Cuttings Transport With Foam Under Simulated Downhole Horizontal Conditions

The use of drilling foams is increasing because foams exhibit properties that are desirable in many drilling operations. A good knowledge of cuttings-transport efficiency under downhole conditions is essential for safe foam drilling. Previous cuttings-transport studies with foam were limited to low-pressure and ambient-temperature (LPAT) conditions. An experimental study of cuttings transport with foam in a horizontal annulus was performed under simulated downhole conditions.

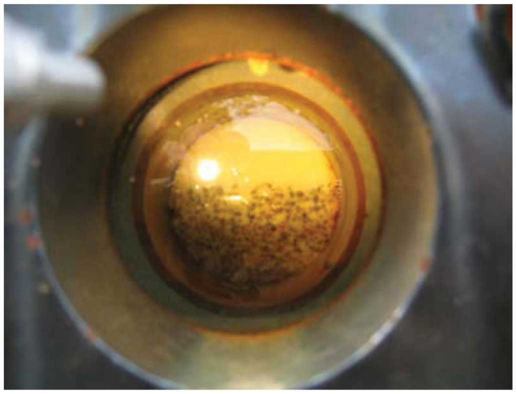

Fig. 1—Photo of cuttings transport with aqueous foam in the annulus test (90%-quality foam, pressure = 100 psi, temperature = 160°F, and velocity = 5 ft/sec).

Introduction

Foam drilling fluid can provide low density as well as flexibility in equivalent-circulating-density (ECD) control. However, the complexity of foam flows makes it difficult to obtain reliable predictions of ECD for foam drilling. When drill cuttings are in the wellbore, the foam/cuttings mixture affects bottomhole pressure, making the complicated compressible foam flow even more complex. Therefore, cuttings transport with foam should be well understood for accurate bottomhole pressure and ECD estimation.

Studies on cuttings transport by foam fluids are limited. Although cuttings in foam affect hydraulics calculations and ECD predictions, it is generally accepted that foam cuttings transport in vertical wells is very efficient. Foam-flow velocity of 120 ft/min is sufficient for most vertical-well foam drilling; in some cases, flow velocity as low as 70 ft/min has been successful. For foam drilling in horizontal wells, the particle-settling velocity is perpendicular to foam-flow direction and drill cuttings tend to settle to the low side of the wellbore. The density of drill cuttings is much higher than the density of foam. Therefore, the mechanisms that govern cuttings transport are different for horizontal wells. Empirical correlations and models developed for vertical wells may not be valid for horizontal and inclined wellbores. This research project studied cuttings transport with foam in simulated downhole conditions for more-reliable bottomhole pressure and ECD predictions.

Experimental Study

Experiments of cuttings transport in foam were conducted at the Advanced Cuttings Transport Facility at the U. of Tulsa. The facility is designed to investigate cuttings transport and hydraulics of both compressible and incompressible drilling fluids under elevated-temperature and -pressure conditions. The facility can simulate both pipe and annular flow at pressures up to 1,500 psig and temperatures up to 200°F for incompressible Newtonian and non-Newtonian fluids. It also accommodates compressible fluids such as aerated fluid and foams.

The test section is a 73-ft-long annulus between a 5.76-in.-inside-diameter outer casing and a 3.5-in.-outside-diameter drillpipe. The drillpipe is designed to rotate as fast as 250 rev/min. Centralizers are placed in the annulus to keep the inner pipe concentric. Differential pressure in the annulus is measured across a length of 57.33 ft. The main components are the pumping system, air-injection system, foam-generation and -breaking system, heating and cooling system, cuttings-injection/-separation system, annular test section, measurement system, and data-acquisition and control system.

Test Procedure. The test procedure was divided into five major stages that are detailed in the full-length paper.

- Prepare and generate foam.
- Inject cuttings and establish steady-state foam/cuttings-mixture flow.
- Perform liquid-holdup procedures.
- Flush and weigh the cuttings.
- Shut down the whole system.

This article, written by Technology Editor Dennis Denney, contains highlights of paper SPE 99201, "Experimental Study on Cuttings Transport With Foam Under Simulated Horizontal Downhole Conditions," by ***Z. Chen,*** *SPE,* ***R.M. Ahmed,*** *SPE,* ***S.Z. Miska,*** *SPE,* ***N.E. Takach,*** *SPE,* ***M. Yu,*** *SPE, and* ***M.B. Pickell,*** *U. of Tulsa, and* ***J. Hallman,*** *SPE, Weatherford Intl. Ltd., prepared for the 2006 IADC/SPE Drilling Conference, Miami, Florida, 21–23 February.*

For a limited time, the full-length paper is available free to SPE members at www.spe.org/jpt. The paper has not been peer reviewed.

Test Matrix. A foam system that is used in the field was used in this experimental investigation, and the formulation of this system is given as: air + water + surfactant (1 vol% Klean-Foam) + hydroxylethylcellulose polymer (0, 0.25, and 0.5 vol% Klean-Vish). The drill cuttings used in this study were simulated with river pea gravel, which has a mean diameter of 3 mm, density of 2.61 g/cm^3, and 38% porosity. The cuttings-injection rate ranged from 15 to 20 lbm/min, which corresponds to a rate of penetration of 50 to 66 ft/hr.

Eight groups of foam cuttings-transport tests were conducted. Experiments were conducted at pressures of 100, 250, and 400 psi; temperatures of 80, 120, and 160/170°F; polymer concentrations of 0, 0.25, and 0.5%; foam qualities of 70, 80, and 90%; and foam-flow velocities of 2 to 6 ft/sec. Pressure was tested up to 500 psig upstream of the foam generator. After the foam generator consumed 100 psi of pressure, the pressure in the annular test section was tested up to 400 psig.

