TUDRP

Predicting Dynamic Barite Sag in Oil Based Drilling Fluids

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This report is prepared for TUDRP Advisory Board Meeting November 13-14, 2006, Tulsa-Oklahoma.

Background of the investigator

2002 – 2004: M.S. of Chemical Engineering at Bach Khoa University, Vietnam – graduation on December 2004

1996 – 2001: B.S. of Chemical Engineering at Bach Khoa University, Vietnam – graduation on March 2001

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Introduction

Barite sag continues to be a recurring, potentially serious problem on many directional wells. It could lead to a variety of major drilling problems, including lost circulation, well-control difficulties, poor cement jobs, and stuck pipe. The term "barite sag" is used because barite is the traditional weight material used in drilling fluids to increase the density. Nowadays, there are barite substitutes like: Micromax (manganese tetraoxide), Hematite, Calcium carbonate, Ilmenite (iron titanium oxide) among others. However, Barite is the most widely used weight material it offers high density with wide availability, favorable economics, and it is evirormentaly friendly.

Unfortunately, barite sag is proving to be a real question for drilling industry. The physics of the phenomenon are deceptively complex, and the problem is often unanticipated. Although much has been done, we have no universal solutions. Moreover, recent advances in drilling technology have resulted in greater numbers of directional wells. These wells are effectively limiting the application of common remedies to mitigate sag.

Sag is not fully understandable since it is affected by many parameters and their interactions are difficult to quantify. While the importance of mud rheology is well known, attempts to find the key rheological parameters have not been completely successful. Additionally, annular velocity, density of drilling fluid, eccentricity, and rotation speed of drill pipe clearly affect the barite sag, but there is not a correlation that combines these paremeters. Furthermore, lack of industry standards to measure and report barite sag has limited the availability of usable field data. Sound engineering strategies and guidelines have helped, but clearly more developments are necessary.

Problem statement

With consideration to eliminating drilling problems such as torque and drag, stuck pipe, and well-bore stability, increasingly wells are being drilled with invert emulsion, oil base muds (OBMs) or synthetic base muds (SBMs). From field experience, more sag problems are encountered with oil based muds (OBMs) than with water base muds (WBMs). First, OBMs are generally more viscous than WBMs[3], and efforts are made to reduce viscosity by minimizing additives used for suspending barite. Second, invert base muds do not develop gel strengths in the same manner as WBMs[4, 9]. As the result, the frequency of problem associated with barite sag is higher with OBMs, compared to water-based systems. Therefore, more research analyzing the use of barite sag in conjunction with OBMs drilling fluids is encouraged.

According to Scott[4], attempts to find the key rheological parameters, especially low shear rate, have not been completely successful. Table 1 demonstrates annular velocity, drillpipe rotation and inclination angle are three important parameters affecting dynamic sag. In addition, each paper analyzes different ranges of inclination angle. Moreover, the combined effects of hole-angle, low annular velocity and drillpipe rotation are conducive to study dynamic barite sag[6]. Therefore, this project will focus on identifying a correlation for predicting dynamic sag in OBMs by analyzing the combined effects of hole angle, low annular velocity, rotational drill pipe and rheology of drilling fluid.

Table 1: Comparisons between annular velocity, rotation speed, and inclination angle

	Annular velocity, v	Rotation speed, rpm	Inclination angle
Hanson et al.[1]	Beds rarely formed when flow was turbulent		Slumping was most prevalent at 45 - 50^0
Bern et al.[6]	Barite sag can be exacerbated by low annular velocity	Barite sag can be exacerbated by stationary drillpipe	The most critical range was 60 – 70^0
Hemphill et al.[3]	The most severe dynamic barite sag was ~ 30 ft/min	The onset of dynamic barite sag occurs at $\gamma < 4\ s^{-1}$ (< 3rpm)	Dynamic barite sag increased as 45 - 60^0

Bern et al.[6] introduced a model to predict barite sag.

$$\frac{1}{R_s} = Y_0 + (1 - Y_0)(1 - t)^a \qquad \text{With} \qquad \frac{1}{R_{st}} = \frac{1}{\exp\left(50\frac{\Delta m_t}{m}\right)}$$

