

## ENCIT-2018 RHEOLOGICAL MODIFIERS IN DRILLING FLUIDS

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**Abstract.** *The loss circulation, that is, the uncontrolled flow of whole mud into a formation, sometimes referred to as a “thief zone”, can happen when the drilling of an oil well is made in a formation which contains fractures (natural or provoked) with high permeability (unconsolidated formation, presence of faults and fractures). The loss of circulation can cause well instability, since the decrease of the level of fluid in the annulus can cause the reduction of the hydrostatic pressure, and consequently the collapse of layers of the formation or the undesired influx of fluids from the formation into the well. The main goal of the present work is the study of additives that can modify rheologically the aqueous drilling fluid, in order to increase its elasticity. A fluid with high elasticity can deform reversibly, i.e. a drilling fluid having high elasticity can deform when it reaches a region of the formation with high permeability, but without invading it. The experiments were conducted with two polymers and one mineral commonly used in the oil industry. The tests performed involved oscillatory and extensional rheology.*

**Keywords:** *loss circulation, drilling fluid, extensional rheology*

### 1. INTRODUCTION

The loss circulation is defined as the loss of drilling fluid for the formation. This event is known as one of the most challenging problems to be prevented or mitigated during the drilling of an oil well (Messenger, 1981). There are two distinct categories of loss circulation, depending on the type of fracture hit by the fluid: natural or artificial. The natural loss circulation occurs when the drilling operation reaches formation regions with vugs, faults and natural fractures. Artificial loss circulation occurs when the pressure applied to the well exceeds the maximum pressure the rock can hold. In this case, hydraulic fractures can be created (Wang, Sweatman, Engelman, Deeg, Whitfill, Soliman and Towler, 2008).

Loss circulation commonly occurs during drilling in carbonates, since they have natural vugs and cavities (Davidson, Richardson and Zoller, 2000; Masi, Molaschi, Zausa and Michelez, 2011; Wang, Jiang, Zheng, Wu, Zheng, Tang and Fan, 2010). Scenarios in which the operational window is narrow are typical of: depletion zones, formations under deep waters, naturally fractured formations and wells containing deviations (Feng, Jones, Gray, 2016). In depletion zones, the reduction of pore pressure may lead to a decrease in the well fracture pressure and, consequently, to a situation where the upper pressure limit is low. In formations under deep water, the pressure of the water column can cause a low fracture pressure and consequently a narrow operating fluid pressure window, which makes maintaining the required pressure in the well a challenge. Unwanted pressure fluctuations due to surge and swab can also make operation difficult. In wells containing deviations, the operating window may decrease due to inclinations in the well, reaching values that make conventional drilling impracticable. Pre-existing fractures in the formation can affect the maximum pressure capacity of the well. A small fracture can reduce the tensile strength of the rock and this fracture can propagate if the well pressure exceeds the neighborhood tension. If a large fracture is present, the maximum pressure a well can withstand can be reduced to the in situ pressure (Feng and Gray, 2012).

In a situation of loss circulation, the level of drilling fluid in the annulus can decrease and cause a reduction of the pressure at the bottom of the well and, consequently, the inflow of fluids from the formation to the well (kick) and loss of control of the operation. This may cause other unforeseen effects, such as the unwanted influx of fluids (blowout) and well collapse (Olberg, Gilhuus, Leraand and Haga, 1991). In some cases, well collapse may cause loss of drilling tools and imprisonment of columns (Lavrov, 2016). The severity of the loss can be measured by the amount of fluid lost to the formation (measured in barrels) per hour. Neyberg (Nayberg, 1987) classifies the intensity of the loss circulation

as: infiltration, 1-10 bbls/h; partial loss, 10-500 bbls/h; and severe loss, > 500 bbls/h. Identification of the severity of the loss is necessary for appropriate corrective decisions to be taken to mitigate or stop it.

Since the last century, the loss circulation has presented itself as a major challenge for the oil industry, causing significant expenses related to the loss of drilling fluid and the unnecessary use of infrastructure, materials, knowledge and manpower (Cook, Growcock, Guo, Hodder, Van Oort, 2011). In the worst scenarios, may be necessary to make a sidewall deviation, the loss of the well or even the loss of the reservoir (Carpenter, 2014). Therefore, the decision whether or not to explore a new region takes into account the possibility of loss circulation (Wang, Sweatman, Engelman, Deeg, Whitfill, Soliman and Towler, 2008).

