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Extending API-Grade Barite

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Abstract

The cost of barite has increased over 100% since 2009, while availability of API-grade 4.2-SG barite has dwindled in the past several years due to supply, transportation, political, or other issues. As a result, the industry has shifted to 4.1 specific gravity (SG) barite to extend the barite reserves. A recent study evaluated potential of other approaches for barite extension, including conservation, recycling, and replacement.

The performance of API-grade barite and potential candidates was compared using a standardized invert drilling fluid formulation. Key properties used for evaluation included rheology, high-temperature/high-pressure (HTHP) fluid loss, and barite-sag tendency. Some potential candidates were further evaluated for abrasiveness. The selection of potential candidates was based on specific gravity, availability, and HSE impact of the materials.

Evaluation results showed that conservation can be achieved by "upgrading" a lower density barite with minerals having an SG greater than 4.2. A small amount of such a heavier mineral could raise the SG from 4.1 to 4.2 without causing adverse changes in various fluid properties.

These heavier minerals also can be used as replacements to barite. However when completely replacing barite with these micronized alternatives, some modifications are needed to alleviate any adverse impacts they may have on fluid properties, such as increased abrasiveness and sag tendency.

Recycling involves recovering barite from used heavy fluids and reusing it in new fluids. However, recovered barite may contain drilled solids that can impart undesirable fluid properties. Micronization of recovered barite, as well as heavier minerals, could provide a solution to not only extend the barite supply but also enhance certain fluid performance.

Introduction

Barite has long been the primary weighting agent for both oil-based and water-based drilling fluid systems. The primary reasons were because of its overall abundance, low cost, the lack of solubility in water, the relative inertness of the material, and the low abrasiveness of the material.

API Spec 13A[1] has defined the standard specifications for "API-grade" barite for a number of decades. Among the properties specified, the grind size is such that a maximum of 3% of the particles are greater than 75 µm and a maximum 30% of the particles are less than 6 µm. This grind size was originally for barite with 4.2 specific gravity (SG), and then adopted for 4.1-SG barite when it was sanctioned in 2010.

The increasing demand for drilling fluids and dwindling reserves of high-quality barite has made sourcing a cost-efficient 4.2-SG barite extremely challenging over the past few years. With the acceptance of 4.1-SG barite for some non-critical operations, barite supplies were extended for a few years. However, the need for 4.2-SG barite for critical wells combined with increasing demands for higher specific gravity barite in general have resulted in the need to look at alternative weighting agents and other approaches for recycling.[2-5]

This paper discusses various techniques to help stem the consumption of 4.2-SG barite. These techniques include conservation, replacement, and recycling in micronized form. Data from various testing as well as the overall viability of implementing these various techniques are discussed.

Method of Study

I. Abrasion

Barite has been a superior weighting material because of its low Mohs hardness (between 3.3 and 3.5), which results in minimal abrasion on drilling tools. The weighting material alternatives evaluated were hematite and ilmenite, which ranked between 5.5 to 6.5 and 5 to 6, respectively on Mohs scale. The Mohs scale values indicate that both alternative weight materials are more abrasive than barite.

In an effort to reduce the abrasiveness of hematite and ilmenite in drilling fluid, micronizing these materials was evaluated. Two separate methods were used to evaluate the abrasiveness of micronized materials. The first was the API abrasion test method, which can be found in Section 7 of API RP 13I/ISO 10416.[6] The other test method used a Taber* fluid abrasion meter.

Using API RP 13I/ISO 10416, Section 7, the abrasion test blade method was used to determine overall abrasiveness of weight materials. The value measurement was the weight loss of an abrasion blade connected to a Hamilton beach mixer after exposure to the weight material suspension.

A second method was deployed to test drilling fluid samples for abrasion with a Taber Multi-Media Abrader. This test method involved measuring the weight loss of metal pins

* Taber Instrument Corporation, New York

as the drilling fluid was rotated across the bottom of the pins through a narrow gap between the pins and a rotating tray (Figure 1). The rotating tray was set to rotate at 60 rpm for 2000 cycles.

II. Conservation and Replacement

The evaluation methods focused on conserving 4.2-SG barite in formulating drilling fluids by replacing the 4.2-SG barite with a less than 4.2-SG barite blended with alternative weighting materials of higher density. The alternative higher density weighting materials were micronized to minimize abrasion. These blended alternative weighting materials were used to make 16-lb/gal drilling fluids with oil/water ratio of 85/15, which were hot rolled overnight at 300°F. These fluids were tested in tandem with a 16 lb/gal drilling fluid made with 4.2-SG API-grade barite. The formulation is shown in Table 1.

Ilmenite and hematite were selected for evaluation as alternative weight materials based on their low health, safety, and environment (HSE) impact along with their overall availability and high specific gravity (4.7 and higher) when compared against other high density alternatives such as galena, sphalerite, rutile, etc. As noted above, both ilmenite and hematite have higher Mohs numbers than barite indicating a greater abrasiveness under the same conditions. To lower the abrasiveness, the ilmenite and hematite were micronized.[3]

Through lab testing, it was determined that a ratio of 93% 4.1-SG barite and 7% 4.7-SG alternative material was required to achieve the desired 4.2-SG weight material blend. Different blend ratios were also tried using barite with a density lower than 4.1 SG. For instance, the blend ratio became 50/50 when using 3.9-SG barite.

In order to observe more impact from the weighting agent blends in the drilling fluids, test fluids were made using a standard 18-lb/gal with oil/water ratio of 85/15 diesel drilling fluid formulation using the 50/50 blend ratio of 3.9-SG barite with the micronized weight alternative (Table 2). The fluid was first mixed using a single spindle mixer, and then sheared on a high-shear mixer at 6000 rpm for a total of five minutes. The rheology and electrical stability (ES) were determined at 150°F. The fluid was then put in a pressure cell and pressurized with nitrogen gas to 300 psi in preparation for hot rolling for 16 hours at 300°F. Following heat aging, the fluids were tested for rheology, HTHP fluid loss, ES, and abrasiveness. The barite sag tendency was also evaluated using the viscometer sag-shoe test (VSST) method (Figure 2) described in the literature.[5] The test results were compared against a 4.2-SG barite 18-lb/gal benchmark fluid.

The replacement method followed a similar procedure except instead of creating a blend of new weighting material, only micronized hematite or ilmenite were used in weighting the fluid system. The goal of testing was to formulate systems that would behave similarly to a micronized barite reference formulation. The formulation used was a 17.5-lb/gal synthetic-based system with an oil/water ratio of 90/10 (Table 3). The rheology and ES were determined at 150°F before hot rolling at 350°F. After hot rolling, the fluids were tested for rheology, dynamic sag, ES, and abrasiveness. These results were compared against a micronized barite benchmark.

III. Recycling

The recycling method focuses on using reclaimed fluid and converting it into a functional micronized drilling fluid. Centrifugation is used to recover base oil from spent drilling fluid. This process results in a low-density effluent consisting of primarily base oil and a bottom discharge of heavy weight barite-rich fluid. Typically, the barite-rich discharge is diluted to make a spike fluid of 17 to 18 lb/gal which can be used to add weight to an existing drilling fluid.

This method was evaluated by taking a field spike fluid and determining the particle size distribution (PSD) of the material. The spike fluid was then micronized to a d_{50} of <2 µm and evaluated in two different ways. The first evaluation was for use in a 19.5-lb/gal micronized spike fluid (Table 4), which is currently a commercialized product. In the second evaluation, the micronized spike fluid was converted to a typical 13.5-lb/gal micronized drilling fluid (Table 5).

The micronized spike fluid was converted to both the 19.5-lb/gal spike fluid and the 13.5-lb/gal drilling fluid and treated to meet preferred specifications based on appropriate benchmarks. The 19.5-lb/gal micronized spike fluid was measured for rheology and ES at 150°F. And the 13.5-lb/gal drilling fluid was measured for rheology, ES, barite sag and HTHP fluid loss.

