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Optimization of Calcium Carbonate Particles and pH in Oil Based Drilling Fluids to Minimize Barite Sag

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Abstract

This study aims to optimize the mixing ratios of barite and calcium carbonate ($CaCO_3$) to reduce barite sag tendencies, while producing a proper equivalent circulating density (ECD). Oil based drilling fluid with various particle sizes and ratios of barite to $CaCO_3$ were mixed in this study. These fluid samples were then tested for the sag potential by using an API modified Viscometer Sag Shoe Test (VSST). A hydraulics simulator was also used to study the effect of the fluid rheological parameters change on ECDs for a standard well geometry. The results show that using the smallest 2-micron $CaCO_3$ particle yields the greatest barite sag mitigation when a mixing ratio between barite and $CaCO_3$ of 70:30 was selected. In addition, mixing the largest 40-micron-$CaCO_3$ particle yields a sag potential greater than that of 100% barite in all mixing tested ratios, but this ratio gave the lowest ECD. The effect of pH on barite sag was also investigated in this study. As the pH values of the samples decrease, sag is significantly increased due to the physical and chemical changes occurred in the drilling fluid. The results of this study will assist mud engineers in designing an optimized drilling fluid which has less sag potential, proper ECD, and a lower likelihood to invade permeable zones, which will prevent formation damage.

Introduction

Barite sag, also known as sag, is defined as the slow settling of barite or other weighting materials in drilling fluid (Saasen et al., 2002). Sag is a common problem within drilling and completion operations. Sag causes changes in the circulating density over time, which may lead to wellbore complications. Some complications include lost circulation, well control issues, as well as problems running casing or cementing (Nguyen et al., 2009). These complications can overcome the benefits of using API grade barite as the solitary weighting material.

API grade barite and calcium carbonate ($CaCO_3$) are two of the well-known weighting materials used in drilling and completion practices. Although there are many other weighting materials used in the industry, these two materials are usually the primary choice. API grade Barite is a mineral that is the most commonly used weighting material in drilling operations. API Barite offers advantages such as, unreactive with other drilling fluid chemical additives, and high specific gravity (SG = 4.2), resulting in less required volume for a higher desired fluid density. Having a high SG can also be a disadvantage when the settling of particles is problematic.

$CaCO_3$ is a mineral that is used as a bridging agent and/or weighting material in drilling and completion fluids. $CaCO_3$ has a SG of 2.7 - 2.8 and is manufactured in a variety of particle sizes. $CaCO_3$ is approximately 98% soluble in hydrochloric acid solution, which is a common inorganic acid used in formation pore stimulation. $CaCO_3$'s acid solubility minimizes the permanent plugging of producing formation pores after stimulation treatments have been conducted. A disadvantage of $CaCO_3$'s low SG is that more volume is needed to obtain higher fluid densities. An advantage to $CaCO_3$'s low SG is that the settling tendencies of the particles are low compared to that of API barite (Zamora, 2009).

During the course of a drilling operation, it is not uncommon for the drilling fluid to become contaminated. These contaminants often change the properties of the drilling fluid, especially the pH, which adversely affect the drilling operations. One of the common contaminant ions are carbonate and bicarbonate (CO_3^-, HCO_3^-). These contaminant ions come from drilling a CO_2-bearing formation, thermal degradation of organics in mud, or over treatment with soda ash and bicarbonate (Nyland et al., 1988). These contaminants cause the mud to have a decrease in pH. Another contamination is when drilling through salt sections or from formation saltwater. These contaminant ions also cause a reduction in drilling fluid pH. Often times adjustments have to be made to the drilling fluid on site to maintain a desired values of pH.

This study focuses on optimizing $CaCO_3$ and API barite to mitigate sag potential. In addition, the effect of pH on barite sag is also investigated.

Experimental Work

An Oil Based Drilling Fluid (OBDF) was prepared using the manufacturer's components recommendations. According to the manufacturer, an OBDF with a fluid density of 12ppg should have an oil/water ratio of 80:20 when barite is being used as the primary weighting agent. The exact quantities specified by the manufacturer are given in Table 1. All OBDF materials were mixed and tested using standard laboratory procedures and equipment recommended by API RP 13B-2.

