

INFLUENCE OF AGING OF DRILLING FLUIDS ON THE RISK OF DIFFERENTIAL STICKING

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Abstract. *The differential sticking is undesirable during the well drilling because it presents big economic losses. Knowing the composition and enhancing the drilling fluids properties are one of the methods to reduce the risk of drillstring differential sticking. The main challenges in fluid formulations is to attend to increasingly severe conditions (high temperatures and pressure) in deeper wells and the environmental requirements. In offshore wells, where the drilling fluids used in the past were based on diesel oil and currently they are synthetic, there is a frequent search for water-based fluid applications that are environmentally friendly and have lower costs. Studies report that bentonite fluids guarantee good rheological and filtration properties and that in drilling with high temperatures, the bentonite does not degrade, but it forms gels with high viscosity values. To confront these operational problems, additives are used, permitting the fluids to be used in deep wells, both onshore and offshore. So, in order to evaluate the drilling fluids properties on the risk of differential sticking, it was studied water-based drilling fluids containing bentonite clay and biodegradable lubricants in various concentrations. The fluids were evaluated in ambient temperature and after aging at 200°F. For the studied fluids it was observed that: the lubricant is primordial to reduce the risk of differential sticking; the aging process causes an increase in the rheological properties of the fluids, but does not alter the efficiency of the lubricant in reducing differential sticking and little concentrations of lubricant are enough to reduce the necessary force to free the differentially stuck drillstrings.*

Keywords: *drilling fluids, clay, differential sticking*

1. INTRODUCTION

The geometry and depth of petroleum wells are increasingly sophisticated. Nowadays, besides the conventional vertical wells, there are the directional and high angle wells (Brantly, 1971). The success of oil well drilling, as well as its cost, depends, in big part of the properties of the drilling fluid, especially when it comes to very deep wells (Barros et al., 2007).

The drilling fluids are generally defined as frequently liquid compositions intended to assist the drilling process of the petroleum wells and perform a series of needful functions to the drilling operations (Amorim, 2003). The performance of these functions is directly dependent on the rheological properties, filtration and lubricity (viscosities, gel consistency, filtered control, cake and lubricity coefficient) of the drilling fluids.

When submitted to high temperatures, water-based drilling fluids suffer alterations in the rheological properties, in a way that their magnitude measure on the surface are always different from those at the bottom of the well, this can be considered as a reduction of its efficiency, since the fluids are dimensioned to obtain specific degrees for each one of their properties, and any alteration in one of them will cause an alteration on the work scenario (Moriyama and Neto, 2008). In general, the drilling of a well can take a long time and be extended according to the needs of each situation, What makes the study of aging of the fluid be taken into consideration due to the constant circulation at high temperatures (Mohammed, 1990).

Therefore, the fluid composition depends of the particular needs of each drilling. According to Lummus and Azar (1986), in simple and shallow drilling, a fluid consisting of water and bentonite clay is appropriate, but in situations of difficult drilling and/or big depths is required a fluid more elaborated, with the introduction of one or more additives.

The main challenges in the formulation of fluids is to attend the increasingly severe conditions (high temperatures and pressures) in deep wells and the environmental requirements. In offshore wells, where the used fluids were diesel oil-based and currently are used synthetic-based fluids, there is a frequent search for the application of water-based fluids that are environmentally correct and have a lower cost.

Studies show that the bentonite guarantees good rheological properties and filtration. (Mihalakis et al., 2004), however, in drillings with elevated temperatures, there is a process of thermal degradation, causing an increase in its viscosity. This increase is because of the gelification process. To face such operational problems, additives are used, permitting the fluids to be used in deep wells, both onshore and offshore (Kelessidis et al., 2005).

Besides the problems caused by the high temperatures, there are those ones caused by the phenomenon called differential sticking. This is caused by a pressure differential (fig. 1), in other words, when the column of drilling fluid exerts excessive pressure on the drill pipe onto the cake that is deposited on a permeable formation (Simon et al., 2005) and occurs when the fluid circulation is maintained, but it is not possible to move or rotate the pipe in any direction (Schlumberger, 2010). Contribute to this type of sticking the bad dimensioning of the drilling fluids and the presence of permeable formations.