Results and Discussion

I. Abrasion

The first series of abrasion tests was performed using the abrasion test method in API RP 13I. For testing, hematite and ilmenite were first ground to near API barite particle sizes and the abrasion compared to API-grade barite. Both hematite and ilmenite had a much greater abrasion value than barite at the API grind size. Then the alternative weight materials were micronized to a finer particle size as shown in Figure 4 and evaluated in the same manner. The abrasion values decreased significantly with levels below that of the API grind size barite reference (Figure 5a).

The second series of testing used the Taber Multi-Media Abrader. The results from this series (Figure 5b) followed the same trend observed with the API 13I abrasion test method. The fluid system weighted up with ilmenite and hematite ground to sizes comparable to API-grade barite produced the highest level of abrasion. As seen with the API 13I abrasion test method, the micronized version of the same minerals showed significant reduction in the abrasion level.

This test series revealed that the micronized ilmenite and hematite have better abrasive characteristics than API-grade barite. These results led to further testing on these micronized minerals in fluid systems as described in the conservation and replacement methods sections.

II. Conservation

A 16-lb/gal diesel drilling fluid using the 4.1-SG barite blended with both micronized ilmenite and hematite was formulated with an identical fluid composition to a benchmark using the 4.2-SG barite. The key properties looked at were rheology, VSST, ES, and HTHP fluid loss. The values obtained through testing were similar to the benchmark 4.2-SG barite weighted fluid. Extra fluid loss additive was required to bring the fluid loss control values close to that of the reference fluid.

Table 1 shows the formulations used to compare the properties of fluids prepared with blended weighting agents and barite. Figures 6-8 show the fluid properties after the test fluids have been hot rolled at 300°F for 16 hours. The rheology profiles in Fig. 4 indicate that the blended materials and barite performed comparably in rheology performance. The blended materials containing the micronized weighting additives resulted in lower VSST values when compared to the barite only fluid (Fig. 7). However, the micronized weighting additives caused some increases in the fluid loss values, probably due to the inability to bridge properly. This is considered as a minor issue that can be treated with adjustment to the PSD range of the micronized alternative or fluid loss control agent (Fig. 8).

The results confirmed that blending the 4.1-SG barite with micronized versions of hematite and limonite can be successfully used to make drilling fluid. However, upgrading the 4.1-SG barite to 4.2-SG weighting material still will consume a large amount of barite due to the low proportion of the alternative materials. Thus, a 3.9-SG low-grade barite was also tested for use in blends for further conservation. This new blend contained about a 50/50 ratio of barite and alternative weighting material which would extend the barite supply more effectively.

The new blends were tested in an 18-lb/gal diesel-based formulation (Table 2). The new blend of weight materials requires more alternative weight material to reach the 4.2-SG density, hence less barite consumption. Initial results showed higher fluid rheology and HTHP fluid loss from the blended weight material samples. A series of re-formulations resulted in a composition that lowered the rheology and fluid loss values to be comparable to those of relative barite fluids (Figures 9 and 10). The new blend requires lower quality and less barite and is thus considerably more efficient at stemming the demand for barite.

The overall effectiveness of using a new blend for reducing barite consumption depends on the blend ratio to achieve a 4.2-SG weight material blend. If 4.1-SG barite is used, then the impact will be a 7% reduction in barite consumption. At this blend ratio, there would be slight changes to the formulation in order to make all fluid properties similar to the comparable drilling fluid with all API-grade barite. The use of 3.9-SG barite in a 50/50 blend with micronized alternative weight material allows for a 50% reduction in barite consumption; however, it requires a much more drastic formula modification to meet the benchmark specifications.

The above conservation techniques show the ability to make a lower grade barite perform similarly to the 4.2-SG barite using micronized hematite and ilmenite.

III. Replacement

The replacement method focused on utilizing the micronized ilmenite and hematite to completely replace barite as a weighting agent. In the first series of tests, the full amount of the 4.2-SG API barite was replaced in a 16-lb/gal diesel-based drilling fluid (OBM) formulation with micronized hematite and ilmenite. The test results showed a substantial increase in rheology along with poor fluid loss performance (Figures 11 and 12). The authors believe the elevated fluid loss was due to the lack of proper bridging because of the narrow PSD in the alternative weight materials.

Once it was determined that a standard API barite-like performance was not achievable in the 16-lb/gal OBM, a 17.5-lb/gal micronized formulation was designed using synthetic base fluid and micronized hematite and ilmenite in place of micronized barite (Table 3). The key performance targets of this micronized fluid system are low rheology and low dynamic sag. In this formulation, the alternative weight materials were satisfactory at replacing micronized barite and providing a low rheology and low dynamic sag value. Figures 13 and 14 show the comparative rheology of micronized weight materials in the 17.5-lb/gal SBM. This scheme for substituting micronized alternative weight materials for micronized barite would reduce some demand on the barite supply.

Directly substituting the micronized alternatives in a system designed for a 4.2-SG API barite may not achieve the comparable performance without changing the formulation. This is because of the adverse impacts from the much smaller particles size distribution on fluid loss control. However, once properly treated, the fluid performance was similar to the reference material.

This technique will allow for the barite to be completely replaced in a fluid system typically using micronized barite as weighting agent. Although the API-grade barite is typically used and micronized barite is a specialty market, this replacement method could reduce the consumption in barite overall.

IV. Recycling

A 17.5-lb/gal spike drilling fluid was ground down to a micronized PSD in a ball mill (Figures 15 and 16). The initial rheology from this weight material was much higher than that of the reference 17.5-lb/gal consisting of micronized barite. After treating the micronized spike system with a thinner, the rheology decreased significantly to the level of the micronized barite-based reference (Figure 17).

A 19.5-lb/gal fluid was also created using the 17.5-lb/gal micronized spike as a seed fluid by adding micronized barite (Table 4). The spike fluid properties were compared against a 19.5-lb/gal micronized barite spike fluid, which showed that the rheology and ES values are comparable. The 17.5-lb/gal micronized spike fluid was then converted to a 13.5-lb/gal drilling fluid using the formulation in Table 5 and the fluid properties again compared successfully with a standard 13.5-lb/gal micronized barite drilling fluid (Figures 18-21).

Converting an API-grade barite-based spike fluid to a micronized spike fluid can also provide secondary economic benefits. The micronized system can improve the solids removal efficiency and help to keep the mud system cleaner and barite in the system longer.

Conclusions

Barite consumption can be extended using conservation, replacement and recycling approaches. Each method has some advantages and disadvantages.

Hematite and ilmenite are two possible alternatives that can be used to conserve barite consumption. These minerals, however, tend to cause severe abrasions on tools unless their particle size is appreciably reduced by micronization.

The micronized alternative weight materials can be blended with lower grade barite of API grind size to achieve a density equivalent to 4.2-SG barite. In turn, the resulting blends can be used to formulate drilling fluids with properties comparable to those formulated with 4.2-SG barite.

In the lower blend ratio which was tested (93/7), little change in fluid formulation is required. At higher blend ratios some adjustment in formulation may be needed. When blending micronized hematite and ilmenite with lower grade barite with a 3.9-SG density, the consumption of barite can be reduced to 50% at a blend ratio of 50/50.

The micronized alternative weighting agents can be used to totally replace barite. However, the fluid formulation would require some re-formulation in order to keep the properties comparable to barite-weighted fluids. This replacement approach would be more expensive and is the least desirable approach.

Micronization of the heavy barite recovered from barite recovery processing not only can extend the consumption of barite but also add additional value to the weighting material. The micronized barite slurry can be converted to a spike fluid of higher density or an actual drilling fluid of lower density achieving desirable properties after some adjustment in composition is made. The micronized barite will stay in the mud system longer as it is not removed by the solids control system.

