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# Modelling the effect of mudstone cuttings on rheological properties of KCl/Polymer water-based drilling fluid



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#### ABSTRACT

Drill cuttings unavoidably enter the annulus and affect the rheology of the drilling fluid in the process of drilling. The rheological properties of drilling fluids containing varying particle size and cuttings amounts were measured by using a rotational viscometer equipped with a widened gap. An algorithm based on Tikhonov regularization was proposed to transform the viscometry data into flow curves. Validity and availability of the presented algorithm were investigated by applying the algorithm to the base drilling fluid (without cuttings). Results showed that the flow curves of the cuttings-laden KCl/Polymer drilling fluids used in this study can be well depicted by the Herschel-Bulkley (H-B) model. Based on the rheological parameters obtained from curve fitting, the empirical correlations for the flow behavior index and the consistency coefficient were proposed. The consistency coefficient increases with the increase of cuttings amounts and the reduction of cuttings size. While the flow behavior index decreases with the increase of cuttings amounts and the reduction of the cuttings size. The proposed rheology determination approach in this study could give an orientative performance for cuttings-laden drilling fluids.

#### 1. Introduction

Drilling fluids rheological properties attach major significance involved in controlling formation pressure, suspending and transporting cuttings out of the wellbore, maintaining wellbore stability and cleaning the wall (Kaiser, 2009; Livescu, 2012; Meng et al., 2012). One of the extensive concerns of rheological properties determination for drilling fluids is the analysis of influencing factor for rheology. Numerous studies have been conducted on rheology determination of water based drilling fluids embroiled in rheology influencing factors such as temperature, pressure, pH, etc. (Benna et al., 1999; Kafashi et al., 2017; KOK and Alikaya, 2005; Romagnoli, 2017; Rommetveit and Bjorkevoll, 1997; Zhao et al., 2017). It is well known that cuttings (a type of particle formed by bit milling a rock mass) are transported into a wellbore annulus by circulating drilling fluids. However, the impact of cuttings on the rheology of drilling fluids has not drawn much attention

Concentric-cylinder rotational viscometer has always been spoken widely in the petroleum industry due to its excellent workability and powerful reliability (Estellé et al., 2008; Jain et al., 2016; Kelessidis and Maglione, 2006; Krieger, 1968; Vajargah and Oort, 2015). For a typical API recommended rotational viscometer, a bob is connected to a torque

measuring device. The torsion spring resists the rotational torque of the shear fluid sample in the annular space disposed between the bob and rotor. Rotor rotations and bob deflections make the torque can be related to the dial reading by the torsion spring. Thus, the shear stress at a distance from the axis can be calculated from the dial readings and apparatus parameters (Kumar et al., 2014). For the API recommended viscometer, which is equipped with a 'narrow-gap', the shear stressshear rate equation has been widely accepted in the petroleum industry. However, a problem arose when measuring the rheology of drilling fluids incorporating cuttings of large size, and it appears that researchers were trapped by this subject for a long time. The major difficulty is that the annular gap between bob and rotor is too narrow to contain drilling cuttings. In addition, as the algebraic form of the rheological equation cannot be prespecified, the knowledge about rheological properties of cuttings-laden drilling fluids is still limited. Therefore, a wider annular gap of rotational viscometer is required to measure the rheology of cuttings-laden drilling fluids. Moreover, a reliable algorithm is also required for the shear rate of cuttings-laden drilling fluids in a 'wide-gap' rotational viscometer.

In this work, for the purpose of investigating the effect of cuttings on the rheological properties of KCl/Polymer drilling fluid, an API recommended rotational viscometer equipped with a widened gap was

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used, and the flow curves were transformed from the viscometry data by using the novel algorithm based on Tikhonov regularization. The rheological model of the drilling fluid has been determined by curve fitting. Flow curves of the cuttings-laden drilling fluids were used to understand the impact of cuttings on drilling fluid rheology. The empirical correlations for the Herschel–Bulkley model parameters were developed to analyze the cuttings effect. This study provides an innovative approach not only in the drilling fluid rheology, but also in the drilling hydraulics considering the cuttings effect.

