

## Enhanced Hole Cleaning and Suspension with Reduced Rheology

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### Abstract

In this new era of flat rheology drilling fluids, many standard rules of thumb no longer apply, especially in regards to hole cleaning. In particular the old adage to maintain the (viscometer) 3-RPM value greater than the hole size.

Hole cleaning is one of the basic functions of any drilling fluid. Cuttings generated by the bit and any cavings and, or sloughing debris must be carried to the surface by the drilling fluid.

Higher Low-Shear-Rate viscosity (LSRV) viscometer values in the larger hole sections are no longer necessary, as novel invert-emulsion drilling fluids designed with flat or reverse rheological profiles using micronized weighting agents demonstrate an improvement in hole cleaning with reduced LSRV while achieving acceptable hole cleaning performance with 3 RPM readings  $\leq 10$ .

This new low rheology invert emulsion drilling fluid technology allowed 5,700ft of an 18.125-in diameter hole section to be drilled at record speed in under 24 hours. Operations observed excellent hole cleaning, followed by drilling extremely narrow hydraulic windows in subsequent sections, with minimal losses.

This innovative system has proven its flexibility in the Gulf of Mexico (GoM) with densities ranging from 9.0 lbm/gal to 17.0 lbm/gal, in over 50 wells.

This paper discusses the improvement in hole cleaning and suspension while using mechanical applications and downhole rheologies throughout different stages of the well and focusing on decreasing LSRV to drill complex well bores.

### Introduction

Hole cleaning is one of the basic functions of any drilling fluid. Cuttings generated by the bit, and any caving or sloughing formation fragments which are indirectly generated during the drilling process must be carried to the surface by the drilling fluid.

Effective hole cleaning becomes much more challenging in deepwater wells where often complex well geometries are encountered, and flowrates are restricted by equivalent circulating density (ECD) or pump pressure considerations when drilling formation horizons with narrow hydraulic fracture gradients. In severe circumstances these factors can lead to

wellbore instability, severe downhole drilling fluid losses and increased non-productive time (NPT).

The introduction of next generation invert fluids allows a much lower rheological profile to be run without compromising on sag stability. These fluids can be effectively used to manage ECD through fluid-pressure sensitive formations, and in some cases help the operator increase rate of penetration (ROP) when drilling smaller annular geometries without incurring catastrophic mud losses.

### Hole Cleaning Rules and Barite Suspension

Hole cleaning is affected by several factors including hole angle and well geometry, drilling fluid properties and drilling parameters, among which only the drilling fluid properties may be adjustable, based on other considerations. Selection of the optimum drilling fluid properties requires careful consideration of all related parameters. Mud weight provides cuttings buoyancy and slows their settling rate, as per Stokes' law, but density is dictated by other requirements such as well control and is not really used to improve hole cleaning.

As a result, the rheological properties of drilling fluid become more critical for cleaning the hole. For vertical wells, yield point historically has been used as the key parameter for hole cleaning. Later evidence concluded that direct-indicating viscometer 6- and 3-RPM values are better indicators of carrying capacity (McLean et al. 2010). One common rule of thumb is to maintain the 3-RPM value so that it is greater than the hole size (as expressed in inches), or to maintain the 6-RPM reading 1.0-1.2 times hole size (Visinescu et al. 2013). Some literature recommends even higher 6-RPM values to prevent sag and ensure hole cleaning, e.g. 1.3-1.6 times hole size (Ramsey et al. 2019) or 1.5-2.0 times open-hole diameter (O'Brien et al. 1985). As an example, Table 1 depicts the typical rheological profile of first-generation flat rheology SBM that was used to drill an 18.125-in section in the Gulf of Mexico.

In addition to hole cleaning improvement, adequate rheology is also required to prevent barite sag in deviated wells. However, high rheological properties can adversely impact ECD management, leading to high ECD which may cause formation losses in drilling scenarios with a narrow hydraulic fracture window.

