AADE-06-DF-HO-28

Turning on Barite Sag with Drillpipe Rotation: Sometimes Surprises Are Really Not Surprises

Terry Hemphill and Kris Ravi, Halliburton

Abstract

Barite sag, especially dynamic barite sag, continues to be a problem for the drilling industry and efforts to deal with it consumes much non-productive time and revenue. Barite sag is not a clearly understood or predictable phenomenon, yet recent advances in fluid dynamics modeling have begun to shed some light on the various mechanisms that lead to its occurrence.

One of the major mechanisms that can induce barite sag is drillstring rotation. Often in the field, while waiting on weather, waiting on materials to arrive, etc., operators will circulate the open hole slowly and rotate the drillstring to prevent differential sticking. A consequence of this practice is that, for an unconditioned drilling fluid, continued rotation of the drillstring at low speeds promotes the occurrence of barite sag. Often operators are caught unawares of what is happening downhole.

In this paper, a model to predict the effect of slow drillstring rotation is discussed. As a part of the modeling, the changes in annular velocity patterns and viscosity with drill string rotation are shown. In addition, the usefulness of minimum drillstring rotation speeds that can inhibit the occurrence of dynamic barite sag are discussed.

Introduction

In the oilfield literature, there has been some work done on the effect of rotation of the drillstring on various properties in the annulus[1,2,3,4]. Much of this work has centered on investigation of changes in circulating pressure drop with drillstring rotation speed in support of slim-hole drilling efforts. Much of this work centered on the modeling of Newtonian fluids.

Recently new work[5,6] investigated the effects of drillstring rotation on local fluid velocity of non-Newtonian fluids in laminar flow where the axial and rotational velocities were coupled. From the coupled velocities, local fluid shear stresses and pressure drop at the conduit walls were determined. Both concentric and eccentric drillstring cases were discussed in these newer works. Previous work on the modeling of barite sag[7] has shown the link between fluid velocity near the conduit wall and the severity of dynamic barite sag. The work showed that the key factor to determine dynamic barite sag is the fluid shear stress at the conduit wall: values of shear stress were inversely proportional to barite sag severity. In high-angled wellbore, where the bulk of incidents of barite sag are known to occur, the key area for study is the region lying immediately below the drillstring, where, due to the effects of gravity, the annular gap is most constricted, particles tend to accumulate, and axial velocities are lowest.

In this paper, the effects of drillstring rotation in an annulus having no axial flow are investigated. Fluid rheological properties and wellbore geometry values shown in **Table 1** are maintained as per the earlier papers for consistency reasons. Changes in fluid velocity, shear stress, and viscosity are modeled in order to demonstrate the link between dynamic barite sag development and drillstring rotation speed. As with previous work, modeling is shown for both concentric and eccentric cases. Low drillstring rotation speeds of 5-25 rev/min are used in this paper, since there is a strong link between low rotation speeds and barite sag incidence.

Drillstring Rotation in Concentric Wellbore

When a drillstring is rotated in a static fluid, i.e. with no axial flow, localized fluid velocities are generated throughout the annulus. In the modeling presented here, it is assumed that there is no gellation occurring at the conduit walls. The predicted velocity distribution for the concentric wellbore case is shown in **Figure 1**. Fluid velocities in the annulus are calculated for five slow rotation speeds (5 – 25 rev/min) and all necessarily have zero (0) value at the wellbore wall. Because of the concentric geometry, fluid velocity patterns across the annular gap will be the same at all positions around the rotating drillstring. As expected, the higher localized velocities across the annular gap are associated with the higher drillstring rotation speeds.

In previous work on barite sag occurrence in fluids subject to axial flow only, it has been strongly suggested that fluid viscosity plays an important role in dynamic barite sag development[8]. In this study of fluid behavior without axial flow, the role of fluid viscosity was evaluated as well. In **Figure 2**, the results for the concentric geometry case are shown. Because the drilling fluid near the rotating drillstring is moving fastest, as was demonstrated earlier, the resulting fluid viscosity is lowest. As the fluid velocities decrease across the annular gap, then the fluid viscosities increase to a maximum at the conduit wall. Particle settling velocities and consequently barite sag development would be expected to be low in a high-viscosity environment. What this means in practical terms is that, under conditions of pipe rotation in 'static' drilling fluid where shear is low, fluid viscosity alone cannot explain the onset and development of dynamic barite sag.