The first method used to prevent loss circulation was the addition of granular materials (Chapman, 1890). Since then, many additives have been used to mitigate the loss circulation. These materials are added continuously to the drilling fluid or periodically to seal fractures previously existing or produced during drilling (Nayberg, 1987). The most commonly used additives to combat loss circulation are particulate materials: graphite, walnut shells, calcium carbonate (calcite), gilsonite, bentonite, asphalt and perlite. They are capable of forming a seal on the face or within the fractures, since they have wide size distribution, high stiffness and resistance to crushing. In addition, these materials are acid soluble and can therefore be removed after the drilling operation (Howard and Scott, 1951; Alsaba and Nygaard, 2014). Laminar materials are also commonly used. They may have high stiffness and are capable of forming a seal on the face of the fractures. Some examples of these materials are: cellulose films, mica, cottonseed peels, vermiculite, crushed corn cobs and flaked calcium carbonate (Alsaba and Nygaard, 2014). Natural fibers can form a mesh capable of covering surfaces with fractures and vugs and reduce the loss circulation. Many natural fibers are also soluble in acids (Howard and Scott, 1951; Alsaba and Nygaard, 2014).

The present work aims to propose the use of rheological modifiers capable of increasing the elasticity of the aqueous drilling fluid to reduce loss circulation. A fluid with high elasticity can deform reversibly, i.e. a drilling fluid having high elasticity may deform when it reaches a region of the formation with high permeability, but may not invade it. The experiments were made with the polyacrylamide and sodium carboxymethylcellulose polymers and with the magnesium, lithium and sodium mineral silicate. The tests performed involved extensional rheology.

## 2. EXPERIMENTAL PART

### 2.1. MATERIALS

The materials used in the experiments were: aqueous drilling fluid (sodium chloride 28.55 g.L<sup>-1</sup>, magnesium oxide 4.28 g.L<sup>-1</sup>, magnesium peroxide 2.85 g.L<sup>-1</sup>, calcium carbonate 75.75 g.L<sup>-1</sup>, starch 22.85 g.L<sup>-1</sup>, xanthan gum 5.71 g.L<sup>-1</sup>, antifoam 1.19 mL.L<sup>-1</sup>, polyethylene glycol oleate 20 g.L<sup>-1</sup>, bactericidal 1.45 mL.L<sup>-1</sup>), ADF; magnesium, lithium and sodium silicate (laponite); sodium carboxymethylcellulose (CMC) and polyacrylamide (PAM).

### 2.2. METHODS

The oscillatory tests were performed at 25 and 60 °C on an Anton Paar Physica MCR301 rheometer with PP50 parallel plates type sensor with a diameter of 49.962 mm. Oscillatory tests are performed with the sample between the two plates separated from each other by 1.00 mm (Figure 1). The lower plate is fixed and the upper one performs oscillatory movements (with a frequency variation of 0.05 to 10.00 Hz) applying a voltage of 1.00 Pa in the sample. The loss modulus (or viscous module) and storage (or elastic modulus) are measured in the sample in response to the applied voltage. Cooling of the thermoelectric pellet (peltier) which keeps the temperature of the sample constant is done through a Lauda E100 thermal bath. Extension tests were performed at 25 and 60 °C on a Thermo Haake CaBER 1 rheometer with a sensor of parallel plate type measurements with a diameter of 4.00 mm. Extensional tests are performed with the sample between the two plates separated from each other by 1.99 mm (Figure 2). The plates are quickly spaced to 19.34 mm. A laser located perpendicular to the axis of the plates measures the diameter of the filament of fluid formed from the moment of the spacing of the plates until the rupture of the sample. The temperature control of the sample is done through a Thermo Haake DC 10 thermal bath.

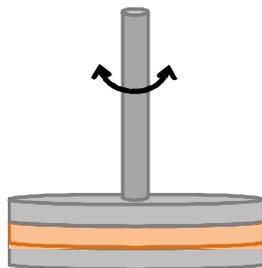


Figure 1. Parallel plates oscillatory rheometer sensor. The sample is positioned between the two plates. The lower plate is fixed and the upper plate oscillates.