Where Δm_t (lbm/gal) is the change of mud weight at time t, m (lbm/gal) is the initial mud weight, t is time in hours, the exponent "a" is the rate of sag, R_{st} and R_s are modified sag register for experiment data and modeled modified sag register. Y_0 is defined as the value of $1/R_s$ after one hour of testing. Y_0 increased with increasing pipe rotation and velocity, indicating decreasing sag for increased flow and pipe rotation. This model was found to be an excellent match for the wide range of data. The authors mentioned that Y_0 is a function of pipe rotation and annular velocity. However, the effect of drill pipe rotation, annular velocity and hole angle on Y_0 is still unknown. Hence, further analysis of this model should be conducted.

Objectives

1. To investigate the effects of oil base mud rheology, annular velocity, rotational drillstring, and inclination angle on barite sag.
2. To develop the correlations and mechanistic models for predicting dynamic barite sag by analyzing the combined effects of drilling fluid rheology, annular velocity, rotational drillpipe, and inclination angle

Preliminary Literature Review

Most papers[1, 2, 4, 6, 7] agreed that the phenomena of barite sag in inclined tubes are similar to the phenomena that were discovered by Boycott. He reported in 1920 that blood corpuscles settled faster in inclined test tubes than in vertical ones. Particles settle vertically even when the tube is inclined. A thin layer of clarified fluid appears immediately below the upper wall and another clarified region develops at the top of the fluid. Particles settle out of the suspension zone and form a sediment bed. Coincident with a downward slide of the bed, a resulting cross sectional density gradient generates a pressure imbalance. This causes convection currents which drive the lighter fluid up and the bed down, accelerating settling in the suspension zone. The combined downward flow and slide of the bed is called slumping.

Hanson et al[1]. focused on practical guidelines to prevent sag and they recognized that preventing dynamic sag is more difficult than preventing static sag. Furthermore, they discovered that the sag tendency was significantly higher in deviated wells than in vertical ones. Low velocities resulted in thicker accumulations and beds rarely formed when flow was turbulent. At angles from vertical of 30-60^0, the sag beds slumped opposite the direction of flow at low flow rates. Slumping was most prevalent at 40-50^0. At higher angles, slumping did not occur even if the bed accumulation was significant. At high velocity, particularly when turbulence was observed, sag beds were removed and incorporated back into the mud.

Hemphill et al.[3, 5, 8] focused on dynamic sag and they concluded that: (1) The onset of dynamic barite sag occurs at shear rates less than 4 s^{-1} in deviated well-bore, using invert-emulsion mud. (2) Dynamic barite sag generally increased as hole angle increased from 45 to 60^0. (3) Ultra-low shear rate viscosity appears to have a greater influence on dynamic barite sag than mud weight. (4) Dynamic barite sag was generally low at annular velocities above 100 feet/minute. (5) There is no apparent trend between mud weight and levels of dynamic sag. (6) Rheological properties taken from 6-speed viscometers did not correlate with dynamic barite sag potential.

Bern et al[6] studied dynamic sag and also gave the operational guidelines to minimize the sag. The authors realized that: (1) barite sag can be minimized by attention to detail in the following key areas: well planning, mud properties, and operational practices. (2) Barite sag and hole cleaning are related in principle, but are distinguished by their bed characteristics. (3) Barite beds are more responsive to removal by mud velocity and pipe rotation than most cutting beds. (4) Barite sag can be exacerbated by low annular velocities, eccentric, and stationary drillpipe. Also the authors introduced a new model to predict barite sag and this one was found to be an excellent match for the wide range of data (see the problem statement).

Recent studies, Tor Henry Omland et al., and Arild Saasen presented that if the traditional calcium chloride $CaCl_2$ salt was replaced with a selection of other salts in invert-emulsion fluids, the sag stability could be affected significantly. The following salts were used in the brine phases: $CaCl_2$, sodium formate (HCOONa), potassium formate (HCOOK), and $NH_4Ca(NO_3)$. They recognized that using $NH_4Ca(NO_3)$ salt for the internal phase provides the best sag stability of the fluids tested in this study.

