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INFLUENCE OF ADDITIVES CMC HV, STARCH AND CALCITE IN RHEOLOGICAL BEHAVIOR OF INHIBITED DRILLING FLUIDS

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Abstract. *The aim of this work was to evaluate the influence of starch, high viscosity carboxymethylcellulose (CMC HV) and calcite in rheological behavior of inhibited drilling fluids. For this, formulations of water base fluids were developed from a base fluid composed by anti-foam, viscosifier, pH controller, clay inhibitors, bactericide and lubricant. The concentration of starch varied from 0 to 12g/350mL of water, the concentration of CMC HV from 0 to 1,5g/350mL of water and the concentration of calcite from 0 to 25g/350mL of water. Using* 2^3 *factorial design, 11 experiments were carried out, where three were in the central point. The fluids were prepared by adding the additives, one by one, in high rotation mechanical agitators, at an interval of 5 to 10 minutes between them. After 24 hours of fluids preparation, the rheological study was done using a Fann 35A viscometer, and then the apparent and plastic viscosities and the yield limit were determined. Analyzing the mathematical models, it was observed that the starch and the CMC HV statistically influence the rheological properties of fluids. It was also observed that the highest values for these properties were obtained in fluids prepared with higher concentrations of starch and CMC HV.*

Keywords: *inhibited drilling fluids, factorial design, rheology.*

1. INTRODUCTION

The American Petroleum Institute (API) considers drilling fluid any circulating fluid that can make a drilling operation viable. Drilling fluids perform fundamental functions, such as cleaning the well bottom and the drill bit, and maintaining the stability of the well (Thomas, 2001).

Fluids whose main constituent of the continuous phase is water are preferred due to their lower cost and lesser damage to the environment when discarded. However, their use during the drilling of active formations such as shales, usually results in problems related to well instability. These problems, in turn, increase when drilling inclined wells and manifest themselves, most of the times, with loss of circulation, imprisonment of the drill pipe, instability of borehole walls, which cause its enlargement, and damage to the formation with reduction of the reservoir's performance (Garcia, 2003).

According to Trenery (2008), about 75% of drilled formations in oilwells contain active shales, and more than 90% of the problems with instability of borehole walls are related to the inability of drilling fluid to control these shales.

Some clay minerals present in shales have a high capacity of cation exchange, which arises as a function of their ability to react with cations present in solutions. Because they contain negative charges on their outer surface (Rabe, 2003). It can become a problem when, during drilling a well, the formation to be crossed is a shale rock containing clay minerals of this type. As a solution, chemicals are used in water based fluids to prevent or minimize, effectively, the hydration process of the clays, known as clay swelling inhibitors. The action mechanism of these inhibitors consists in fixing, by physical or chemical adsorption, the cationic fraction on the negative surface of the clay, releasing the original cation present in the clay mineral to the environment (Mello, 2001).

Fluids prepared with clay inhibitors are called inhibited drilling fluids, and are employed in drilling of wells with hydratable shales to prevent swelling of found clays (Félix et al, 2007).

Starch is among the additives studied in this work, a polymer whose structural molecule presents a slightly anionic character, and is, therefore, considered a hydrophilic polymer. This characteristic makes it able to absorb large quantities of water, what allows it to act as a controller of fluid loss to the formation. The large particles in its chain are

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an important feature of this polymer which helps in minimizing the penetration of drilling fluid in the formation (Guimarães, 2008).

The carboxymethylcellulose (CMC) is a polymer derived from cellulose which is insoluble in water but becomes soluble when modified to the form of a polyelectrolyte (Amorim, 2003). According to Pereira (2002), the CMC is used in water based fluids as a filtrate reducer, to reduce losses by filtration and produce very thin filter cakes that are capable of preventing fluid flowing through the geological formations that are being drilled.

Rheology is the science of deformation and flow of matter. Rheological parameters define the behavior of fluid flow, which directly influences the calculation of head losses in pipes and the transport velocity of the cuttings. By making certain rheological measurements of the fluid, it is possible to determine how the fluid will flow under varied conditions of temperature, pressure and shear rate (Thomas, 2001).

Apparent viscosity is the viscosity of a fluid, considered Newtonian, at a determined shear rate. Plastic viscosity, in turn, describes the flow features after it has been initiated. In other words, it is the flow resistance caused by friction between the dispersed particles and between the individual molecules of the dispersant liquid. Finally, yield limit is the viscous parameter determined by the interaction forces between dispersed particles (Machado, 2002).

