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Improve Drilling Economics Using Dynamic High Angle Sag Testing (DHAST)

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Abstract

Sag is an ongoing problem while drilling oilfield wells, whether the drilling fluid is static or dynamic. A combination of gravitational force and fluid rheological properties can cause an increased sag rate in any kind of deviated well. Consequently, the ability to control, reduce, or eliminate sag is a continuing task for operators and drilling fluid companies alike.[1-5] Several fluids have been designed that have little sag when properly maintained. Nonetheless, the problem lies with determining the likelihood of sag during the drilling process. Until recently, no reproducible and quantifiable method was available for measuring sag under realistic downhole conditions. Now, using a dynamic high angle sag test (DHAST) instrument[6] it is possible to determine the likelihood of sag in drilling fluids. This allows us to study the change in fluid behavior as a function of different environmental properties before recommending additive treatments or formulations, thus avoiding the chance of costly over-treatment.

Introduction

Barite sag, usually manifested in deviated wells, can cause severe drilling problems, such as excessive torque, drag and lost circulation due to increased equivalent circulating density (ECD). Typically, mitigating barite sag is a reactionary process. When barite sag is suspected, clay and other products are added to the fluid system in an attempt to slow or stop it; sometimes successfully and sometimes not. This reactionary process can create other problems such as excessive riser viscosity and even higher ECDs.

Rheological properties, such as low shear rate viscosity, tau0, PV, YP, gel strength and others, have been used as guidelines to design drilling fluids and eliminate barite sag. Recommended ranges for these properties have evolved with time. Generally, the safe ranges have crept up as sag incidents continued to occur. Some of these properties are better than others at indicating sag resistance, but all fall short of being a reliable measure of sag potential. The DHAST instrument fills this void in drilling fluid equipment technology by providing an important tool for drilling fluid design and optimization against barite sag. The dynamic high angle sag test was developed to aid in the analysis of dynamic and static barite “sag” in drilling fluids. The DHAST system provides a wide range of shear rate, temperature, and pressure options used to simulate downhole conditions. Since the beginning of 2003, the DHAST has been used successfully as a planning and diagnostic tool in high angle well projects. As new fluid systems emerge and drilling challenges becomes more intense, the DHAST has provided new insights into drilling fluid design, sag prevention and sag remediation.

Inside the DHAST pressure vessel is the fluid sample assembly. The sample assembly is supported near its center by a very low friction pivot. Also included in the sample assembly are fluid expansion compensation and isolating pistons. These pistons allow rapid system temperature and pressure changes while maintaining system equilibrium and isolating the test fluid from the pressurization fluid. The sample assembly has a coaxial internal bob that provides shear to the test fluid. A wide range of shear rates are possible with its magnetically coupled drive.

The DHAST sample assembly is maintained at 45 degrees during testing. As barite settles in the sample assembly, the center of mass of the fluid sample will change. The weight difference causes the sample assembly to tilt slightly, much like a beam balance. The DHAST control system energizes external coils to drive the assembly back to its initial zero position. Once it is driven back, the required coil current is measured. The sag rate is calculated using the coil current, fluid density, composition, geometry, and calibration considerations.

DHAST experiments typically involve measuring and calculating the sag rate for a given fluid at multiple shear rates in a single experiment. We have determined that this methodology gives us enough information to determine the propensity for a drilling fluid to undergo weighted material settling. In this paper we present our current analysis protocols and results that gave operators an opportunity to reduce their drilling costs.

Experimental

Two example fluids (and treatments) are outlined in this report. The well details for each are outlined below:

Fluid 1 – The well was in the Gulf of Mexico (offshore). Sample was taken at 30,000 ft, with an approximate bottomhole temperature of 275°F. The borehole was 8.5”.

Fluid 2 – The well was in Gulf of Mexico, in a different location than **Fluid 1**. A sample was taken at 20,000 ft, with an approximate bottomhole temperature of 350°F. The borehole was 6.5".

Each of these samples was received in the labs and underwent an extensive drilling fluid analysis (including rheology and DHAST). **Tables 1-4** outline the rheology and DHAST results for each of the field samples used in this study. The initial samples were analyzed, and then treated on the basis of the data obtained. Each sample was analyzed again with a second (and third) treatment necessary to optimize the treatment of **Fluid 2**.

Rheology was carried out as per API specifications using a Fann-35A rheometer, with the fluid at a temperature of 120°F. DHAST analysis was undertaken using a standard 50 mL sample size at a pressure of 2000 psi and temperatures of 275°F and 325°F (for **Fluids 1** and **2** respectively).