As discussed earlier, the role of fluid shear stress at the wellbore wall has been shown to be of key importance to barite sag development. In **Figure 3**, the calculated fluid shear stresses across the concentric annular gap are shown for five drillstring rotation speeds in the static drilling fluid. For the fluid having the rheological properties given in **Table 1**, the fluid shear stresses for the modeled cases are predicted to range between 3.8 and 4.4 Pa (7.9 - 9.2 lb_f/100 sq ft). The lower drillstring rotation speeds produce the lower shear stress values, and consequently provide a more severe environment for barite particles to settle. The exact drillstring rotation speed needed to initiate or produce barite sag in this example would still need to be determined.

Drillstring Rotation in Eccentric Wellbore

Barite sag has been rarely known to occur in concentric wellbore, but rather nearly always in high-angled wellbore where much of the drillstring lies in an eccentric position. Hence any modeling of dynamic barite sag occurrence should be performed under eccentric conditions. In this study, because the modeled rates of drillstring rotation are low (5-25 rev/min only), it is assumed that the drill string is lying near the low side of the hole (deviated wellbore assumed). The bulk of the drillpipe joint does not lie immediately against the wellbore wall due to tool joint standoff. Accordingly, an eccentricity value of 0.7143 is assigned to the rotating drill string.

In **Figure 4**, the distribution of fluid velocity across the annular gap immediately under the rotating drillstring is shown (velocity opposite the tool joints excluded). Here, because the annular gap is narrowest, the fall in fluid velocity, and consequently shear rate, across the gap is sharp. Compared to the concentric geometry case shown earlier, the effects of geometry on rotational velocities are much more pronounced. As was seen earlier in the concentric case, the higher rotation speeds produce the higher velocities across the gap.

The effect of drillstring rotation on fluid viscosity, shown in **Figure 5**, follows the general pattern seen earlier for concentric wellbore: the higher fluid viscosities are seen near conduit wall and the lower viscosities are found immediately next to the rotating drillstring. A significant drop in fluid viscosity is seen when drillstring rotation speed is increased from 5 to 10 rev/min, and thereafter the decrease in fluid viscosity is not that drastic. Because of the geometry effects, the levels of and range in fluid viscosity with drillstring rotation are much less for the eccentric case than for the concentric case.

The effects of drillstring rotation speed on fluid shear stress in an eccentric wellbore case are shown in **Figure 6**. Here, as in the concentric geometry case, the lowest shear stress levels are those having the lowest drillstring rotation speeds. However, the spread in fluid shear stress with drillstring rotation is greater for the eccentric geometry case than for the concentric geometry case. In practical terms, this means that the ability to change fluid shear stress levels with drillstring rotation in at least a part of the annulus is easier when the geometry is eccentric. With increased fluid shear stress under the drillstring provided by rotation at higher speeds, fluid suspension characteristics improve and the likelihood of development of barite sag is lessened.

Dynamic Barite Incident

On a well drilled in the North Sea in 2005, an incident of barite sag occurred in a low-toxicity oil-based mud (LTOBM). This incident fit the general pattern of barite sag as noted in the industry literature:

- LTOBM was used
- Hole angles were high
- First noted after a long trip out of the hole while running in
- Rollercoaster effect in fluid density (MW) coming out of the hole: first light MW, then heavy MW, then light MW, then heavy MW, etc.
- Lessening of the effect with circulation time.

In this well, variations in fluid density caused by the sag problem ranged between 120-250 kg/m^3 (1-2 lbm/gal). Samples of the fluid were sent to the Houston laboratory for testing on the Dynamic High-Angle Sag Tester[9] (DHAST). In this unit, small samples of drilling fluid are subjected to rotation of an inner pipe (without axial flow) at a fixed angle of 45° from vertical. The rotation serves to generate a low shear rate environment in which barite particles could settle and slip down the tube. Movement of the center of mass of the fluid down the tube, described as a sag coefficient and given in units of mm/hr, is correlated with barite sag development. Fluids prone to sag development will exhibit high sag coefficients while those not prone to sag will exhibit little-to-zero sag coefficients.

Figure 7 shows the experimental results obtained during the test for the LTOBM. Clearly one can see the link between barite sag development and drillstring rotation speed for drilling fluids prone to sag, with the highest sag rates reported at the lower rotation speeds. The experimental results clearly show that the LTOBM tested was prone to sag and is in agreement with the modeling approach presented and discussed.

