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Performance of fiber-containing synthetic-based sweep fluids

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ABSTRACT

Cuttings transport from the bit to the surface in horizontal or highly inclined wells is a critical component of overall drilling performance. The associated increase in bottomhole pressure and equivalent circulating density due to increased cuttings concentration and formation of cuttings bed in the wellbore can exceed the limits of the marginal operating pressure window that often exists in deepwater drilling. Fiber-containing sweeps, or “fiber sweeps”, have been shown to be effective in cleaning highly inclined wells by eliminating cuttings beds, thereby reducing the friction pressure loss. Incorporating fiber in a drilling sweep enhances its hole-cleaning performance and minimizes friction loss contributions from cuttings beds without significantly impacting flow properties of the fluid.

This article presents the results of an experimental study conducted on the wellbore cleaning efficiency of fiber sweeps. Wellbore cleaning experiments were conducted with sweeps of synthetic-based drilling fluid (SBM) of density 1.27 g/mL treated with a monofilament synthetic fiber of density 0.9 g/mL, length 10 mm and diameter 100 μm. Fiber concentration was varied up to 0.06% w/w (0.54 g of fiber/L of fluid). The flow loop contained an annular test section and was fitted with a pipe viscometer. Cuttings bed heights in the flow loop annulus were measured at flow rates up to 300 L/min and pipe rotation speeds up to 50 rpm with the annulus configured horizontally (90°) and inclined at 72°. The results indicated that in the inclined configuration, addition of fiber to hole-cleaning sweeps substantially improves cuttings removal, but only when the pipe is rotated. When the annulus is horizontal or the pipe is not rotated, addition of fiber has only a small effect on cuttings bed removal.

1. Introduction

In the oil and gas industry, drilling sweeps are used to improve borehole-cleaning when conventional drilling fluid fails to clean the wellbore sufficiently. Often they are applied immediately prior to tripping operations to clean the wellbore and reduce excessive annular pressure losses. The sweeps remove cuttings that cannot be transported to the surface during normal drilling operations by providing additional vertical lift to the cuttings. Sweeps can be performed in all well inclinations from vertical to horizontal, as required by wellbore conditions. Drilling sweeps can be an effective remedy for poor hole-cleaning, a problem that often results in increases in non-productive time, stuck pipe, premature bit wear, slow rate of penetration, formation fracturing, and high torque and drag (Ahmed and Takach, 2008).

Multiple field-tested techniques have been introduced over the years to reduce the tendency of drilled cuttings to settle within the wellbore and improve cuttings transport and hole-cleaning. Cuttings transport in directional wells is dependent on fluid rheology and density, drilling rate, rotary speed of the drillpipe, mud circulation rate and wellbore geometry (Valluri et al., 2006). Increasing viscosity and/or density generally increases a fluid's cutting transport capability, while decreasing viscosity, especially to generate turbulent flow, can help to lift cuttings beds. Conventional sweeps, generally more economical than whole mud treatment, typically rely on modification of these properties. Hole-cleaning sweeps are commonly categorized as (i) high-viscosity; (ii) high-density; (iii) low-viscosity; (iv) combination; and (v) tandem sweeps (Hemphill and Rojas, 2002). Hole-cleaning sweeps can reduce cuttings bed thickness, thereby decreasing annular pressure loss and surface torque and drag. Increasing the mud flow rate also provides extra lifting potential; however, increased flow rate increases the pressure along the wellbore, which can augment the risk of lost circulation. Effects on pressure loss along the wellbore must also be considered when designing and applying sweep fluids. This was a concern initially when hole-cleaning sweeps were first treated with fibers. However, it was learned that the right kinds of fibers added at a small concentration could improve hole-cleaning performance with a negligible increase in mud viscosity and pressure loss (George et al., 2011). Indeed, there appears to be a critical fiber concentration below which the apparent viscosity of

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Nomenclature

A	dimensionless parameter
B	dimensionless parameter
C	dimensionless parameter
C_f	fiber concentration
D	dimensionless parameter
DAS	data acquisition system
DP	differential pressure
$D_{hyd,s}$	hydraulic diameter based on zero bed height
D_h	hole diameter or inner diameter of a casing
D_p	outer diameter of the inner pipe
E	dimensionless parameter
ECD	equivalent circulating density
F	dimensionless parameter
G	dimensionless parameter
h	bed height
$\bar{k}$	diameter ratio
k	fluid consistency index
n	fluid behavior index
Q	flow rate
Re_s	modified Reynolds number based on zero bed height
SBF	synthetic-based fluid (0.89 g/mL)
SBM	synthetic-based mud (1.27 g/mL)
Ta	Taylor number
V_s	superficial mean flow velocity computed based on zero bed height
WBM	water-based mud (1.00 g/mL)
XG	xanthan gum

