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OPTIMAL DRILLING FLUID RHEOLOGICAL CONSIDERATIONS FOR AVOIDING STUCK PIPE AND FLUID LOSS UNDER HT HORIZONTAL WELL CONDITION: GULF OF GUINEA AS A SCENARIO

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Abstract

This article takes an overview of stuck pipe and fluid loss problems, which are very expensive problems that occur during drilling of oil and gas wells. It further investigates the use of fluid loss additives as a way of mitigating these problems and optimal rheological consideration when selecting these additives. In addition, the Gulf of Guinea geology was examined and is seen to possess certain features that make it a potential scenario for the application of starch derived fluid loss additives (FLA).

Keywords: drilling mud; fluid loss agent; stuck pipe; fluid loss; gel strength; yield point; plastic viscosity; horizontal well; Gulf of Guinea.

1. Introduction

With the world's demand for energy continuously rising beyond easily accessible oil reserves, drilling for oil and gas has taken a new dimension, as we now have to drill under conditions that were initially considered too risky and expensive because of the level of financial, technical and technological investment needed upfront to exploit these unconventional fields. Every drilling operator wants to safely drill a well with forethought of preventive measures to take in order to mitigate possible problems like stuck pipe, loss of circulation etc. These problems are very undesirable due to the level of expenditure needed to solve them and even more so for a HT unconventional well condition. Since drilling fluid makes up a considerable portion of the entire drilling process, one of the best practices for a mud engineer, who is part of the drilling team, is to ensure that the drilling mud is treated with special mud additives like fluid loss additives (FLAs) amongst other. In doing so, a key consideration is the rheology of the drilling mud and these additives. A proper drilling fluid rheology can help mitigate possible drilling problems, saving the drilling operator(s) time and unnecessary expenses. This article will be investigating the optimal drilling fluid rheology for mud additives that can help prevent the problems of stuck pipe and fluid loss under high temperature well condition.

2. Overview of mud rheological properties

The main characteristics of drilling fluids are rheological parameters: gel strength (GS), yield point (YP) and plastic viscosity (PV). Rheology is an extremely important property of drilling muds, drill-in fluids, workover and completion fluids, cements and specialty fluids. As a result, mud rheology is measured on a continual basis while drilling and adjusted with additives to meet the needs of the operation [1-2]. Temperature, downhole pressure and water quality for water-based mud all play an important role in the behavior and interactions of the water, clay, polymers and solids in a mud.

Viscosity is the measurement of the thickness of a fluid. Viscosity measurements are important in horizontal wells but are important for different reasons than in vertical drilling. A primary objective in horizontal wells is to maintain flow; exactly what viscosity is in resistance to. In as much as gel strength and filtration are of more importance in horizontal wells than viscosity, viscosity is a by-product of achieving these desirable properties, which makes viscosity somewhat of a necessary evil in horizontal drilling. Reason being that excessive viscosity is undesirable because of the pressures that can be generated by higher viscosity in the borehole when pumping horizontally [3].

Gel strength is the measurement of the suspension properties of a drilling fluid. It is measured with a rheometer or shearometer and is reported in pounds per 100 square feet. GS is of the utmost importance, especially in coarse-grained soils (sand, gravel and rock). As the bit or reamer performs the cutting operation by cutting a bore-path through the soil and mixes the soil that is being cut into slurry with the fluid, it becomes the responsibility of the fluid to suspend these solids and maintain this suspension until they can be transported out of the hole. This resulting slurry becomes the conveyor belt to remove at least enough solids to make room for the product line. The slurry aids in supporting the ceilings of these horizontal bore-paths. The solids will not remain in suspension to maintain the slurry without GS [3-5].

Yield point is a parameter of the Bingham plastic model. It is the yield stress extrapolated to a shear rate of zero. YP is used to evaluate the ability of a mud to lift cuttings out of the wellbore annulus. A high YP implies a non-Newtonian fluid, one that carries cuttings better than a fluid of similar density but lower YP. In other words, YP is a measurement of the drilling fluids carrying capacity in a dynamic state, or when the fluid is moving along the borehole unlike GS, which is a measurement of the carrying capacity of the drilling fluid when the fluid is static or when the fluid is not moving in the borehole [6].

3. Overview of fluid loss and stuck pipe

Fluid loss is the leakage of the liquid phase of drilling fluid, slurry or treatment fluid containning solid particles into the formation matrix while stuck pipe is a situation when the drill string cannot be moved from the well while. The pipe may be partially moved and you may be able to circulate and rotate the pipe. Complications related to stuck pipe can account for nearly half of total well cost, making stuck pipe one of the most expensive problems that can occur during a drilling operation [7]. Stuck pipe often is associated with well-control and lost-circulation events—the two other costly disruptions to drilling operations-and is a significant risk in high-angle and horizontal wells [8].