Acknowledgments

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Table 1. 16-lb/gal Fluid Formulation Used to Compare Alternative Weighting Agents

Diesel Base Oil, g	156.5
Organophilic Clay, g	4
Lime, g	3
Emulsifier, g	8
Brine, g	44
Fluid Loss Additive, g	5
Weighting Material, g	429
Solids Contamination, g	25

Table 2. 18-lb/gal Fluid Formulations Used to Compare Alternative Weighting Agent Blends			
	4.2 Barite	3.9-SG Barite with Micronized Hematite Blend	3.9-SG Barite with Micronized Ilmenite Blend
Diesel, g	134	130	130
Organophilic Clay ,g	2.5	2.5	2.5
Secondary Organophilic Clay, g	1.5	1.5	1.5
Lime, g	6	6	6
Emulsifier, g	10	10	10
Secondary Emulsifier, g	-	2	2
Brine, g	37.5	36.5	36.5
Weighting Material, g	540.4	542	542
Rheology Modifier, g	2	2	2
Solids Contamination, g	15	15	15
Fluid Loss Additive, g	8	8	8
Dispersant, g	-	2.5	1.25

Table 3. 17.5-lb/gal Micronized Fluid Formulation Blend to Evaluate Micronized Weighting Agents	
Synthetic Base Fluid, g	131
Organophilic Clay, g	0.75
Lime, g	10
Emulsifier, g	22
Brine, g	25
Fluid Loss Control Additive, g	12
Micronized Barite, g	538
Micronized Hematite, g	521
Micronized Ilmenite, g	529
Dispersant, g	1.5

Table 4. Formulation to Convert 17.5-lb/gal Micronized Spike Fluid to 19.5-lb/gal Micronized Spike Fluid	
17.5-lb/gal Micronized Spike, g	282
Synthetic Base Fluid, g	76
Micronized Barite, g	451
Emulsifier, g	10

Table 5. formulation to Convert 17.5-lb/gal Micronized Spike Fluid to 13.5-lb/gal Micronized Drilling Fluid	
17.5-lb/gal Micronized Spike, g	468
Synthetic Base Fluid, g	87
Emulsifier,g	5
Brine, g	7.5

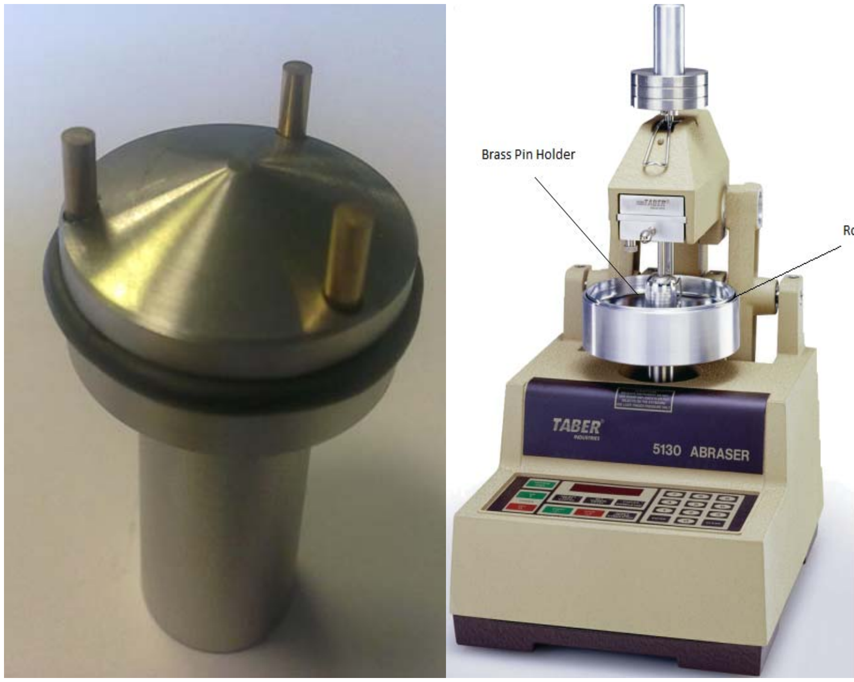


Figure 1. The Taber Multi-Media Abrader with brass pins. The weight loss of the brass pins after exposure determines the abrasion from the test; the more the weight loss, the higher the abrasion caused by the suspended solids in the fluid.

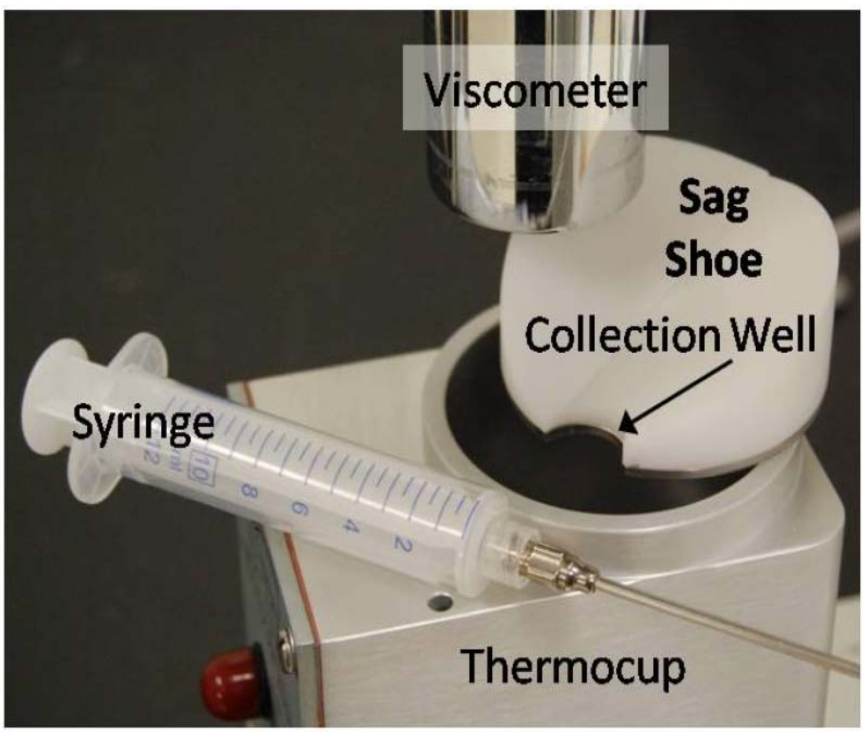


Figure 2. VSST showing the Sag Shoe, which is inserted into the bottom of the thermocup, and the collection well where the settled solids are collected to determine the dynamic sag.[6]

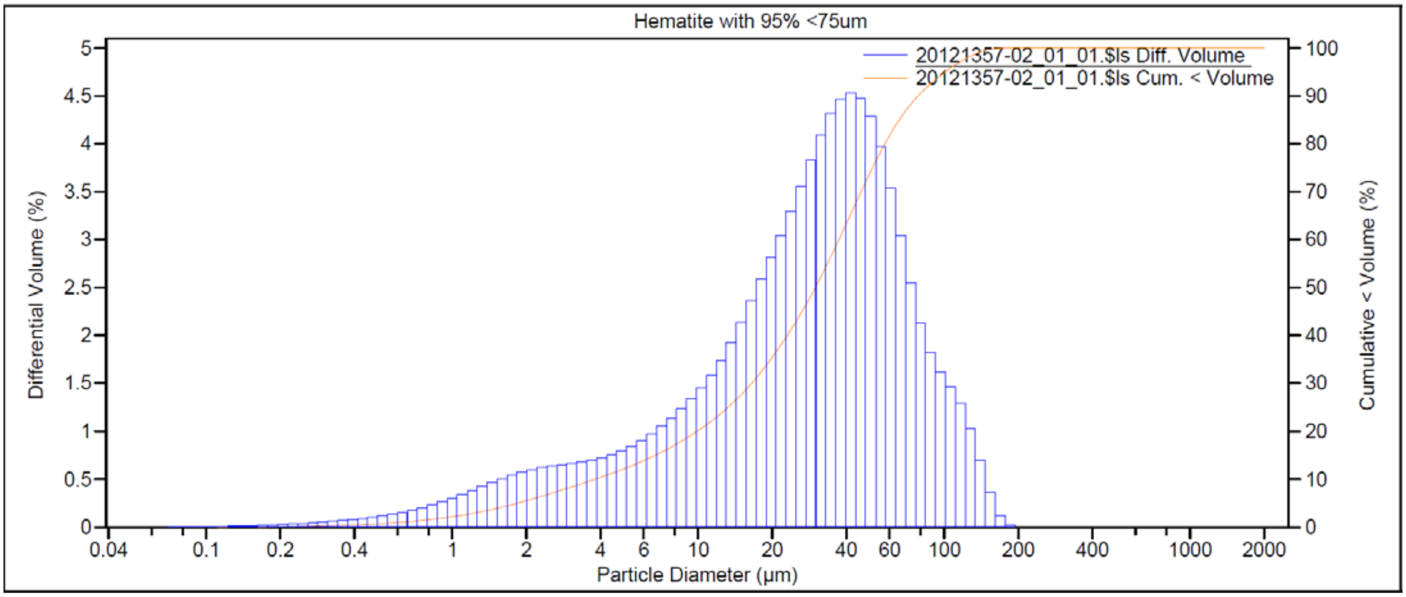


Figure 3. PSD of the hematite samples ground to near API grind spec.