As part of a larger study of the barite sag occurrence on the well, testing was performed in the laboratory in which the drilling fluid properties were measured under simulated downhole conditions using a high-pressure high-temperature (HPHT) viscometer. Using the six-speed viscometer readings under the HPHT conditions, the fluid rheological parameters were calculated as reported in **Table 1**. The low shear rate environment provided by low rotation speed best simulated conditions at the well during the time of barite sag. Therefore the effects of slow rotation were used to study or predict barite sag occurrence.

In **Figure 8**, the fluid shear stress levels calculated using the fluid downhole rheological properties are shown. These values range from 3.1 – 3.6 Pa (6.5-7.5 $lb_f/100\ ft^2$). As with the shear stress results shown earlier for both concentric and eccentric cases, values of fluid shear stress at the conduit wall are lower than those near the rotating drillstring.

Such information can be used to stay out of trouble in the field. If, for example, modeling results recommended a minimum value of fluid shear stress at the conduit wall of 3.5 Pa (7.3 $lb_f/100\ ft^2$) in order to avoid occurrence of barite sag, then the results in **Figure 8** demonstrate that pipe rotation speeds should be maintained at 25 rev/min or greater. Any pipe rotation at lower speeds could turn on the unwanted occurrence of barite sag, thereby making it no longer a 'surprise' but rather an expectation.

Conclusions

- The effects of drillstring rotation for 'static' fluids (those not experiencing axial flow) can be modeled for both concentric and eccentric cases. These results are valid for non-Newtonian fluids in laminar flow.
- With drillstring rotation, local velocities and fluid shear stress levels across the annular gap decrease with distance away from the rotating drillstring,
- Local fluid viscosities are lowest near the rotating drillstring and increase with distance across the annular gap. Fluid viscosities are highest at the conduit wall.
- The effects of drillstring rotation are complex but should be taken into account in order to better understand complicated field problems.
- There is a clear link between a low shear environment generated by pipe rotation speed and barite sag development, which can be clearly demonstrated in the laboratory.
- Previously-developed correlations for drilling fluid critical shear stress levels developed for axial flow can be used to predict dynamic barite sag occurrence in the field.

Acknowledgments

The authors thank Halliburton management for permission to publish this paper. The authors also thank the Baroid laboratory workers in Houston and Aberdeen for the experimental testing discussed in this paper.

Nomenclature

DHAST= Dynamic High Angle Sag Tester
ECD = Equivalent circulating density
HPHT = High-pressure high-temperature
LTOBM= Low toxicity oil-based mud
MW = Mud density / weight

References

1. Bailey, W.J. and Peden, J.M., "A Generalised and Consistent Pressure Drop and Flow Regime Transition Model for Drilling Hydraulics Suitable for Slimhole, Underbalanced and Horizontal Wells," paper SPE/IADC 39281 presented at the 1997 SPE / IADC Middle East Drilling Conference in Bahrain, 23-25 November.
2. Ooms, G. and Kampman-Reinhartz, B.E., "Influence of Drilpipe Rotation and Eccentricity on Pressure Drop Over Borehole With Newtonian Liquid During Drilling," *SPE D&C* (December 2000) 249-253.
3. McCann, R.C., Quigley, M.S., Zamora, M., and Slater, K., "Effects of High-Speeed Pipe Rotation on Pressures in Narrow Annuli," paper SPE 26343 presented at the 1993 SPE Annual Technical Conference and Exhibition in Houston, October 3-6.
4. Delwiche, R.A., Lejeune, M., Mawet, P., and Vigheto, R., "Slimhole Drilling Hydraulics," paper SPE 24596 presented at the 1992 SPE Annual Technical Conference and Exhibition in Washington, DC, October 4-7.
5. Hemphill, T. and Ravi, K., "Calculation of Drill Pipe Rotation Effects on Fluid in Axial Flow: An Engineering Approach", paper SPE 97158 presented at the 2005 SPE ATCE in Dallas (9-12 October).
6. Hemphill, T. and Ravi, K., "Pipe Rotation and Hole Cleaning in an Eccentric Annulus", paper IADC/SPE 99150 presented at the 2006 IADC/SPE Drilling Conference in Miami (21-23 February).
7. Hemphill, T. and Rojas, J.C., " Improved Prediction of Barite Sag Using a Fluid Dynamics Approach" paper AADE-04-DF-HO-20 presented at the AADE 2004 Drilling Fluids Conference in Houston (6-7 April).
8. Dye, W., Hemphill, T., Gusler, W., and Mulen, G., "Correlation of Ultra-Low Shear Rate Viscosity and Dynamic Barite Sag", *SPE D&C*, 16:1 (March 2001) 27-34.
9. Jamison, D., et al, United States Patent 6,584,833.