At LPAT conditions (100 psig and 80°F, respectively), experiments were designed to find the critical velocity with a near-zero cuttings bed in the annulus. However, to evaluate cuttings-transport efficiency at higher-pressure/-temperature conditions, tests were designed to keep foam quality and velocity constant and compare cuttings concentrations at different pressure and temperature conditions.

Results

During tests, flow patterns of cuttings in the horizontal annulus were recorded through the two view ports. At low foam velocity, cuttings were deposited at the bottom of the annulus and a stationary bed was formed. At higher velocity (e.g., 6 ft/sec for 90%-quality foams at LPAT conditions), fully suspended flow of cuttings was observed.

Fig. 1 shows the foam/cuttings-mixture flow at steady-state conditions. The upper layer is foam with a negligible amount of cuttings; the bottom layer is a stationary cuttings bed with an equilibrium cuttings bed. At the interface, particles are bouncing and rolling along the stationary-bed surface.

LPAT Conditions. ***Cuttings Concentration vs. Mean Velocity.*** The velocity effect on cuttings transport with 90%-quality foam was studied. For aqueous foam (i.e., foam without polymer), when velocity was increased from 3 to 5 ft/sec, cuttings concentration decreased slightly. However, when flow velocity was increased from 5 to 6 ft/sec, cuttings concentration decreased dramatically to 3%. Similarly, for 0.25% polymer-based foam with foam velocity less than 3 ft/sec, cuttings concentration increased dramatically. Even at 2.5 ft/sec, the cuttings concentration was 30.4% for 0.25% polymer foam; between 3 and 5 ft/sec, the cuttings-concentration was approximately the same. However, when velocity increased from 5 to 6 ft/sec, the cuttings concentration decreased from 18.2 to 2.2%. For 0.5% polymer-based foam, the cuttings-concentration change was more evident; when velocity increased from 3 to 5 ft/sec, cuttings concentration decreased from 18.8 to 3.1%.

Cuttings Concentration vs. Polymer Concentration. At a velocity of 3 ft/sec, when polymer concentration was increased from 0 to 0.5 vol%, cuttings concentration decreased from 24.8 to 18.8%; at a velocity of 5 ft/sec, the positive effect on cuttings transport was more definite. When the polymer concentration was increased from 0 to 0.5 vol%, cuttings concentration decreased from 18.6 to 3.1%. Therefore, adding polymer to the foam system was beneficial for cuttings transport. But it also led to an increased frictional pressure loss. In addition to cuttings-transport considerations, proper design of hydraulics of polymer foam is important in planning foam-drilling operations.

Cuttings Concentration vs. Foam Quality. Cuttings concentrations in the annulus were measured vs. flow velocities for aqueous foam with different foam qualities (70, 80, and 90%). The maximum cuttings concentration was 37.5% with 70%-quality aqueous foam flowing at 2 ft/sec; the lowest cuttings concentration was 3% and occurred for 90%-quality aqueous foam flowing at 6 ft/sec. As flow velocity increased, the general trend was decreasing cuttings concentration. In general, lower foam qualities resulted in higher cuttings concentrations (i.e., the hole-cleaning efficiency decreased as foam quality decreased).

Analysis showed that for 90%-quality foams, a flow velocity of 6 ft/sec was sufficient to clean the horizontal annulus. Attempts were made to clean the annulus with 80%- and 70%-quality foams by adding polymer (0.5%) into the liquid phase and increasing flow velocity (up to 6 ft/sec). Cuttings concentration was still high (greater than 20%), even with foam velocities of 5 and 6 ft/sec for 70%- and 80%-quality foams, respectively.

Temperature Effect. Cuttings concentrations were compared vs. foam-flow velocity at 80, 120, and 160°F for 90%-quality aqueous foams. When temperature was increased from 80 to 160°F, the cuttings concentrations increased by 3, 2.6, and 3.2% for flow velocities of 3, 4, and 5 ft/sec, respectively. Examination of differential-pressure drop in the annulus indicated that as temperature increased, the differential-pressure drop decreased by a maximum of 30%. Despite the slight increase in cuttings concentration, this change may not affect cuttings-transport efficiency substantially for practical foam-drilling operations with aqueous foams.

Secondary Pressure Effect. The primary effect of pressure on foam flow was to influence the foam quality, which was critical for cuttings transport. In addition, there were secondary effects of pressure on foam rheology, hydraulics, and cuttings transport, which often are observed when comparing foams having the same quality at different pressures. It was observed that pressure slightly affected the cuttings concentration in the annulus. As pressure increased, there was a slight decrease in cuttings concentration for 80%- and 90%-quality foams; this effect was negligible for 70%-quality foam.

Combined Effects of Pressure and Temperature. When both temperature and pressure were increased (i.e., temperature from 80 to 120 to 170°F and pressure from 100 to 250 to 400 psi), cuttings concentrations slightly increased for 80%- and 90%-quality foams. However, the change was insignificant, with a maximum change in volumetric concentration of only 5%.

On the basis of the experimental results for all combinations of pressure and temperature conditions, it was found that at elevated-temperature and/or -pressure conditions, even though there were slight changes in cuttings-transport concentrations, the changes were fairly limited. Therefore, foam maintains its cuttings-transport properties very well under simulated downhole horizontal conditions. JPT