THIXOTROPIC BEHAVIOR OF DRILLING MUDS

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Abstract. *In oil industry, materials known as drilling fluids or muds usually present a complex non-Newtonian behavior that must be precisely designed so as to ensure the safety and success of drilling processes. The accurate knowledge of rheological properties of drilling muds is fundamental for drilling a well. Therefore, in this paper we discuss in detail the rheometry of drilling muds and the main sources of error in rheological measurements, such as apparent wall slip, sedimentation of solids and evaporation of solvents. Moreover, we perform flow curves, thixotropic tests and oscillatory-stress-amplitude sweeps with two drilling muds, pointing out their thixotropic behavior. A thixotropy model recently proposed by de Souza Mendes (2009) is used to describe the rheological behavior of these materials.*

Keywords: *thixotropy, drilling muds, rheometry*

1. INTRODUCTION

Drilling a well requires the use of a drilling mud carefully designed in order to fulfill a number of functions, such as: maintain the well integrity; avoid damaging the formation; prevent inflow of fluids from the wellbore; cool, clean and lubricate the drill bit and carry rock cuttings from the well (Caenn and Chillingar, 1996; Hamed and Belhadri, 2009). Therefore, the accurate knowledge of rheological properties of drilling muds is fundamental so as to guarantee the safety and success of drilling processes.

This kind of material can be an oil, water or, in small percentage, air based solution or dispersion (Caenn and Chillingar, 1996) that can form a microstructure leading to a complex non-Newtonian behavior which is shear-rate-, time-, and temperature-dependent. With respect to shear rate, drilling muds are shear-thinning materials, while the time dependence indicates a thixotropic behavior, which implies reversibility of the microstructure changes (Mewis and Wagner, 2009).

Besides the lack of understanding thixotropy and the different definitions and methods for measuring yield stress, the rheometry of drilling muds involves problems found in the rheological characterization of complex materials. The most important ones are apparent wall slip, sedimentation of dispersed solids and evaporation of solvents (Nguyen and Boger, 1992; Barnes, 1995). Thus, in this paper we discuss in detail the rheometry of drilling muds. Moreover, we perform the rheological characterization of two drilling muds, highlighting the thixotropic behavior of these materials.

2. THE THIXOTROPY MODEL

Recently a thixotropy model was proposed in order to describe the rheological behavior of structure fluids (de Souza Mendes, 2009). Basically, it consists in a stress equation (eq. (1)), an evolution equation of λ (structure parameter) (eq. (4)) and a steady-state viscosity function (eq. (6)), as described below. This model is able to predict the main trends reported for thixotropic materials and is expected that it can also be used for describing the behavior of drilling muds in order to improve the design of drilling processes.

$$\tau + \theta_1 \dot{\tau} = \eta_v \left(\dot{\gamma} + \theta_2 \ddot{\gamma} \right) \tag{1}$$

$$\theta_1(\lambda) = \left(1 - \frac{\eta_\infty}{\eta_v(\lambda)}\right) \frac{\eta_v(\lambda)}{G(\lambda)} , \qquad \theta_2(\lambda) = \left(1 - \frac{\eta_\infty}{\eta_v(\lambda)}\right) \frac{\eta_\infty}{G(\lambda)} \tag{2}$$

$$G = \frac{G_o}{\lambda^m} , \qquad \eta_v(\lambda) = \left(\frac{\eta_o}{\eta_\infty}\right)^\lambda \eta_\infty \tag{3}$$

$$\frac{d\lambda}{dt} = \frac{1}{t_{eq}} \left[(1-\lambda)^a - (1-\lambda_{ss})^a \left(\frac{\lambda}{\lambda_{ss}}\right)^b \left(\frac{\tau}{\eta_v(\lambda)\dot{\gamma}}\right)^c \right] \tag{4}$$

$$\lambda_{ss}(\dot{\gamma}) = \left(\frac{\ln \eta_{ss}(\dot{\gamma}) - \ln \eta_\infty}{\ln \eta_o - \ln \eta_\infty} \right) \tag{5}$$

$$\eta_{ss}(\dot{\gamma}) = \left[1 - \exp\left(-\frac{\eta_o \dot{\gamma}}{\tau_o} \right) \right] \left\{ \frac{\tau_o - \tau_{od}}{\dot{\gamma}} e^{-\dot{\gamma}/\dot{\gamma}_{od}} + \frac{\tau_{od}}{\dot{\gamma}} + K\dot{\gamma}^{n-1} \right\} + \eta_\infty \tag{6}$$