An ideal drilling fluid features low-rheology, low-sag and ensures good hole cleaning. This High-Performance Invert-

Emulsion Fluid (HPIEF) was developed to address these key requirements. This new non-aqueous invert drilling fluid technology has enhanced emulsion stability and provides reduced sag and lower ECD compared to first-generation flat rheology SBM.

The size and shape of weighting agent particles and the viscosity of the fluid can have a large impact on suspension stability. Since a large volume fraction of weight material is generally used to provide density to the drilling fluid, the particle size distribution (PSD) and surface chemistry are important considerations in any new fluid design. Stokes' law alone cannot accurately model particle settling rates in non-Newtonian fluids, it is generally accepted that smaller and less dense particles settle at a slower rate.

Increasing the number of smaller particles also significantly increases particle-particle interactions as a result of the increased surface-to-volume ratio, which can further hinder settling. Using a unique combination of surfactants (Vickers et al. 2020) and micronized barite, it is possible to deliver a thinner fluid without compromising on sag stability, whereas, first-generation flat rheology SBM with so-called API-grade barite normally requires much higher rheological properties for barite suspension.

One of the key benefits of this HPIEF is that it allows much lower rheological properties to be maintained in comparison with first-generation flat rheology SBM, even for large hole sections, which means that the 6-RPM and 3-RPM values can now effectively be run with significantly less than an equivalent hole size. Furthermore, hole cleaning and solids suspension have not been an issue based on an extensive number of field applications. This innovative system has proven its flexibility in the Gulf of Mexico, in drilling over 50 wells, with densities ranging from 9.0 lbm/gal to 17.0 lbm/gal.

## **Field Applications**

### **Hole cleaning performance field case #1**

Lower ECD is a key performance metric offered by the HPIEF technology, which is achieved with the low rheological profile and low gel strengths of the fluid. Traditionally, hole cleaning is one of the main challenges while running rheologically lower fluids, especially in large hole size sections. This was not seen with the HPIEF and, in fact, low-rheological fluid allows higher flowrates to be pumped without exceeding the pump pressure limit, which can contribute to improved hole cleaning in some cases. The HPIEF with reduced rheological profile was used for an 18.125-in section holding 31° angle. Table 2 shows the typical rheological profile of this HPIEF while drilling this section.

This rheology could be considered as too low for an 18.125-in section based on the old rule of thumb. However, the HPIEF provided a clean hole, even with a high instantaneous ROP, exceeding 500 ft/h for this well. Figure 1 shows the ECD and ROP comparison for the well drilled with HPIEF and offset

wells drilled with first-generation flat rheology SBM that have comparable well geometry and drilling parameters.

The low-rheology HPIEF provided a 0.1- 0.15 lb/gal lower ECD at the beginning of this section as compared to the offset wells, which made it possible to drill this section with higher ROP. The ECD could be maintained at the same level as compared to offset wells, even with the increased ROP. The BHA was tripped out of hole without resistance and the casing was run to the desired depth smoothly. It is fair to conclude that the hole was very clean, and no cuttings bed was formed during drilling.

This case study attested that the HPIEF with lower rheological properties has comparable hole cleaning performance for large hole sections as compared to first-generation flat rheology SBM without the need to dilute the fluid prior to tripping pipe or cementing. Reduced fluid treatment resulted in appreciable efficiency savings in time and the overall drilling fluid engineering cost.

A detailed rheological comparison between HPIEF and first-generation flat rheology SBM is presented in Figure 2; this includes both the upper 18.125-in and lower 12.25-in sections. The LSRV was reduced to single digits during drilling of the 12.25-in section, which is much lower than the first-generation flat rheology SBM and below the "rule of thumb" guideline range. However, the HPIEF provided a very clean hole and ensured the subsequent trouble-free tripping and casing running.

The reduction of the rheology also eliminated the formation losses during casing running and cementing operations for the lower section which had a smaller clearance between casing/liner and open hole, i.e., the 12.25-in section. Table 3 lists the formation losses distribution for each well during casing/liner running and cementing operations.