The mass ratio of barite and $CaCO_3$ used in each sample were varied as follows: 100:0, 70:30, 60:40, and 50:50. Before mixing any test samples containing $CaCO_3$, a reference fluid was mixed using 100% barite (ratio of 100:0). This conventional OBDF mixture became the reference point for all future tests as this is widely recognized as an industry standard OBDF configuration. This fluid will be referred as the reference fluid throughout this paper. In addition to API grade barite, a range of $CaCO_3$ particle sizes varied from 1 – 48 microns were selected and mixed at different mentioned ratios.

Table 1: Manufacturer specified OBDF

Material	Quantity
Base Fluid	213.15ml
Water	52.5ml
Emulsifier	8g
Wetting Agent	2g
Lime	8g
Organophilic clay	3g
Filtration control additive	6g
Calcium Chloride	18.5g

After each sample set was prepared, sag was then measured in ppg using the modified Viscometer Sag Shoe Test (VSST). This test uses a rotational viscometer, Sag Shoe, and a thermos-cup. The modified VSST procedures were followed as per API RP 13B-2 recommendations. To quantify the sag potential by using the modified VSST, the Sag Number (SN) in pound per gallon (ppg) was used as presented in Eq. (1). The SN has been accepted widely by the oil and gas industry to check for the sag potential as well as to be correlated with the ECD.

$$SN = 0.834(MW_1 - MW_2) \quad (1)$$

where MW_1 and MW_2 are the initial and final mass of the sag fluid in grams in the collection well of the sag shoe after the VSST has concluded, respectively.

The second part of this experimental study focuses on the influence of pH on barite sag without the presence of $CaCO_3$. The pH values of the previously mixed samples were reduced from a value of 8 – 4 at different concentrations of calcium chloride ($CaCl_2$). The chemical used to reduce the pH value of the fluid samples was hydrochloric acid (HCl). The fluid samples were changed from a basic alkaline solution to an acidic solution. The sag shoe test was then carried out on the new samples. The SN was then analyzed at different $CaCl_2$ concentrations and different pH values.

Results and Discussion

The fluid rheological properties were the first parameters to be tested and compared to the reference fluid of 100% barite. All the tests were conducted at the temperature of 120 ^{o}F. Fig. 1 shows the rheological comparison of different fluid samples, which have different $CaCO_3$ particle sizes. The results show that the sample, which has the smallest size of $CaCO_3$ of 2-microns, generates the highest rheological property. The rheological property of the 20-micron and 40-micron-samples are very similar. This is an expected result due to the inter-particle reactions occurring when the small particles of the $CaCO_3$ interact with the fluid. The smaller the particle size, the higher the number of particles in a specific volume there is. This leads to higher colloidal encounters to occur, affecting the way the fluid behaves rheologically (Omland et al., 2009, and Hemphill et al., 2009).

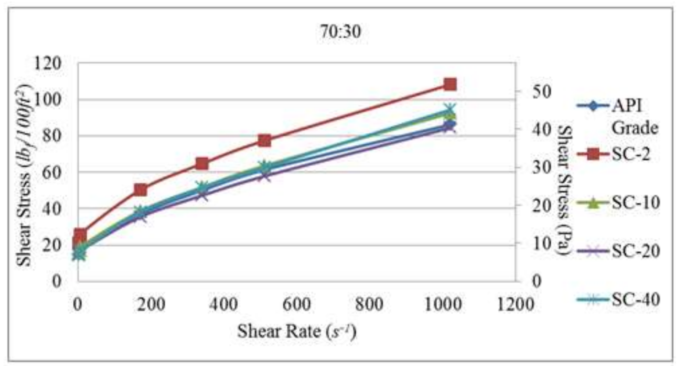

Figure 1: Comparison of tested fluids rheology in the 70:30 ratio configuration, with all $CaCO_3$ particle sizes and reference fluid represented

The next tested parameter was the sag number. As reported in the Experimental Work section, the SN is measured in ppg and calculated using Eq. (1). Fig. 2 illustrates the effect of $CaCO_3$ particle sizes on the SN in the mass ratio between barite and $CaCO_3$ of 70:30. Each bar in the figure represents a fluid sample tested with its corresponding weighting material specifications. Each ratio was tested three times for sag using the same fluid to check for the consistency and irregularities. The uncertainty analysis was then carried out for each sample and reported as the 95-percent confident levels shown as red bars. The data reveals that using the 40-micron $CaCO_3$ generates the highest SN and even higher than that of the reference fluid (ratio of 100:0). The 10-micron and 2-micron $CaCO_3$ mixture offers a lower SN of 26% and 76%, respectively, in comparison with that of the reference fluid. Therefore, in terms of preventing sag, the 2-micron $CaCO_3$ is the most promising candidate out of all the tested particle sizes.