Tools to predict and manage barite sag

Rheology of drilling fluids

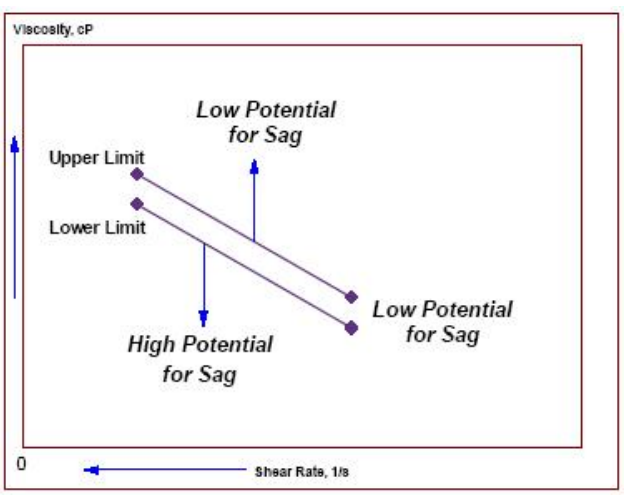
Saasen et al.[2] attempted to see the relationship between sag ability and Fann rheology measurements. They plotted the static sag, presented by the sag number (see the definition of sag number in appendix), as a function of the 3 RPM Fann reading and 10 min gel reading for several drilling fluids. The results showed that there are some correlations between measured gel, shear rate and observed sag. Similarly, they also plotted dynamic sag (also presented by sag number) with 3 RPM Fann reading and the result indicated that viscosity can play a role in avoiding dynamic sag.

Dye et al.[3] focused on dynamic conditions and they recognized that the onset of dynamic barite sag occurs at shear rate less than 4 s^{-1} in deviated well-bores.

A common theme in the published literature is that low shear rate viscosity is a rheological parameter of importance in determining the capacity of a drilling mud to minimize or prevent the occurrence of barite sag, particularly dynamic barite sag. Interestingly, according to Scott et al.[4], mud rheology probably by itself will never totally prevent sag regardless of how much money is spent.

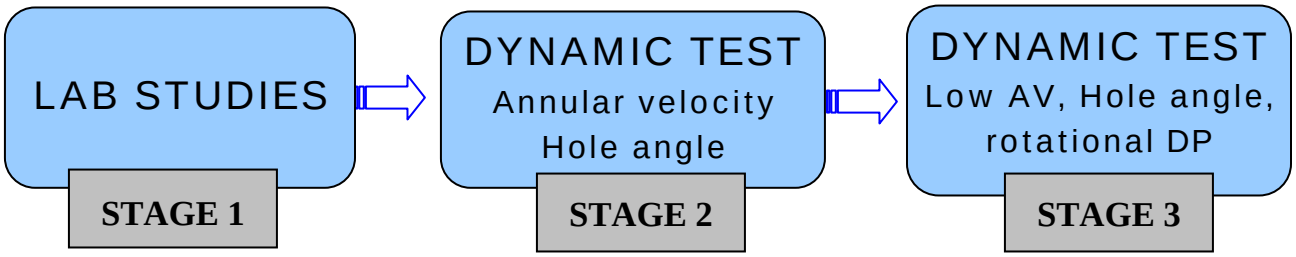
Prevention Window PW (Dynamic sag window DSW)

A Prevention Window (PW) was developed By Dye et al.[3] as a tool to predict dynamic barite sag ability through direct ultra-low shear rate viscosity measurements. Since dynamic barite sag and rotational viscosity measurements were made at equivalent shear rates, it was reasoned that one could predict dynamic barite sag probability by comparing rotational viscosity to the limits of the PW. Viscosity levels (viscosity of drilling fluid) below the lower limit of the "Prevention Window" correlate with severe dynamic barite sag. Conversely, viscosity levels above the upper limit indicate a low potential for dynamic sag but are excessive in terms of requirements for barite sag prevention. Finally, viscosity levels within the limits of the "Prevention Window" are preferred, and indicate a low probability for dynamic barite sag.