Table 1: Drilling Fluid and Operational Parameters Used in Simulations

Parameter	Units	Base Case	HPHTcase
Mud density	kg/m^3	1438	1438
Hole ID	in	8.5	8.5
Drill pipe OD	in	5	5
Drill pipe tool joint diameter	in	6	6
n		0.8	0.883
K	Pa sec^n	0.144	0.0603
τ_0	Pa	3.83	3.0
Eccentricity (ε)		0, 0.7143	0.7143
Pipe rotation	rev/min	5 – 25	5 – 25

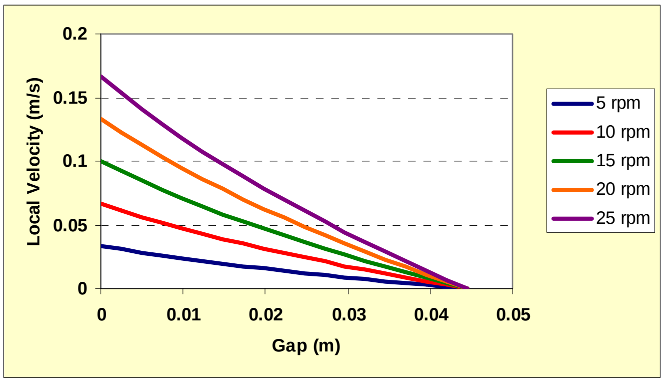

Figure 1: Local fluid velocities across the annular gap for 5 drillstring rotation speeds, concentric geometry case.

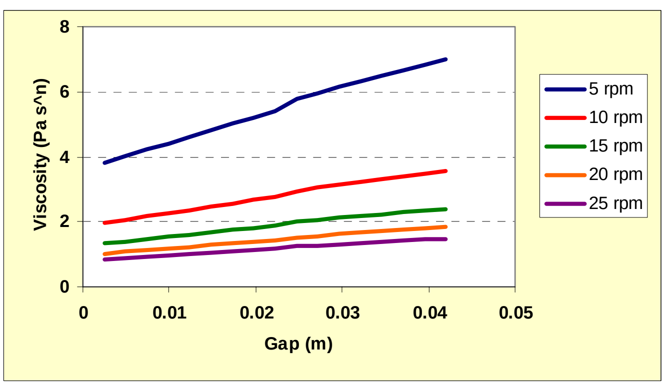

Figure 2: Local fluid viscosity across the annular gap for 5 drillstring rotation speeds, concentric geometry case.

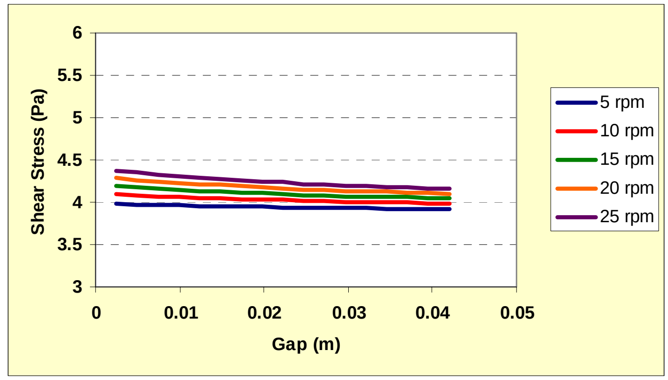

Figure 3: Local fluid shear stress values across the annular gap for 5 drillstring rotation speeds, concentric geometry case.

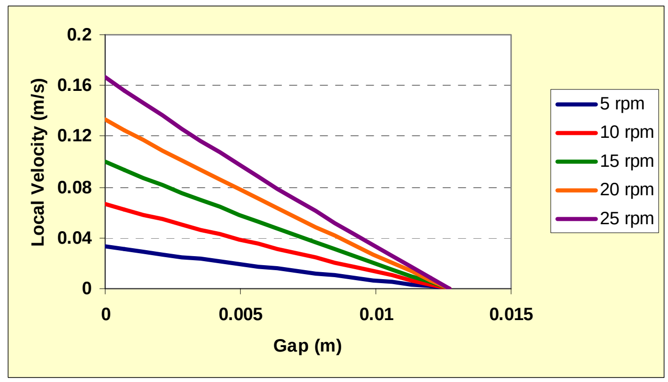

Figure 4: Local fluid velocity across the annular gap under the rotating drillstring for 5 rotation speeds, eccentric geometry case.