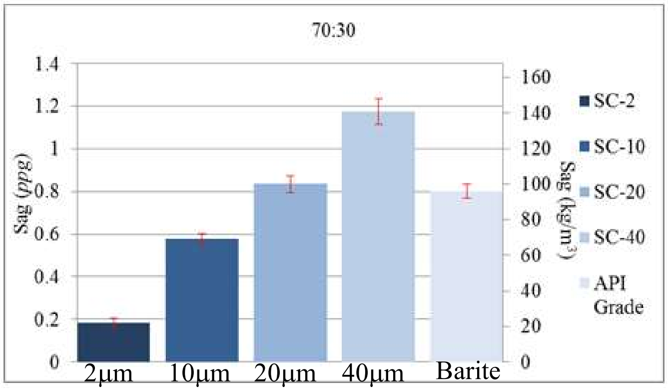

Figure 2: Comparison of sag number in the 70:30 mixture SC-2 represents the 2micron $CaCO_3$ particle size and so forth

Fig. 3 shows the effect of the mass ratio between barite and $CaCO_3$ on the ECD and the sag number of the 2–micron $CaCO_3$ particle size mixture. As the mass ratio changes from 100:0 to 50:50, the sag and ECD increase. The 70:30 ratio sample set shows to have a minimum SN and higher ECD than that of the reference fluid. The difference in SN between the reference fluid and the 70:30 ratio mixture is 0.62 ppg in the 2-micron sample set. This can be considered to be a relatively high difference when comparing this difference to narrow drilling windows. Some drilling windows have been reported to be 0.4 ppg (Naesheim et al., 2012). Therefore, being able to reduce the sag of an optimized drilling fluid to such extents could prove to be beneficial. Although, the ECD of the 70:30 sample is higher than that of the reference fluid, reducing the sag by such a significant amount could outweigh the effects of an increased ECD by mitigating Non-Productive Time (NPT) caused by sag. The 50:50 ratio of the 2-micron sample set resulted in the highest ECD difference when compared to that of the reference fluid, which was 0.37ppg. This result is considered to be high for the same narrow drilling window example previously mentioned. Therefore, the ECD in the 50:50 ratio would be unacceptable, because a minimal fluctuation in ECD could result in a costly NPT or safety imperative well control issues. Generally speaking, to mitigate the sag potential and to keep the ECD in an acceptable value, the 2-micron $CaCO_3$ with ratio of 70:30 is recommended.

The sag associated with the 40-micron and mixing ratio of 70:30 sample set is too high to be considered for use in a well with a narrow drilling window as shown in Fig. 4. However, the 40-micron and mixing ratio of 50:50-sample-set configuration could possibly have another benefit. Although, the SN increase of about 10%, the ECD has been reduced to about 3% with a reduction of 50% of insoluble barite. This means that in wells where sag is less of an issue, but pore invasion due to small particle size of weighting materials is a great concern, then this fluid could be a possible solution. The reduced ECD could minimally compensate for the increased sag. Moreover, this 50:50-ratio will reduce the pore invasion and insoluble barite in the fluid by 50%. The other ratio samples tested resulted in an increase in the SN of less than 8% and minor decrease in ECD compared to that of the reference fluid. This minor reduction in ECD would not compensate for the sag results. Therefore, these samples do not offer any significant findings.

