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Hole-cleaning performance comparison of oil-based and water-based drilling fluids

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ABSTRACT

Cuttings transport is a topic of great interest in the oil and gas drilling industry. Insufficient cuttings transport leads to several expensive problems. Knowledge and selection of the drilling fluids is one of the important factor for efficient hole cleaning. It has been observed, however, that the hole cleaning performance of drilling fluids can be different even if the fluid rheological properties are similar as measured in accordance with API specifications. The reasons for stated difference in the behavior of drilling fluids are not well understood. The main objective of present work is to evaluate hole cleaning efficiency of an oil-based drilling fluid (OBM) and a water-based drilling fluid (WBM) whose viscosity profiles are similar as per API specifications.

Hole cleaning efficiency of an oil-based drilling fluid and a water-based drilling fluid whose viscosity profiles are similar was investigated. The fluids tested were industrial fluids used in the field and were sent to us after reconditioning. Experimental studies were performed on an advanced purpose-built flow-loop by varying flow velocities and drill string rotation rates. The flow loop had a 10 m long annulus section with 4″ inner diameter wellbore and 2″ outer diameter fully eccentric drill string. Pressure drop and sand holdup measurements were reported. Rheological investigations of the same fluids were used to understand the difference in the behavior of the drilling fluids tested. Higher pressure drop was observed for WBM compared to OBM, and for both fluids, the pressure drop increased with drill string rotation speed. In case of no drill string rotation, better hole cleaning performance was observed with the oil-based fluid compared to the water-based fluid. With the presence of drill string rotation, hole cleaning performance of both the fluids was nearly the same.

1. Introduction

Significant resources are spent by oil and gas companies annually on drilling, out of which a large fraction is lost due to various drilling problems. One such drilling problem which has been in focus for many researchers for several decades is inadequate cuttings transport. It is considered to be a major issue in high angle oil well design. Cuttings generated during drilling have to be transported to the surface, in order for the drilling operation to proceed. Insufficient hole cleaning may result in reduced rate of penetration (ROP), formation fracturing with resulting fluid loss, premature bit wear, increased drill string torque and drag, and stuck pipe. Previous studies indicate that cuttings transport is influenced by many factors, such as cuttings characteristics, drilling fluid type and rheology, operational parameters including drill pipe rotation, pump rate, weight on bit, ROP, eccentricity and diameter of hole and drill pipe, and wellbore inclination (Okrajni and Azar, 1986; Sifferman and Becker, 1992; Zeidler, 1972). A comprehensive review of cuttings transport studies was reported by Kelin et al. (2013) and Nazari et al. (2010).

Cuttings are transported to the surface by circulating a drilling fluid and it is vital for the drilling operator to be able to select an appropriate fluid for each individual well, including the decision of using oil-based or water-based fluids or “muds” (OBM or WBM). Each of these two fluid types has its own advantages and disadvantages, as shown in the review by Apaleke et al. (2012). Over the years drilling fluids have become more complex and expensive in order to satisfy diverse requirements and there is a need to increase the knowledge of drilling fluid behavior in order for the operator to select and apply the appropriate fluid.

Oil based drilling fluids have been claimed to be superior to water based drilling fluids when it comes to hole cleaning, even if the fluid rheological properties are similar as measured in accordance with API

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specifications. The reasons for this difference are not completely understood, but a theory was put forward by Saasen (1998). There are no standards available which suggest the type of drilling fluid to be used for a particular well. According to industry wisdom and field practice, water-based fluids are used when possible, and oil-based fluids are used when needed. Field studies show that drilling ROP improves by using OBM, whereas laboratory evaluations have indicated that it is not obvious that drilling ROP improves with OBM. Many researchers have been working with oil-based and water-based drilling fluids to understand and identify differences in their behavior, but conclusions differ. Results from some studies contradict results from other studies. Some researchers have reported that oil-based drilling fluids with similar rheological properties as water-based drilling fluids behave similarly in terms of hole cleaning, while other researchers have reported that hole cleaning performance of oil-based fluids and water-based fluids differ in spite of similar rheological properties. Hareland et al. (1993) reported that except at hole inclinations of 40° to 50°, oil-based muds and water-based muds with similar rheological properties behave similarly, whereas at 40° to 50° hole inclinations water-based muds outperform oil-based muds. Hemphill and Larsen (1996) found out that oil-based and water-based drilling fluids with similar rheological properties and at a particular velocity behave similarly at all the hole inclinations from 0° to 90°. Seeberger et al. (1989) reported that above a particular fluid velocity, drilling fluids with similar rheological properties behaves in an equivalent fashion, whereas, below that particular fluid velocity water-based mud has better performance that oil-based mud. The above conclusions are drawn from laboratory investigations performed at various conditions which may or may not represent the actual field conditions closely. However, Saasen and Løklingholm (2002) also found that the efficiency of oil-based drilling fluids is better compared to water-based drilling fluids with somewhat similar viscosity profiles when they were evaluating field data.

As noted by (Saasen et al., 1998), cuttings transport efficiency is closely related to annular pressure loss. The cuttings transport efficiency of drilling fluids increases with increasing shear stress acting on the bed which in turn contributes to frictional pressure loss. Therefore, frictional pressure loss estimation is important to study the hole cleaning behavior of drilling fluids.