#### 2. Experimental

#### 2.1. Materials

KCl/Polymer water-based drilling fluid was selected to investigate the effect of cuttings on the rheological properties for its strong ability in transporting cuttings. This type of drilling fluid is widely used because it has a good inhibitory effect on the hydration and swelling of mudstone (KOK and Alikaya, 2005). Commercial additives were provided to produce KCl/Polymer water-based drilling fluid. Xanthan gum (XC), amphoteric polymer (FA-367), walchowite (SPNH), sulfonated phenolic resin (SMP-2), sulfonated-methyl lignite (SMC) and KCl were prepared as necessary chemical additives. As fluid loss agents, SMC, SPNH and SMP-2 work synergistically to resist high temperature from 180 to 220 °C and to resist salt. Table 1 demonstrates the composition of the drilling fluid used in this study.

This formulation of drilling fluid was prepared in accordance with industry practice procedures. First, bentonite was dispersed in tap water at 40  $^{\circ}\text{C}$  and stirred at 600 rpm for 30 min in order to promote bentonite dispersion. The macromolecular polymer additive xanthan gum was then added to tap water at 40  $^{\circ}\text{C}$  and stirred at a rotational speed of 600 rpm. After the bentonite dispersion and xanthan gum solution were aged at room temperature for 16 h, various other additives were sequentially added to the mixed liquid of the bentonite dispersion and the xanthan gum solution. Finally, the prepared drilling fluid was aged for 24 h at ambient temperature for sufficient hydration and stable performance.

Mudstone formation is always troublesome in the drilling process, and considerable accidents occurred in mudstone formations. Mudstone cuttings, therefore, were chosen into rheological test cases. For the sake of conducting the experiment and statement, drill cuttings were classified into three grades as A, B and C according to their median  $(D_{50})$  diameter (see Table 2).

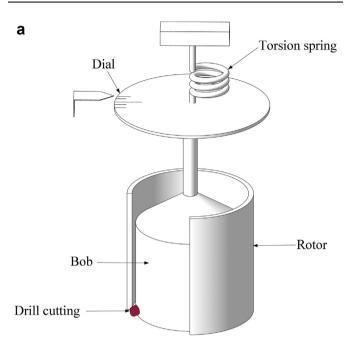
Cuttings were sieved by using varying mesh sieve and were added into the base drilling fluid (BDF) to formulate the tested cuttings-laden drilling fluid samples. Generally, the concentration of drill cuttings in the annulus during drilling is not more than 5% (Njobuenwu and Wobo, 2007). For this reason, the concentration of cuttings cannot be too high. If the amount of drill cuttings is too low, the effect on the rheology of the drilling fluid will be minimal. Therefore, the amounts of cuttings in the experiment were 1.25, 2.50 and 3.75%, respectively.

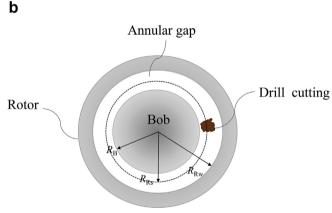
**Table 1** Composition of the drilling fluid.

Function	Component	Amount (%)
Viscosifier & filtration control	Bentonite	4.0
Rheology control	Xanthan gum	0.2
Coating agent	FA-367	0.3
Fluid loss agent (1)	SMC	1.0
Fluid loss agent (2)	SPNH	3.0
Fluid loss agent (3)	SMP-2	2.0
Shale inhibitor	KCl	3.0

**Table 2**Particle size grades of the cuttings.

Size grade	Cuttings type	Density (g/cm <sup>3</sup> )	D <sub>50</sub> (mm)
A	Mudstone	2.5	0.60
B	Mudstone	2.5	1.12
C	Mudstone	2.5	1.72





**Fig. 1.** Schematic geometry of rotational viscometer: (a) the structure of the rotational viscometer, (b) the plane view of the bob and rotor combination.

### 2.2. Methods

Rheological measurements were performed using a Fann-35SA type rotational viscometer. A schematic diagram of rotational viscometer is shown in Fig. 1.

For a Fann-35SA viscometer, following the API-recommended standard, the width of the original annular gap (small gap) between bob and rotor is 1.17 mm. However, the diameter of most drill cuttings is more than 1 mm, and thus cuttings would be stuck or blocked in the annular gap during rheological measurements (Fig. 1a). A plane view of the annular gap was observed that cuttings would be stuck in the small gap but not get stuck in a wide gap in the rheological measurement for cuttings-laden drilling fluids (Fig. 1b). Therefore, the outer cylinder of the rotational viscometer was widened so that the gap can accommodate cuttings.

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