to the client covering drilling and fluid practices. Perhaps, the Geomechanics study done in the area indicates the required MW ranging from 80 up to 100 lb./ft3 is required to achieve a stable wellbore, but losses are observed into some micro-fractures and fault – related zones with 90 lb./ft3, giving a narrow mud weight window in some areas.

A close monitoring in all field application for 6-3 RPM values and gels strengths were key to manage the drilling ECD, keep the required suspension combined with the required string rotation for maintaining an excellent drilling performance, and to minimize ballooning effect along due to excessive surge and swab effects, exacerbated by tight clearance between BHA and wellbore. Having the right oil water ratio along with the right water phase salinity values for the exposed shale sections was also very important to control the osmotic pressure and chemical balance between the FROBS and the lithology being drilled.

While drilling in many fields, it is a must to raise the MW up to 100 lb./ft3 with calcium carbonate only, based on indications of wellbore instability and hole pack off.

- Drilled operations were carried out successfully by maintaining flat rheology profile utilizing 100 lb./ft3 Flat rheology system
- Gel structure for 100 lb./ft3 @150 F was 18/27/30 which is very flat although fluid had very high solids content.
- Achieved low break circulating pressure (390 psi), Low ECD (104.5 lb./ft3), and no surge or swab was observed, attributed mainly to flat rheology profile and non – progressive gel structure.

To minimize the thickness of the filter cake and reduce the risk of differential sticking, the system was loaded with 1% latex co-polymer, a variety of sized calcium carbonates and fibrous materials, selected to seal the pore throats and micro-factures, as prevention against the differential sticking and seepage losses risks identified in the analysis of the offset wells and formation data. The efficiency of the bridging materials was monitored through permeability plugging test (PPT), hourly doses of addition were performed while drilling to replenish the materials discarded by the shakers and grinded by the bit, to ensure a proper PSD, a tight HPHT fluid loss, PPT spurt-total and impermeable filter cake

One of the biggest challenges of these wells is hole cleaning, due to the high overbalance the flow rate is limited to minimize the ECD and avoid add extra pressure in the system, to avoid compromise the hole cleaning, the conventional NAF systems use the pumping tandem pills to ensure good hole cleaning in horizontal sections, this practice destabilizes the mud properties and generates unnecessary pressure shocks to the wellbore due to the use of unweighted mineral oil. After the engineering and simulation analysis done with the flat rheology system was realized that the circulation pressure was lower than conventional NAF which allowed to enhance the flow rates and change the approach of pumping tandem pills to the use of only weighted pills to sweep the hole and provide very good hole cleaning. A close monitoring in the drilling properties was done while drilling such as; torque and drag charts, pick up and slack off weights, hydraulics simulations, and a sweep tracking sheet was implemented to warranty an excellent hole cleaning. As result of the close monitoring and follow up, the frequency of the high weighted pills was reduced to minimize wellbore disturbance, pressure spikes and mud properties fluctuations.

Sagging control is one of the most critical aspect in NAF systems, especially when it is heavy loaded of weighting agent. Exposed to HPHT condition the weighting agent (CaCO3) may drop out resulting in downhole pressure imbalances. The barite free flat rheology system has been proven in the field providing better sag control than the conventional NAF system due to its stable rheological profile. To eliminate any potential weighted agent sagging, drilling fluid was regularly tested in field using VST (Viscometer sag test) to ensure the sag factor was always within acceptable ranges.

Finally, the recycle conventional NAF drilling fluid existent in the field and LMP was converted to flat rheology system in order to minimize logistic requirements. Indeed, logistic requirement play a critical role due to the reduced layout available at rig site. Around 30 – 40% of rig space is reduced with the use of FROBS. The usage of FROBS successfully tackled all challenges mentioned previously, saving cost and time, finally the converted flat rheology fluid has been recycled from well-to-well providing flexibility for quick adjustments of the mud properties and the ability to define a specific treatment to achieve the expected mud properties.

Summary

Successfully drilled wells in different fields and different designs using flat rheology system as drilling fluid without any related to fluid. Also successfully landed 100% of all–lower completions, with 4 ½” and 5 ½” ICD screens deployed on bottom

- Cooperation between client team and vendor team contributing in the successful delivery of numerous challenges wells
- The synergy of between engineering and software analysis allowed to optimize the bit hydraulics and wellbore cleaning and the formation strengthening by selecting an optimum blend of bridging materials.
- Optimizing flat rheology, LSRY and flow rates were the key factors to improve hole cleaning and minimize ECD, consequently improved ROP significantly.
- Eliminate pumping of tandem pills for hole cleaning, resulting in more stable drilling fluid properties and improved wellbore stability.