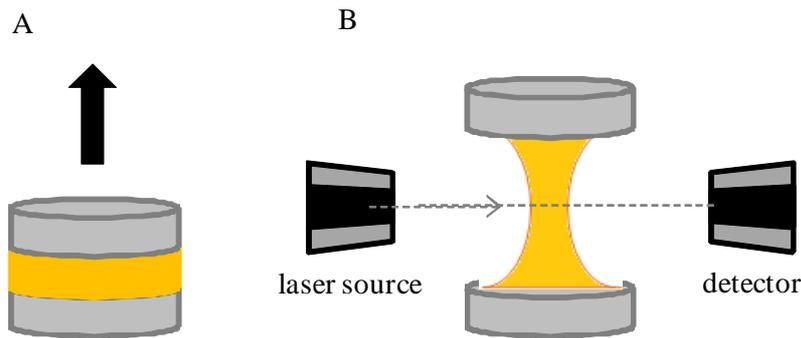
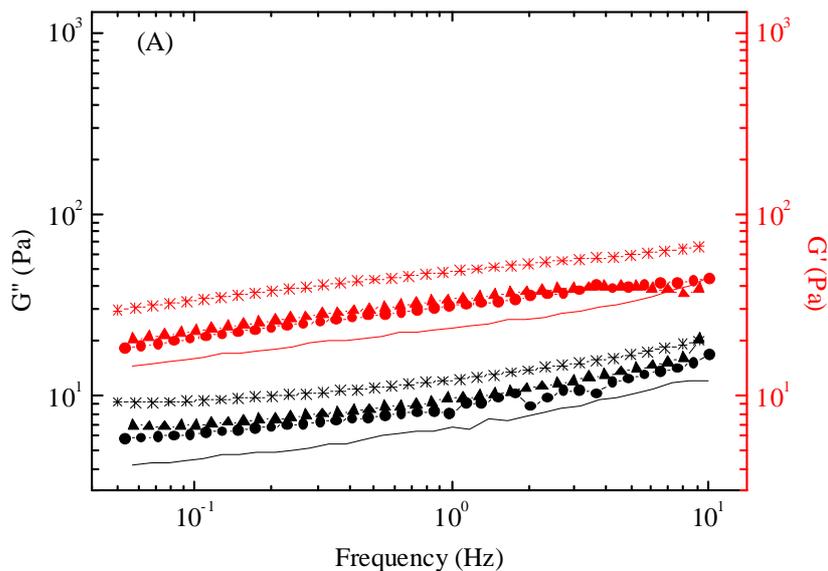


Figure 2. Parallel plate extensional rheometer sensor. (A) The sample is positioned between the two plates. (B) The plates are quickly spaced and a laser measures the diameter of the fluid filament.

### 3. RESULTS AND DISCUSSION

The oscillatory tests were done with the aqueous drilling fluid, in which the rheological modifiers laponite, CMC and PAM were dissolved in concentrations of 1, 3 and 5%. Figure 3 shows the results of the experiments performed at 25 °C. By analyzing the graph shown in Figure 3 (A) it can be seen that the solutions presented values of elastic modulus larger than the values of viscous modulus. In addition, the modules presented higher values, the higher the concentration of laponite. However, even with 5% laponite the elasticity of ADF is still low and probably inefficient to reduce circulation loss. ADF with CMC (Figure 3 (B)) also showed higher elastic and viscous modulus values the higher the CMC concentration. And higher than the values of the modules found for ADF with laponite. However, at the 1% CMC concentration, the viscous modulus values were higher than the elastic modulus values. At the CMC concentration of 3%, the values of both modules are close and only at the 5% concentration did the elastic modulus values exceed the viscous modulus values. Increasing the elasticity of the drilling fluid can reduce the loss of circulation. However, increasing the viscosity may be an obstacle for pumping the fluid. The ADF with PAM (Figure 3 (C)) showed the highest values of elastic modulus of the three additives. The viscous modulus values were also higher, however, lower than the elastic modulus values.