When drilling mud is pumped into the wellbore, it passes inside of the drill column, then out through the nozzles of the drill bits into the wellbore annulus. As it makes its way up out of the wellbore, the fluid makes contact with the un-cemented wellbore. In almost all drilling operations, the operator attempts to maintain a hydrostatic pressure greater than the formation pressure (a relationship that is called an overbalanced condition) and, thus, to prevent kicks [9], that is to prevent the reservoir fluid from entering the wellbore. A process known as "killing the well". In some other cases, when drilling highly permeable rock or rock with naturally formed fractures, the rock's tensile strength could also be lower than hydrostatic pressure thereby causing the rock to fracture, when this occurs, part of the drilling mud can leak off into these zones known as thief zones while the solid particles or filtrates collect on the wellbore wall and form what is known as a filtercake (see Figure 1), a large thickness of which results in a stuck pipe condition. In other instances, when the drilling fluid is not properly transporting cuttings and cavings out of the annulus due to inadequate GS or YP properties, the debris accumulate around the drill string causing a pack off. When this occurs freeing the pipe can be quite expensive and time consuming and the chance of success is lower for deviated and horizontal wells as laboratory work has demon-strated that drilling at an inclination angle greater than approximately 30° from vertical poses problems in cuttings removal that are not encountered in vertical wells [10].

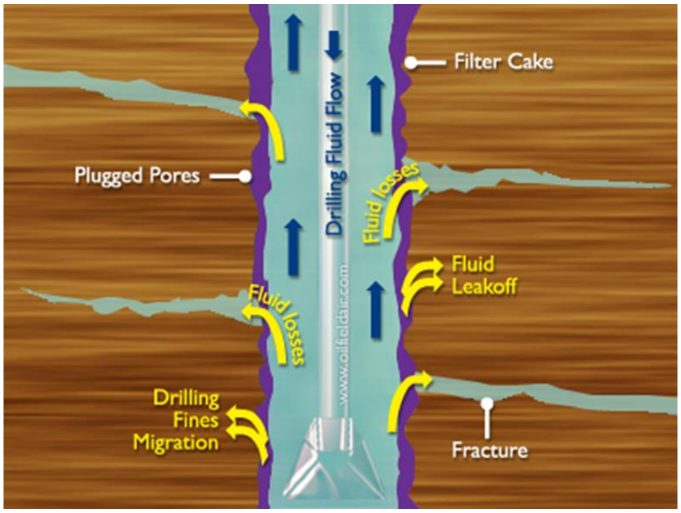

Figure 1. An illustration of loss of circulation [11]

4. Impact of fluid loss and stuck pipe

Drilling mud constitutes about 15% of the drilling process cost with a single well costing approximately $8.7million in 2013 according to the Petroleum Services Association of Canada. Lost circulation always has been one of the most costly issues facing the industry, giving rise to nonproductive time spent on regaining circulation. Lost circulation was responsible for more than 10% of nonproductive time spent when drilling in the Gulf of Mexico between 1993 and 2003. The inability to cure losses and resume drilling may necessitate sidetracking or abandonning the well in worst-case scenario [12-14].

According to another estimate, the cost of drilling fluids amounts to 25%-40% of total drilling costs [15]. The economic impact of lost circulation includes cost of the lost drilling fluid and of the treatment used to cure the problem. Given that both regular drilling fluids and lost circulation materials are often quite expensive, the direct economic impact of losing these substances into the formation may be substantial. The cost issue is especially relevant for oil-based muds that are usually more costly than water-based fluids.

In addition to the direct economic impact (cost of expensive drilling fluid and nonproductive time), lost circulation may cause additional drilling problems. In particular, the reduced rate of returns may impair cuttings transport out of the well. This leads to poor hole cleaning, especially in deviated and horizontal wells. Poor hole cleaning may eventually result in pack-offs and stuck pipe [16-17].

The drilling industry has suffered a lot because of lost circulation. In the United States and Canada, a well that has lost circulation will have a mud cost of anywhere from $8000 to $50000. This is not including the rig costs because of the time lost, damage to the drill pipe and/or blowout [16-19].

British Petroleum statistics show the cost of stuck pipe at more than $30 million per year. The chances of stuck pipe increases as the wellbore angle of deviation increases [20].

5. Preventing stuck pipe

The problem of stuck pipe can be prevented and a lot of money, time and resources saved by maintaining proper mud weight, avoiding restrictions in the annular space and updating formation pore pressure and fracture gradients for better accuracy with log and drilling data. However, FLAs has in recent time gained popularity as a preventive measure for controlling fluid loss. Even though total prevention of fluid loss during drilling is virtually impossible, reason being that certain rocks zones have natural caverns, fractures, large pores, or high permeability.

