EVALUTION OF DISPERSANT ADDITIVES IN DRILLING FLUIDS TO CONTROL THE FILTER-CAKE THICKNESS AND THE DIFFERENTIAL STICKING COEFFICIENT

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Abstract. *The drillstring sticking is a common problem which occurs during the drilling of wells. One of the types of sticking is the differential sticking, caused by a pressure differential, in other word, when the drilling fluid column exerts excessive pressure on the drillstring over the cake deposited on a permeable formation. The drillstring, once it is stuck to the walls in the hole, needs to be freed by a local treatment. The presence of permeable formations is a determinant factor for the occurrence of differential sticking. This occurs due to the accumulation of cake during the drilling. The cake thickness increases while the fluid loses water to the geological formations, preventing the loss of water by filtration. In this form, because it is common the presence of permeable formations, the occurrence of differential sticking is inevitable in vertical wells as well as horizontal wells, doesn't matter if they are located onshore or offshore. Given this situation, this work has the aim of using dispersants in water-based drilling fluids with bentonite for the control of filter-cake thickness and the differential sticking. To evaluate the influence of the clay concentration, type of dispersant and dispersant concentration (entrance variables) over the differential sticking coefficient (DSC), cake thickness (CT) and fluid loss (FL), it was used a* 2^3 *factorial design, being the tests performed in duplicate, totalizing 16 experimental runs. Through the obtained results, it was verified that the properties of CT, FV and DSC are affected mainly by the concentration of Clay and by the type of dispersant used in the preparation of the fluids. Fluids with lower cake thickness and lower risks of presenting differential sticking are the ones with dispersant D1.*

Keywords: *drilling fluids, dispersant, differential sticking.*

1. INTRODUCTION

The drilling fluids are indispensable for the petroleum industry and are defined as circulation fluids used to support the petroleum well drilling operations (Amorim, 2003).

Depending on the type of geological formation to be drilled, the fluid can be composed only of water and, as the solids that result of the drilling be incorporated to the water, it will be produced a water and clay based drilling fluid, named as natural fluid. In other formations, it is necessary to incorporate clay to the water to form a fluid before the beginning of the drilling operation, being these called conventional water based fluids with addition of clay or clay and water based (Darley and Gray, 1988).

The bentonite is the most used commercial clay in freshwater based fluids, being added to perform one or several of the following functions: increase the cleaning efficiency of the well by increasing the fluids viscosity; reduce the infiltrations in the permeable formations by the deposition of a low permeability membrane (cake) and maintain the solids in suspension during connections and maneuvers. This last function can be performed because of the ability of forming thixotropic gels (Darley and Gray, 1988).

According to Darley and Gray (1988), the drilling fluids perform the following functions: transport the gravel from the drilling and permit its separation at the surface, cool down and clean the bit, reduce the friction between the stem of the drilling pipe and the borehole wall, maintain the stability of the well, prevent the leakage of the drilling fluid into the geological formations, form a low permeability film, called cake, on the borehole walls, and permit an evaluation of the gravels and the perforated formations. The execution of these functions depends directly on the physical and chemical properties of the fluids, in other words, viscosity, gel consistency, filtrate and cake control.

The cake can be defined as a membrane which is formed by the deposition of the clay particles on the borehole walls as the liquid phase (water) of the fluid penetrates in its pores. The thickness of this membrane increases inasmuch as the fluid loses water to the geological formations that it is in contact with, and once a determined thickness is achieved, tend to waterproof the well, impeding the loss of water by filtration (Ferraz, 1977).

The forming of the cake is important for the consolidation of the geological formation, guaranteeing the stability of the well and the reduction of the losses by filtration. The lack of control of the cake thickness can cause various problems during the perforation, such as: excessive filtrate invasions in the geological formations, hydratable formation collapse, reduction of the hole diameter, imprisoning of the drill pipe, damage to the aquifer formations, wrong evaluation of the investigated formations and differential sticking, being this last one of great relevance (Darley and Gray, 1988).

According to Ferraz (1977), a great part of these problems is caused mainly by the high thickness of the cake; the only problems caused by the excessive loss of fluid are the errors in the formation evaluation and the damage in the formations. And she adds that, the control of the cake thickness is the solution to the problems generated by the inadequate filtration properties.