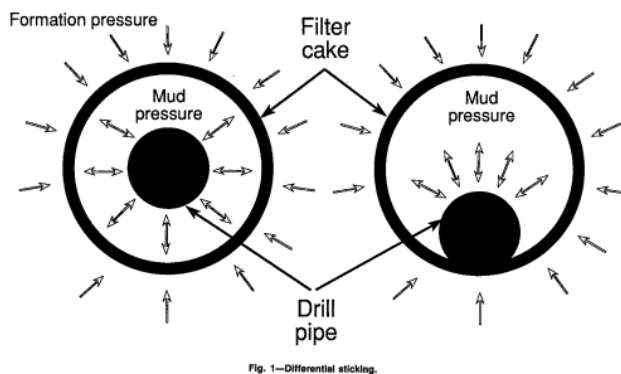


Figure 1. Differential sticking scheme.

The differential sticking phenomenon occurs in both onshore and offshore drillings, doesn't matter if the well is vertical, directional or even of long extension. And, in spite of the high technology developed and used in the drilling of these wells, we have to live with the increased risk of differential sticking on the column of the pipes (Santos, 2000).

Studies published in 1991 show that the differential sticking was responsible for 61% of the total costs in wells drilled in the Gulf of Mexico. To reduce the probability to occur such problem, some parameters must be adjusted and, between them, the ones related to the drilling fluid (Bradley et al., 1991).

The drilling fluids have fundamental importance in this scenario, being it to avoid the phenomenon, to minimize the problems caused by the sticking of the pipes, or even to release the tubes that are stuck because of the sticking differential. The correct choice of the type of fluid, as well as the adequate dimensioning of its properties are the key to reduce the risks of differential sticking and guarantee the success of the drilling.

Therefore, this study aims to evaluate the behavior of aqueous drilling fluids on the risk of differential sticking after submitted to thermal aging

2. MATERIALS AND METHODS

2.1. Materials

For the development of this work, there were studied clay and water fluids prepared with a sample of sodic bentonite clay, with and without lubricant additives. Table 1 shows the compositions of the studied fluids

Table 1. Compositions of the clay and water based fluids.

Fluids	Water (10^{-6} m^3)	Clay (10^{-2} kg/L)	Lub. 1 (10^{-2} kg/L)	Lub. 2 (10^{-2} kg/L)
F1	500	4.86	--	--
F2	500	4.86	1.0	--
F3	500	4.86	2.0	--
F4	500	4.86	3.0	--
F5	500	4.86	--	1.0
F6	500	4.86	--	2.0
F7	500	4.86	--	3.0

The fluids F2 to F7 were submitted to thermal aging and in its denomination were added the letter e, as follows: F2e, F3e, F4e, F5e, F6e and F7e.

The bentonite clay was provided by Company Bentonit União Nordeste Ltda. – BUN, and the lubricant additives were provided by Company System Mud Indústria e Comércio Ltda.

2.2. Methods

2.2.1. Preparation of the Fluids

The fluids were prepared based on the rule N-2605 (Petrobras, 1998a); the clay was mixed with $500 \times 10^{-6} \text{m}^3$ of deionized water, at a speed of 17000rpm during 1200s in a Hamilton Beach mechanical mixer model 936. After, the fluid remained at rest during 8400s in a closed container. Passed this period, the lubricant was added under constant mixing in the same mechanical mixer at a speed of 17000 rpm during 60s.

2.2.2. Rheological Study

After rest for 86400s, the fluids were mixed during 300s in a Hamilton Beach mechanical mixer, model 936, at a speed of 17000rpm. After the mixing, the fluids were transferred to the Fann model 35A viscometer's container. The viscometer was activated at a 600rpm speed during 120s and the reading was made. Right after, the speed was changed to 300rpm, the reading was taken after 15s.

To obtain the initial gel force, the fluid was submitted to a 600rpm speed during 15s, and then, remained at rest during 10s. Then, the viscometer was activated at a speed of 3rpm and the reading was taken. To obtain the final gel force, the fluid remained at rest during 600s and, then, the reading was done at a speed of 3rpm.

With the readings data obtained with the viscometer, was calculated the apparent viscosity (AV), plastic viscosity (PV) and gel strength (SG) according to the rule N-2605 (Petrobras, 1998a), using the equations (1), (2) and (3):

-Apparent Viscosity (AV):

$$AV = L_{600} / L_{300} \quad (10^{-3} \text{ Pa. s}) \quad (1)$$

- Plastic Viscosity (PV):

$$PV = L_{600} - L_{300} \quad (10^{-3} \text{ Pa. s}) \quad (2)$$

- Gel Strength (SG):

$$SG = G_i - G_f \quad (\text{N/m}^2) \quad (3)$$

2.2.3. Lubricity

The lubricity coefficient of the fluids was determined in an OFITE EP-Lubricity tester. The fluid was mixed for 300s in a Hamilton Beach mechanical mixer, model 936, with a speed of 17000rpm. After that, the fluid was transferred to the equipment's container, with initial torque of zero and a speed of 60rpm; was slowly applied a force of 150lb/in during 300s, being done the reading of the torque exerted by the fluid. With the reading obtained by the torque of the water, was calculated the correction factor (CF), according to the equation (4) and the lubricity coefficient (LC) according to equation (5).