5.1. Comparing FLAs

The different types of fluid loss additives can be divided into 2 kinds namely cellulose derivatives and starch derivatives. The major difference between both is that, unlike cellulose derived FLAs like PAC, the starch derived FLAs like HM-FL TROL are frequently used under HT conditions, at which point rapid hydrolysis and degradation take place [21].

Table 1 below compares the rheological properties of starch and cellulose derived FLAs as presented in different independent papers from various experiments conducted by Kakoli *et al.*, Samavati *et al.*, and MI SWACO (a Schlumberger company) [22-24].

Table 1.Comparing rheological properties of starch and cellulose derived FLAs at 250F

Rheological Properties	Starch derived FLA	Cellulose derived FLA
Fluid loss (ml)	1	4.7
Plastic viscosity (cP)	15	38
Gel strength (10s, 10min)	1, 1	1, 1.5
Yield point (lb/100ft^2)	7	50
YP/PV ratio	0.47	1.32

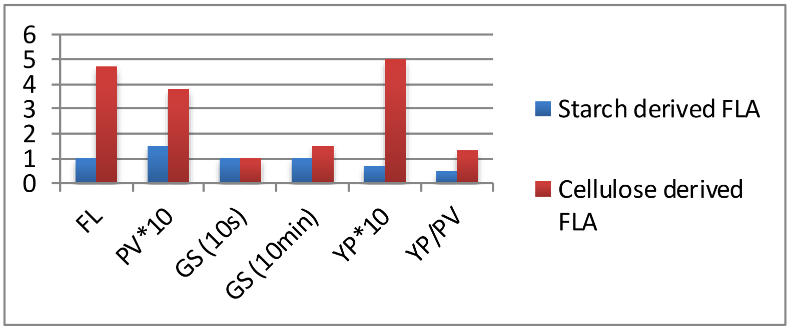

Figure 2. Graphical comparison of rheological properties of starch and cellulose derived FLAs

As earlier explained, yield point, gel strength and filtration are especially important for horizontal drilling, more so than viscosity. Horizontal drilling requires fluids with higher gel strengths than fluids used in vertical applications. The reason for this is that, vertical drilling has the benefit of fluid velocity, to aid in direct counteraction of the force of gravity. Lack of adequate gel strengths and yield point can lead to stuck pipe, loss of circulation, caving in, or loss of wellbore, in severe circumstance [8].

Excessive viscosity is undesirable because of the pressures that can be generated by higher viscosity in the borehole when pumping horizontally. In a vertical hole, we remove solids with viscosity and velocity. Whereas, in horizontal drilling, we don't have velocity working on our side because of the pumps we use and the size of reamers we may be using, we can't depend on annular velocity. In addition, annular velocity rates that may be desirable in vertical applications may erode the less consolidated soils that are encountered at shallow depths as are often encountered in horizontal drilling [5-7].

Another very important parameter is yield point and plastic viscosity (YP/PV) ratio. Higher YP/PV provide better cutting transport especially in laminar flow, which is the tendency for horizontal wells due to their inclination.

Cellulose derived FLA appears to have better rheological properties, as compared to starch derived FLA. However, the well condition will ultimately dictate our decision and priority. Under conventional well condition of normal pressure and temperature, cellulose derived FLA might be preferred for a horizontal well. In a situation, whereby we have an unconventional well condition of high temperature up to 250F and possible fluid loss situation, the drilling mud is better off treated with a starch derived FLA as our priority here is to prevent possible loss of circulation, especially when the mud consists of other additives already compensating for it's carrying capacity, which is almost always the case. Failure to do this might lead to a costly stuck pipe situation or even loss of the entire wellbore if care is not taken.

6. Starch FLA applicability scenario

As depicted in the Figures 4, 5, the fields' area, categorized into various fault blocks, contain patterns of Plio-Pleistocene age sandstones, which are also called D-1, Biafra and Qua Iboe Sandstones. These sands are found at a drill depth of over 3,000ft subsea. The oil deposits are located in zones of high temperature (up to 250F) [24].

According to one of the drilling operators in this fields, it was reported that fluid loss is a well-known hazard encountered when drilling the landing section and crossing the bounding fault zone to their targets in the Okwok field.

With the above-described scenario, exploration of these reservoirs makes starch based fluid loss agent a good candidate for the treatment of drilling mud. This will in turn prevent the possibility of having a drilling-mud-induced stuck pipe situation, thereby avoiding uncalled-for losses of resources.