Salts act as inhibitors of active formations in order to reduce the hydraulic flow to the formation, mainly due to the viscosity of its filtrates and by stimulating the flow of water from clay formation to drilling fluid, causing a reverse flow that reduces the hydration of formation and the formation pores pressures around the well (Guimarães, 2008). Thus, it is important to study the rheological behavior of inhibited drilling fluids.

Based on the above considerations, the aim of this work is to study the effects of additives starch, high viscosity carboxymethylcellulose (CMC HV) and calcite in rheological properties (apparent viscosity, plastic viscosity and yield limit) of inhibited water based drilling fluids, inhibited by potassium citrate.

2. MATERIALS

Base water based fluid developed by Lucena (2011) was used to prepare the drilling fluids. The following additives were used: viscosifier (xanthan gum and high viscosity carboxymethylcellulose), filtrate reducer (starch), clay inhibitor (potassium citrate), anti-foam, bactericide, sealant (calcite), lubricant e pH controller (MgO). The additives samples were provided by Company System Mud Indústria e Comércio Ltda., located in Otávio Muller Street, 204, Carvalho, Itajaí, SC.

The additives used, with their respective functions and concentrations, are listed in Tab. 1.

Table 1. Additives, functions and concentrations used in fluids' preparation.

Additive	Function	Concentration/ Concentration range
Water (mL)	Additives dispersion environment	350
Anti-foam (mL)	Avoids the excess foam	0,4
Xanthan gum (g)	Viscosifier	1,5
Starch (g)	Filtrate reducer	0,0 a 12,0
CMC HV (g)	Viscosifier	0,0 a 1,5
MgO (g)	pH controller	1,0
Potassium Citrate (g)	Clay inhibitor	16
Bactericide (g)	Prevents the additives degradation	0,7
Lubricant (mL)	Reduces the friction	10,5
Calcite (g)	Sealant	0,0 a 25,0

3. METHODS

3.1 Development of drilling fluids formulations

To develop the studied drilling fluids' formulations, a factorial experimental design type 2^3 was used, with three experiments at the center point, totaling 11 experiments. Thus, it was possible to evaluate the influence of the input variables (starch, high viscosity carboxymethylcellulose and calcite) on the rheological properties of the fluids (apparent and plastic viscosities and yield limit). A regression of the experimental data was done using the software Statistica, version 5.0 (Statsoft, 2004). The codified levels and the real values of the input variables used in the planning are shown in Tab. 2, and the experimental planning matrix is shown in Tab. 3.

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Table 2. Codified levels and real values of the input variables used in the factorial planning.

Input variables	Codified levels		
	-1	0	+1
Starch (g/350mL)	0,0	6,0	12,0
CMC HV (g/350 mL)	0,0	0,75	1,5
Calcite (g/350 mL)	0,0	12,5	25,0

Tabela 3. Experimental planning matrix.

Fluid	Concentration of Starch	Concentration of CMC HV	Concentration of Calcite
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
9	0	0	0
10	0	0	0
11	0	0	0

3.2 Preparation of drilling fluids

The drilling fluids were prepared using *Hamilton Beach*, model 936, high rotation mechanical agitators. Initially, the anti-foam was added to the water, and after 5 minutes stirring at low speed (13.000 rpm), the other additives were added, one at a time, and each one of them remained another 5 minutes at low agitation, except the starch, the CMC HV and the calcite, which remained stirring for 10 minutes. Finally, the last additive was added and the stirring speed was increased to 15.000 rpm.

After preparation, each fluid remained at rest for 24 hours, and then tests were conducted to determine their rheological parameters. Figure 1 shows photos of the studied drilling fluids.

Figure 1. Fluids 2 and 8 prepared according to the formulation shown in Table 3.

3.3 Rheological study

After a 24-hour rest, the fluid was stirred for 5 minutes under constant agitation at 13.000rpm speed using a *Hamilton Beach* agitator. Then, the rheological study of the fluid was done using *Fann* viscometer, model 35A (Fig. 2), under API rules (2005). The equipment was operated at speed 600rpm and after stabilization, the reading was taken. The same proceeding was done at speed 300rpm.

Apparent viscosity (AV) is the value obtained from the reading at 600 rpm divided by 2, in cP, and plastic viscosity (PV) is the difference of the values obtained from readings at 600rpm and 300rpm, also given in cP. Yield limit (YL) is the difference between the value obtained from the reading at 300rpm and plastic viscosity.

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Figure 2. Viscometer Fann 35A.

4. RESULTS AND DISCUSSION

Table 4 shows the results for apparent viscosity (AV), plastic viscosity (PV) and yield limit (YL) obtained with fluids prepared according to the experimental design contained in Tab. 3.