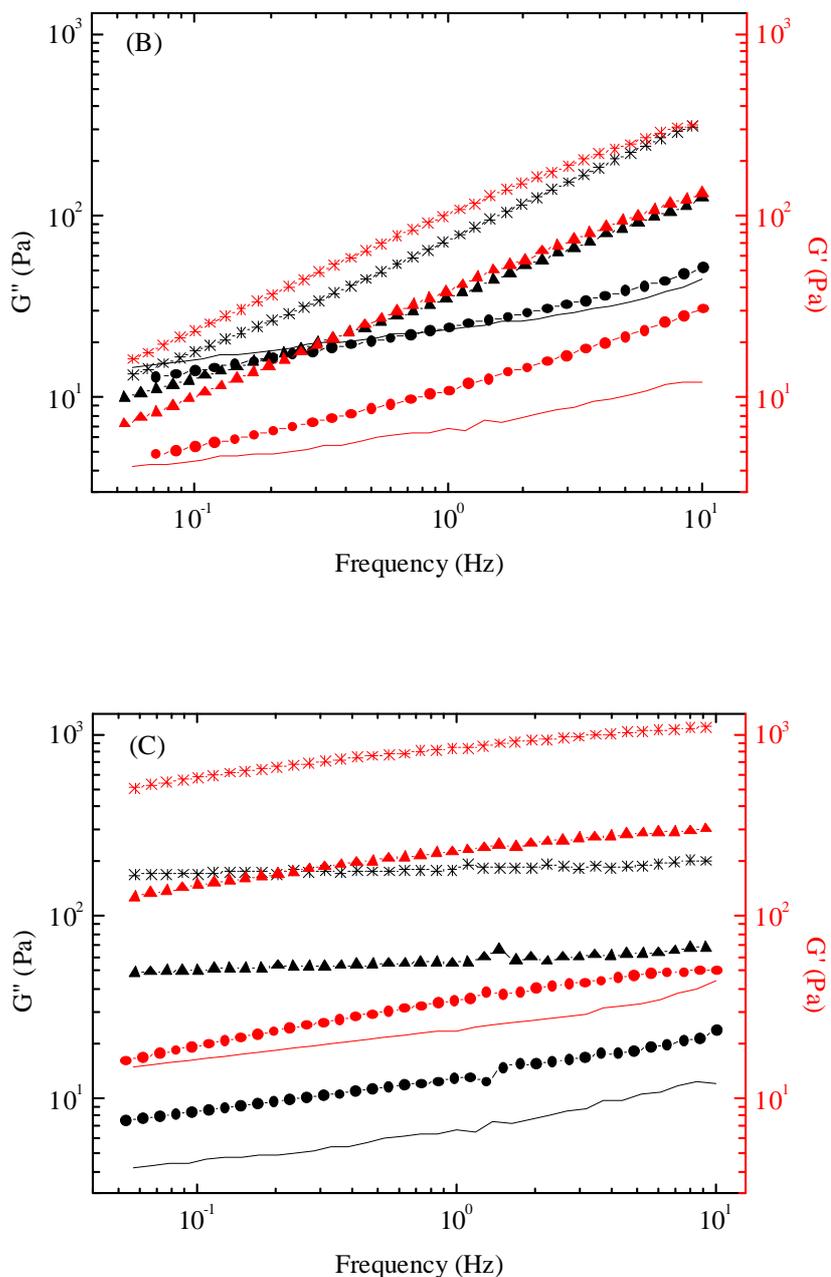
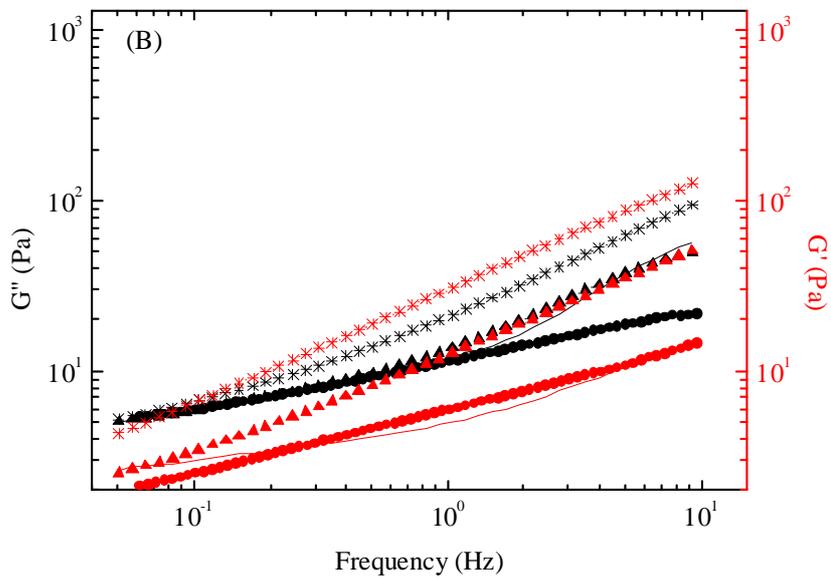
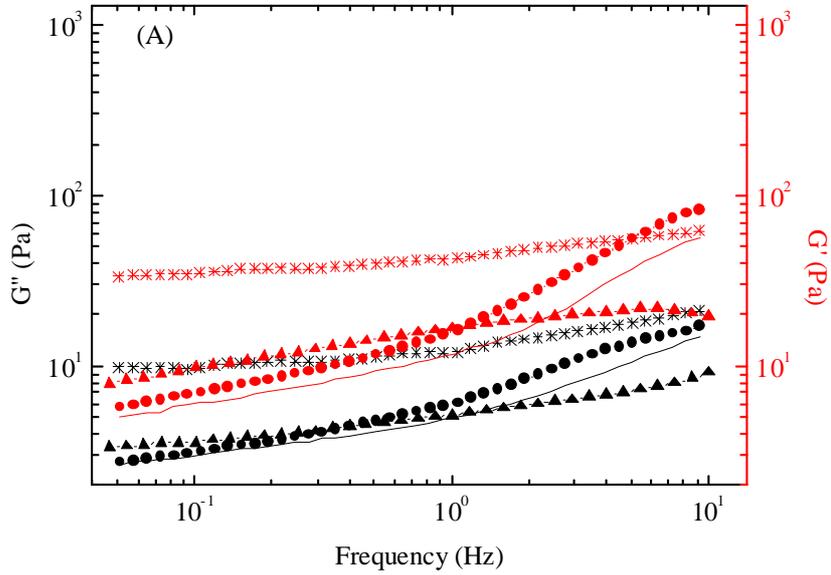