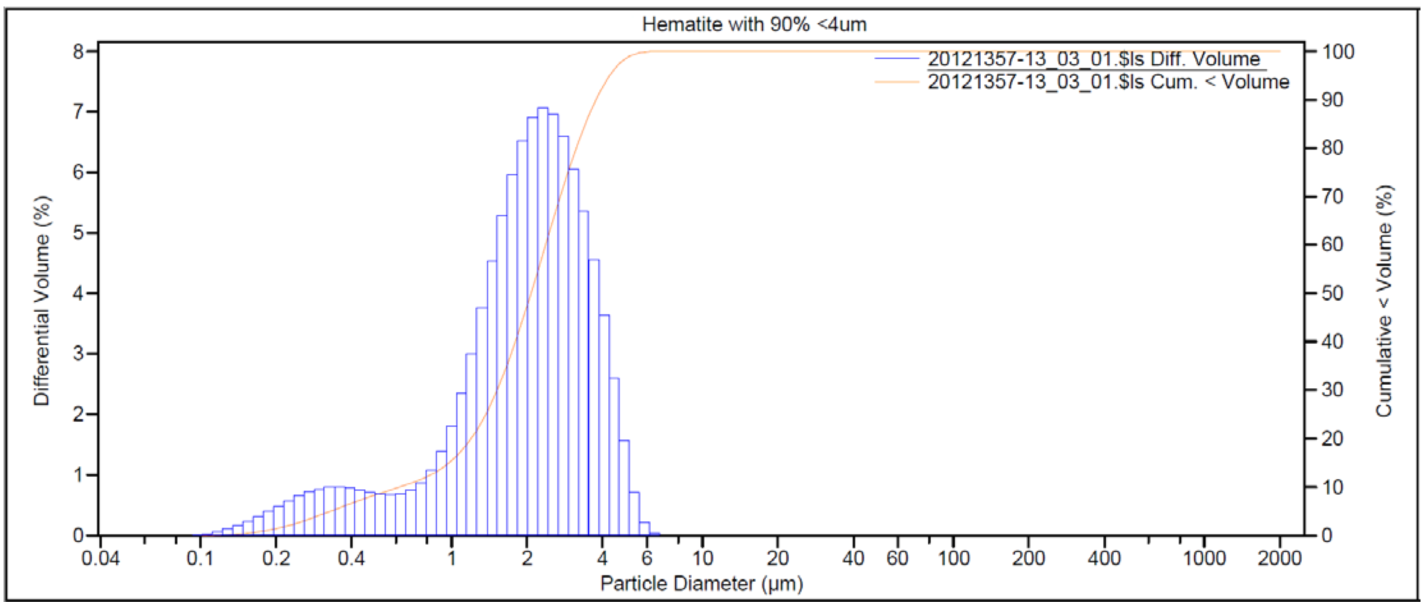
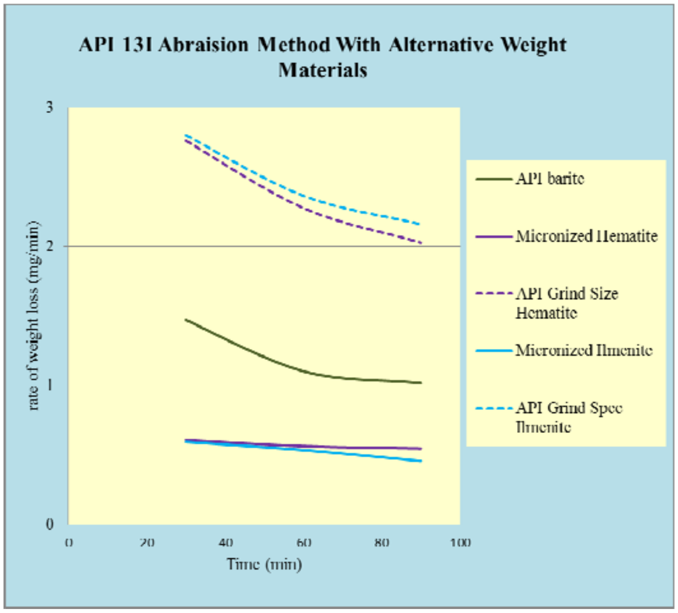
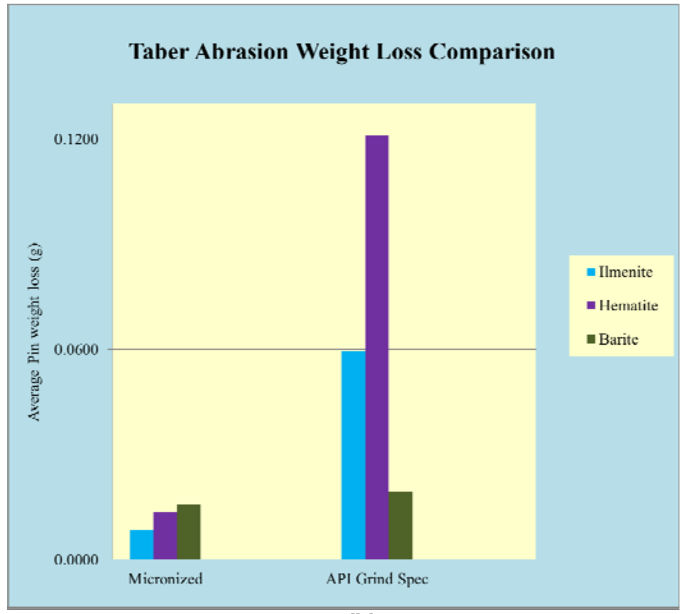


Figure 4. PSD of the hematite samples ground to a micronized grind specification.



(a)



(b)

Figure 5. Abrasion testing with: (a) API 13I abrasion test method; (b) Taber test method.

