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INFLUENCE OF THERMAL AGING ON THE DIFFERENTIAL STICKING COEFFICIENT OF BENTONITE CLAY AND WATER BASED DRILLING FLUIDS WITH POLYMER AND LUBRICANT ADDITIVES

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Abstract

The differential sticking is a phenomenon that occurs when the drill pipe becomes stuck, without rotation, impeding it to move up and down inside the well, but with the drilling fluid flowing normally. The properties of the cake, the differential pressure, the deficiency in the well cleaning, and an unstable well are some of the factors responsible for the pipe sticking. Several studies affirm that the formulation of the fluid has direct influence on the risk of differential sticking incidents. Thus, the present work aims to evaluate the influence of thermal aging

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on the differential sticking coefficient of clay, and water drilling fluids with polymer and lubricant additives. To this end, 14 formulations of clay and water fluids were studied, varying the polymer type, and the type and amount of lubricant. The rheological properties (apparent viscosity (AV); plastic viscosity (PV); and gel strength (GS)) were determined by using a Fann 35A viscometer. The filtration properties (fluid loss (FL) and cake thickness (CT)) in a Fann filter press and extensometer, the lubricity coefficient (LC) in an EP-lubricity tester from Ofite, and the differential sticking coefficient (DSC) in a differential sticking tester from FANN. In general, the results showed that the addition of lubricants to the clay, and water fluids with polymer additives constitutes one of the main factors for the thermal resistance, improvement of the lubricity coefficient, and reduction of the risk of differential sticking of the fluids.

1. Introduction

Non-productive time of the rig is result of problems found during the well drilling. According to Cerqueira [6], a problem is any undesirable result of an activity or process. For any study of problems, the most important is to know how to identify its nature (type), and how it expresses itself (symptoms). However, the nature of the problem that occurs with a well during the drilling operation is not easily discernible.

Among the problems that are faced, can be mentioned, such as difficulty in maneuver and advance, loss of circulation, kick and blowouts, unstable wells, failure in the well trajectory, balled bits, collapse of the well and pipe imprisoning, besides the wearing of the equipment’s, and others.

According to Miura et al. [18], most of the non-productive times in the drilling operation are due to problems classified as maneuver difficulties, advance difficulties, and tube imprisoning. Such problems can be avoided or minimized with proper use of the drilling fluids, so that these can perform all the functions that are required (Reid et al. [23]).

The differential sticking is caused by a pressure differential, in the other words, when the fluid column exerts excessive pressure to the drill pipe over a cake that was deposited on a permeable formation (Simon et al. [24]). In this category, the drill pipe loses the axial and radial movements, but the fluid circulation is maintained. Generally, this occurs when the pipe is stopped (for maneuvers and/or connections) and the drill collars are found facing permeable formations, especially in sandstones, where the cake is formed on the walls of the hole, due to the filtration of the drilling fluid, and originating the deposition of solids (Isamburg et al. [11]). The difference of pressure generated in this interval with the cake exerts a suction effect on the drill collars can be highlighted that the circulation is maintained despite the pipe is or is not stuck. In directional wells, there is a bigger susceptibility for the occurrence of this abnormality, because the contact between the hole's walls and the drilling pipe (more specifically, the bottom borehole assembly) is bigger (Cardoso Júnior [5]).

Differential sticking is, most of the times, associated to inadequate drilling fluids, with excessive solid contents, high densities, high filtrate rates, and cake (Pereira [21]), as well as the formation properties, and the contact area between the drill pipe and the permeable formation (Reid et al. [23]). For the sticking to occur, two conditions must exist: (i) the hydrostatic pressure must exceed the pressure of the formation (overbalance) and (ii) the presence of permeable formations. The combination of these two conditions results in loss of fluid to the formation, and the deposition of the cake (Anonymous [2]).

It is impossible to eliminate all the conditions associated to the pipe sticking. Few parameters of the drilling can be altered to reduce the probability of occurring a differential sticking, being the drilling fluid, the parameter most easily adjusted.

Therefore, exist the possibility of reducing the risks of differential sticking by making use of some drilling practices, such as reduce the difference of pressure in a overbalance condition, maintaining the fluids weight the lowest as possible; reduce the contact area between the tubes and the hole's walls, using the minimum length of drill collars necessary to apply a weight on the bit; reduce the cake thickness; maintain a low filtration rate; and improve the lubricity of the fluid (Anonymous [2]).

Of all the mentioned practices, most of them involve the drilling fluids properties. In this form, a method to reduce these risks is to know the composition and optimize of the drilling fluids properties (Anonymous [2]). Variables like density, solid content, type, and formulation of the fluids, fluid loss and cake quality (cake thickness, resistance, and cake lubricity), influence in a significant way in the differential sticking, and its control can guarantee the success of the drilling. Besides this, the presence of a lubricant is another factor to reduce the risk of differential sticking, because there will be a decrease of the friction between the drill stem and the surface of the cake and, consequently, lower torque is necessary to initiate the columns movement (Krol [15]).