Figure 3. Oscillatory tests of viscous modulus,  $G''$  (in black), and elastic modulus,  $G'$  (in red), as a function of frequency, measured with ADF (continuous lines), ADF with 1 (circles), 3 (triangles) and 5 % (stars) of the rheological modifiers additives (A) laponite, (B) CMC and (C) PAM. The temperature of the system during the tests was maintained at 25 °C.

As in the experiments performed at 25 °C, in the tests performed at 60 °C (Figure 4 (A)), ADF with laponite presented values of elastic modulus larger than the values of viscous modulus. In frequency values up to 1 Hz, the modulus presented higher values, the higher the concentration of laponite. At higher frequency values 1 Hz, ADF and ADF with 1% of laponite presented an abrupt increase, in both modules, with increasing frequency. The results of the ADF with CMC at 60 °C (Figure 4 (B)) also showed similar behavior to the results obtained at 25 °C. Values of the higher elastic and viscous modules were also observed as the concentration of CMC increased. And higher than the values of the modulus measured for ADF with laponite. The ADF with 1% CMC showed viscous modulus values greater than the elastic modulus values. At frequencies lower than 0.6 Hz, the ADF solution with 3% CMC showed viscous modulus values greater than the elastic modulus values. At higher frequencies, both modules are close. Only at the concentration of 5% the elastic modulus values exceeded the viscous modulus values. The ADF solutions with PAM

at 60 °C (Figure 4 (C)) also showed the highest values of elastic modulus of the three additives. The viscous modulus values were also higher, however, lower than the elastic modulus values.