- Correction factor:

$$CF = \frac{34,0}{\text{Reading water}} \quad (4)$$

- Lubricity coefficient:

$$LC = \frac{CF \times \text{Reading obtained}}{100} \quad (5)$$

2.2.4. Filtrate volume

To determine the filtrate volume, the fluids were mixed during 60s, in a Hamilton Beach mechanical mixer, model 936, at a speed of 17000rpm. Then, it was transferred to the container of the API filter press, submitting it to a pressure of 100psi. After 1800s, the filtrate was collected and its volume was measured, and expressed in m³.

2.2.5. Cake thickness

To determine the cake thickness (CT), was used a methodology developed by Farias (2006) in Labdes (Laboratório de Referência em Dessalinização) based on the rule API 13B-1 (2003). This methodology consists on the following steps.

- collect the filter paper with the cake after the experiment for determination of the filtrate volume;
- wash the filter paper three times at a flow of approximately 110L/h with a container of constant level with adjustable flow, at a distance of approximately 0.07m of the flow controller that has a diameter of 0.015m and angle of attack of the flux of water approximately 45°.
- put the filter paper with the cake between two glass slides and apply a pressure of approximately 277.6N/m² for a period of 120s and
- measure the cake thickness using an extensometer.

There were made five measures of the thickness of the glass slides and of the paper with the cake in distinct points. After obtaining the measures, it was made an arithmetic average of the five determinations.

2.2.6. Differential sticking

The experiments to determine the differential sticking coefficient (DSC) were performed on equipment Differential Sticking Tester from the Fann brand with the torque tool flat plate (flat plate of torque). The methodology used was the one suggested by the manufacturer, in which the fluids were agitated during 300s in a Hamilton Beach mechanical mixer, model 936, and then was transferred to the interior of the equipment's cell. Then, the fluid was submitted to a pressure of approximately 477.5psi (3292kPa) during 600s for the formation of a cake. After this period, using a lever, the flat plate was lowered and maintained in this position for 120s to guarantee that it would get stuck to the cake. After that, were made six measures (with a 30s interval between the measurements) of torque with a torque meter that was coupled to the flat plate. The torque that was read represents the force necessary to move the flat plate. Once we have the torque measurements, it is possible to calculate the differential sticking tendency coefficient according to equation 6:

$$DSC = \frac{T_m}{1000} \quad (6)$$

Where,

DSC is the differential sticking tendency coefficient and
T_m is the average of the torque measurements

2.2.7. Aging of drilling fluids

The clay and water fluids were submitted to aging for 16h at 366.45K (94°C) in an aging chamber (Roller Oven) from Fann and, then, were determined their rheological properties, filtration, lubricity and coefficient of tendency of the sticking of the drilling column the methodology described in items 2.2.2 to 2.2.6.

All the experiments were done in duplicate. When one of the obtained values differed in more than a 10% margin, this was automatically eliminated and the experiment was repeated.

3. RESULTS AND DISCUSSION

To evaluate the influence of the drilling fluids in the risk of differential sticking it is necessary to investigate the rheological properties, of filtration and lubricity, to determine if the fluids attend to all the specifications necessary and required for an adequate perforation. So, table 2 shows the results of the rheological properties, of filtration and cake thickness of the clay and water fluids before and after aging.

According to table 2, the fluids prepared with 4.86x10⁻²Kg/L of clay (F1) present good results of apparent viscosities and plastic with values within the specifications from PETROBRAS (1998b). The reference values

according to PETROBRAS (1988a) are: apparent viscosity (AV) equal or superior to 18×10^{-3} Pa.s and plastic viscosity (PV) equal or superior to 4×10^{-3} Pa.s.

There were not observed significant variation on the values of the properties of the fluids with addition of lubricants; the fluids F1 presented values of AV close to 15×10^{-3} Pa.s, while that after the addition of lubricants, the values of AV ranged between 13.5×10^{-3} Pa.s (for the fluids F7) to 16.0×10^{-3} Pa.s (for the fluids F3).