From the drilling engineering point of view, the drilling fluids must attend to some performance requirements, such as penetration rates, well cleaning, and loss of fluid minimization. While from the reservoir engineering point of view, the fluids need to control the formation pressure, and permit an adequate evaluation of the productive zone (Moreno et al. [19]). Therefore, for the drilling fluids to become efficient, and indispensable in a gas and oil exploration system, they must present a set of functions, like transport the sweepings to the surface, so that it can clean the bottom of the hole the detritus generated by the bit and transport them to the surface; exert hydrostatic pressure over the formations, to prevent the influx of undesirable fluids (kick), and stabilize the walls of the wells; cool and lubricate the drill column, and the bit (Thomas [25]); help in the evaluation of the sweepings and the drilled formations, and besides that, form a low permeability film (cake) on the hole walls, important to consolidate the geological formation, guaranteeing the stability of the well and the reduction of the filtrate loss, in the other words, the flow of the continuous phase fluid into the interior of the geological formations (Darley and Gray [8]).

The flow properties are typical for shear thinning fluids but differ on two points; presence of yield stress and/or thixotropy (Malfoy et al. [17]).

The present work aims to evaluate the influence of thermal aging on the differential sticking coefficient of clay and water drilling fluids with polymer and lubricant additives.

2. Materials and Methodology

2.1. Materials

Table 1 presented the compositions of the clay and water drilling fluids.

The clay and water fluids prepared with a sample of sodic bentonite clay, from Paraíba state, Brazil, with contents of 12.5g/500mL of water, with two polymer additives, denominated Pol.1 and Pol.2, with contents of 0.8g/500mL of water and two types of lubricants, denominated Lub.1 and Lub.2, with contents of 5mL, 10mL, and 15mL/500mL of water were studied.

Table 1. Compositions of the clay and water drilling fluids with and without lubricants

Fluids	**Water** (mL)	**Clay** (g)	**Pol.1** (g)	**Pol.2** (g)	**Lub.1** (mL)	**Lub.2** (mL)
F1	500	12.5	0.8	0.0	0.0	0.0
F2	500	12.5	0.8	0.0	5.0	0.0
F3	500	12.5	0.8	0.0	10.0	0.0
F4	500	12.5	0.8	0.0	15.0	0.0
F5	500	12.5	0.8	0.0	0.0	5.0
F6	500	12.5	0.8	0.0	0.0	10.0
F7	500	12.5	0.8	0.0	0.0	15.0
F8	500	12.5	0.0	0.8	0.0	0.0
F9	500	12.5	0.0	0.8	5.0	0.0
F10	500	12.5	0.0	0.8	10.0	0.0
F11	500	12.5	0.0	0.8	15.0	0.0
F12	500	12.5	0.0	0.8	0.0	5.0
F13	500	12.5	0.0	0.8	0.0	10.0
F14	500	12.5	0.0	0.8	0.0	15.0

The fluids from F2 to F7, and F9 to F14 were submitted to thermal aging, and to their denomination were added the letter ‘e’, as follows: F2e, F3e, F4e, F5e, F6e, F7e, F9e, F10e, F11e, F12e, F13e, and F14e.

2.2. Methodology

2.2.1. Preparation of the fluids

The clay and water drilling fluids were prepared based on the rule N-2605 (Petrobras [22]); the clay and the polymer were mixed with 500mL of deionized water, at a speed of 17000rpm during 20 min, in a mechanical mixer from Hamilton-Beach, model 936. Then, the fluid remained at rest during 24h in a closed container. After this period, the lubricant was added at a constant agitation in the same mechanical mixer at a speed of 17000rpm during 1min.

2.2.2. Rheological study

After a 24h rest, the fluid was agitated during 5 min, in a mechanical mixer from Hamilton-Beach, model 936, at a speed of 17000rpm. After that, the fluid was transferred to the Fann 35A viscometer's container. The viscometer was activated at a speed of 600rpm during 2 min and the reading was taken. Right after, the speed was changed to 300rpm, the reading was taken after 15s.

For obtaining of the initial gel strength, the fluid was submitted to mixing at a speed of 600rpm for 15s, then, remained at rest for 10s. Then, the viscometer was activated at a speed of 3rpm, and the reading was taken. To obtain the final gel force, the fluid was maintained at rest for 10 min, and the reading was taken at a speed of 3rpm.

With the data of the readings obtained on the viscometer, was calculated the apparent viscosity (AV), plastic viscosity (PV) according to rule N-2605 (Petrobras [22]), and gel strength (GS) by using the equations shown below:

$^{*}\text{Apparent viscosity (AV)}:$

$$AV = L_{600}/2(\text{cP}). \tag{1}$$

*Plastic viscosity (PV) :

$$PV = L_{600} - L_{300}\,(cP). \tag{2}$$

*Gel force (GF) :

$$GF = Gf - Gi(N/m^2). \tag{3}$$

2.2.3. Lubricity coefficient

The lubricity coefficient of the fluids was determined in an EP-lubricity tester from Ofite according to the manufacturer's methodology. The fluid was agitated during 5 min, in a mechanical mixer from Hamilton-Beach, model 936, at a speed of 17000rpm. After, the fluid was transferred to the equipment container, with initial torque zero and a speed of 60rpm; gently was applied a force of 150lbf/in (equivalent to a pressure of 34.5KPa to 69KPa) during 5 min, the reading of the torque applied by the fluid was taken. With the reading obtained by the torque of the water, was calculated the correction factor (CF), and the lubricity coefficient (LC), according to the Equations (4) and (5)

*Correction factor (CF) :

$$CF = 34.0 / \text{Reading}_{\text{water}}. \tag{4}$$

*Lubricity coefficient (LC) :

$$LC = \frac{CF \times \text{Reading}_{\text{obtained}}}{100}. \tag{5}$$

2.2.4. API fluid loss

The fluid loss (FL) of the fluids was determined in an API filter-press by applying the fluid to a pressure of 100psi (7.0Kgf/cm²). After 30 min, the fluid loss was collected and measured in mL.