Table 4. Apparent viscosity (AV), plastic viscosity (PV) and yield limit (YL) of inhibited fluids.

Fluids	AV (cP)	PV (cP)	YL (N/m^2)
1	17.5	8.5	18.0
2	32.6	16.8	31.8
3	50.5	22.0	57.0
4	92.0	43.5	97.0
5	21.0	12.0	18,0
6	42.5	23.0	39.0
7	52.0	21.5	61.0
8	92.5	37.0	111.0
9	44.0	21.0	46.0
10	43.5	21.0	45.0
11	42.5	20.0	45.0

Based on Tab. 4, it was observed that increasing the concentration of CMC HV provided higher values of rheological properties of the fluids, and this increase became larger when the concentrations of CMC HV and starch were increased together. This result is evident when comparing the results obtained for the fluids 4 and 8 (composed by the maximum amounts of CMC HV and starch) as well as 3 and 7 (composed by the maximum amount of CMC HV, but without starch), with the other fluids.

We observed that CMC HV is a viscosifier and its action takes place as expected. The starch, on the other hand, although used as a filtrate reducer, also contributes to the increase of fluids' viscosity, which is displayed when the results for the fluids 1 and 2 are compared, both with the same composition, but with the addition of starch in the second. The same can be seen by comparing fluids 3 and 4 and fluids 7 and 8, whose differences in composition are only the concentration of starch.

In relation to the calcite, an increase in viscosity is expected with the increase of its concentration, given that this additive has low degree of solubility and is present in fluids in the form of a dispersed solid, which increases the resistance to fluid flow. In general, this behavior is observed in studied fluids.

Table 5 presents the analysis of the variance and the codified mathematical models (regression equation) for variables AV, PV and YL of studied fluids. 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 the regression equation in relation to the total variance of the responses, ranging from 0 to 100% (Rodrigues, 2010).

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Table 5 - Analysis of the variance (ANOVA) and codified mathematical models of the apparent viscosity (AV), plastic viscosity (PV) and yield limit (YL) of the inhibited fluids for the applied experimental planning.

Variation source	**AV**	**PV**	**YL**
Correlation coefficient (R)	0.991	0.989	0.99
% of explained variation*	98.2	97.8	98.0
$F_{calculated}/F_{tabulated}$	5.88	4.73	5.42

Codified mathematical models for the inhibited drilling fluids.

AV (cP) = **(48.24** ± 1.56) + (14.83A** ± 1.83) + (21.67B** ± 1.83)** + (1.92C ± 1,83) + **(5.67AB** ± 1.83)** +(0.67AC ± 1.83) – (1.42BC ± 1.83)
PV (cP) = **(22.39** ± 0.71) + (7.03A** ± 0.84) + (7.97B** ± 0.84)** – (0.34C ± 0.84) + (2.22AB ± 0.84) – (0.41AC ± 0.84) – (2.09BC ± 0.84)
YL (N/m^2) = **(51.7** ± 1.96) + (15.59A** ± 2.3) + (27.41B** ± 2.3)** + (3.16C ± 2.3) + **(6.91AB** ± 2.3)** + (2.16AC ± 2.3) + (1.34BC ± 2.3)

Being: A = starch, B = CMC HV and C = calcite.

$*R^2 = \left(\frac{SQ_R}{SQ_T}\right) x\ 100$, being: SQ_R the quadratic sum from the regression, SQ_T the total quadratic sum.

** Statistically significant at the level of 95.0% of reliability.

For the inhibited fluids prepared according to the experimental planning, the analysis of the statistical significance showed that the correlation coefficients (R) and the explained variation coefficients of the experimental results for AV, PV and YL were extremely satisfactory, with values around 0,99 e 98%, respectively, for all variables. It indicates that the mathematical models presented have more than 98% of the variations obtained explained by the model.

According to the mathematical models obtained, the starch, the CMC HV and their interaction, statistically influence the properties AV and YL of the fluids studied. Only the starch and the CMC HV statistically influence the variable PV.

Test F presents the ratio between $F_{calculated}$ and $F_{tabulated}$; when this relation is bigger than 1, the regression is statistically significant. In other words, there is a relation between independent and dependent variables. When this value is bigger than 5, the regression is statistically significant and predictive (Rodrigues, 2010). For the evaluated parameters, variables AV, PV and YL presented Test F values bigger than 1 that indicates that the model is statistically significant, at a 95% confidence level. For the properties AV and YL, statistically significant and predictive models were obtained.

Figures 3, 4 and 5 present the response surfaces obtained from the mathematical models presented on Tab. 5 to AV, PV and YL.