The differential sticking is caused by a pressure differential, in other words, when the fluid column exerts excessive pressure on the drilling pipe to the cake formed on a permeable formation (Simon, 2005). The circulation of the fluid is maintained, but it is not possible to move or rotate the pipe in either direction (Schlumberger, 2011).

This phenomenon is always associated to inadequate drilling fluids, with excessive solid content, high density, high filtration rates and cake (Pereira, 2010), as for the characteristics of the geological formation and the contact area of the drill pipe with the permeable formation (Reid et al., 1996).

Its occurrence represents non productive time of the platform (Bachelot et al., 2004) and, in this form, becomes one of the main causes for the increase of costs in the drilling operation, because maneuvers must be done to try to release the pipe, increasing the time for the drilling operation (Yarim et al., 2007).

According to Pereira (2010), the differential sticking constitutes one of the most severe problems during perforation of wells and occurs due to the imprisoning of the drilling tool. Collages and adhesions can occur in any interval of the well depth. Most wells aren’t totally vertical, being very common for the pipe to touch the borehole walls, especially in connections and maneuvers. These walls are strongly pressed by the fluid column, creating a differential pressure.

The drilling pipe, once it is stuck to the borehole walls, has to be freed by a previous treatment with dispersants and humectants (Pereira, 2010).

According to Darley and Gray (1998), the dispersants are substances used to reduce the filtration and the cake thickness, to minimize the effect of the water on the perforated formations and to stabilize the fluid properties in high temperatures. The dispersants normally have a relatively large anionic component that is adsorbed on the positive sites of the clay particles, reducing the attractive forces between the particles without affecting its hydration.

The dispersants most commonly used in drilling fluids are: vegetal tannins, polifosfates, lignites and lignosulfonates (Darley and Gray, 1988).

According to the exposed, this work aims to study the application of dispersants in water-based drilling fluids with bentonite for the control of the cake thickness and differential sticking.

2. MATERIALS AND METHODS

2.1. Materials

For the preparation of the drilling fluids, were used a sample of clay and two samples of dispersants as shown below.

- Bentonite Clay

It was studied a sample of sodic bentonite clay, with high swelling rate, widely used in the petrol industry as viscosifier, filtrate reducer and gel-forming agent. This clay is commercially known as Brasgel PA and was provided by Company Bentonit União Nordeste Indústria e Comércio Ltda.

- Dispersants

There were studied two samples of dispersants, called D1 and D2. The dispersants were provided by Company System Mud Indústria e Comércio Ltda.

2.2. Methods

- Experimental Design

To evaluate the influence of the entrance variables (clay concentration, type of dispersant and concentration of dispersant) on the differential sticking coefficient (DSC), cake thickness (CT) and fluid loss (FL), was used a 2^3 factorial planning, being the test done in doubles, with a total of 16 experiments (Barros Neto et al., 1996). A regression of the experimental data was done using the software Statistic, version 5.0 (Statsoft, 2000). The codified levels and the real values of the entrance variables applied in the planning are shown in Table 1. In Table 2, it is shown the experimental planning.

Table 1: Codified levels and real values of the entrance variables of the experimental planning 2^3.

Entrance Variables	Codified Levels	
	Level -1	Level +1
Clay Concentration - CC (kg/L)	0.04	0.08
Dispersant type - DT	D1	D2
Dispersant Concentration – DC (kg/L)	0.02	0.04

Tabela 2: Experimental planning matrix.

Experiments	Clay Concentration	Dispersant Type	Dispersant Concentration
1	-1	-1	-1
2	1	-1	-1
3	-1	1	-1
4	1	1	-1
5	-1	-1	1
6	1	-1	1
7	-1	1	1
8	1	1	1

- Preparation of the Drilling Fluids

For the preparation of the drilling fluids, it was added to water, the bentonite clay and the dispersant under a stirring in a Hamilton Beach mixer, model 936. Then, the mixture was maintained under stirring during 20 minutes at a rotation speed of 17.000 rpm. The fluids were prepared using the entrance variables according to the experimental planning presented in Table 2 and using the concentrations shown in Table 3. There were prepared 16 fluids, being 2 fluids for each experiment.