2.2.5. Cake thickness

To determine the cake thickness was used a methodology developed by Farias [9] at laboratory reference in Desalination/Federal University of Campina Grande based on rule API 13B-1 [3], with use of an extensometer. This methodology consists on the following steps:

- Collect the filter paper with the cake after the experiment to determinate the fluid loss.

- Wash the paper three times at a flow of approximately 110L/h with the help of a container of constant level with adjustable flow, at a distance of approximately 7.0cm from the flow controller that has a diameter of 15.0mm and angle of attack of water of approximately 45^o.

- Put the filter paper with the cake between two glass slides and apply a pressure of approximately $277.6 N/m^2$ for a period of 2 min.

- Measure the cake thickness by using an extensometer.

Five measures of the slide's thickness, and paper with the cake were made in different points. After obtaining the measures, an arithmetical average was made of the 5 values.

2.2.6. Differential sticking coefficient

The differential sticking coefficient (DSC) of the fluids was determined in differential sticking tester equipment from Fann with the flat plate. The methodology used was suggested by the manufacturer, in which the fluids were agitated during 5 min, in a mechanical mixer from Hamilton-Beach, model 936, and then transferred to the interior of the equipment's cell. After, the fluids were submitted to a pressure of approximately 477.5psi (3292KPa) during 10 min, so that the cake formation could occur. Past this period, using a lever, the flat plate was lowered and maintained in this position for 2 min to guarantee that it would stick to the cake. Then, six measures were made (with 30s interval between one and another) of torque by using a torquemeter coupled to the flat plate.

The read torque represents the force necessary to move the flat plate. With the torque's values were calculated, the differential sticking coefficient according to the Equation (6)

$$DSC = T_m / 1000, \tag{6}$$

where DSC is the differential sticking coefficient and T_m is the arithmetical average of the torque measures.

2.2.7. Aging of the drilling fluids

The fluids were submitted to aging for 16h at 94ºC (200ºF) in a roller oven from Fann, and then, their rheological properties were determined, API filtration properties, lubricity, cake thickness, and differential sticking coefficient according to the methodology described before.

The rheological properties were determined at 49ºC (120ºF) by using a thermal cup from the Fann viscometer, according to rule API. The aging aims to evaluate the stability of the fluid's properties at high temperatures.

All the experiments were done in duplicate and when one of the values differed in a 10% range, this was automatically eliminated and the experiment was repeated.

3. Results and Discussions

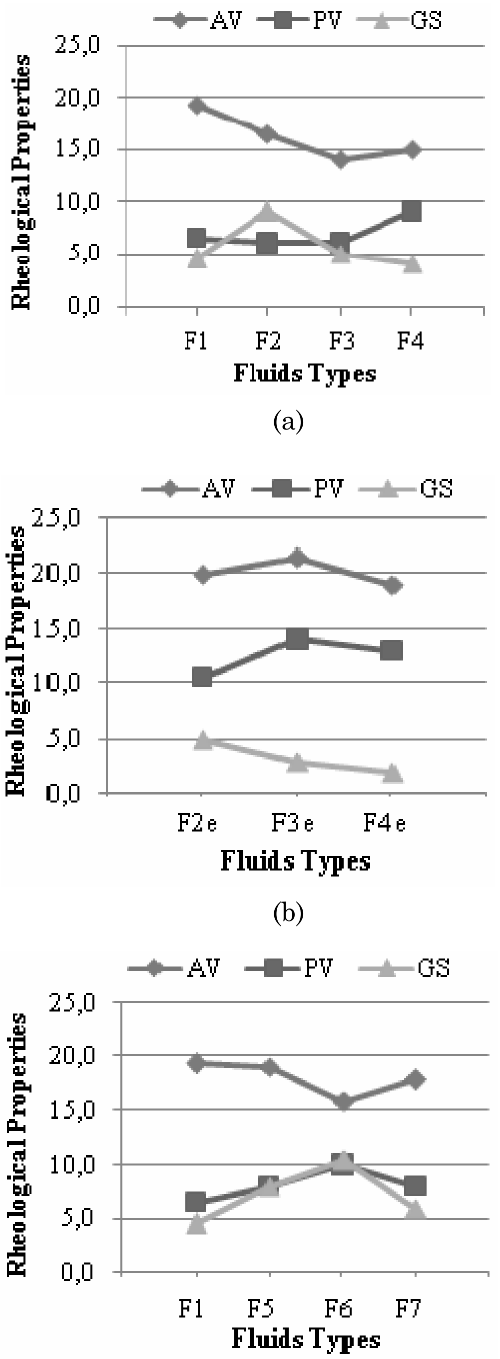
Figure 1 illustrated the results of the rheological properties (apparent and plastic viscosities, and gel strength) of the clay and water fluids with polymer, and lubricant additives before and after aging.