Table 1. Rheology Data For Fluid 1

Formulation	Base	Treat 1
Base mud, bbl	1	1
Emulsifier, lb	—	3
Rheological modifier, lb	—	0.3
Clay, lb	—	5
Oil mud conditioner, lb	—	0.8
Fann 35 dial readings at 120°F		
600 rpm	148	195
300 rpm	83	112
200 rpm	60	82
100 rpm	36	48
6 rpm	8	9
3 rpm	7	7
PV, cP	65	83
YP, lb/100 ft^2	18	29
10-sec gel, lb/100 ft^2	9	10
10-min gel, lb/100 ft^2	19	30
ES, Volts	522	922

Results

Analysis of the initial submitted fluids indicates that there was weighted material settling in both fluids. While this is not easily discernable by looking at the rheology data, a review of the DHAST data clearly indicates that both fluids are considered "atypical." This is a DHAST fluid classification that indicates there is some tendency for the weighted material to sag.

A single standard DHAST experiment determines the sag rate at 5 shear rates: 0.35 s^{-1}, 1.76 s^{-1}, 10.55 s^{-1}, 21.09 s^{-1}, and static. The calculated sag rate is measured in units of millimeter per hour and indicates the relative velocity of weighted material that might settle in a given unit time. An understanding of a fluid's propensity to settle can be determined from these rates using an algorithm developed from a multivariate analysis of past samples. A sample DHAST output is outlined in **Figure 1**. and the resulting settling rates are calculated from a least means fit to this output data. Drilling fluids are then categorized based on their propensity to sag. Fluids can be categorized with four distinct labels: Early Depletion, Late Depletion, Atypical Fluid, and Good Fluid. In addition, we are able to back calculate a hole angle at which we believe the fluid may have increased propensity to sag. Combining these data allows accurate prediction for a fluid's tendency to sag.

Table 2. Rheology Data for Fluid 2

Formulation	Base	Treat 1	Treat 2	Treat 3
Base Mud, bbl	1.0	0.95	0.95	0.95
Diesel Base Oil, bbl	—	0.05	0.05	0.05
Suspension Agent, lb	—	4	3	3
Lime, lb	—	6	6	6
Emulsifier, lb	—	2	2	—
Barite, lb	—	60	60	60
Fann 35 dial readings at 120°F				
600 rpm	209	250	193	218
300 rpm	120	153	117	131
200 rpm	90	117	88	98
100 rpm	57	77	57	65
6 rpm	18	28	22	24
3 rpm	16	26	20	22
PV, cP	89	97	76	87
YP, lb/100 ft^2	31	56	41	44
10 Sec gel, lb/100 ft^2	20	28	20	27
10 Min gel, lb/100 ft^2	27	37	32	34
ES, Volts	1300	2000+	2000+	2000+

Table 3. DHAST Data for Fluid 1

	Sag Rate (mm/hr)	
Shear Rate	Base	Treat 1
0.35 s^{-1}	5.98	0.333
1.76 s^{-1}	2.86	1.687
10.55 s^{-1}	3.69	3.177
21.09 s^{-1}	2.92	4.04
0.00 s^{-1}	2.12	2.24
Classification	Atypical	Good
Angle (°)	21	All

Table 4. DHAST Data for Fluid 2

	Sag Rate (mm/hr)			
Shear Rate	Base	Treat 1	Treat 2	Treat 3
0.35 s^{-1}	5.98	0.333	1.60	0.703
1.76 s^{-1}	2.86	1.687	2.42	1.244
10.55 s^{-1}	3.69	3.177	2.29	1.659
21.09 s^{-1}	2.92	3.04	1.14	1.20
0.00 s^{-1}	2.12	0.24	0.69	1.14
Classification	Atypical	Good	Good	Good
Angle (°)	18	All	34	All

A close look at the data for **Fluid 1** indicates that a simple treatment program that included emulsifier, rheological modifier and clay was sufficient to reduce the barite settling. The DHAST data indicates a significant reduction of the sag rate at each of the lower shear rates. Historically, this has been a good indicator of sag behavior for a drilling fluid. Consequently, our prediction model shows that we now have a “good” fluid behavior. This categorization indicates that the fluid under consideration has little or no tendency to undergo weighted material settling in any significant amount.