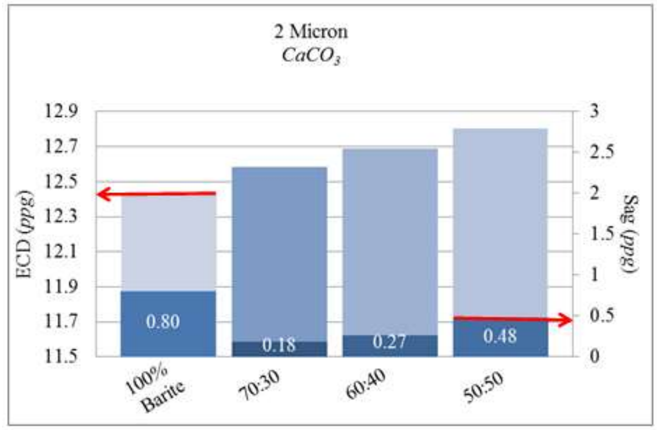

Figure 3: Effect of the 2- micron $CaCO_3$ particle size on the sag number and ECD

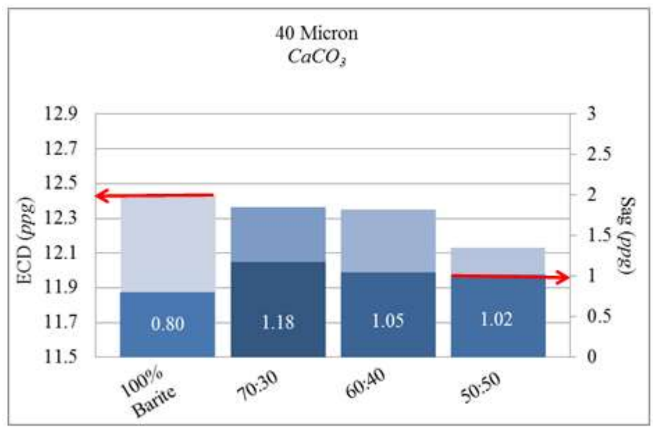

Figure 4: Effect of the 40- micron $CaCO_3$ particle size on the sag number and ECD

The effect of pH on the fluid rheological properties and sag potential of OBDFs (without $CaCO_3$) will be discussed in this section. Fluid samples with main compositions presented in Table 1 were used for conducting the experiments. The pH values were varied from 8, 6, 4, and 2 by increasing the concentration of HCl. In addition, the effect of Calcium Chloride ($CaCl_2$) on the sag potential was also investigated. Finally, filtration tests were conducted for all the tested samples. Fig. 5 shows that as the pH values decrease from 8 – 4, the yield point remains very similar, but the consistency index is increased. In other words, the fluid is more viscous as the pH values decrease. As a result, less sag potential and higher ECD would be expected. Filtration tests showed further that the fluid loss was about 50% more in comparison to that of the sample with pH value of 8. Observations also revealed that flocculation upon the reduction of pH occurred severely. The structure of the fluid was deteriorated clearly as the pH value reduces down to 4. Figs. 6a shows how the fluid was deteriorated when the pH value was maintained at 6. At a pH value of 2 as shown in Fig. 6b, the oil base fluid had lost its emulsion property and is broken down completely. Therefore, results for pH value of 2 were not included in this analysis.