The viscosity of the fluids changes according to the polymer used. Also, was observed a reduction of the viscosity with the addition of a lubricant. This effect is due to the interaction of the clay and the lubricant, which acts as a surfactant, blinding the charges in the surface of the clay, reducing its viscosity (Amorim [1]).

The fluid F1, without lubricant, presented higher values of AV when compared to the fluids F2 to F7, which contain lubricant in their composition. The fluids with Pol.2 additive did not present significant variations. For all the studied fluids, the thermal aging promoted a subtle increase of the rheological properties.

The additives used in the fluids are polymers, whose active matters are xanthan gum (Pol.1), which disperses easily in aqueous environment, forming a gel with elevated viscosity (even in low concentrations), and sodium carboxymethylcellulose (Pol.2). These polymers present high resistance to heating and shear, for that reason, significant changes were not observed in the aged fluids' properties (F2e to F7e and F9e to F14e) when compared to the fluids in ambient temperature (F2 to F7 and F9 to F14).

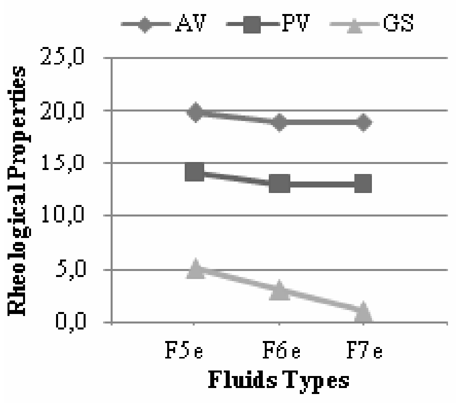
The lubricant was added to the fluids with the finality of improving their lubricity, although, it is important to observe that its addition changed, the rheological properties, and in higher concentrations, resulted in a decrease of AV, as observed in the fluids F2 to F4. This behaviour was expressive when Lub.1 was added.


AV
PV
GS
Rheological Properties
25,0
20,0
15,0
10,0
5,0
0,0
F1
F2
F3
F4
Fluids Types
F2e
F3e
F4e
F5
F6
F7

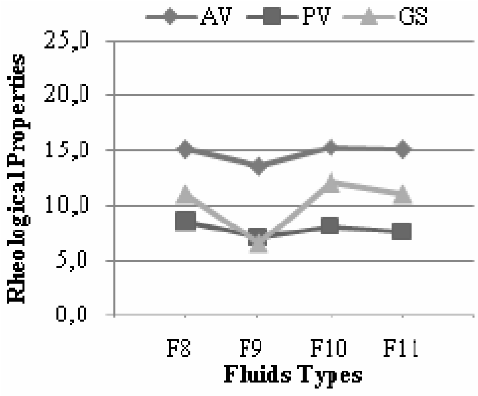
(a)

(b)

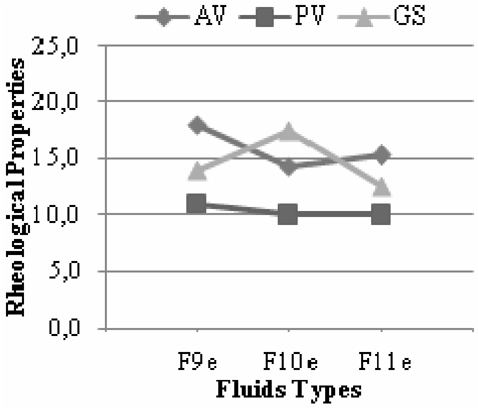
(c)


AV
PV
GS
Rheological Properties
25,0
20,0
15,0
10,0
5,0
0,0
F5e
F6e
F7e
Fluids Types

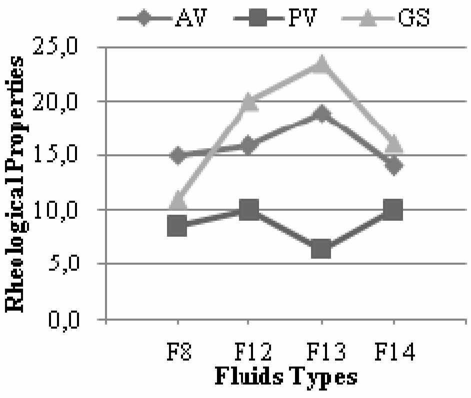
(d)


AV
PV
GS
Rheological Properties
25,0
20,0
15,0
10,0
5,0
0,0
F8
F9
F10
F11
Fluids Types

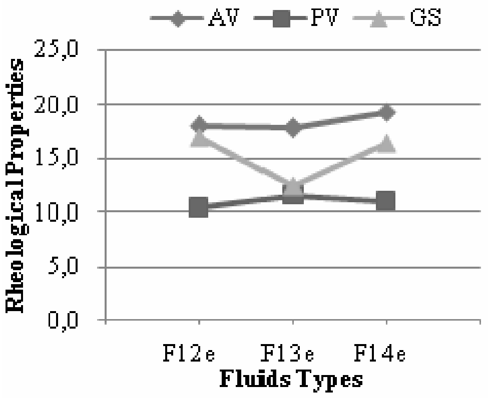
(e)