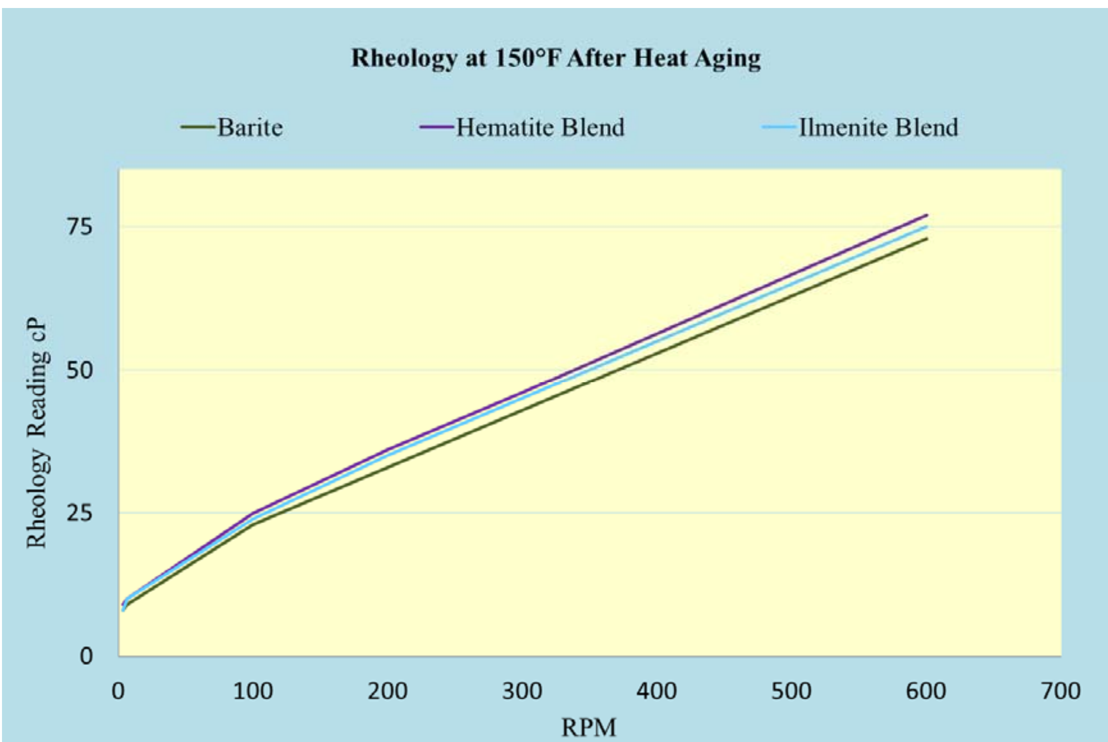


Figure 6. Rheology testing on 16-lb/gal drilling fluids containing 93/7 blended weight material (93% 4.1-SG barite and ~7% micronized alternative weight material).

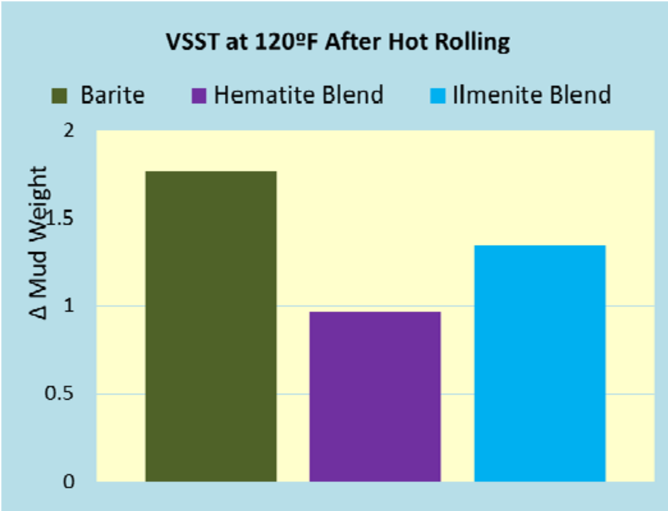


Figure 7. Dynamic sag of fluids containing the blended material of Figure 4.

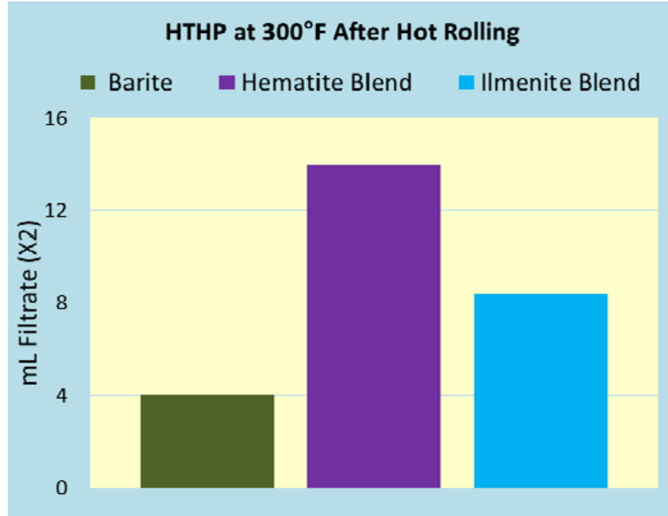


Figure 8. Fluid loss of fluids containing the blended weight materials of Figure 4.

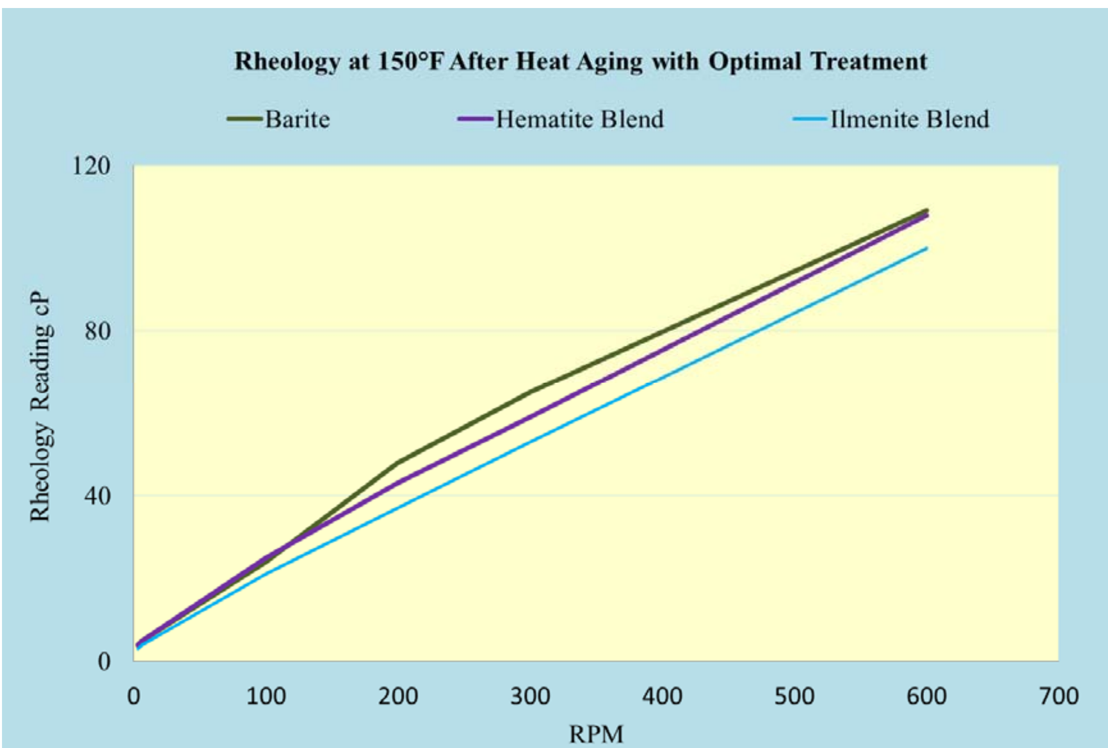


Figure 9. Rheology data of 18-lb/gal diesel-based drilling fluids containing the 50/50 blended weight materials.

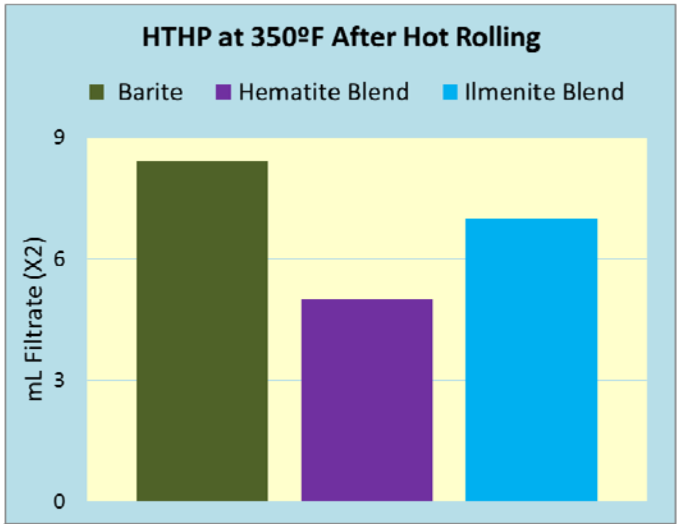


Figure 10. Fluid loss properties of fluid developed with the 50/50 blend ratio of 3.9-SG barite and micronized alternative minerals.