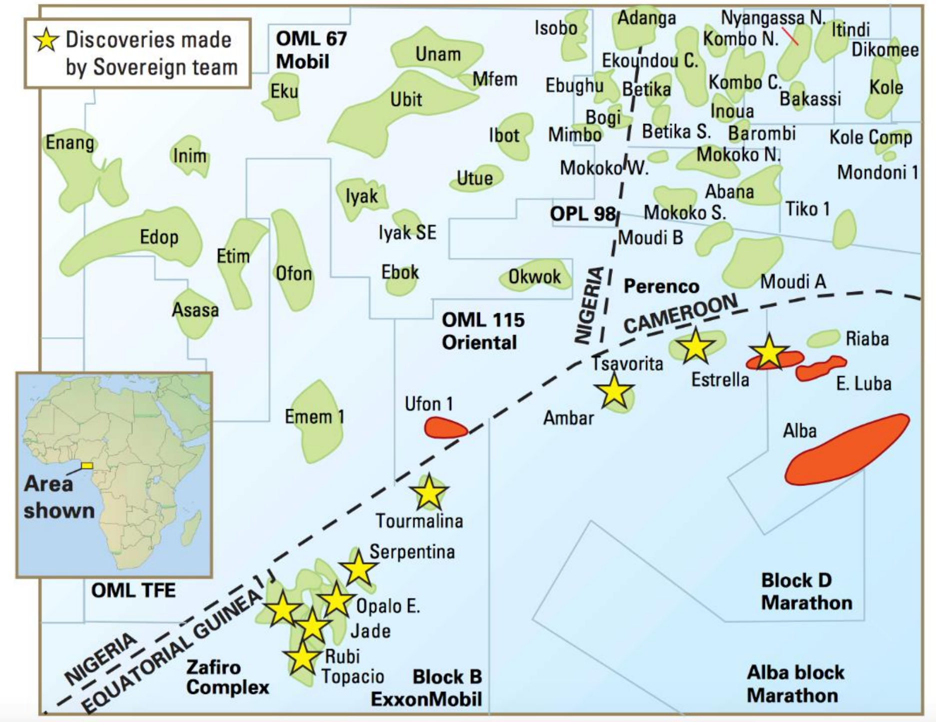

Figure 3. Gulf of Guinea golden rectangle oil, gas fields [25]

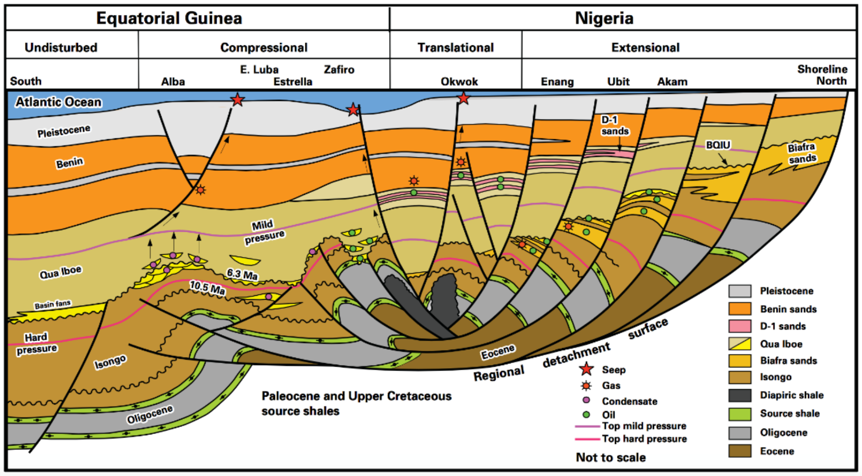

Figure 4. Play concept diagram for Nigeria's golden triangle [25]

7. Conclusion

1. Stuck pipe and fluid loss are very expensive problems, the occurrence of which leads to great loss of costly materials, equipment and time.
2. These problems can be mitigated with the use of FLAs as a preventive measure
3. The main characteristics of drilling fluids and its additives are rheological parameters, which are extremely important for horizontal well drilling as they speak of the ability of a mud system to carry, suspend and keep the wellbore clear of cuttings.
4. Possible fluid loss zones and the FLA's ability to maintain its rheological properties under high temperature and are things to be considered while choosing the right FLA.
5. Starch FLA is best suited for treating a mud system in a case of other additives compensating for the necessary rheological properties.
6. The geology of oil fields located in the Gulf of Guinea presents a good scenario where starch derived fluid loss additive can be applicable and therefore, is recommended for the exploitation of this area.

Abbreviations:

FLA - fluid loss agent; GS - gel strength; YP - yield point; PV - plastic viscosity; HT – high temperature.

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