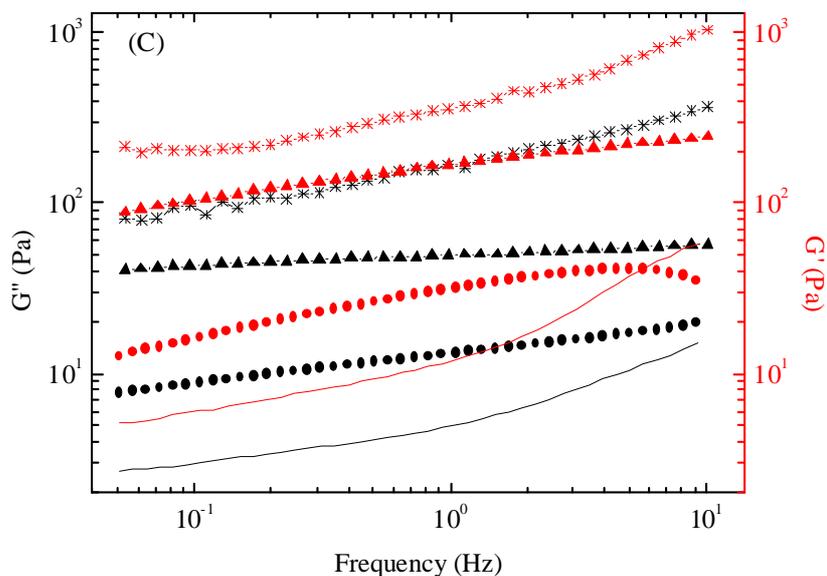
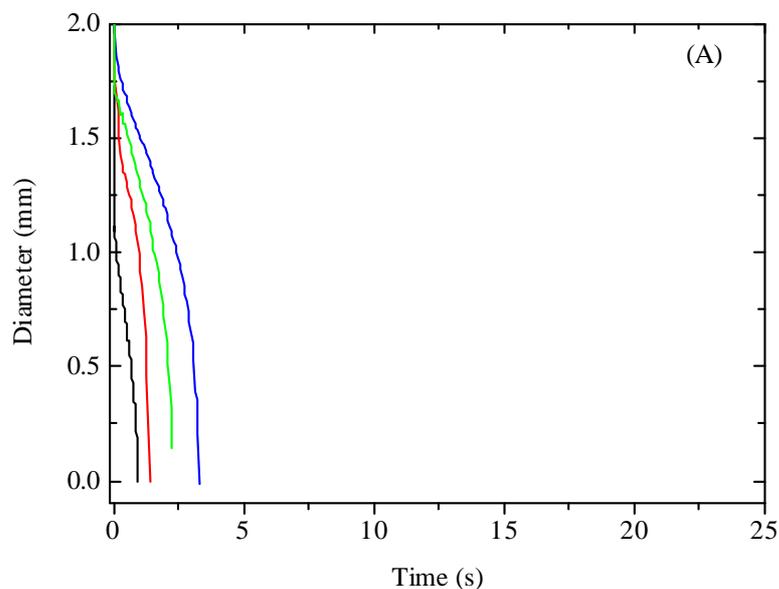


Figure 4. Oscillatory tests of viscous modulus,  $G''$  (in black), and elastic modulus,  $G'$  (in red), as a function of frequency, measured with ADF (continuous lines), ADF with 1 (circles), 3 (triangles) and 5 % (stars) of the rheological modifiers additives (A) laponite, (B) CMC and (C) PAM. The temperature of the system during the tests was maintained at 60 °C.

Figure 5 shows the results of the extensional rheology experiments done with ADF and ADF with laponite, CMC and PAM, at 25 °C. The time evolution of the measured filament diameter is directly related to the elasticity level of the material. The longer the filament rupture, the greater the extensional viscosity and the more elastic the material. By comparing the results of the experiments, it can be seen that the filament diameter measured for ADF with laponite decreases and breaks in a shorter time than the filament formed by ADF with CMC and ADF with PAM. In tests with the three additives it is observed that increasing the concentration of additives causes the breakage time of the filament to increase. The ADF with PAM showed the longest time until the filament rupture, which may be related to the high elasticity of the ADF solutions with PAM observed in the oscillatory tests.