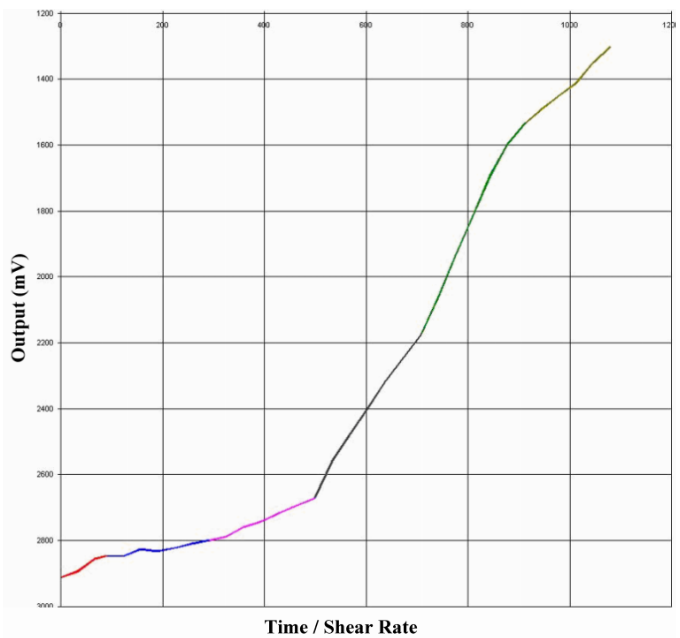

Figure 1. Sample DHAST Data Output

The DHAST data for **Fluid 2** shows several iterations of additive additions. This study is an excellent example of how DHAST has been utilized to optimize a treatment program. As will be shown, it is important to note that this same optimization would not have been possible using standard rheology and filtrate data.

The initial **Fluid 2** sample was categorized as an atypical fluid with a fairly low angle (18°). The overall sag rate for this sample was very high at low shear. This is an indicator that the drilling fluid will have a tendency to sag. This confirmed information from the rig, which indicated that this fluid was having some sag problems and that it needed to be addressed. Importantly, a glance at the rheological data does not indicate anything abnormal about the fluid. In fact, most cursory glances would say that the fluid was not “thin”, and would not have a tendency to sag – the opposite of the actual situation.

Fluid 2 was treated with a typical treatment for this type of fluid and mud weight. The treatment (Treat 1) provided an exceptional drilling fluid. The DHAST indicated good fluid (low or no sag) behavior. The results were so good that we decided to reduce the initial treatment (Treat 2). Removing 1 lb of suspension agent had no measurable effect on the categorization, but our angle calculation shows there is a slightly increased tendency to sag in more highly deviated holes. From a dynamic sag test viewpoint, the fluid was good, but part of the treatment protocol was to have the treated fluid’s rheological properties similar to those of the submitted fluid. To achieve this and still keep the sag tendency acceptable, the emulsifier part of the treatment was eliminated (Treat 3). The loss of 2 lbs of emulsifier from the treatment increased the rheology and to nearly identical levels to those in the original submitted sample. Of interest though is the DHAST data, which indicated a good fluid behavior with respect to sag and with an improved angle calculation. This is an important observation since it indicates that while the classical rheology measurements are consistent between the original sample and the third treatment, the tendency to sag has been significantly reduced.

Determining a fluid treatment that prevents sag in the field is a critical part of the drilling fluid industry. From an economic standpoint, mistreatment or no treatment of sag can result in costly events ranging from increased fluid losses into the formation, stuck pipe, and a possibly disastrous loss of well. However, here we have shown an example where a dynamic sag test has allowed us to optimize a sag treatment and reduce the amount of additive per barrel of fluid. Given that the well in question was at a depth of 20,000 ft, and this equates to an opportunity that could save an operator greater than $50,000 in drilling costs, this is money saved drilling with a relatively inexpensive diesel-based fluid. While the reduced additive costs amount to approximately $25,000-$30,000, further savings may be collected because the reduced rheology of this treatment could easily prevent lost returns. In addition, there can be an overall improved efficiency of the drilling process that would accompany the treatment.

Conclusions

We have shown that dynamic high angle sag testing is a powerful tool that can be used to help determine the propensity of a drilling fluid to sag. In particular it is very effective in predicting settling characteristics of fluids that would appear to have no-sag tendency using classical rheology methods. Finally, the sensitivity of this instrument allows the iteration of treatments such that recommendations of treatment can be optimized based not only rheology and filtration concerns, but also with respects to sag, and ultimately cost to the operator.

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Nomenclature

DHAST = Dynamic High Angle Sag Test

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