- Differential Sticking Coefficient

After 24 hours of rest, was done a test to determine the differential sticking coefficient (DSC) on the equipment Differential Sticking Tester from Fann (Figure 1) with the flat plate tool. The test consisted in stirring the fluids for about 5 minutes in a Hamilton Beach mixer, model 936. After, the fluids were transferred to the interior of the equipment's cell. Then, it was submitted to a pressure of approximately 3.292 KPa for 10 minutes for the formation of the cake. After this period, the flat plate was lowered, using a lever, and maintained in this position for 2 minutes to guarantee that it will stick to the cake. After, there were done six torque reading (with 30 second interval between one and another) using a torquimeter coupled to the flat plate. The torque that was read represents the necessary force to move the flat plate. With the values of torque, it was able to calculate the differential sticking coefficient according to the equation below:

$$DSC = \frac{T_m}{1000} \quad (1)$$

Being:

DSC = differential sticking coefficient
Tm = arithmetical average of the torque measures

Figure 1: Differential Sticking Tester Fann and flat plate.

- Fluid Loss

The fluid loss was measured using the same equipment used to determine the differential sticking coefficient. The fluids were stirred for about 5 minutes in a Hamilton Beach mixer, model 936, and then, transferred to the Differential Sticking Tester cell, in which it was maintained for 10 minutes under a pressure of 3.292 KPa. At the end of this time, the fluid loss (FL) was measured.

- Cake Thickness

To determine the cake thickness, was used the methodology developed by Farias (2005), that consists in the following steps. Initially, the filter paper was collected with the formed cake after the test to obtain the fluid loss. Then, this paper was washed three times at a flow of approximately $30.5x10^{-3}$ L/s with a constant level recipient with adjustable flow, at a distance of approximately $7.0x10^{-2}$m from the flow controller that has a diameter of $15.0x10^{-3}$ m and an angle of attack of approximately 45^o. After washing to remove the fluid excess on the surface of the cake, the filter paper was put in between two glass slides and submitted to a pressure of approximately 277.6 Pa for about 2 minutes with the aim to equalize the surface of the cake. After this period, the cake thickness was measured using a extensometer. There were made 5 measures of the thickness of the slides and the filter paper with the cake in distinct points. After obtaining the measurements, was taken the average value between the 5 measurements and the thickness of the slides and the paper was discounted, being determined only the thickness of the cake (CT) in millimeters with approximation in hundredths. The results are expressed in meters.

3. RESULTS AND DISCUSSION

In table 3, are show the results of fluid loss (FL), cake thickness (CT) and differential sticking coefficient (DSC) obtained for the fluids prepared according to the experimental planning in table 2.

Table 3: Fluid loss (FL), cake thickness (CT) and differential sticking coefficient (DSC) of the water and clay drilling fluids.

Experiments	FL (10^{-6} m^3)	CT (10^{-3} m)	DST
1 (0.04 kg/L, D1, 0.02 kg/L)	4.9	0.417	0.121
2 (0.08 kg/L, D1, 0.02 kg/L)	3.0	0.605	0.126
3 (0.04 kg/L, D2, 0.02 kg/L)	6.0	0.386	0.144
4 (0.08 kg/L, D2, 0.02 kg/L)	3.4	0.624	0.141
5 (0.04 kg/L, D1, 0.04 kg/L)	4.9	0.368	0.110
6 (0.08 kg/L, D1, 0.04 kg/L)	3.1	0.461	0.110
7 (0.04 kg/L, D2, 0.04 kg/L)	5.6	0.285	0.147
8 (0.08 kg/L, D2, 0.04 kg/L)	3.4	0.505	0.142

According to table 3, it could be observed that the increase in the concentration of clay provided a reduction on the FV of the studied fluids. This behavior is evidenced when comparing with the results obtained with the experiments 1 (0.04 kg/L, D1, 0.02 kg/L), 2 (0.08 kg/L, D1, 0.02 kg/L), 3 (0.04 kg/L, D2, 0.02 kg/L), 4 (0.08 kg/L, D2, 0.02 kg/L), 5 (0.04 kg/L, D1, 0.04 kg/L), 6 (0.08 kg/L, D1, 0.04 kg/L), 7 (0.04 kg/L, D2, 0.04 kg/L) and 8 (0.08 kg/L, D2, 0.04 kg/L).

With the fluids prepared in the experiments 2 (0.08 kg/L, D1, 0.02 kg/L) and 6 (0.08 kg/L, D1, 0.04 kg/L) were achieved the lowest values for FV, $3.0x10^{-6}$ m^3 e $3.1x10^{-6}$ m^3, respectively.