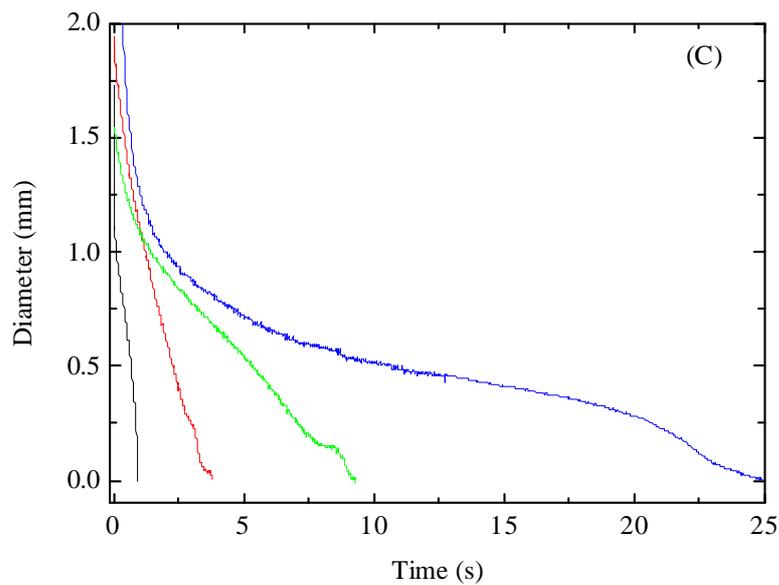
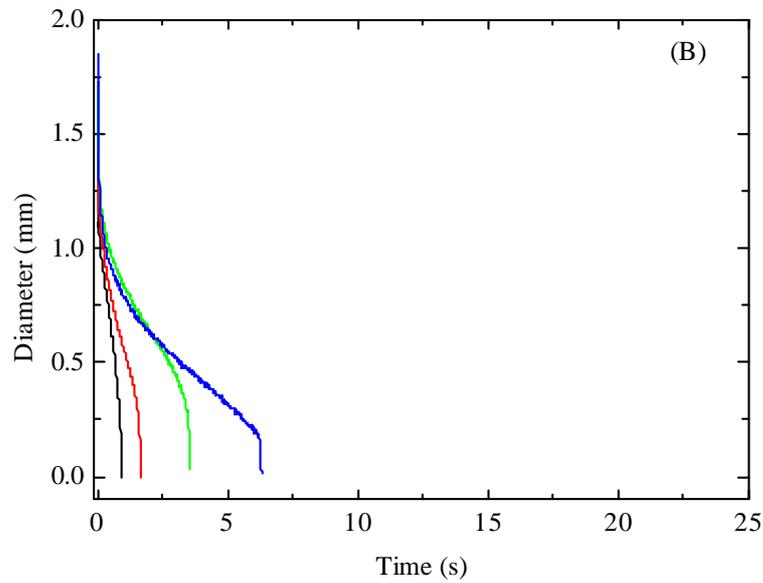
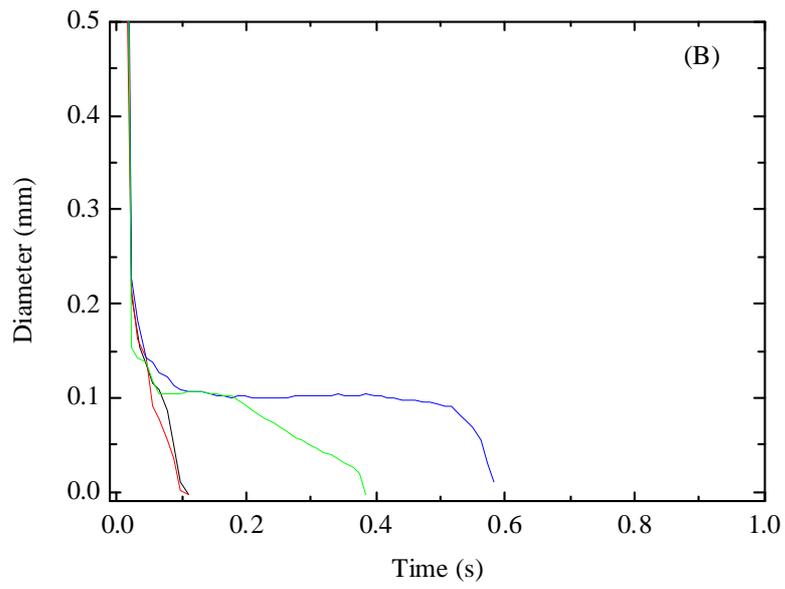
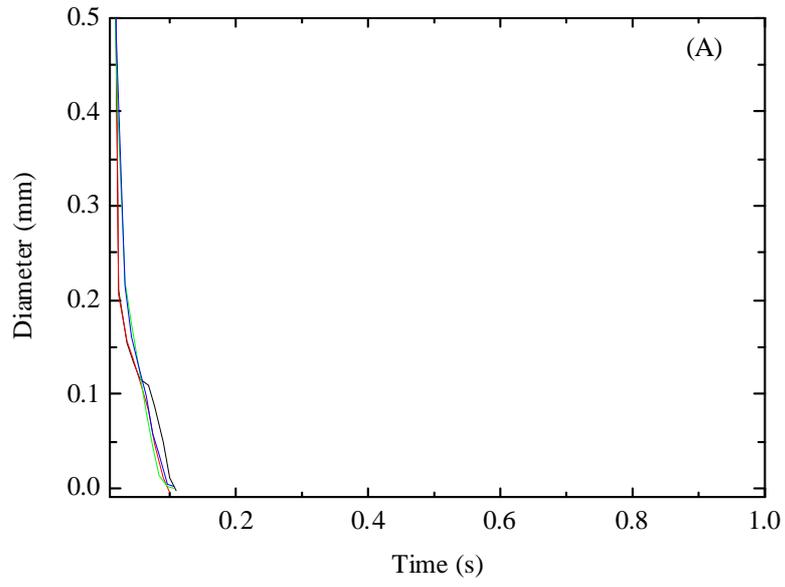