Approach

In considering the effects of pipe rotation, low annular velocity, hole angle, and rheology of drilling fluid (OBMs), this project will consist of three main stages that include both experimental as well as theoretical study.



Stage one: The purpose of this stage is to become more familiar with OBMs and also to study the different physics phenomena of barite sag in Newtonian fluid (water) and non-Newtonian fluid (WBMs and OBMs) by using a microscope. The correlations to compute the time for settling of barite in a vertical tube in water, and OBMs will be investigated (time permitting). In addition, the number of tests will be designed by using statistical methods to optimize them. In this way, the number of dynamic experements will be considerably simplified.

Stage two: The drilling fluid parameters including density ρ, flow index n, consistency index K, and yield stress τ_0 will be identified for each fluid. In this dynamic test, the affects of rheology of OBMs, low annular velocity and hole angle on barite sag will be studied. This test will not consider the pipe rotation.

The sweep loop that is available in TUDRP will be modified for this test. The schematic of the testing set up is provided in appendix. The test procedures will be performed flowing steps:

1. Mix drilling fluid in the mud tank and take the samples to measure density ρ, flow index n, consistency index K, and yield stress τ_0.
2. Adjust the test section to the desired angle θ.
3. Circulate the fluid with high velocity to make it uniform.
4. Reduce the flow rate to get the desired annular velocity v and circulate the fluid with the constant velocity v.
5. After time τ_1 measure density at the bottom and the top of the test section by using two nuclear densitometers.
6. Flush test section by circulating at maximum flow rate and confirm the density is uniform
7. Reduce the flowrate to zero
8. Remain static for a time τ_2 and measure the density at the top and bottom.

Stage three: Based on the results from the second stage, the best ranges of annular velocity and inclination will be identified. These ranges combined with rotational drill pipe will be tested similar to stage two.

Analyzing these data will give the correlations and mechanistic models of combined effects of hole angle, annular velocity, rotational drillpipe and rheology of OBMs for predicting dynamic sag in oil base drilling fluids. The loop will be modified again for pipe rotation.

Deliverables

Advisory Board Meeting Progress Reports

Experimental data from the loop without pipe rotation

Experimental data from the loop with pipe rotation

Correlations for predicting dynamic barite sag

Final report

Scope of work

Because of the current facility in TUDRP, the project will not cover the effect of temperature on dynamic sag.

Preliminary time table

	2006	2007			2008
	Fall	Spring	Summer	Fall	Spring
Literature review					
Lab working					
Flow loop without pipe rotation set up					
Dynamic tests without pipe rotation					
Flow loop with pipe rotation set up					
Dynamic tests with pipe rotation					
Correlation for dynamic barite sag					
Final report					

References

1. P.M Hanson, Fluids; T.K Trigg Jr., Mobil E&P Services; and G. Rachal and M. Zammora, M-I Drilling Fluids: "Investigation of Barite Sag in Weighted Drilling Fluids in Highly Deviated Well" paper SPE 20423 presented at the 65th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers held in New Orieans, LA, September 1990

2. Arild Saasen, *RF-Rogaland Research; Dawei Liu, Liao He Oilfield; C.D. Marken, *Njal Sterri and G.W. Halsey, *RF-Rogaland Research; and Patrick Isambourg, Elf Petroleum Norge "Prediction of Barite Sag Potential of Drilling Fluids from Rheological Measurements" paper SPE SPE/IADC 29410 presented at the 1995 SPE/IADC Drilling Conference Held in Amsterdam, February 1995.

3. William Dye, Terry Hemphill*, William Gusler and Gregory Mullen*, Baker Hughes INTEQ *SPE members "Correlation of Ultra-low Shear Rate Viscosity and Dynamic Barite

Sag in Invert-Emulsion Drilling Fluids" paper SPE 56636 presented at the 1999 SPE Annual Technical Conference and Exhibition held in Houston, Texas, October 1999.