A increase in the clay concentration of the water-based drilling fluids has direct influence in its rheological properties and also filtration properties, according to Amorim et al., (2005). In accordance with these authors, an increase in the clay concentration promotes a higher intensity of the electrical interactions and of mass between the particles. These interactions promote the formation of reticulates somewhat rigid, that retain the water molecules decreasing the quantity of free water in the system, and therefore, the fluid loss.

The results obtained (table 3) for CT presented a behavior similar to the one of FV. It was also observed that when the dispersant 2 was used together with higher clay concentrations, the cake thickness increased in a significant way, being this behavior more explicit in experiment 4 (0.08 kg/L, D2, 0.02 kg/L).

Analyzing table 3, it could be observed that the type of dispersant influences in a significant way on DSC; the fluids prepared with dispersant D1 presented the lowest values for DSC, being them obtained in the experiments 5 (0.04 kg/L, D1, 0.04 kg/L) and 6 (0.08 kg/L, D1, 0.04 kg/L).

The Table 4 presents the variance analyses and the codified mathematical models (regression equation) for the fluid loss (FL), the cake thickness (CT) and the differential sticking coefficient (DSC) for the studied fluids.

Table 4: Analysis of the variance (ANOVA) and codified mathematical models of the fluid loss (FL), cake thickness (CT) and differential sticking coefficient (DSC) of the Clay and water based fluids for the applied experimental planning.

Variation source	FV	CT	DSC
Correlation Coefficient (R)	0.99	0.99	0.99
% Explained Variation*	99.9	99.2	99.9
$F_{calculated}/F_{tabulated}$	0.638	0.092	1.037
Codified mathematical models for the clay and water based fluids			
FL (10^{-6} m^3) = 4.2 x 10^{-6}** ± 3.7 x 10^{-8} – (1.1 x 10^{-6}CC** ± 3.7 x 10^{-8}) + (0.3 x 10^{-6}DT ± 3.7 x 10^{-8}) – (0.04 x 10^{-6}DC ± 3.7 x 10^{-8}) – (0.13 x 10^{-6}CC.DT ± 3.7 x 10^{-8}) + (0.06 x 10^{-6}CC.DC ± 3.7 x 10^{-8}) – (0.06 x 10^{-6}DT.DC ± 3.7 x 10^{-8})			
CT (10^3 m) = 4.56 x 10^{-4}** ± 1.0 x 10^{-5} + (0.92 x 10^{-4}CC ± 1.0 x 10^{-5}) – (0.06 x 10^{-4}DT± 1.0 x 10^{-5}) – (0.052 x 10^{-4}DC ± 1.0 x 10^{-5}) + (0.022 x 10^{-4}CC.DT ± 1.0 x 10^{-5}) – (0.014 x 10^{-4} CC.DC ± 1.0 x 10^{-5}) – (0.003 x 10^{-4}DT.DC ± 1.0 x 10^{-5})			
DSC = 0.13** ± 0.00037 – (0.00037CC ± 0.00037) + (0.01337DT** ± 0.00037) - (0.00287DC ± 0.00037) – (0.00162CC.DT ± 0.00037) – (0.00087CC.DC ± 0.00037) + (0.00387DT.DC ± 0.00037)			

Being: SQ_R the sum of the squares from the regression, SQ_T the total sum of the squares, CC is the clay concentration, DT is the type of dispersant and DC the concentration of the dispersant.

$*R^2 = \left(\frac{SQ_R}{SQ_T}\right) x\ 100$

**Statistically significant at a 95.0% level.

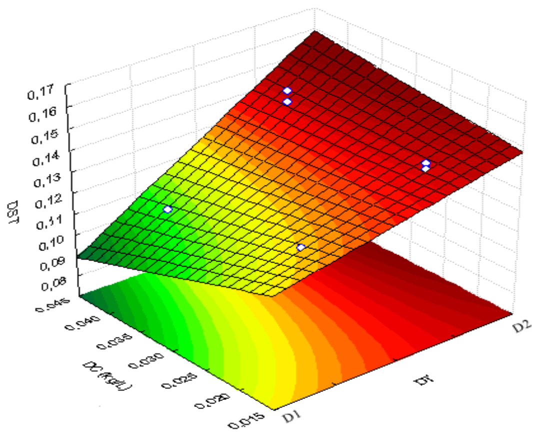
The determination or explanation coefficient (R^2) quantifies the quality of the adjustment, as it provides a measure of the proportion of the variation explained by regression equation in relation with the total variance of the responses, ranging from 0 to 100% (Rodrigues and Ielma, 2000).