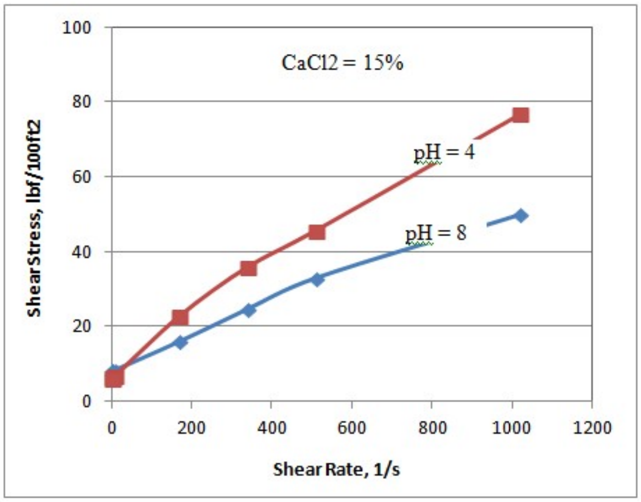

Figure 5: Effect of pH on the fluid rheological properties

a: pH = 6 b: pH = 2

Figure 6: The deterioration of fluid property

As mentioned in the previously, SN should be expected to be lower when decreasing the values of pH, causing the fluid to be more viscous. However, the experimental results showed an unexpected opposite trend. Figure 7 illustrates the effects of pH on sag tendency in the drilling fluid samples at various $CaCl_2$ concentrations. The results show that as the $CaCl_2$ concentration increases from 15 wt% to 35 wt%, the SN tendency decreases at all tested pH values. Drilling fluid sample with salt concentrations of 35 wt% recorded sag of 0.01ppg at pH value of 8. Reducing pH values of this sample from 8 – 6, resulted in an increase of 99% in SN (3.09ppg). Samples with salt concentrations of 20% and 25% were recorded 92% increase in SN when the pH values decrease from 8 – 6. The authors believed that the reason for this significant increase in sag number is the physical and chemical changes occurred in the drilling fluid. As the pH values are lowered, the emulsifiers and organophilic clay lost their functions. Therefore, the fluid is unable to suspend the weighting materials and offer a high quality mud cake to support the fluid loss.

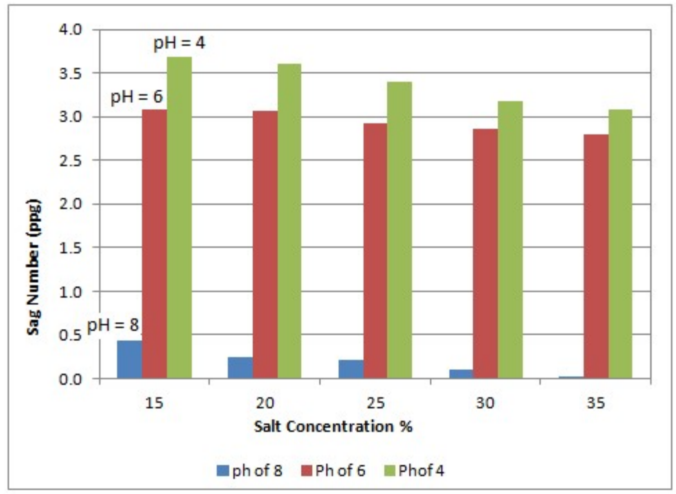

Figure 7: Effect of pH and salt concentration on barite sag

Further reduction in pH values resulted in a small increase in SN for all salt concentrations tested samples. SN only increased by 16% when the pH values were reduced from 6 to 4 at the salt concentration of 15 wt%. For concentrations of 20 wt%, 25 wt%, 30 wt% and 35 wt%, the difference in SN is progressively reduced as the pH values of the drilling fluid samples were reduced from 6 – 4. The majority of the increase in the SN was recorded when the initial pH occurred from 8 – 6. As soon as the fluid sample became acidic, further decrease in pH resulted in a little increase in the sag of the drilling fluid samples. This is a significant finding that operators must pay attentions during drilling operations. The pH values of drilling fluid must be monitored closely and frequently to make sure that the fluid is alkaline at all time.

Concluding Remarks

In this study, sag numbers and ECDs were tested and calculated for OBDFs with different particle sizes and ratios of barite to $CaCO_3$. The effect of pH and $CaCl_2$ on barite sag were also investigated. Some key findings are summarized as follows:

- Combining API barite and 2-micron calcium carbonate at the mass ratio of 70:30 offers the lowest sag potential and the acceptable ECD values.
- A 50:50 Mixing Ratio of API barite and 40-micron-$CaCO_3$ particle size can be used for wells where sag is less of an issue, but pore invasion due to small particle size of weighting materials is a great concern. This 50:50 ratio mixture may reduce the pore invasion because of larger particle size and reduce insoluble barite in the fluid by 50%, which helps to reduce the formation damage.
- If drilling fluids are contaminated and pH values lower than 8, then sag will occur severely regardless

of the fluid rheological properties and calcium chloride concentrations. As soon as the drilling fluids become acidic, further decrease in pH has little impact on sag potential.

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Nomenclature

API	=	American Petroleum Institute
$CaCO_3$	=	Calcium carbonate
$CaCl_2$	=	Calcium chloride
ECD	=	Equivalent circulating density
HCl	=	Hydrochloric acid
OBDF	=	Oil base drilling fluid
g	=	gram
ml	=	Milliliter
MW	=	Mud weight
SG	=	Specific gravity
SN	=	Sag number
VSST	=	Viscometer Sag Shoe Test
μm	=	Micron

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