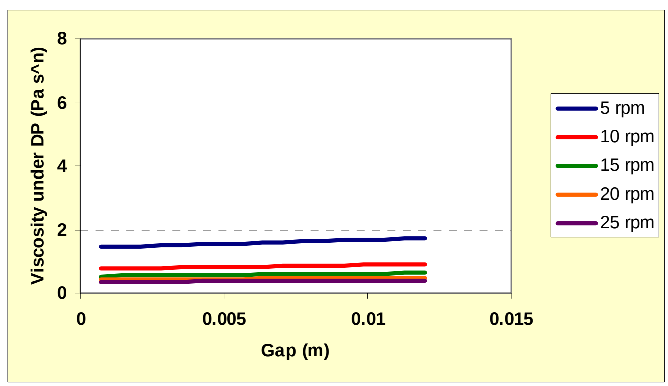

Figure 5: Local fluid viscosity across the annular gap under the rotating drillstring for 5 rotation speeds, eccentric geometry case.

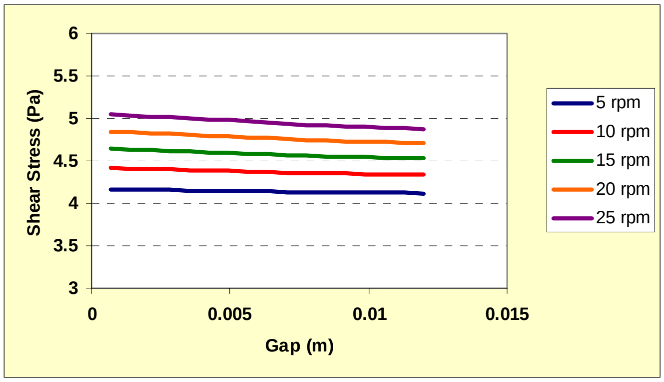

Figure 6: Local fluid shear stress values across the annular gap under the rotating drillstring for 5 rotation speeds, eccentric geometry case.

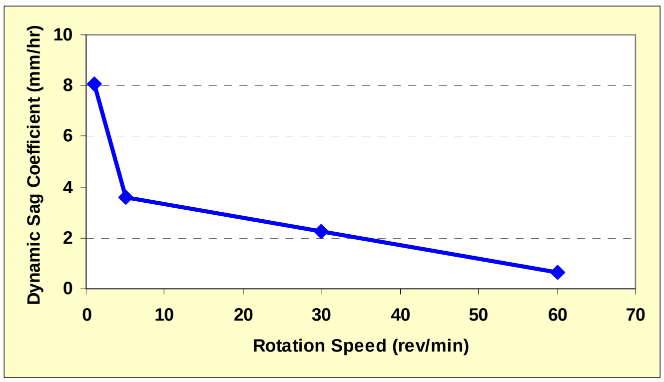

Figure 7: Pipe rotation speeds vs measured DHAST sag coefficients, North Sea LTOBM fluid.

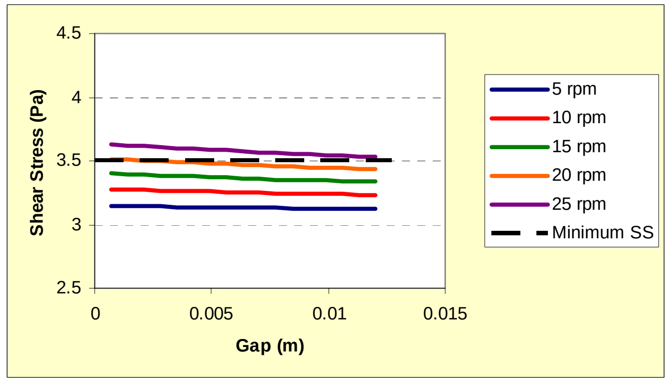

Figure 8: Local fluid shear stress values across the annular gap under the rotating drill string for 5 rotation speeds and minimum recommended fluid shear stress (dashed line), simulation of downhole HPHT conditions, North Sea LTOBM fluid.