For the clay and water fluids prepared according to the experimental planning, the analysis of the statistical significance showed that the correlation coefficients (R) and the variation explained of the experimental results for FV, CT and DSC were satisfactory, with values of 0.99 and 99% respectively. So, the mathematical models presented have more than 99% of the variations obtained explained by the model.

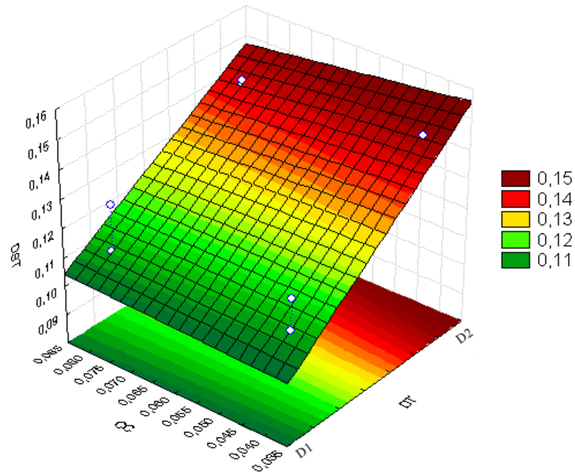
The test F presents a ratio between the $F_{calculated}$ and the $F_{tabulated}$; when this relation is bigger than 1, the regression is statistically significant, in other words, there is a relation between the independent variables and the dependent (Rodrigues, 2010).

For the evaluated parameters, only the DSC presented value of test F bigger than 1, indicating that the model is statistically significant at a 95.0% level of confidence. For neither of the properties was obtained a predictive model, once the ratios between the test $F_{calculated}$ and the test $F_{tabulated}$ presented values inferior to 5 (Rodrigues and Ielma,2010).

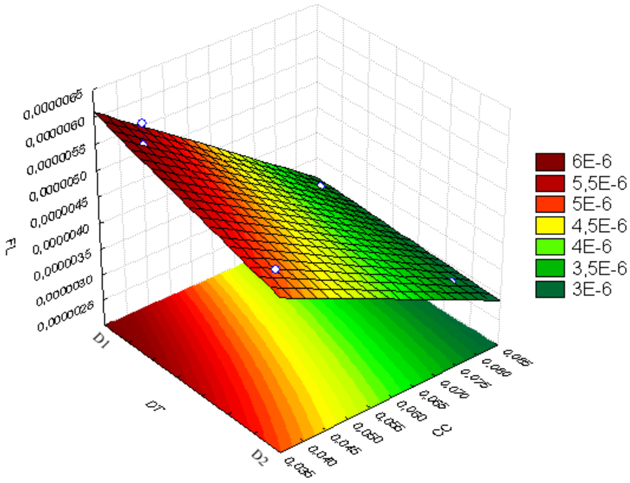
In figures 2 and 3 are presented the surfaces of response obtained from the codified mathematical models presented in table 4, for the DSC, FV and CT.



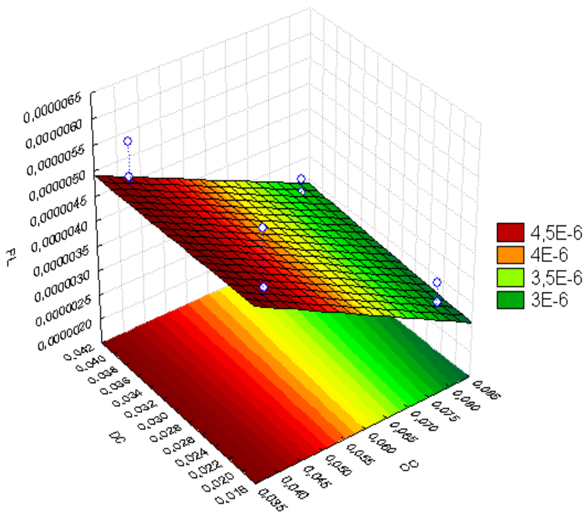
(a)



(b)