Figure 5. Diameter of the fluid filament formed after the spacing of the plates in an extensional rheology experiment. The measurements were done with ADF (black line), ADF with 1 (red line), 3 (green line) and 5% (blue line) of the rheological modifier additives (A) laponite, (B) CMC and (C) PAM. The temperature of the system during the tests was maintained at 25 °C.

Figure 6 shows the results of the extensional rheology experiments done with ADF and ADF with laponite, CMC and PAM, at 60 °C. The same behavior difference between the additives observed in the experiments at 25 °C can also be observed in the experiments at 60 °C. However, the time at which the sample filament breaks at 60 °C is shorter.



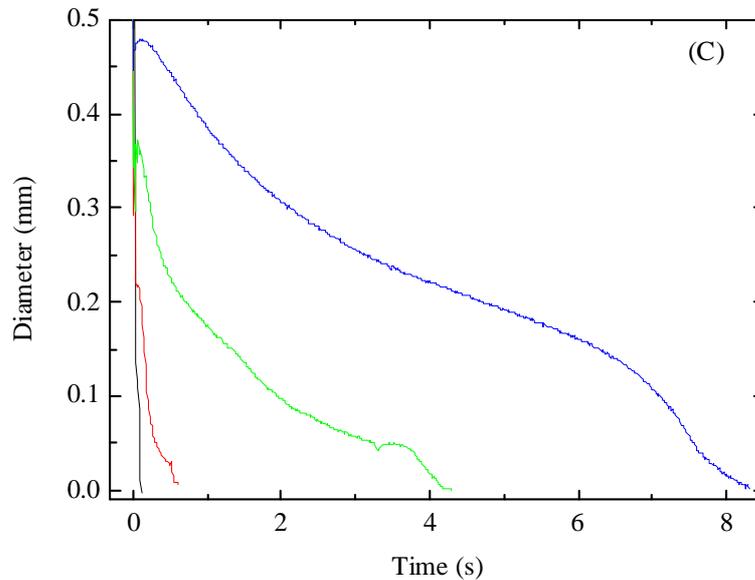


Figure 6. Diameter of the fluid filament formed after the spacing of the plates in an extensional rheology experiment. The measurements were done with ADF (black line), ADF with 1 (red line), 3 (green line) and 5% (blue line) of the rheological modifier additives (A) laponite, (B) CMC and (C) PAM. The temperature of the system during the tests was maintained at 60 °C.

#### 4. CONCLUSIONS

The results of the rheological experiments showed that laponite, CMC and PAM can increase the elasticity of the drilling fluid. The oscillatory experiments with ADF with laponite, however, showed that the increase in elasticity was low, compared to the results shown in the tests with the polymers. The viscosity increase, however, was also low.

The oscillatory experiments with ADF with CMC showed a higher elasticity increase, however, the viscosity increase was also high. PAM caused the highest increase in ADF elasticity. Further, the viscosity increase was proportionally less than the increase in viscosity caused by the CMC.

The results of the extension rheology tests showed a high elasticity of ADF with PAM. The time required for the rupturing of the sample filament formed with the detachment of the plates, at 25 °C, is approximately five times as high as the time required for the filament rupture of the ADF sample with laponite and CMC. At 60 °C, the time required for the disruption of the ADF with PAM filament is approximately ten times higher than the time required for filament rupture of the ADF with laponite and CMC.

The polyacrylamide dissolved in the aqueous drilling fluid may therefore be an alternative for reducing the loss of circulation.

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