The addition of 1.0×10^{-2} Kg/L of Lub. 1 (F2) and 2.0×10^{-2} Kg/L of Lub. 2 (F5) reduced lightly the values of AV, PV, FV and CT. The studied lubricants have a variable behavior depending on the solution in which it is exposed. Because Lub. 1 is a chemically modified vegetal-oil based lubricant made to be soluble in water, when it is added to the fluid containing bentonite clay, it acts like a dispersant, neutralizing the charges present on the surface of the clay particles reducing the values of AV, PV, FV, and CT (Medeiros et al., 2008). With the increase of the concentration of Lub. 1 to 2.0×10^{-2} Kg/L, it was observed an inverse behavior and this is due, most probably, to the fact that the content of 2.0×10^{-2} Kg/L be sufficient to achieve its critical micellar concentration (c.m.c).

Table 2. Rheological, filtration and cake thickness properties of the fluids before and after aging.

Fluids	AV (10^{-3} Pa.s)	PV (10^{-3} Pa.s)	SG (N/ m ²)	FV (10^{-6} m ³)	CT (10^{-3} m)
F1	15.0	8.0	10.0	19.4	1.738
F2	14.0	8.0	12.0	18.0	1.631
F2e	26.3	15.0	4.0	25.6	5.039
F3	16.0	9.0	9.0	12.6	1.393
F3e	23.0	15.5	1.5	20.4	4.574
F4	15.5	9.0	16.0	10.6	1.412
F4e	26.3	17.0	3.0	18.0	4.217
F5	15.0	8.0	8.0	19.8	1.981
F5e	36.5	17.5	13.0	24.5	3.605
F6	14.0	8.0	8.0	18.4	1.877
F6e	38.3	18.0	12.0	21.9	3.386
F7	13.5	8.0	8.0	17.8	1.602
F7e	40.0	20.0	12.0	22.4	3.611

To the fluids additivated with Lub. 2, it is necessary a bigger content to reduce the rheological and a filtration properties. This result can be justified since Lub. 2 has a bigger molecular chain than Lub. 1.

The fluids submitted to aging (F2e and F7e) presented higher rheological properties (AV, PV and SG) when compared with the fluids without aging (F2 and F7). The filtration properties (FV) and cake thickness (CT) were also affected with the aging. According to Satoyo (2001) these results are from a gelification process, due from a thermal degradation in the chemical structure of the fluids, occasioning in an increase of the viscosity.

The rheological behavior of the suspensions depends on the concentration of the clay particles, of the pH of the suspension, of the presence of ions in the suspension (mainly electrolytes) and temperature. In temperatures close to 393.15K (120°C) and in conditions of high salinity, the bentonite suspensions start to thicken very quickly. Different studies indicate that the effect of temperature over the rheological properties of the clay and water fluids is unpredictable and not any proposed mechanism of action is amply accepted (Kelessidis et al., 2005).

For the filtration properties, was verified a reduction in FV and CT of the fluids after additivation with the lubricant and increasing its content. This behavior is due to the dispersant action of the studied lubricants. It is important to highlight that an increase in the concentration of the lubricant resulted in a considerable decrease of the cake thickness from 1.631×10^{-3} m to 1.393×10^{-3} m for the fluids F2 with 1.0×10^{-2} Kg/L of Lub. 1 and F3 with 2.0×10^{-2} Kg/L of Lub. 1, respectively. In a similar way, the filtrate volume was reduced from 18.0×10^{-3} m (fluid F2) to 12.6×10^{-3} m (fluid F3).

The presence of Lub. 2 did not alter the cake thickness and filtration properties.

For the aged fluids, the same behavior was observed; the increase in the concentration of lubricant results in a reduction of the FV and CT values.

In Figure 2 are illustrated the results of the lubricity coefficient and the differential sticking coefficient of the clay and water fluids before and after aging.

For both aged and not aged fluids was observed, through Figure 2, that the addition of lubricant caused a reduction in the values of LC and DSC. The lubricants assist in the control of the temperature, provide the cleaning of the equipments, protecting from corrosion recurrent from the oxidation process, and can also act as force and movement transmitting agent (Gomes and Filho, 2005). The LC and the DSC of the fluids were reduced from 0.4 and 0.12 (for the fluids F1) to 0.156 and 0.075 (for the fluids F2).

It was possible to verify that the fluids without aging F5 to F7 additivated with Lub. 2 presented excellent LC and DSC, once according to Medeiros (2009), the fluids, to have adequate lubricity, must present LC of about 0.1, value commonly found in oil based drilling fluids (taken as a standard) or in fluids additive with lubricant agents (Darley and Gray, 1988). The same behavior was observed for the DSC.