Greek Letters

Δ	differential
$\gamma_{w,s}$	average wall shear rate based on zero bed height
$\mu_{app,s}$	apparent viscosity based on zero bed height
θ	inclination angle
ρ	fluid density
$\tau_{w,s}$	average wall shear stress based on zero bed height
τ_y	fluid yield stress
ω	angular speed of inner pipe

fiber–polymer suspensions increases only slightly with increasing fiber concentration. Above the critical concentration, the apparent viscosity increases substantially with a small increase in fiber concentration (Guo et al., 2005; Marti et al., 2005; Rajabian et al., 2005). Fiber concentrations used in the field and during this study are relatively low and well below the critical threshold.

Previous experimental studies (Ahmed and Takach, 2008; Elgaddafi, 2011) and field investigations (Cameron et al., 2003; Bulgachev and Pouget, 2006) reported that adding a small amount of synthetic monofilament fiber (less than 0.1% by weight) improves solids transport and hole-cleaning efficiency of the sweep over comparable non-fiber sweeps, with little to no change in fluid shear viscosity (George et al., 2011). Adding fiber enhances hydrodynamic drag and subsequently reduces settling tendency of suspended high-density solids (Harlen et al., 1999; Bivins et al., 2005; Elgaddafi et al., 2012). This favorable performance may be attributed to the dynamic influence between the adjacent fibers. When fully dispersed in the sweep fluid, fiber can form a stable network structure that tends to support cuttings due to fiber-fiber and fiber-fluid interactions. The fiber-fiber interactions can be by direct mechanical contact and/or hydrodynamic interference among fiber particles. Mechanical contact among fibers improves the solids-carrying capacity of the fluid (Ahmed and Takach, 2008). The mechanical contact between the fibers and the cuttings beds also aids in re-suspending cuttings deposited on the low-side of the wellbore. As the fibers flow through annulus, momentum exchange occurs between the settled cuttings and fiber particles, which helps to re-suspend the cuttings, while the fiber networks carry the solids to the surface. Also aiding in cuttings transport is the fiber-fiber hydrodynamic interference that enables the fiber network to move as a plug. Hence, at the surface of the cuttings bed, the fiber may have a higher velocity than the fluid phase, which is typically very low. These fast moving fibers can therefore transfer more momentum to the deposited solids, overcoming the cuttings bed stabilizing forces and initiating particle movement. Gravity and fluid yield stress have stabilizing effects on deposited solid particles (Ahmed et al., 2001).

Previous laboratory scale studies (Ahmed and Takach, 2008; Elgaddafi, 2011) on fiber sweep considered water-based fluid systems. Currently, systematic base fluids are preferable in drilling deep-water and water-sensitive formation. Hole cleaning is a major problem in drilling deep-water wells. Synthetic drilling fluids are invert-emulsion and they exhibit structure like foams and emulsions, As a result, the behavior of fiber containing synthetic fluid can be different from water-based fiber sweeps. This study will concentrate on identifying the behavior and performance of synthetic fluid based fiber sweeps within the operational boundaries that are utilized in industry. The primary objectives of this investigation are to (i) evaluate hole-cleaning efficiency of fiber-containing synthetic-based mud (SBM), and (ii) identify the effects that flow rate, inclination angle, pipe rotation and fiber concentration have on fiber sweep effectiveness.

2. Experimental approach

In deepwater drilling operations, SBMs are the drilling fluids of choice, due to their relative temperature stability, improved lubricity, environmental performance, and low reactivity to shale formations. Therefore, flow loop sweep experiments were predominantly conducted using SBMs. In order to calibrate the equipment and develop the experimental procedures, some initial shear viscosity measurements and hole-cleaning experiments were carried out with an unweighted water-based drilling fluid viscosified with xanthan gum (XG).

2.1. Experimental setup

Fiber sweep experiments were conducted using a flow loop apparatus (Fig. 1). This device, as currently configured (Fig. 2), provides the capability to perform sweep (i.e. cuttings removal) tests, as well as pipe viscometer and annular hydraulic measurements on any given fluid. The primary components of the flow loop system are: (i) 600-L mixing tank; (ii) circulation pump; (iii) annular and pipe test sections; (iv) hydrocyclones; (v) cuttings collection and injection tanks; and (vi) data acquisition and control system (DAS).

To carry out an experiment, the test fluid is first agitated in the mixing tank using a propeller type agitator. The fluid is then circulated by the centrifugal pump through 50 mm steel piping, the cuttings injection tank (when opened), and into the two