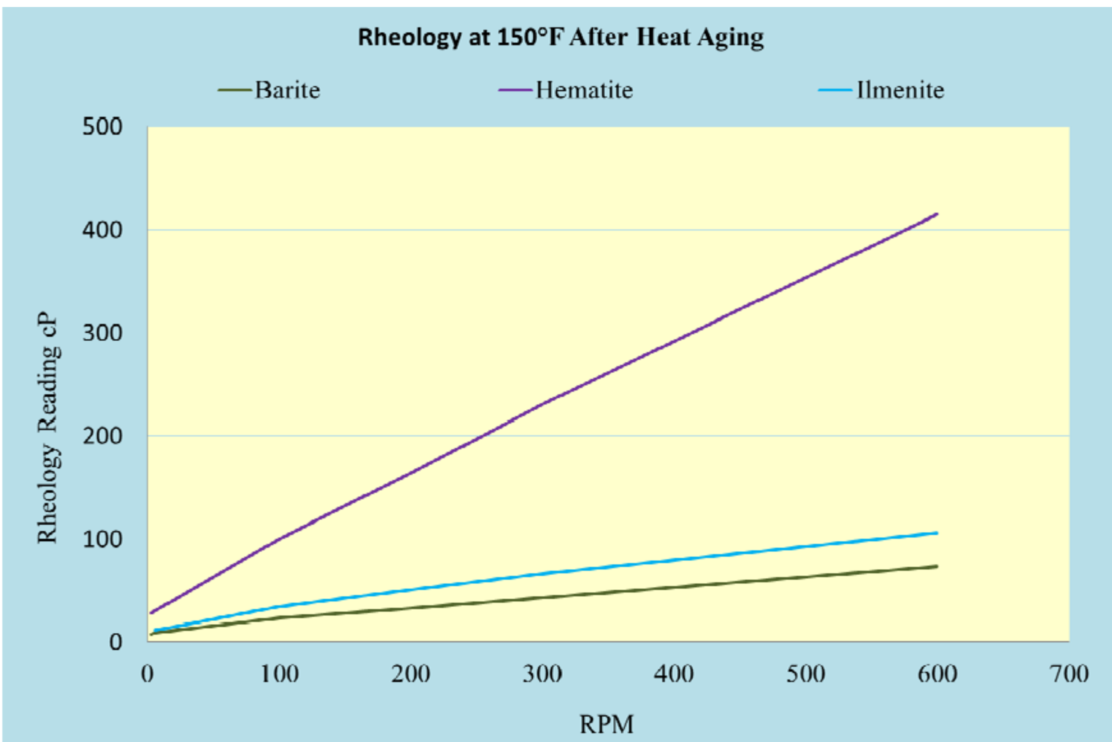


Figure 11. Rheology of 16-lb/gal drilling fluid systems weighed up with only the micronized weight materials. The data shows the viscosity of the material with the alternative weight materials increased in comparison to the rheology of the systems containing only micronized barite as the weight material.

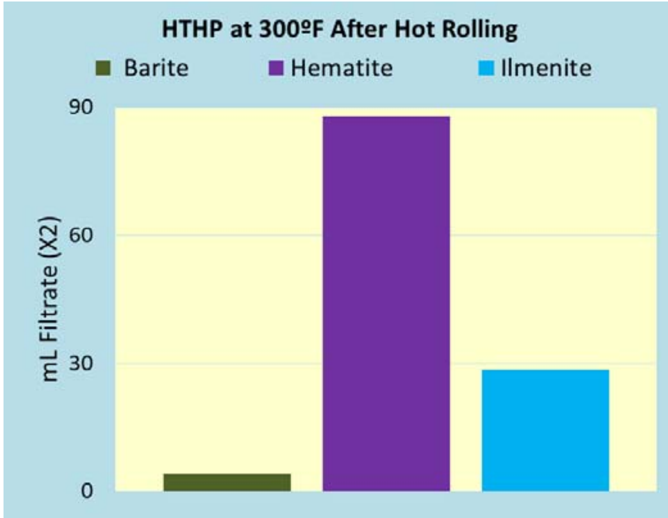


Figure 12. Impact on fluid loss with the micronized barite and alternative weight materials in the 16-lb/gal fluid system.

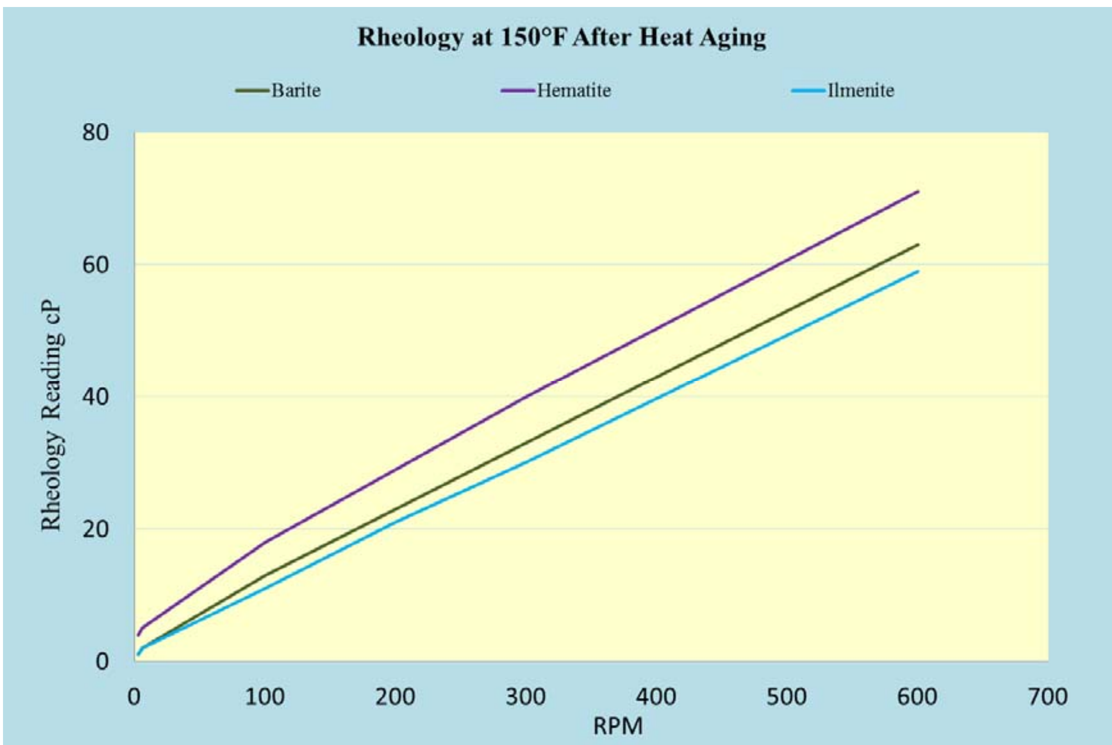


Figure 13. Comparison of rheology of 17.5-lb/gal SBM systems using the micronized barite and alternative weight materials.

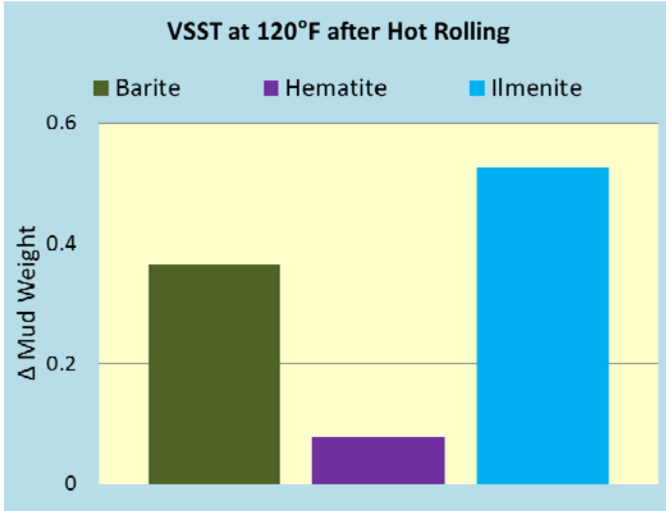


Figure 14. Dynamic sag of 17.5-lb/gal SBM systems using micronized barite and alternative weight materials.