4. Paul D. Scott, SPE, Marathon Oil Company; Mario Zamora, SPE, M-I L.L.C. and Catalin Aldea, SPE, MM-I L.L.C. "Barite-Sag Management: Challenges, Strategies, Opportunities" paper SPE IADC/SPE 87136 presented at the IADC/SPE Drilling Conference held in Dallas, Texas, U.S.A. March 2004

5. W. Dye, SPE, G. Mullen, SPE, and W. Gusler, SPE, Baker Hughes Drilling Fluids "Field-Proven Technology To Manage Dynamic Barite Sag" paper IADC/SPE 98167 presented at the IADC/SPE Drilling Conference held in Miami, Florida, U.S.A., February 2006.

6. P.A. Bern, Amoco; Eric Van Oort, SPE, and Beatrice Neustadt, SPE, Shell; Hege Ebeltoft, SPE, Statoil; Christian Zurdo, SPE, Elf; and Mario Zamora, SPE, and K.S. Slater, SPE, M-I Drilling Fluids "Barite Sag: Measurement, Modeling, and Management" paper SPE 62051 presented at the 1998 IADC/SPE Asia Pacific Drilling Technology Conference held in Jakarta, September 1998.

7. Tor Henry Omland, SPE, Statoil ASA; Tron Albertsen, M-I Norge AS; *Knut Taugbϕl, ** SPE, Arild Saasen, SPE, and Kare Svanes, Statoil ASA; and Per Amund Amundsen, U of Stavanger "The Effect of The Synthetic-and Oil Based Drilling Fluid's Internal Water Phase Composition on Barite Sag" paper SPE 87135 presented at the 2004 IADC/SPE Drilling Conference, Dallas, March 2004.

8. William Dye, SPE, Gregory Mullen, SPE, and William Gusler, Baker Hughes INTEQ Drilling Fluids "Drilling Processes: The Other Half of the Barite Sag Equation" paper SPE 80495 presented at the SPE Asia Pacific Oil and Gas Conference and Exhibition held in Jakarta, Indonesia, April 2003.

9. Arild Saasen, SPE, Statoil ASA "Sag of Weight Materials in Oil Based Drilling Fluids" paper IADC/SPE 77190 presented at the IADC/SPE 77190 presented at the IADC/SPE Asia Pacific Drilling Technology held in Jakarta, Indonesia, September 2002.

10. Terry Hemphill, Baroid product service line, Halliburton "Low Shear Rate Rheology: Clarifying Muddied Water" paper AADE-02-DFWM-HO-14, presented at the AADE 2002 Technology Conference Drilling & Completion Fluids and Waste Management held at the Radisson Astrodome Houston, Texas, April 2002.