Proper estimation of the frictional pressure loss is also important for pump capacity design and in order to keep ECD within the pressure margin. Several researchers investigated the drill string rotation effect on the annulus pressure drop by ascribing to the flow regime (laminar or turbulent), formation of Taylor vortices, drill pipe eccentricity and various other parameters (Ahmed and Miska, 2008; Cartalos and Dupuis, 1993; Erge et al., 2015a, 2015b, 2015c; McCann et al., 1995; Ozbayoglu and Sorgun, 2010; Saasen, 2013; Sorgun et al., 2011).

In the literature, there are very few comparative studies reported for OBM and WBM under equivalent conditions, to understand their difference in behavior in cuttings transport. Hemphill and Larsen (1996) provide an overview of laboratory experiments conducted at the University of Tulsa, more than two decades ago. Apparently, not much research has been conducted in this area since then. Clearly, the identification of the differences in performance of OBM and WBM determined at controlled flow loop conditions will increase the understanding of the fluid's behavior and enable the development of improved drilling fluids, both operationally and environmentally, for both oil-based and water-based fluids. In this study flow loop experiments will be performed on a custom built flow-loop apparatus. The main objective of this work is to evaluate hole cleaning performance of an oil-based drilling fluid and a water-based drilling fluid whose viscosity profiles are similar. Hole cleaning efficiency will be evaluated at various operational conditions. Operational parameters are selected to represent actual field conditions like an eccentric annulus, realistic flow velocities, ROP and drill string rotational speeds. This study is designed to understand the difference in the hole cleaning behavior of fluids with similar rheological profiles. In addition, this study helps to identify if the observation made in the field that OBM cleans better than WBM is due to differences in the behavior of the fluids cuttings transport capability or if other factors, like interaction with the formation can cause the effects.

2. Experimental

2.1. Flow loop

A schematic diagram of the experimental facility is shown in Fig. 1. All the experiments are conducted on an advanced purpose-built flow rig. The flow rig consists of a 10 m long test section, a processing unit (sand injection, sand separation, fluid storage tanks and pumps), connecting hoses, valves, and instrumentation (see Fig. 2).

The test section consists of replaceable hollow cylindrical elements of concrete with an inner diameter of 100 mm representing the wellbore (see Fig. 1) and a steel rod of 50 mm diameter, representing a drill string. One end of the rod is connected to a drive motor to simulate a variable speed system and the rod is supported laterally at both ends using universal flexible joints allowing free whirling (lateral) motion within the constraints of the wellbore. Movement of the drill string in the axial direction is constrained. Thus flow loop is fully eccentric due to the gravity of the drill string. The flow loop can also be tilted to an angle of 30° from horizontal. A transparent section is placed in the middle of the test section to visualize the formation of cuttings bed (Ytrehus et al., 2014). However, in this case, drilling fluids are opaque, which makes visual measurements difficult.

Instrumentation includes a Coriolis flow meter and differential pressure (DP) transducers connected to the logging system. Differential pressure cells measure differential pressure between pressure ports which are located at positions 3 m, 7 m and 8 m from the inlet. DP cell measurements (DP1815) which measured the pressure difference between ports at 3 m and 7 m location are reported. The DP transducers are flushed regularly before each experiment to ensure that there are no air bubbles in the test section. Sand injection system is calibrated to a preset sand rate. The outlet of the test section is connected to sand separator unit, where the fluid and sand gets separated. Fluid storage system is capable of holding 5 m^3 of drilling fluid. Load cells under the processing unit are used to measure the variation in weight due to the corresponding variation in the amount of sand in the test section. Thus, the cuttings holdup in the system could be calculated as a function of time.

The loop is designed for ambient pressure and temperature conditions, which was considered sufficient for the purpose of this investigation, and is much less expensive than performing experiments at reservoir conditions.

2.2. Fluids

Various oil-based and water-based fluids are tested. Results from the experimental investigation of oil-based fluids were reported (Sayindla et al., 2016). This paper presents comparative results of the oil-based and water-based fluids. An oil-based fluid OBMB and a water-based fluid KCl with similar rheological profiles were chosen for our study. These fluids were provided by the company MI Swaco. These fluids were industrial fluids used in the field, and were reconditioned and cleaned and were delivered to us for our research activities. Oil-based fluid OBMB will be referred to as OBM and water-based fluid KCl will be referred to as WBM in the rest of paper. The Herschel- Bulkley parameters of the drilling fluids were obtained by a least squares fit to Anton Paar rheometry data and are listed in Table 1 along with matched Herschel-Bulkley parameters. Matching was conducted for shear rates below 400 s^{-1}, which is the most relevant range for the flow loop experiments. Table 2 presents the composition of OBM and WBM fluids.

Flow curves of the two fluids OBM and WBM are shown in Fig. 3. The shear rates encountered in the flow loop and in field conditions are below about 400 s^{-1}, as shown in Fig. 6. Within that shear rate range, viscosity profiles of the drilling fluids OBM and WBM are similar as seen from