AV
PV
GS
Rheological Properties
25,0
20,0
15,0
10,0
5,0
0,0
F9e
F10e
F11e
Fluids Types

(f)



(g)



(h)

Figure 1. Rheological properties of the drilling fluids prepared with (a) Pol.1 e Lub.1, (b) Pol.1 e Lub.1 aged, (c) Pol.1 e Lub.2, (d) Pol.1 e Lub.2 aged, (e) Pol.2 e Lub.1, (f) Pol.2 e Lub.1 aged, (g) Pol.2 e Lub.2, and (h) Pol.2 e Lub.2 aged.

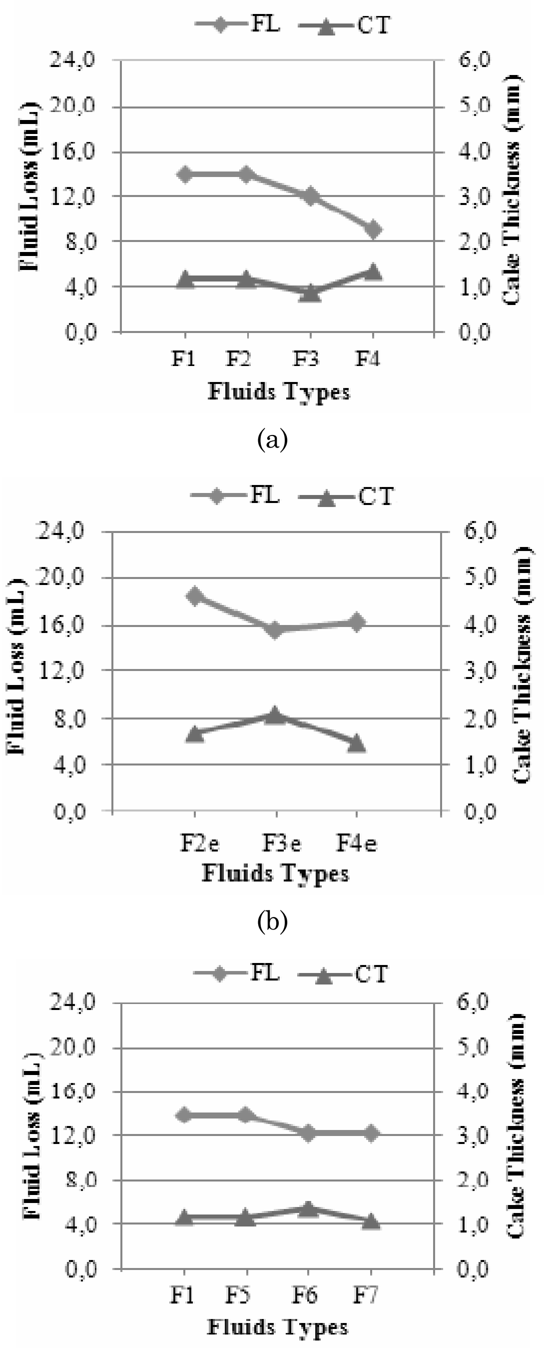
The fluids from F2e to F7e and from F9e to F14e presented good performances at a temperature of 94ºC (200ºF) that is the condition of the experiments of this work. Remembering that the clay and water fluids are sensitive to high temperatures and when exposed for long periods, they form hard gels that can compromise the drilling operations (Clark [7]). Also, was possible to observe that increasing the lubricant content in the fluids did not reduce the rheological properties, as observed at ambient temperature.

According to Kok and Alikaya [14], the polymers are used to overcome some drilling problems that the conventional fluids present depending on its composition and concentration, the fluids that contain polymers present better carrying capacities, less fluid loss, and cake.

Figure 2 illustrated the results of the filtration properties (fluid loss and cake thickness) for the clay and water fluids with polymer and lubricant additives before and after aging.

According to Figure 2, could be verified that, among the fluids with polymer and lubricant additives, the ones which presented the highest values of cake thickness were the fluids F4 and F6 (without aging) and the fluids F5e and F7e (with aging). According to Ferraz [10], the cake is formed by the deposition of the clay particles on the hole walls during the loss of water to the formations, in the other words, how higher the filter loss, more thicker will be the cake. In general, the CT is directly related to the FL, this happens because a fluid with a larger quantity of free water, when submitted to a determined pressure will result in a higher FL, consequently, the cake will be thicker.