We observe in Fig. 3a that higher values of AV are obtained when the fluids are prepared using higher concentrations of starch and CMC HV. This behavior was observed when setting the calcite concentration in 12.5g/350mL of water. Fig. 3b shows that higher values of AV are obtained using higher concentrations of CMC HV, and calcite does not statistically influence this variable. It proves that the results obtained using the mathematical model. This behavior was observed by setting the starch concentration in 12.0g/350mL of water.

Analyzing the surface responses presented in Figs. 4 and 5 to the variables PV and YL, respectively, we observed that the same behavior presented by VA: higher values of PV and YL are obtained when the fluids are prepared using higher concentrations of CMC HV and starch, while the calcite does not influence these variables statistically.

Through their analysis, it is observed that the highest values for the rheological properties (AV, PV and YL) occur in greater concentrations of starch and CMC HV, and the calcite, in turn, doesn't have important influence on these properties. This information was obtained by setting the concentration of calcite in 12,5g/350mL of water and, then, the concentration of starch in 12g/350mL of water.

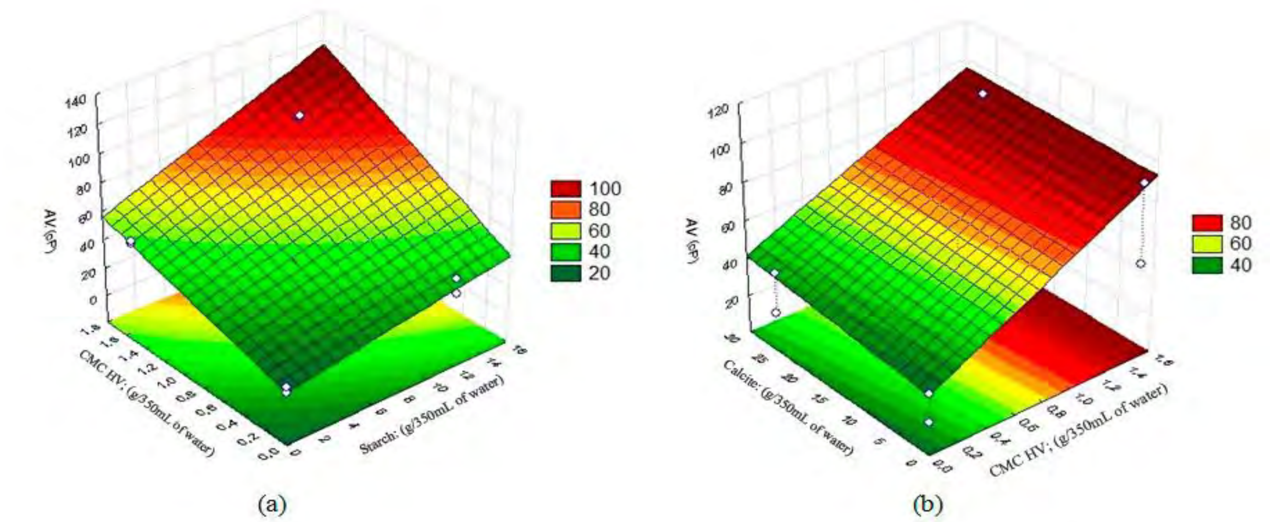

Figure 3. Response surfaces for AV, setting: (a) concentration of calcite at 12.5g/350mL of water and (b) concentration of starch at 12g/350mL of water.