As mentioned above, the combination of finer-PSD weighting material and the novel surfactant chemistry used in HPIEF ensures a lower risk of barite sag. After the HPIEF was left static in the hole for 3-days for wireline logging of the 12.25-in section, no mud weight fluctuation was observed while cementing nor displacing the well to clear brine. The low-rheology HPIEF application on this well exceeded the operator's expectation. As a result of this successful trial, the fluid was deployed on other rigs for this operator and the low-rheology profile HPIEF became widely accepted in the GoM for drilling deepwater wells.

Figure 3 shows complementary ECD reduction rates at section TD for comparable 18.5 x 22-in well intervals, drilled with HPIEF compared to a first-generation flat rheology SBM offset. The hole geometries, inclination, ROP and flow rates were comparable for these two wells. The HPIEF had a slightly higher mud weight (0.1 lb/gal nominal difference) compared to the first-generation flat rheology SBM and clearly shows a larger rate of reduction of ECD, indicating an improved hole cleaning efficiency with the HPIEF.

### **Hole cleaning performance field case #2**

The rheological properties of HPIEF was optimized further during field trials. Applying this new technology allowed

5,700ft of an 18.125-in diameter hole section to be drilled at record speed in under 24 hours. The rheological properties were maintained at even lower levels, as presented in Table 4.

The ROP was maintained at between 300-400 ft/h with a stable ECD, and excellent hole cleaning was observed throughout the 18.125-in interval. Figure 4 depicts the ECD and ROP of this well when drilling the 18.125-in section.

The subsequent section was drilled through an extremely narrow hydraulic window with minimal losses.

In cases where low fracture gradients were encountered, “stress cage” wellbore strengthening additives have also been successfully used with this new fluid system without significantly impact on the rheology. Proprietary wellbore fracture-sizing and particulate blending software was used to design lost circulation material (LCM) blends for effective wellbore strengthening. Subsequently, this allowed the HPIEF drilling fluid to be weighted-up to a density higher than equivalent leak-off test (LOT) density to drill the well without any losses. Furthermore, proprietary software was also used to successfully design the LCM pills. The low rheology, combined with our proprietary LCM and wellbore strengthening software program recommendations, minimized the formation losses for this well.

### Sag performance

Field samples were collected to perform sag flow loop measurements. This test measures the density of the circulating fluid at different flowrates, pipe rotation under preestablished angle and eccentricity. In this case 60-degree angle, 0.9 eccentricity was applied, and it was performed in 120 minutes. Since mud weight is impacted by temperature variation during the test, the mud weight was calibrated to a constant 120°F equivalent for better comparison. We can see from Figure 5 that the density drop at low flowrate was minimal, and the mud weight increase shortly after pipe rotation commenced.

The Viscometer Sag Shoe Test (VSST) is a well site and laboratory test that measures weight material sag propensity of field and lab-prepared drilling fluids under dynamic conditions. The VSST test data shown in Figure 6 was obtained from a typical HPIEF well drilled with a 45-degree hole angle, and shows VSST dynamic sag was maintained at  $\leq 0.5$  lbm/gal throughout this well, and no corresponding mud weight fluctuations were detected while displacing the HPIEF from the hole.

### Maintenance and Flexibility

The HPIEF system provides an approximate 40% reduction in treatment cost compared to the first-generation of flat rheology fluids with its unique chemistry, micronized solids and reduced dilution requirement. Figure 7 shows a comparison of consumption rate of emulsifier and wetting agent with HPIEF, offset wells and first-generation flat rheology SBM. The HPIEF system is extremely stable and reduced consumption of emulsifier and wetting agent are needed at the rig site to maintain the emulsion stability.

Since the introduction of the HPIEF more than 50 wells have been successfully drilled with the new technology, offering significant drilling efficiency improvements. An overview of the number of HPIEF wells and mud weight distribution from 9 to 17 lbm/gal at various depths is illustrated in Figure 8.

### Conclusions

The low-rheology HPIEF can achieve comparable hole cleaning performance compared to offset wells and ensure trouble-free drilling operations.