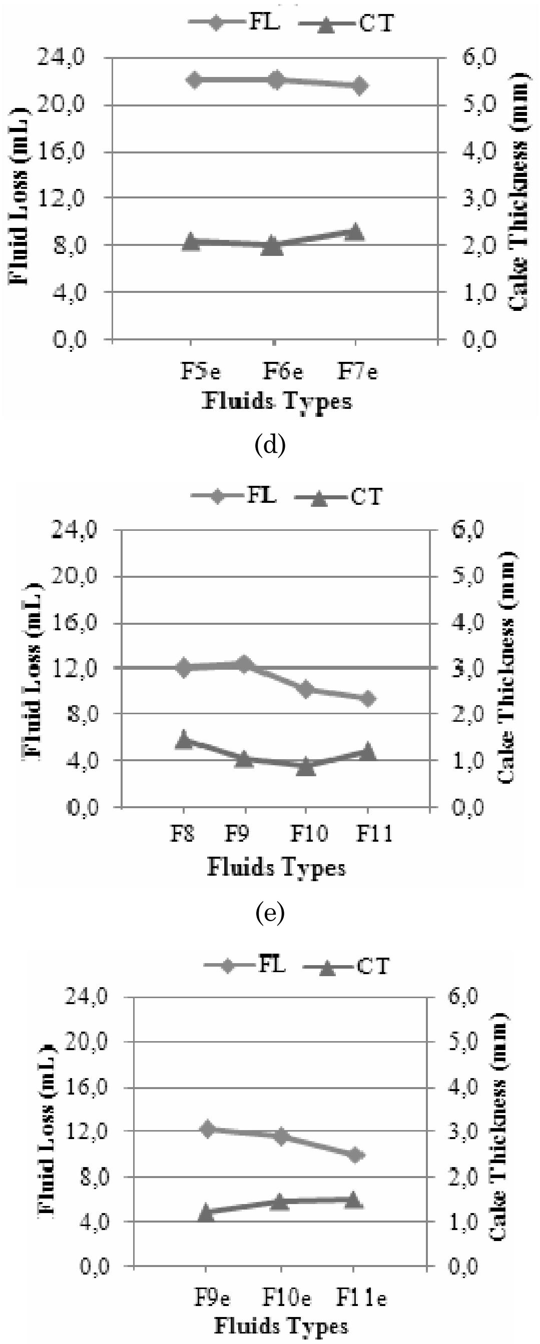
The values of FL and CT presented variations after aging; significant increase of these properties was observed. The FL of the fluids F4 before the aging was 9.0mL, and after aging, it increased to 16.2mL (F4e). The increase of CT was among 1.215mm. The fluids F3 presented values of CT near 0.876mm. With the aging, the increase was 2.091mm (F3e).


FL
CT
Fluid Loss (mL)
Cake Thickness (mm)
24,0
20,0
16,0
12,0
8,0
4,0
0,0
6,0
5,0
4,0
3,0
2,0
1,0
0,0
F1
F2
F3
F4
Fluids Types
F2e
F3e
F4e
F5
F6
F7

(a)

(b)

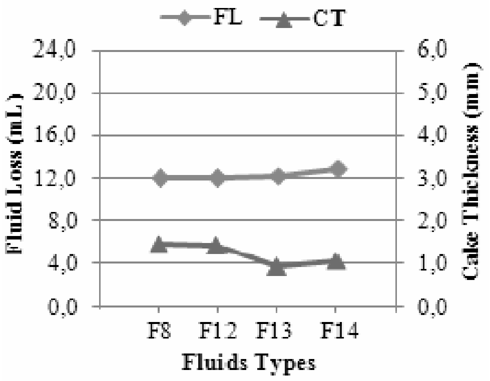
(c)


FL
CT
24,0
20,0
16,0
12,0
8,0
4,0
0,0
6,0
5,0
4,0
3,0
2,0
1,0
0,0
Fluid Loss (mL)
Cake Thickness (mm)
F5e
F6e
F7e
Fluids Types
F8
F9
F10
F11
F9e
F10e
F11e

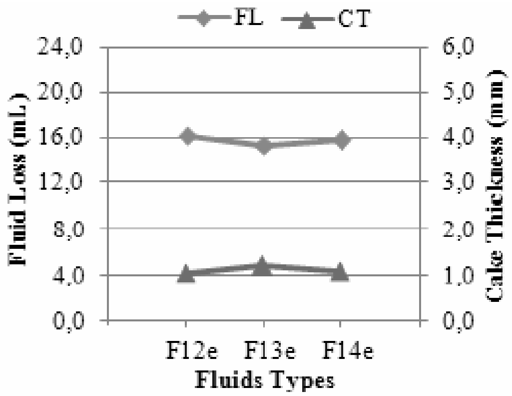
(d)

(e)

(f)



(g)



(h)

Figure 2. Filtration properties of the drilling fluids prepared with (a) Pol.1 e Lub.1, (b) Pol.1 e Lub.1 aged, (c) Pol.1 e Lub.2, (d) Pol.1 e Lub.2 aged, (e) Pol.2 e Lub.1, (f) Pol.2 e Lub.1 aged, (g) Pol.2 e Lub.2, and (h) Pol.2 e Lub.2 aged.