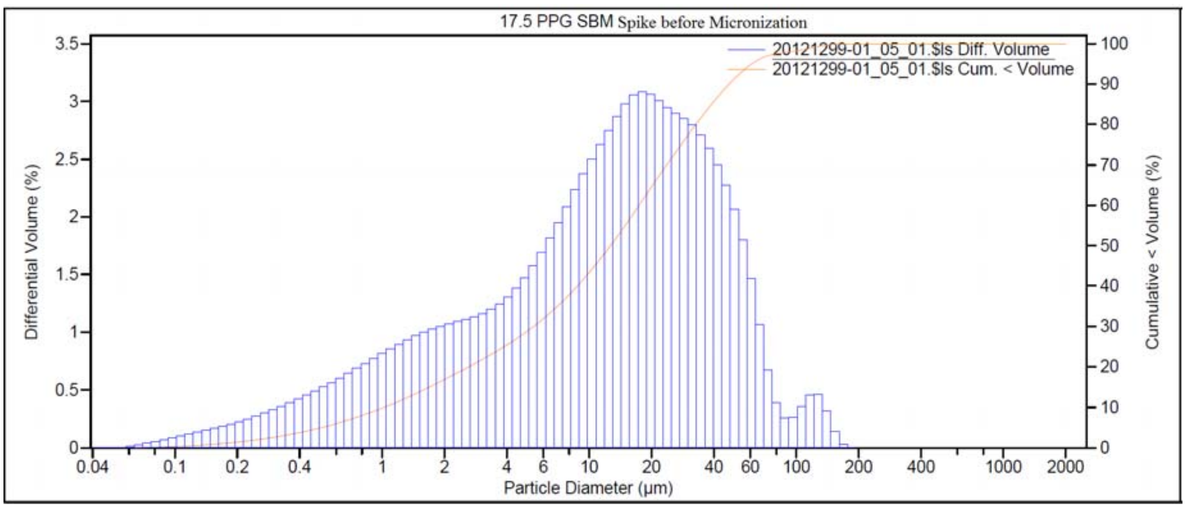


Figure 15. **PSD of the 17.5-lb/gal Spike Fluid before micronization.**

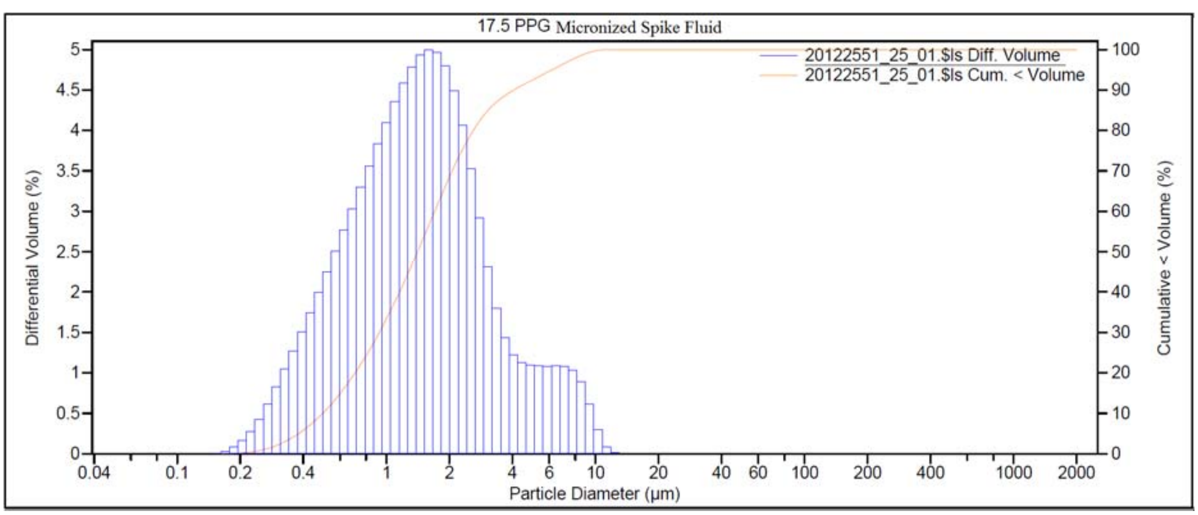


Figure 16. **PSD of the 17.5-lb/gal Spike Fluid after micronization.**

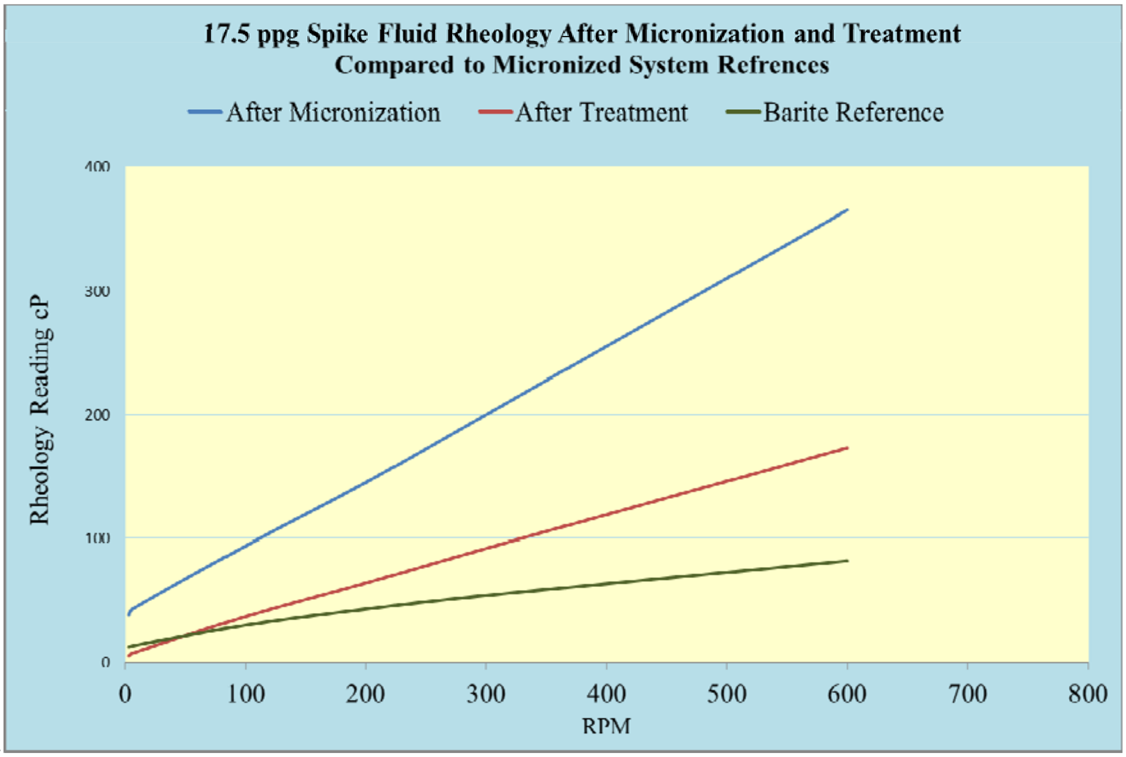


Figure 17. Effect of the micronization process on rheology of the 17.5-lb/gal spike fluid.