Fig 1 – Rheological properties of conventional invert drilling fluid vs. temperature

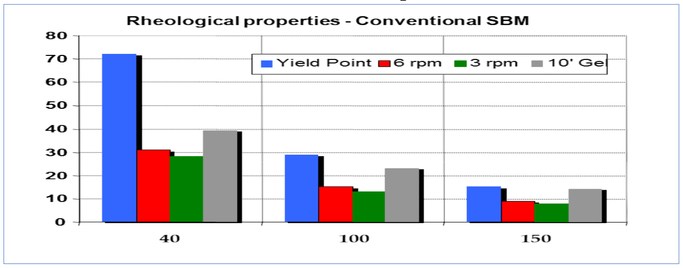
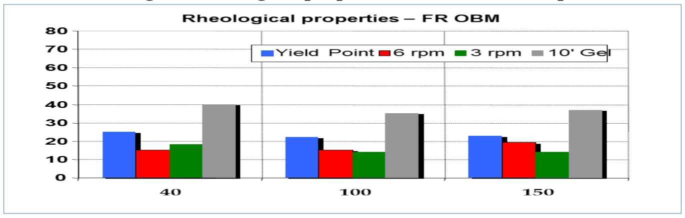
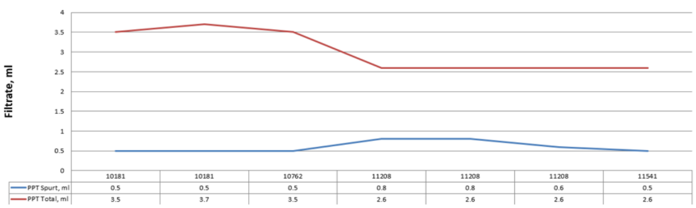


Fig 2 – Rheological properties FR OBM vs. temperature.



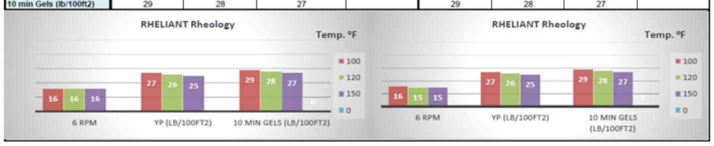
Graph-1



	10181	10181	10762	11208	11208	11208	11541
PPT Spurt, ml	0.5	0.5	0.5	0.8	0.8	0.6	0.5
PPT Total, ml	3.5	3.7	3.5	2.6	2.6	2.6	2.6

Graph-2

Sample Depth/TVD	10184 / 6528				10184 / 6528			
Rheology Temp (F)	100	120	150		100	120	150	
6 rpm	16	16	16		16	15	15	
YP (lb/100ft2)	27	26	25		27	26	25	
10 min Gels (lb/100ft2)	29	28	27		29	28	27	



Graph-3

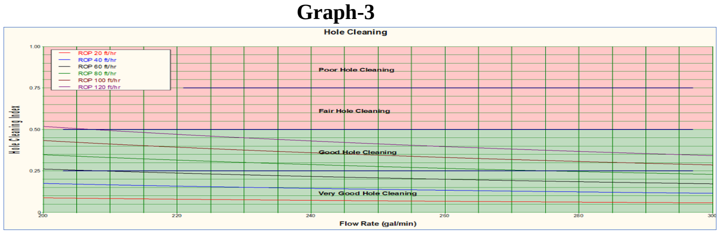


Table-1

Pressure Losses

Drill String (psi)	2835	Annulus (psi)	276
MWD (psi)	300	Surface Equip (psi)	119
Motor (psi)	0	U-Tube (psi)	21
Bit (psi)	614	Surf Ann Press (psi)	0
Bit On/Off (psi)	0	Total (psi)	4165

ECDs at Casing Shoe		ECDs at Total Depth	
ESD (lb/ft³)	97.8	ESD (lb/ft³)	97.9
ESD+Cuttings (lb/ft³)	98.3	ESD+Cuttings (lb/ft³)	98.4
ECD (lb/ft³)	102.9	ECD (lb/ft³)	104.0
ECD+Cuttings (lb/ft³)	103.4	ECD+Cuttings (lb/ft³)	104.5

By-Pass Pressure Loss		Breaking Circulation	
Drill String (psi)		Pump Pressure (psi)	390
By Pass (psi)		ECD @Shoe (lb/ft³)	101.2
		ECD @TD (lb/ft³)	101.4

VRDH Results