TUDRP

Study of Cuttings Transport Using Foam with Drill Pipe Rotation under Simulated Downhole Conditions

Mingqin Duan, The University of Tulsa, Drilling Research Projects

This report is prepared for TUDRP Advisory Board Meeting November 14-15, 2005, Tulsa-Oklahoma.

Introduction

Foam is gaining increasing applications in drilling, cementing, fracturing and oil displacement, etc. in the petroleum industry. In underbalanced drilling applications, foam not only helps to reduce formation damage and deal with drilling problems such as lost circulation, differential pressure sticking, low drilling rate, etc., but also initiates earlier production if pressure is properly controlled. This reduces the time for recovering the drilling cost, especially for many of the low pressure, low permeability reservoirs. Compared with conventional and aerated drilling fluids, foam is a compressible and relatively homogeneous mixture. This makes possible a great flexibility for pressure control. Areas where there is a high demand for control of multi-pressure systems will find useful application for this flexibility. An important potential application of foam is in Deep Water Drilling, where the margin between pore pressure and facture pressure is very narrow. While great efforts are putting on Dual Gradient Drilling [17], foam may serve as a "Continuous/Multiple Gradient Drilling" fluid by properly controlling the surface foam properties, back pressure and flow rate.

Statement of Problem

The main purpose of using foam is to keep an underbalanced downhole pressure, however, the actual downhole pressure may be overbalanced if foam hydraulics is not properly controlled. A good understanding of foam rheology is a key to the control of foam hydraulics. Limited information is available for foam drilling hydraulics under downhole conditions. Studies on foam flow at elevated pressure and elevated temperature (EPET) has started only very recently . [1, 2] How to characterize and predict foam behavior at static and flowing

conditions is still a challenge. Further investigation is needed to understand how the base fluid's composition and rheology, foam texture and wall slip affect foam rheology and hydraulics under EPET conditions.

The importance of efficient cuttings transport during drilling operations has been widely recognized. How to efficiently remove cuttings during foam drilling is of critical significance. Drilled cuttings not only create the same problems as in conventional drilling, but also change foam properties, which may completely alter the downhole pressure control plan. As such, cuttings transport with foam at downhole drilling conditions needs to be investigated. To our knowledge, only one study in cuttings transport with foam at EPET conditions was recently completed, but without pipe rotation. [2]

Literature review indicates that there is no single study in cuttings transport using foam with pipe rotation. Complexity of the flow caused by pipe rotation has been a bottleneck in the development of predictive tools for drilling hydraulics and cuttings transport. No mechanistic model has been developed to predict pressure losses for foam drilling or cuttings transport with pipe rotation. Pipe rotation effects in foam drilling are more complex because of foam compressibility and non-Newtonian behavior. Rotary drilling is still the most popular worldwide drilling technique. Cuttings transport with pipe rotation has to be understood in order to achieve safe, fast and cost-effective drilling.

Objectives

(1) Study drilling foam rheology and characterization under elevated pressure and elevated temperature (EPET) conditions using both pipe and rotational viscometers;

(2) Experimentally investigate the effects of drill pipe rotation on foam drilling hydraulics and cuttings transport with foam under EPET conditions;

(3) Develop mathematical model(s) for foam drilling hydraulics and cuttings transport with foam under simulated drilling conditions.

Preliminary Literature Review

Cuttings Transport with Foam

As summarized in Appendix B, ten studies on cuttings transport with foam have been found so far. Most of these studies, however, were conducted on lab-scale flow loops at low pressure and ambient temperature (LPAT) conditions. The drilling parameters whose effects have been studied include inclination angle, gas/liquid flow rate, foam quality, cuttings size, ROP, annular geometry, type of base liquid (water or polymer solution), pressure and temperature. Critical foam flow rate/velocity, gas-liquid ratio and back pressure for optimum cuttings transport were studied at LPAT conditions. [3-5]