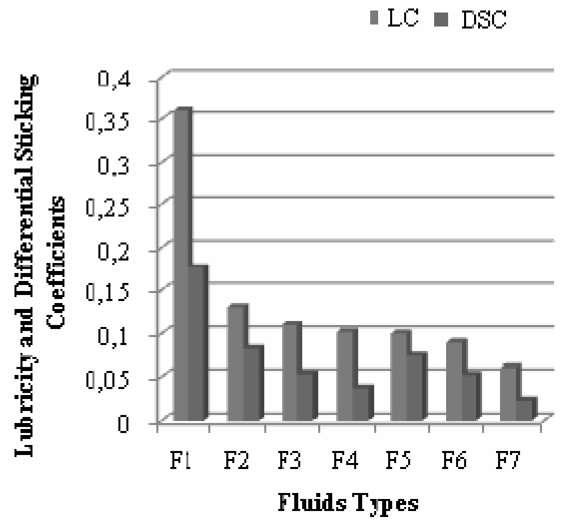
The rheological behaviour of the suspensions depends on the concentration of the clay particles, of the pH of the suspension, of the presence of ions in the suspension (mainly electrolytes), and temperature. At temperatures near 120ºC (250ºF) and in conditions of high salinity, the bentonite suspensions present very high viscosities. Various studies indicate the effect of the temperature over the rheological properties is unpredictable, and no mechanism of action proposed is widely accepted (Kelessidis et al. [12]).

According to Darley and Gray [8], three factors are fundamental to the variation of the filtration properties of the drilling fluids submitted to high temperatures, such as the alteration of the viscosity of the fluids; the electrochemical balance; and the chemical degradation of the fluid's components. The increase of the temperature promotes a reduction in the filtrates viscosity, therefore, is observed an increase of the filtrates volume. Changes in the temperature can also affect the electrochemical balance that regulates the flocculation degree and aggregation of the suspensions, altering the permeability of the cake, and consequently, the filtrate volumes. At last, most components present in fluids begin to degrade significantly at temperatures over 100ºC (212ºF); the increase of the degradation promoted by the increase of the temperature also alters the filtration properties.

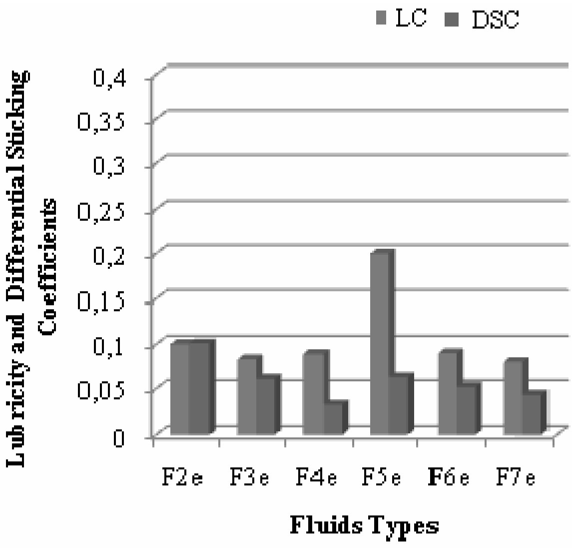
Figure 3 illustrated the results of the lubricity, and differential sticking coefficients of the clay and water drilling fluids with polymer, and lubricant additives before and after aging.

The fluids F5 to F7, and F12 to F14, that have Lub.2 in their composition, presented excellent values of LC, since according to Nascimento and Amorim [20] and with Darley and Gray [8], the fluids, to have adequate lubricity, must present LC of about 0.1mL, value commonly found in oil-based drilling fluids (taken as a standard), or in fluids with lubricant additives.

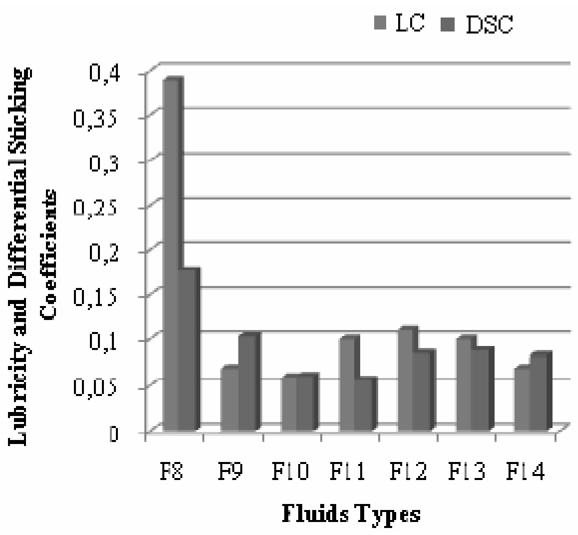
Also, was possible to observe that an increase in the content of the lubricants in the fluids did not change the LC in a significant way, being 5mL/500mL of water sufficient to give the fluids an adequate LC.


LC
DSC
Lubricity and Differential Sticking Coefficients
0,4
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
F1
F2
F3
F4
F5
F6
F7
Fluids Types

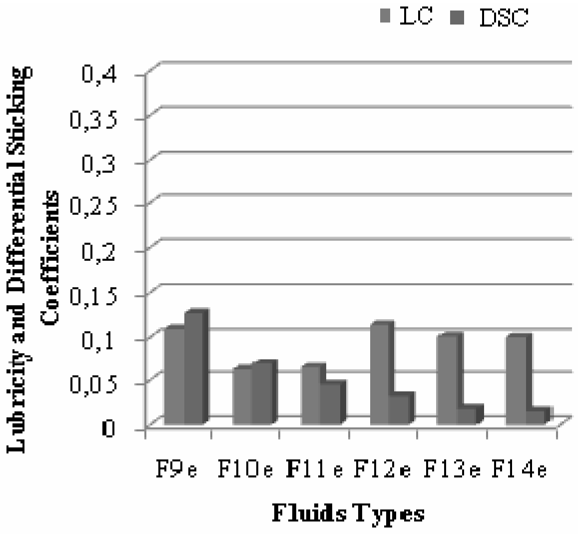
(a)