3. THE EXPERIMENTS

Two oil-based drilling muds with different solids concentration were rheologically characterized with the aid of an ARES and AR-G2 rheometers from TA Instruments. To circumvent apparent-wall-slip problems different profiled geometries were tested and compared with smooth geometries. Sedimentation was avoided by choosing drilling muds with small solid particles. In addition, a solvent trap was used, so that evaporation was not a problem.

4. RESULTS AND DISCUSSION

Figure 1 shows the flow curves obtained with different geometries, namely smooth-parallel plates, cross-hatched plates, and smooth and grooved Couette. From these curves it is possible to note an apparent slip region as indicated, in which each geometry leads to a different result (the lower the stress is, the higher is the apparent wall slip in this region). It can also be observed that the cross-hatched-plates geometry was the best one for this material to avoid apparent wall slip in the range of low shear rates where no flow occurs between the protrusions. However, increasing the shear rate above a certain value promotes the flow between protrusions in cross-hatched plates and the stress becomes lower than it should be, as it can be seen in Fig. 1. Therefore, the correct flow curve is obtained by combining a cross-hatched flow curve in the low shear rate range with a curve obtained with a smooth parallel plates in the high shear rate range. This procedure was used for both muds tested.

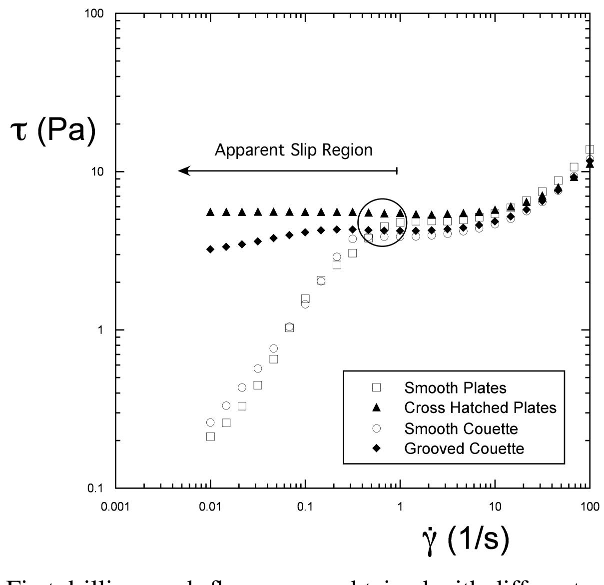
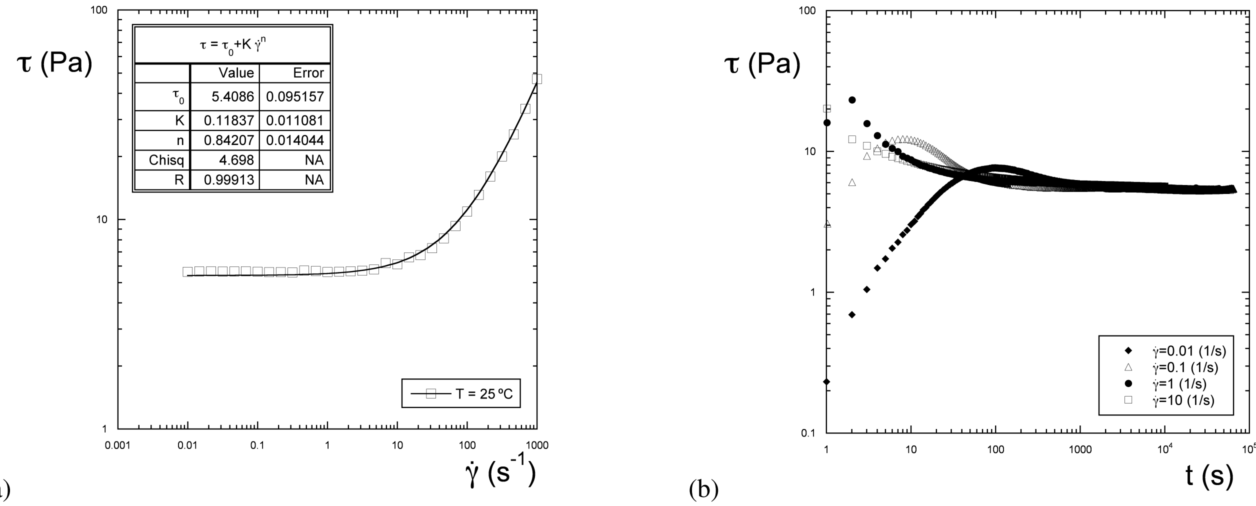