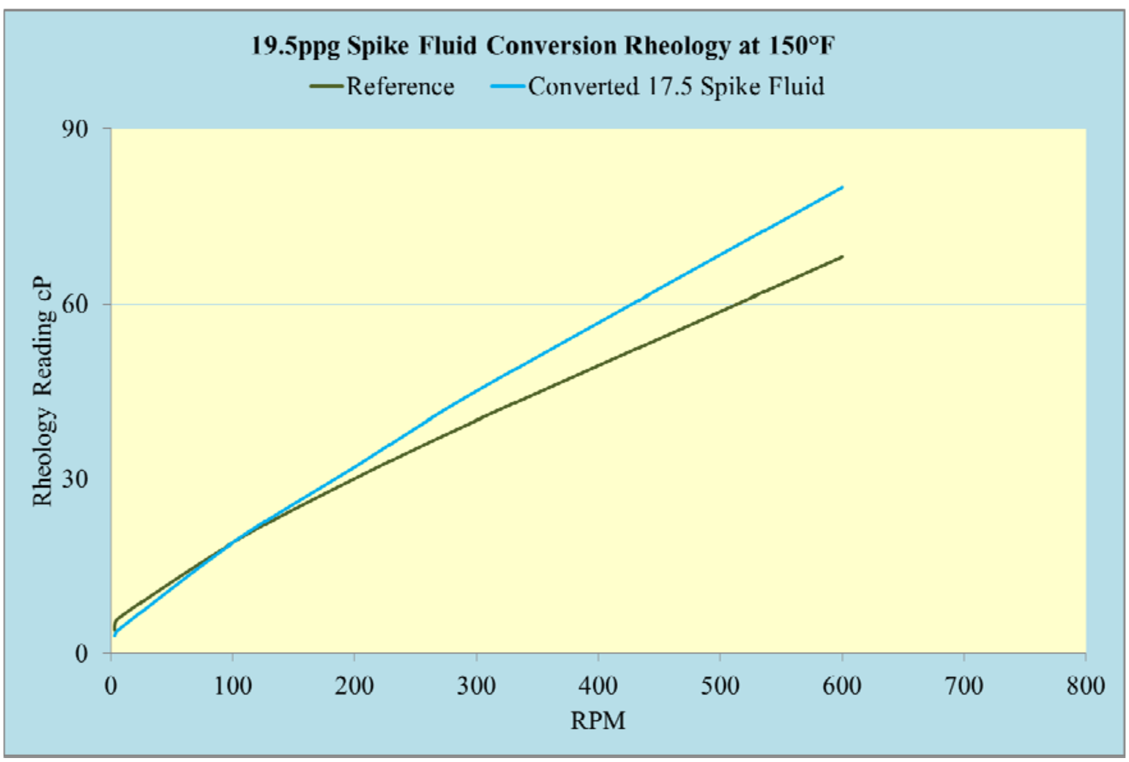


Figure 18. Rheology profiles of 19.5-lb/gal spike fluids, one converted from a 17.5-lb/gal spike fluid and one was a standard micronized spike fluid.

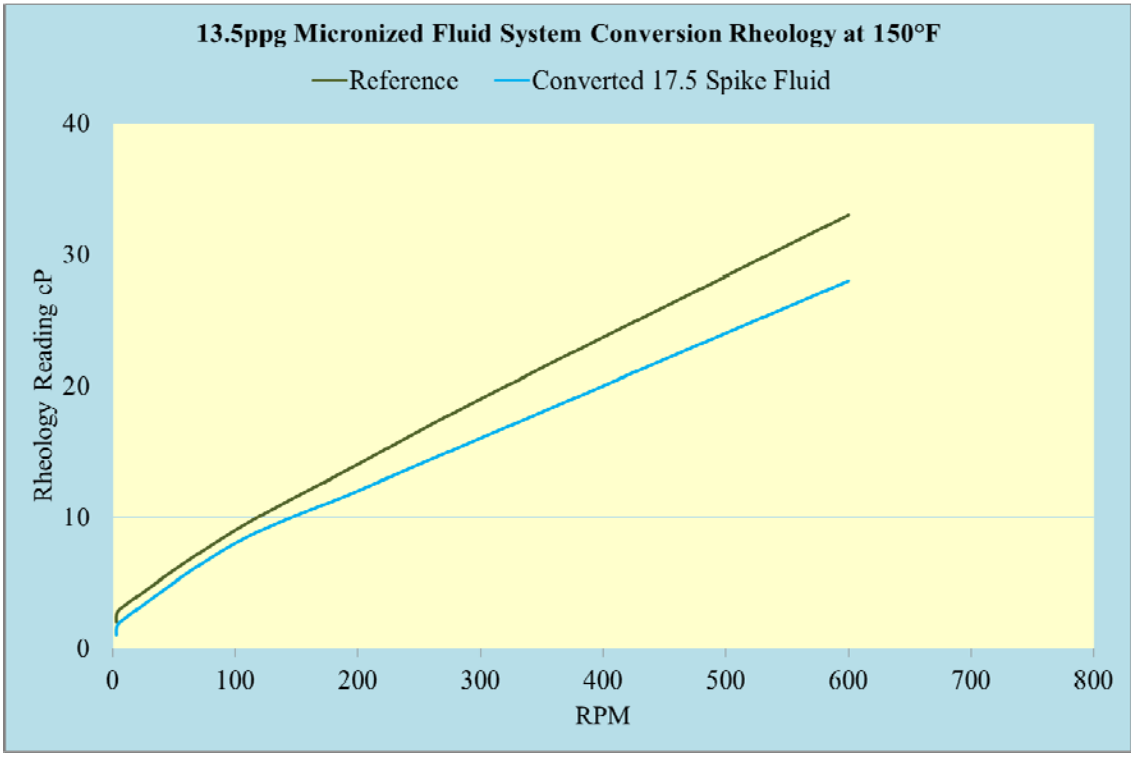


Figure 19. Rheology profile of a converted 17.5-lb/gal spike fluid (to a 13.5-lb/gal spike fluid) versus a standard 13.5-lb/gal micronized drilling fluid.

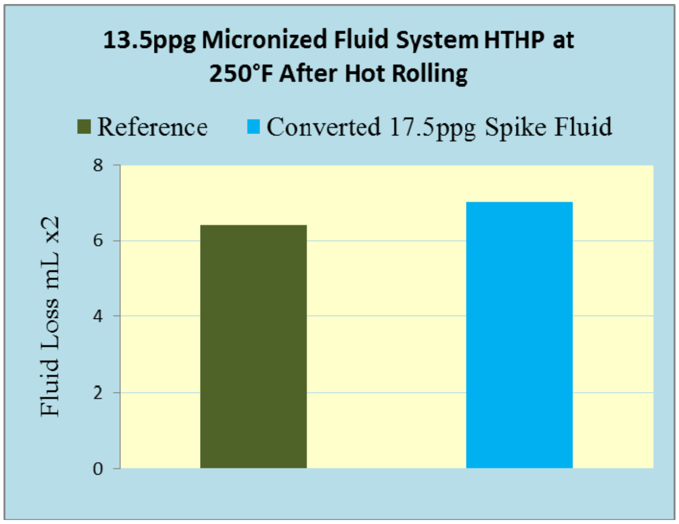


Figure 20. Fluid Loss of the converted spike fluid compared to 13.5-lb/gal drilling fluid.

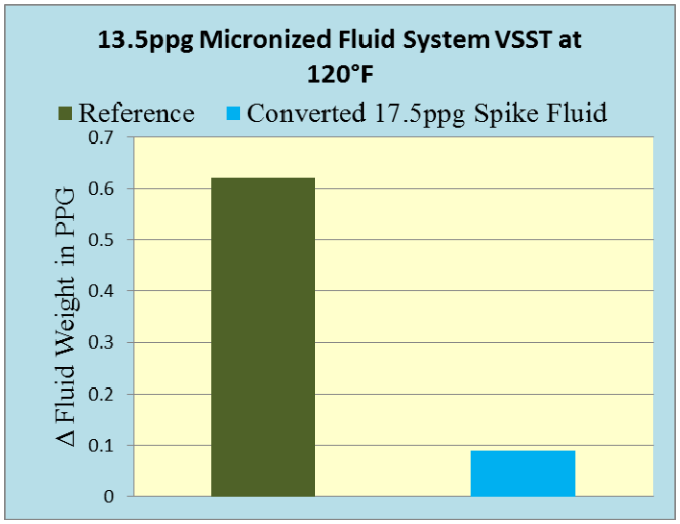


Figure 21. Dynamic sag of the spike fluid which was converted to a micronized 13.5-lb/gal drilling fluid versus that of a standard 13.5-lb/gal micronized drilling fluid.