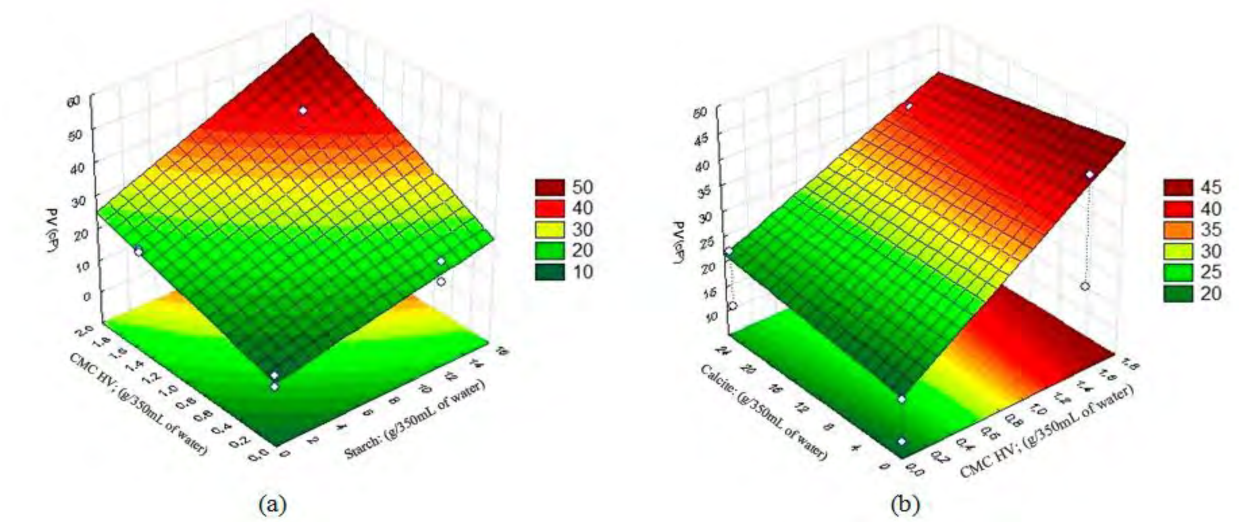

Figure 4. Response surfaces for PV, setting: (a) concentration of calcite at 12.5g/350mL of water and (b) concentration of starch at 12g/350mL of water.

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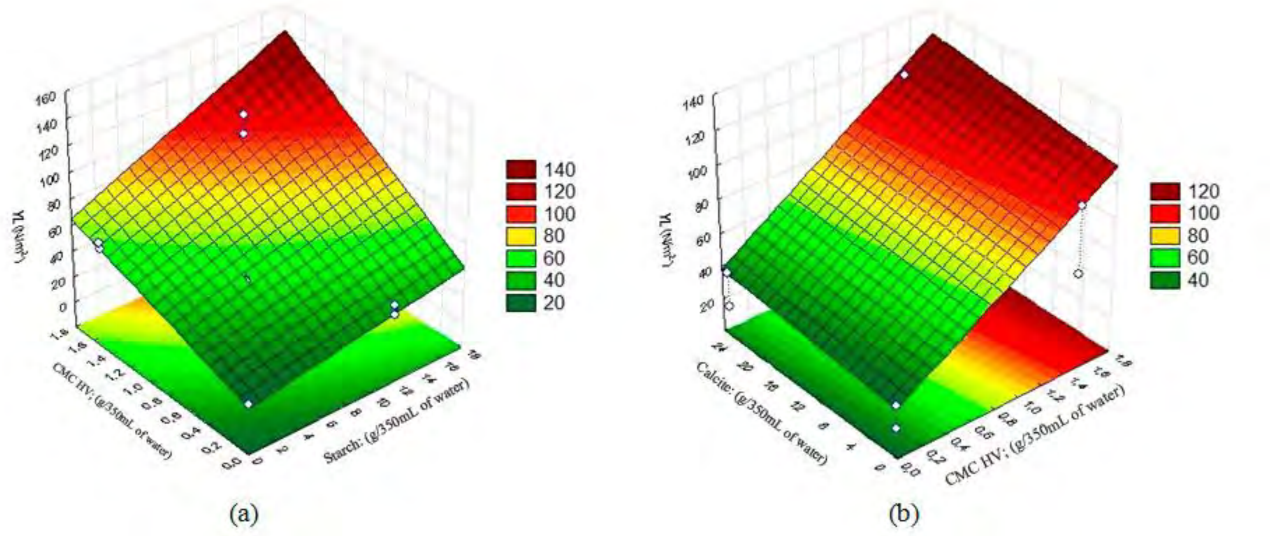

Figure 5. Response surfaces for YL, setting: (a) concentration of calcite at 12.5g/350mL of water and (b) concentration of starch at 12g/350mL of water.

5. CONCLUSIONS

Analyzing the results obtained in the study of the influence of additives starch, high viscosity carboxymethylcellulose and calcite in rheological parameters of inhibited drilling fluids, it was concluded that:

- Concentrations of starch and CMC HV statistically influence the properties apparent and plastic viscosities and yield limit of drilling fluids, either alone or together, at a 95% confidence level, being obtained the highest values for these properties when the fluids have in their composition 12g of starch/350mL of water and 1.5g of CMC HV/350mL of water;
- The mathematical model obtained is statistically significant, at a 95% confidence level, for the three studied properties, and it is statistically significant and predictive for the properties apparent viscosity and yield limit.

Thus, we observed that the association of higher concentrations of starch and CMC HV in inhibited drilling fluids with potassium citrate is more effective, in rheological terms, for the correct performance of their functions, as well as to the success of the drilling operation.

6. AKNOWLEDGEMENTS

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