Figure 1. First drilling mud: flow curves obtained with different geometries.

In Fig. 2(a) is presented the flow curve of the first drilling mud obtained with both the cross-hatched and smooth plates (depending on the shear rate range), and Fig. 2(b) shows the thixotropic curves obtained for the same mud with different shear rates. In this figure it can be seen that for low enough shear rates an overshoot is observed, that decreases with a decrease in the shear rate. It can also be observed that for long enough times the stress achieves a steady state, which allows us to mark a point in the flow curve (once each point in the flow curve can only be marked if the steady state is achieved).

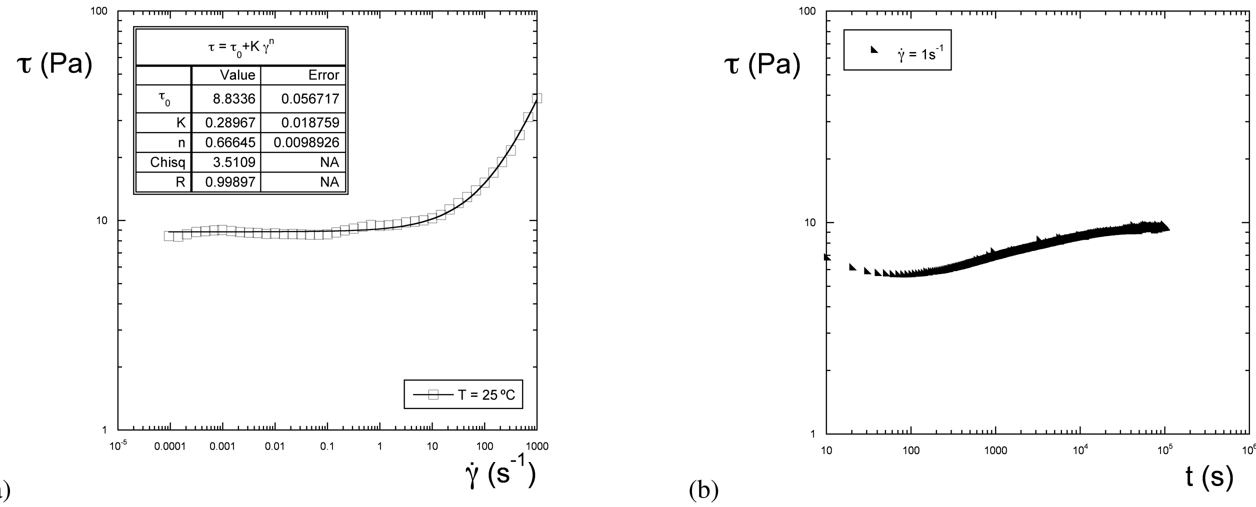
Figures 3(a) and 3(b) show respectivelly the flow curve and a thixotropic test obtained for the second drilling mud. The second drilling mud possess a higher yield stress than the first one as expected, once it has more solid particles. From Fig. 3(b) it can be seen an undershoot before achieving the steady state, indicating that a different transient behavior can occur.

Probably if the time axis had started at one second, an overshoot before this undershoot could be observed. Therefore, more investigation is required.



(a) (b)

Figure 2. First drilling mud: (a) flow curve and (b) thixotropic tests.