Effects of Drill Pipe Rotation

A number of experimental studies on cuttings transport involving pipe rotation have beeb conducted for conventional drilling fluids at LPAT conditions.[6-8] The conclusion is that drill pipe rotation within 150 rpm generally improves cuttings transport. It helps to reduce cuttings concentration, bed height and the minimum fluid velocity required for efficient hole cleaning. Pipe rotation also reduces bed erosion time and residual cuttings concentration when drilling is stopped.[7] However, the level of improvement depends on other variables, such as hole inclination, mud viscosity, cuttings size and flow rate, etc.[6] Drill pipe rotation is one of the major factors controlling hole cleaning efficiency in horizontal and high angle boreholes. Effects of pipe rotation on cuttings transport are more pronounced for smaller cuttings when higher viscosity fluid is used.[8] At low flow rate, higher pipe rotary speed is recommended. When drill pipe is eccentric in an annulus, which is the case for most horizontal or high angle wells, the improvement in hole cleaning due to pipe rotation is more significant.

However, these studies mainly focused on cuttings transport with conventional fluids. No experimental or theoretical study was found for foam drilling with pipe rotation. There is no mechanistic model addressing rotation effects on pressure drop and cuttings transport. The engineering approaches most recently proposed by Diaz et al. (2004) [9] and Hemphill et al. (2005) [10] represents the first attempt to mathematically characterize rotation effects on pressure drop. They are mainly applicable to incompressible laminar flow in a concentric annulus without cuttings.

Foam Rheology

Various empirical or semi-empirical correlations have been proposed to describe foam flow behavior. Most of these investigations were conducted at LPAT conditions. Very limited number of studies on drilling foam rheology under EPET conditions have been found.

Study of Beyer (1972)[11] et al. on aqueous foam flow in pipes may be one of the earliest investigations into pressure (up to 860 psi) and temperature (up to 180 °F) effects. It was observed that an increase in pressure increases the shear stress while an increase in temperature decreases the shear stress. Elson and Marsden (1978)[12] reported that some foamers that seems to work well at room temperature may loss function with time when temperature is raised to 212 °F (100 °C). Cawiezel and Niles (1987)[13] observed that pressure affects foam apparent viscosity by affecting foam texture. Foam viscosity increases with increasing pressure and decreases as temperature increases to a critical value of 150 °F. Harris and Heath (1996)[14] also reported that foam viscosity achieves its maximum value at 75 °F and then declines as temperature increases to 300 °F.

Bonilla et al. (2000)[15] studied foam flow in pipes with pressure up to 1000 psi and temperature up to 175 °F. They found that high temperature tends to reduce foam apparent viscosity. Sani et al. (2001)[16] got similar

results regarding temperature effects. Lourenco et al. (2002)[1] made the first extensive investigation of drilling foam based on experiments conducted on a full scale flow loop under simulated downhole conditions. The pressure was up to 700 psi and temperature was up to 185 °F. Foam texture was found to have dominant effects on foam rheology, while pressure and temperature have secondary effects. Chen et al. (2005)[2] studied polymer based foam rheology using both pipe and rotational viscometers at ambient temperature conditions. Polymer concentration was found to have strong influence on foam rheology. Further tests at higher pressure and temperature conditions were recommended.

Approach

The proposed project incorporates both experimental investigation and theoretical study. A field scale Advanced Cuttings Transport Facility (ACTF) (Fig. A1) will be used for cuttings transport experiments using foam. It allows tests to be conducted with inner pipe rotation at pressure up to 600 psi and temperature up to 180 °F. Foam rheology at pressurized and elevated temperature conditions will be investigated using a novel rotational viscometer, Foam Generator/Viscometer (FGV) (Fig. A2). Foam quality, bubble size, pressure and temperature can be controlled with this apparatus. Depending on facility availability, either ACTF or a recently developed indoor flow loop, the Dynamic Testing Facility (DTF) (Fig. A3), may be used as a pipe viscometer to investigate wall slip and compare test results from the FGV. An Online Foam Characterization Cart (OFCC) (Fig. A4) will be connected to the ACTF or DTF to characterize foam texture while foam is flowing through the flow loop at EPET conditions.