LC
DSC
Lubricity and Differential Sticking Coefficients
0,4
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
F2e
F3e
F4e
F5e
F6e
F7e
Fluids Types

(b)



(c)



(d)

Figure 3. Lubricity and differential sticking coefficients of the drilling fluids prepared with (a) Pol.1 e Lub.1 e Lub.2, (b) (a) Pol.1 e Lub.1 e Lub.2 aged, (c) Pol.2 e Lub.1 e Lub.2, and (d) (c) Pol.2 e Lub.1 e Lub.2 aged.

For the differential sticking coefficient, a similar behaviour was observed. The presence of a lubricant and an increase in its concentration reduced the values of DSC, being the Lub.2 the most efficient lubricant. Probably, the lubricant formed a coat on the surface of the flat plate, facilitating the sliding on the cake. So, as consequence, there is a reduction of the force necessary to free the equipment stuck to the cake.

The presence of Lub.1 in the fluids that have Pol.2 (F9, F10, and F11), brought the best results, once the LC was reduced from 0.38 (F8) to 0.07 (F9), and 0.06 (F10). While Lub.2 presented a better efficiency when combined with Pol.1, whose LC was 0.09 (fluids F6), and 0.06 (fluids F7).

As was observed for the lubricity coefficient, the content of 5mL of lubricant was sufficient to guarantee a reduction of the risk of column sticking. However, can be highlight that, for all the fluids, the increase in the content of the lubricant to 10mL and 15mL promoted a continuous reduction of the DSC, this leads to affirm that with an increase in the concentration of the lubricant, less will be the risk of stuck tubes.

The drilling fluid, in this case, with the lower DSC was the F7, that had Lub.2 additive, considered as environmentally correct, biodegradable and non-toxic.

As the Lub.2 does not have electrical charges, and is immiscible in water, it forms micelles in the fluids and when it gets in contact with the metallic surfaces it loosens out, adhering to the equipment’s surface, lubricating it. In a different way, the mechanism of action of Lub.1 occurs between the clay particles itself and the equipment’s surface.

Still according to Figure 3, was possible to observe that the fluids with Lub.2 additive (F5e to F7e and F12e to F14e) presented values of LC superior to the ones with Lub.1 additive (F2e to F4e and F9e to F11e), opposite result to the observed for the fluids at ambient temperature. Probably, during the aging, because Lub.2 is a vegetal oil-based ester, this could have hydrolyzed losing its lubricant capacity.

The fluids with Lub.1 additive presented better results of LC. This additive is an vegetal oil-based product, chemically modified to be soluble and, hereby, able to resist to elevated temperatures.

The fluids F10e (that have 10mL of Lub.1) presented the lower values of LC (0.062), while the fluids that have 5.0mL of Lub.2 (F5e) presented LC of 0.2.

Related to the DSC was observed that the fluids with Lub.2 additive presented the best results, the inverse behaviour to the one observed on the LC. The Lub.2 probably adhered to the cake, lubricating it. Once lubricated, the friction generated by the contact with the flat plate is minor, presenting lower values of DSC. As the LC is measured between two metallic surfaces (a block and a ring), this effect was not observed.

According to Magalhães [16], the mechanism of action of the lubricants depends, if the system is at rest or moving. In this form and considering the differences existent between the equipments and the methodologies of the experiments for the determination of the DSC (experiments where the system remains at rest, and only after a period, it moves when a lever is lowered), and the lubricity (LC) (experiments where the system is found in continuous motion), the Lub.2 can be considered the most efficient for systems at rest.

According to Bushnell-Watson and Panesar [4], in water-based fluids as well as oil-based fluids, the use of a lubricant affects significantly the way that the tubes are released. In the absence of a lubricant, the tubes are released in the cake/formation interface, while that when there is a lubricant, the tubes are released in the tube/cake interface, reducing the risks during the drilling.

These results suggest a direct correlation between lubricity and differential sticking, in a way that lower values of LC result in lower values of DSC.

4. Conclusion

According to the obtained results was possible to conclude that

- The aging did not alter the rheological properties in a significant way, and little alterations were observed for the filtration properties.

- Little lubricant contents are sufficient for the reduction of the lubricity and differential sticking coefficient of the fluids.

- No significant alterations were observed in the differential sticking coefficient with the thermal aging.

- The lubricants presented inverse behaviour when the fluids were submitted to aging when it comes to the lubricity coefficient, in the other words, after the aging, the lubricant (Lub.1) conferred to the fluids the best lubricity coefficient results. However, the best differential sticking coefficients were reached with Lub.2.

- The aging promoted a reduction of the differential sticking coefficient of 18% for the F14 fluids.

In general, the addition of lubricants to the clay and water fluids with polymers constitutes one of the major factors for the increase of the thermal resistance, improvement of the lubricity coefficient, and reduction of the risk of differential sticking of the fluids.

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