The presence of the lubricant and the increase in its concentration reduce the values of DSC, being Lub. 2, for the fluids without aging, the lubricant that was most efficient. Probably, the lubricant formed a coat on the surface of the flat plate, reducing the friction between the cake and the surface of the flat plate, making easier for it to slide on the cake. So, as consequence, there is a reduction of the force necessary to release the equipment stuck to the cake.

For the aged fluids, it was observed that the fluids additive with the Lub. 2 (F5e to F7e), presented higher values of lubricity coefficient than the fluids additive with the Lub. 1 (F2e to F4e). Probably, during the aging process, as Lub. 1 is a vegetal oil based ester, this additive must have hydrolyzated, losing its lubrication capacity. The fluids additive with Lub. 1 presented better results of LC. Although Lub. 1 is a product that is vegetal oil based, it is chemically modified to be soluble in the fluid and, because of this, it is capable to resist to elevated temperatures.

The fluids F2e (added of 1.0×10^{-2} Kg/L of Lub. 1) presented the lowest value of LC (0.079), while the fluids F7e (added of 3.0×10^{-2} Kg/L of Lub. 2) presented LC of 0.244. According to Magalhães (2010), the mechanism of the lubricant action depends if the solution is at rest or in movement. With this, and considering that for the determination of the DSC the solution is kept at rest for a period of time before the movement of the lever to obtain the torque and for the determination of LC the solution keeps moving continuously, the Lub. 2 can be considered the most efficient, for the solution at rest.

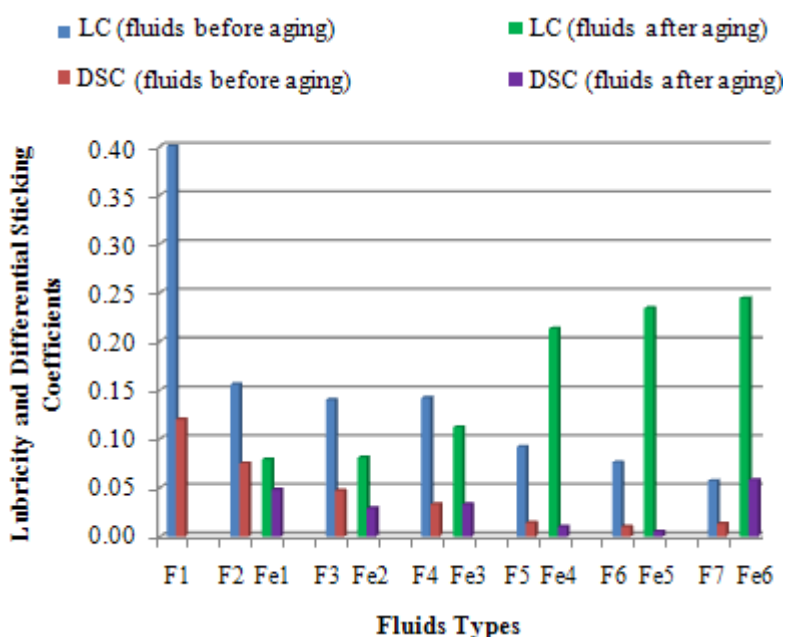


Figure 2. Lubricity and differential sticking coefficients of the clay and water fluids before and after aging

According to Bushnell-Watson and Panesar (1991), both in water based and oil based fluids, the use of a lubricant affects significantly the way in which the tubes are freed. With the absence of a lubricant, the tubes are freed in the cake/formation interface, while with the presence of a lubricant; the tubes are freed in the tube/cake interface, reducing the risks during the drilling process.

According to Santos (2000), the mechanism that most probably contributes to the sticking of the tubes is the friction between the drill pipe and the wells walls. This friction is quite influenced by the overbalance pressure (fluid pressure is bigger than the formation pressure, causing an unbalance of pressure). So, how bigger is the overbalance pressure, bigger is the friction force (Santos, 2000).

Given these results, it is suggested a direct correlation between lubricity and differential sticking, so lower values of LC result in lower values of DSC. In this case, the lubricant fluid becomes indispensable during the drilling of oil wells.

4. CONCLUSIONS

According to the results, it is possible to conclude that: (i) the addition of lubricants reduces efficiently the LC and the DSC, being, therefore, its use of primordial importance in the reduction of the differential sticking risk; (ii) the aging causes an increase in the rheological and filtration properties of the fluids, but it does not change the efficiency of the lubricant in the reduction of differential sticking risk and (iii) low concentrations of lubricant are sufficient to reduce the force necessary to release the pipes that are stuck because of the differential sticking.

5. ACKNOWLEDGEMENTS

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