Based on the experimental data, the existing foam hydraulic models may be verified, modified or new models may be developed. Mathematical modeling for pipe rotation will start from incompressible flow in a concentric annulus without cuttings, and then extended to compressible foam flow. The last step is to apply pipe rotation effects to cuttings transport. Numerical techniques and semi-empirical approaches based on newly obtained test data will be employed for these modeling efforts.

Scope of Work

Preliminary Test Matrix for Foam Rheology

Test Variable / Test Facility	Foam Quality	Temperature (ºF)	Pressure (psi)	Foam Velocity (ft/s)
Foam Generator / Viscometer	0.6-0.95	80-160	50/100/200	\
Dynamic Testing Facility or ACTF	0.7-0.90	80-160	50/100/200	1-6 depending on pipe diameter

The test matrix was designed to make test variables comparable between FGV and DTF or ACTF. Specific combinations of these variables are to be determined based on test results.

Preliminary Test Matrix for Cuttings Transport

Drill Pipe Rotation (rpm)	Foam Quality	Temperature (ºF)	Pressure (psi)	Foam Velocity (ft/s)	Approximate Number of Tests
0	0.8/0.9	80	100	3-6	5
40	0.7/0.8/0.9	80-160	100-400	3-6	15
80	0.7/0.8/0.9	80-160	100-400	3-6	12
80	0.7/0.8/0.9	80/160	100/400	3/6	8
Total	\	\	\	\	40

The design of this test matrix considers connection and continuity between this study and previous studies so that previous experimental results can be directly used in this study. Cuttings concentration and pressure drop will be measured as dependent variables. This is not a square test matrix. Specific combinations of the independent variables are to be determined gradually based on experimental results.

Preliminary Timetable

Tasks \ Time	2005		2006				2007			
	8-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12
Literature review										
Foam rheology tests										
Cuttings transport tests										
Test data analysis										
Model development										
Final report										

Deliverables

(1) An experimental database that can be used to better understand foam rheology and cuttings transport using foam with pipe rotation;

(2) Mathematical model(s) and computer codes to predict foam drilling hydraulics and cuttings transport with foam;

(3) Semi-annual Advisory Board Meeting (ABM) reports and the Final Report.

References

1. Affonso M.F. Luorenco and Stefen Miska, et al., "Study of the Effects of Pressure and Temperature on the Viscosity of Drilling Foams and Frictional Pressure Losses", SPE 84175, 2003.
2. Zhu Chen, "Study of Cuttings Transport with Foam under Elevated Pressure and Elevated Temperature Conditions", PhD dissertation, University of Tulsa, 2005.
3. Mehmet Evren Ozbayoglu, et al., "Cuttings Transport with Foam in Horizontal & Highly-Inclined Wellbores", PhD dissertation, University of Tulsa, 2002.
4. Jesus Capo, et al., "Cuttings Transport with Aqueous Foam at Intermediate Inclined Wells", SPE 89534, 2004.
5. A.L. Martins, et al., "Foam Property Requirements for Proper Hole Cleaning While Drilling Horizontal Wells in Underbalanced Conditions", SPE 74333, 2001.
6. Bassal Adel Ali, "The Effect of Drillpipe Rotation on Cuttings Transport in Inclined Wellbores", MS thesis, University of Tulsa, 1995
7. R.A. Sanchez, "Effect of Drillpipe Rotation on Hole Cleaning During Directional-Well Drilling", SPE 56406, 1999.
8. Mingqin Duan, "An Experimental Study Of Small Sand –Sized Cuttings Transport In Horizontal And High Angle Boreholes", MS thesis, University of Tulsa, 2005.
9. H. Diaz, S. Miska, N. Takach and M. Yu, "Modeling of ECD in Casing Drilling Operations and Comparison with Experimental and Field Data", SPE 87149, March 2004.
10. T. Hemphill and K. Ravi, "Calculation of Drillpipe Rotation on Fluids in Axial Flow-An Engineering Approach", SPE 97158, October 2005.
11. A.H. Beyer, R.S. Millhone, R.W. Foote, "Flow Behavior of Foam as a Well Circulating Fluid", SPE 3986, 1972.
12. T.D. Elson and S.S. Marsden, "The Effectiveness Of Foaming Agents At Elevated Temperatures Over Extended Periods Of Time", SPE 7116, 1978.
13. K.E. Cawiezel and T.D. Niles, "Rheological Properties of Foam Fracturing Fluids Under Downhole Conditions", SPE 16191, 1987.
14. P.C. Harris and S.J. Heath, "Rheology of Crosslinked Foams", SPE 28512, 1996.
15. L. F. Bonilla, et al., "Experimental Investigation on the Rheology of Foams", SPE 59752, 2000.
16. Abu M. Sani, et al., "Experimental Investigation of Xanthan Foam Rheology", SPE 67263, 2000.
17. J. C. Eggemeyer et al. "SubSea MudLift Drilling: Design and Implementation of a Dual Gradient Drilling System", SPE 71359, 2001