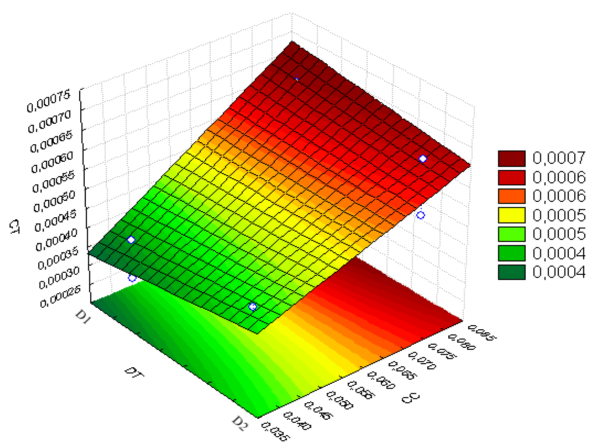


(c)

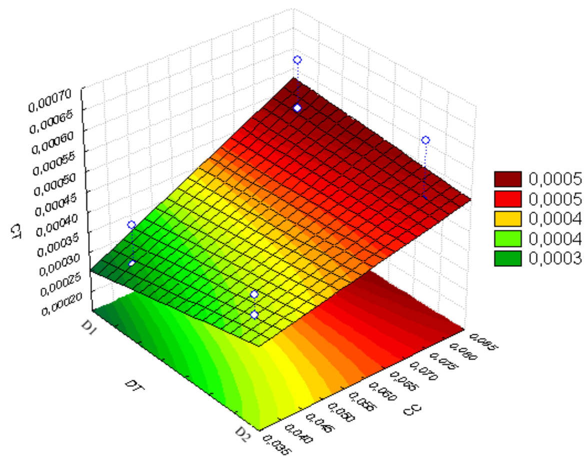


(d)

Figure 2: Surfaces of response for DSC and FL, setting (a) clay concentration at 0.08 kg/L, (b) content of dispersant at 0.04 kg/L, (c) content of dispersant at 0.04 kg/L and (d) type of dispersant at D1.



(a)



(b)

Figure 3: Surfaces of response for CT, setting (a) content of dispersant at 0.02 kg/L and (b) content of dispersant at 0.04 kg/L.

Through the figure 2a, it was observed that the lowest, and therefore, best values of DSC were obtained with the dispersant D1 in higher concentrations. This behavior was observed by setting the concentration of clay to 0.08 kg/L. For figure 2b, it could be observed that the best values of DSC were achieved with the dispersant D1, and that the concentration of the clay has no statistical influence over this variable. This behavior was observed setting the dispersant at 0.04 kg/L.

Analyzing the figures 2c and 2d, in which were obtained setting the dispersant concentration at 0.04 kg/L and the type of dispersant at D1, respectively, it was observed that the lowest and, therefore, best results for FV are obtained when the fluids are prepared with higher concentrations of clay. These results confirm the experimental data presented in table 3 and discussed previously. In the figure 2b, it could be observed, as well, that the type of dispersant does not influence statistically the FV of the studied fluids.

For the variable CT is observed the following tendency: (i) for the obtainment of lower values of CT, the drilling fluids must be prepared with low concentrations of the Brasgel PA clay and be prepared with dispersant D1. This tendency is valid for the interval of concentrations of the studied dispersant, in other words, of 0.02 to 0.04 kg/L.

4. CONCLUSIONS

With the aim to study the influence of the application of dispersants in water-based drilling fluids with bentonite for the control of cake thickness and differential sticking, it could be concluded that:

- The clay concentration influences statistically the fluid loss of the drilling fluids, in a 95,0% confidence level, being obtained lower and, therefore, better values of fluid loss with the increase of clay concentration from 0.04 to 0.08 kg/L;
- The variables clay concentration, type of dispersant and concentration of dispersant did not present significant statistical influence on the cake thickness of the studied fluids, however, the tendencies presented are extremely valid and showed that the cakes with lower thickness can be obtained with fluids prepared with low concentrations of clay and with use of dispersant D1 and;
- The mathematical model obtained for DSC is statistically significant at a 95.0% confidence level and evidenced that minor, and therefore, better values of DSC are obtained with addition of dispersant D1 to the fluid.

In short, this work investigated the influence of two dispersant additives on the fluid loss control, cake thickness and differential sticking coefficient of clay and water-based drilling fluids and showed that these properties are affected mainly by the clay concentration and by the type of dispersant used in the preparation of the fluids. Fluids with lower cake thicknesses and lower risks of tool sticking by differential pressure were the ones prepared with dispersant D1.

5. AKNOWLEDGEMENTS

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