(a) (b)

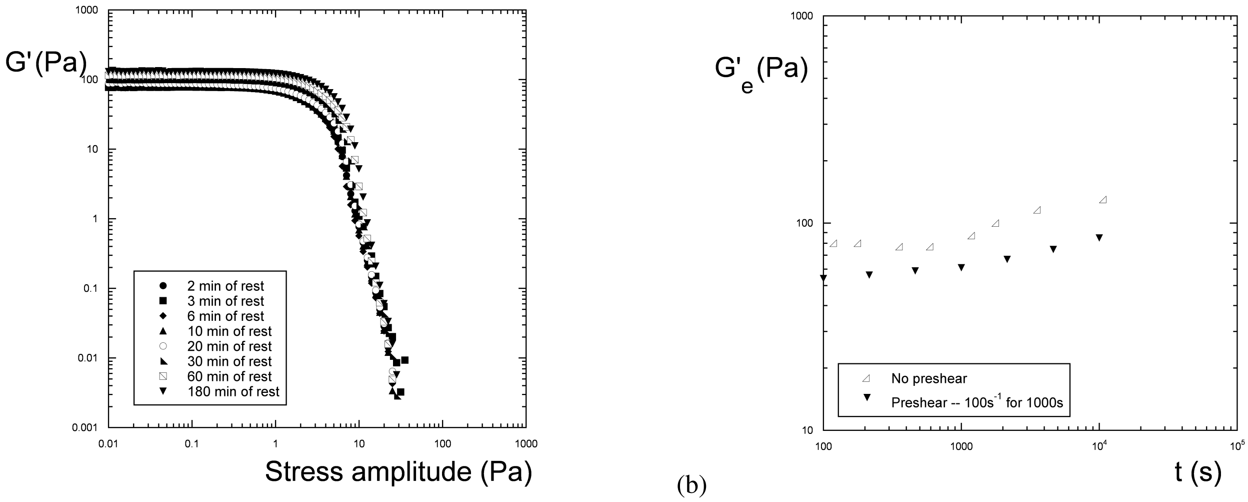
Figure 3. Second drilling mud: (a) flow curve and (b) thixotropic test.

Figure 4(a) illustrates the stress-amplitude-sweep tests performed with the second drilling mud. From this figure it can be seen that increasing the resting time before starting the test causes a slight increase in the linear viscoelastic storage modulus and in the static yield stress (defined as the stress amplitude where G' is equal to G''). This former trend can also be seen in Fig. 4(b), where the same tests are plotted, but also including results for presheared samples, showing that the drilling mud can recover the structure with resting time.

In Fig. 5 both the storage (G') and loss modulus (G'') of the second drilling mud are plotted. These curves were obtained after enough resting time before starting the test in order to fully recover the structure. It is interesting to note that unlike other time-dependent materials, there is not any hump in the loss modulus before the sudden decrease.

5. FINAL REMARKS

A complex rheological behavior including thixotropy and yield stress was shown for two different oil-based drilling muds. To perform a reliable rheological characterization for this kind of material it is necessary to deal with apparent wall slip, sedimentation of particles and evaporation of solvents. This is an ongoing research and a thixotropy model will be used to describe the behavior of these materials. More detailed information will be presented at the conference.



(a) (b)

Figure 4. Second drilling mud: (a) effect of resting time in elastic modulus and (b) linear viscoelastic modulus as a function of resting time.

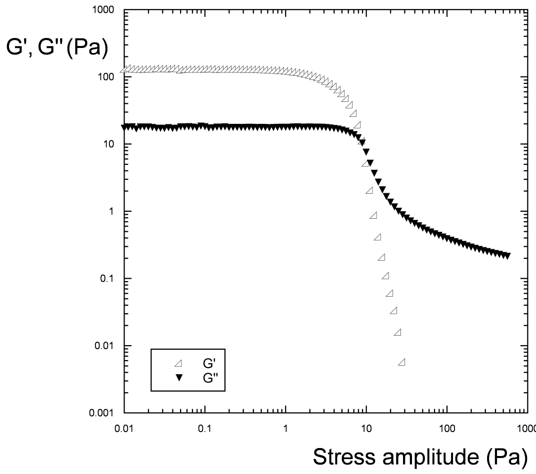


Figure 5. Storage and loss moduli as a function of stress amplitude – 180min of resting time before the test.

6. ACKNOWLEDGEMENTS

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