Appendix A

Pictures of Experimental Facilities

Figure A1 Advanced Cuttings Transport Facility

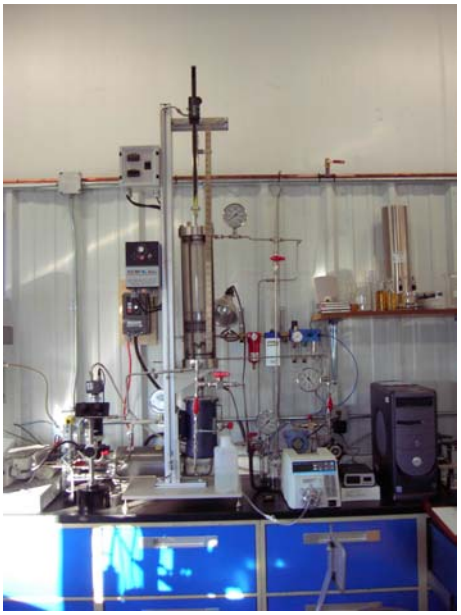

Figure A2 Foam Generator/Viscometer

Figure A3 Dynamic Testing Facility

Figure A 4 Online Foam Characterization Cart

Appendix B

Summary of Investigations on Cuttings Transport with Foam

(All these investigations were conducted without pipe rotation)

Principle Investigator	Year	Independent Variables Investigated									Dependent Variables Investigated
		Hole Angle (º)	Base Fluids	Foam Quality	Flow Rate / Velocity	Annular Geometry	ROP (ft/hr)	Cuttings Size (mm)	Pressure (psi)	Temper-ature (ºF)	
Okpobiri	1982	0	Water	0.64-0.94	various	Concentric annulus, 4.5”×1.5”	30/60/90	1.4-2.6	20-160	Ambient	Friction factor, minimum volumetric foam requirement
Rankin	1989	0+ inclined +90	Water	unknown	1-2 ft/s	Concentric annulus, 2”×1”	\	unknown	Low	Ambient	Pressure loss, hole cleaning efficiency (mixture density)
Guo	1994	Model development considering cuttings transport velocity									Bottom hole pressure
Herzhaft	2000	0-80	Water + Clay	0.84-0.96		Pipe	\	\	Low	Ambient	Particle concentration
Doan	2000	0	\	\	various	Eccentric annulus	various	\	\	\	No experiments, model minimum flow rate/critical velocity
Saintpere	2000	0-80	Water+ polymer	0.84-0.96	various	Pipe	\	\	Low	Ambient	Particle concentration
Martins	2001	45/75/90	Water	\	various	Eccentric 3.9”×1.7”	\	6	Low	Ambient	Foam stability, bed height
Ozbayoglu	2002	70/80/90	Water	0.7/0.8/0.9	1-16 ft/s	Eccentric 8”×4.5”	20-90	3.5	Low	Ambient	Pressure drop, bed height
Capo	2003	45-65	Water	0.7-0.8	3-5 ft/s	Eccentric 8”×4.5”	15-50	2.3	Low	Ambient	Cuttings concentration
Chen	2005	90	Water+ polymer	0.7/0.8/0.9	1-6 ft/s	Concentric 5.76×3.5”	\	3	100-400	80-170	Pressure drop, cuttings concentration

\ : Effects of this variable were not studied