Appendix

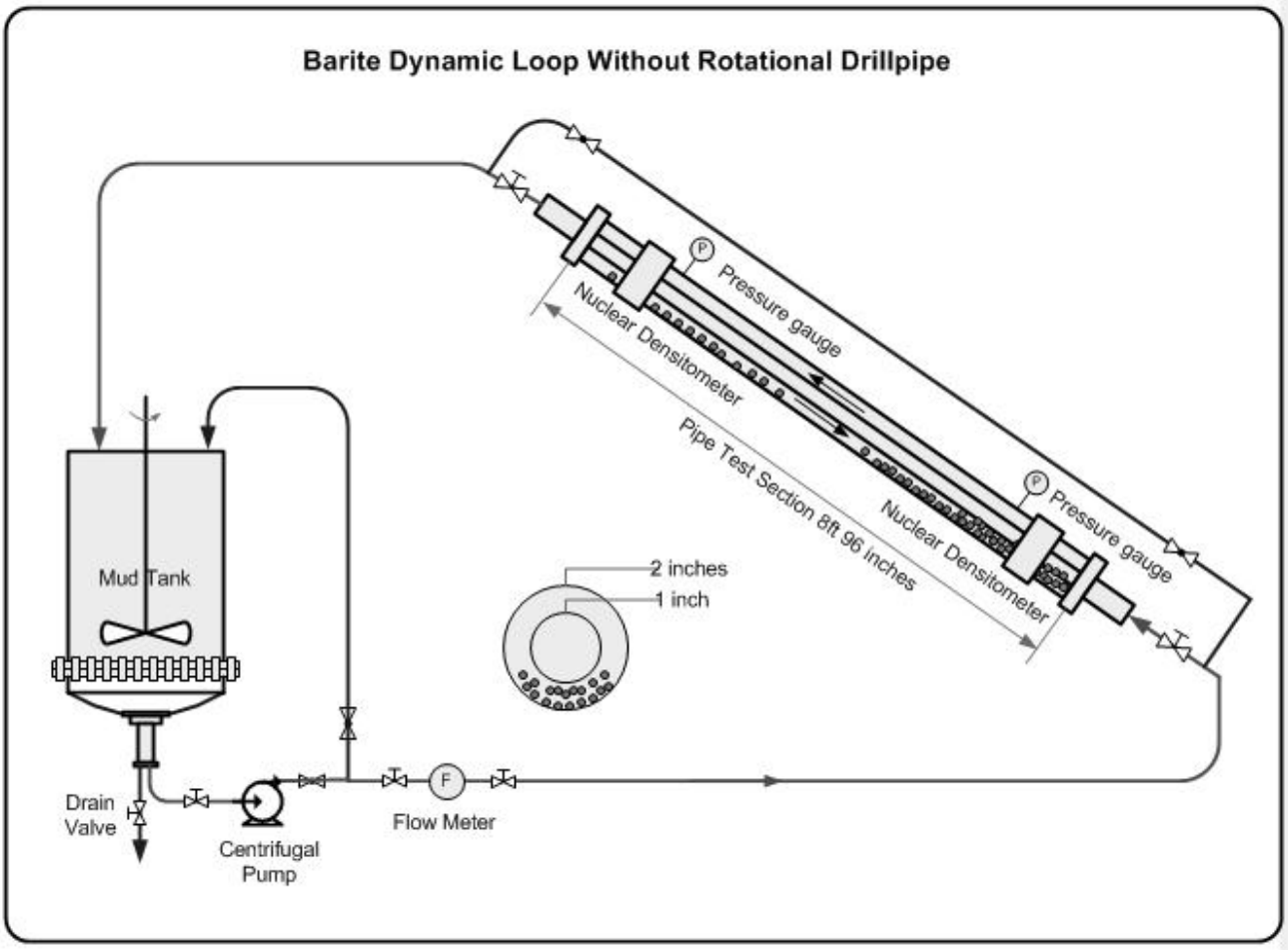


Figure 1 – The schematic flow loop modified from sweep loop without drillpipe rotation

Fig. 2 – Sweep loop without rotational drillpipe

Saasen et al.[2] developed the term "sag number". The sag number needs to reflect the changes in density over the length of the sag cell. The sag number was generated by the following three steps:

1. The average of all density readings minus the average of the density at positions A1, A2, and B1
2. The average of all density readings minus the average density at positions C4, B5, and C5
3. The sag number is the average of the absolute value of these two calculated differences.

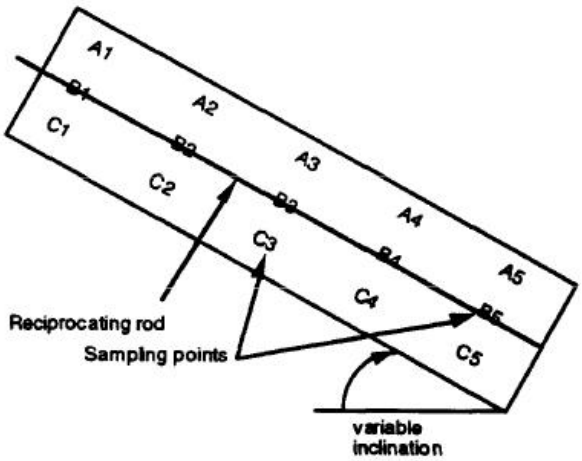


Fig. 3 - Schematic view of sag cell