LSRV can be maintained at lower values than those traditionally suggested by “hole size” rule of thumb guidelines, whilst still ensuring good hole cleaning.

The HPIEF provides the opportunity to drill large diameter holes with higher ROP while maintaining similar ECD.

The HPIEF has minimal sag risk, even with lower rheological profile.

### Acknowledgments

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### Nomenclature

Define symbols used in the text here unless they are explained in the body of the text. Use units where appropriate.

*BHA* = Bottom-hole Assembly

*ROP* = Rate of Penetration

*ECD* = Equivalent Circulating Density

*LSRV* = Low-Shear-Rate Viscosity

*SBM* = Synthetic-based Mud

*HPIEF* = High-Performance Invert-Emulsion Fluid

*NPT* = Non-Productive Time

*LOT* = Leak-off Test

### References

- McLean A., Wilde A., Zamora M. and Rafferty M.: “The Top 10 Mud-Related Concerns in Deepwater Drilling Operations – Revisited After 10 Years.” AADE-10-DF-HO-04, AADE Fluids Conference and Exhibition, Houston, April 6-7, 2010.
- O’Brien T.B. and Dobson M., Hole Cleaning: “Some Field Results.” SPE/IADC 13442, 1985 SPE Drilling Conference, New Orleans, March 5-8. 1985.
- Ramsey, M.S.: “Practical Wellbore Hydraulics and Hole Cleaning, Page 95, Gulf Professional Publishing, January 2019.
- Visinescu V. and Bouguetta M., “Drilling Fluids for ERD: Rheology Requires More Than a Quick Look.” AADE-13-FTCE-27, AADE National Technical Conference and Exhibition, Oklahoma City, February 26-27, 2013.
- Vickers D., Williford M., Huang W., Cliffe S., Jaimes J.P., Zeng W., “Next Generation Flat Rheology Fluid Unlocks a New Dimension in Drilling Operations.” AADE-20-FTCE-107, AADE Fluid Conference and Exhibition, Houston, April 14-15, 2020.

Table 1: Typical rheological profile for a first-generation flat rheology SBM for 18.125-in section

<b>Mud Weight, lbm/gal</b>	<b>10.6</b>		
<b>Mud Temp, °F</b>	<b>68</b>		
<b>Rheology Temp, °F</b>	<b>40</b>	<b>100</b>	<b>150</b>
<b>R600, °VG</b>	153	76	62
<b>R300, °VG</b>	94	50	44
<b>R200, °VG</b>	74	41	38
<b>R100, °VG</b>	51	30	29
<b>R6, °VG</b>	18	14	18
<b>R3, °VG</b>	17	13	16
<b>PV, cP</b>	59	26	18
<b>YP, lb./100 ft<sup>2</sup></b>	35	24	26
<b>LSYP, lb./100 ft<sup>2</sup></b>	16	12	14
<b>10-sec Gel, lb./100 ft<sup>2</sup></b>	17	16	20
<b>10-min Gel, lb./100 ft<sup>2</sup></b>	37	33	34

Table 2: Typical rheological profile for a HPIEF for 18.125-in section

<b>Mud Weight, lbm/gal</b>	<b>10.6</b>		
<b>Mud Temp, °F</b>	<b>68</b>		
<b>Rheology Temp, °F</b>	<b>40</b>	<b>100</b>	<b>150</b>
<b>R600, °VG</b>	124	66	58
<b>R300, °VG</b>	70	41	38
<b>R200, °VG</b>	52	31	32
<b>R100, °VG</b>	33	23	24
<b>R6, °VG</b>	12	10	12
<b>R3, °VG</b>	11	9	11
<b>PV, cP</b>	54	25	20
<b>YP, lb/100 ft<sup>2</sup></b>	16	16	18
<b>LSYP, lb/100 ft<sup>2</sup></b>	10	8	10
<b>10-sec Gel, lb/100 ft<sup>2</sup></b>	12	11	13
<b>10-min Gel, lb/100 ft<sup>2</sup></b>	26	25	25



Figure 1: ECD and ROP comparison with offset wells

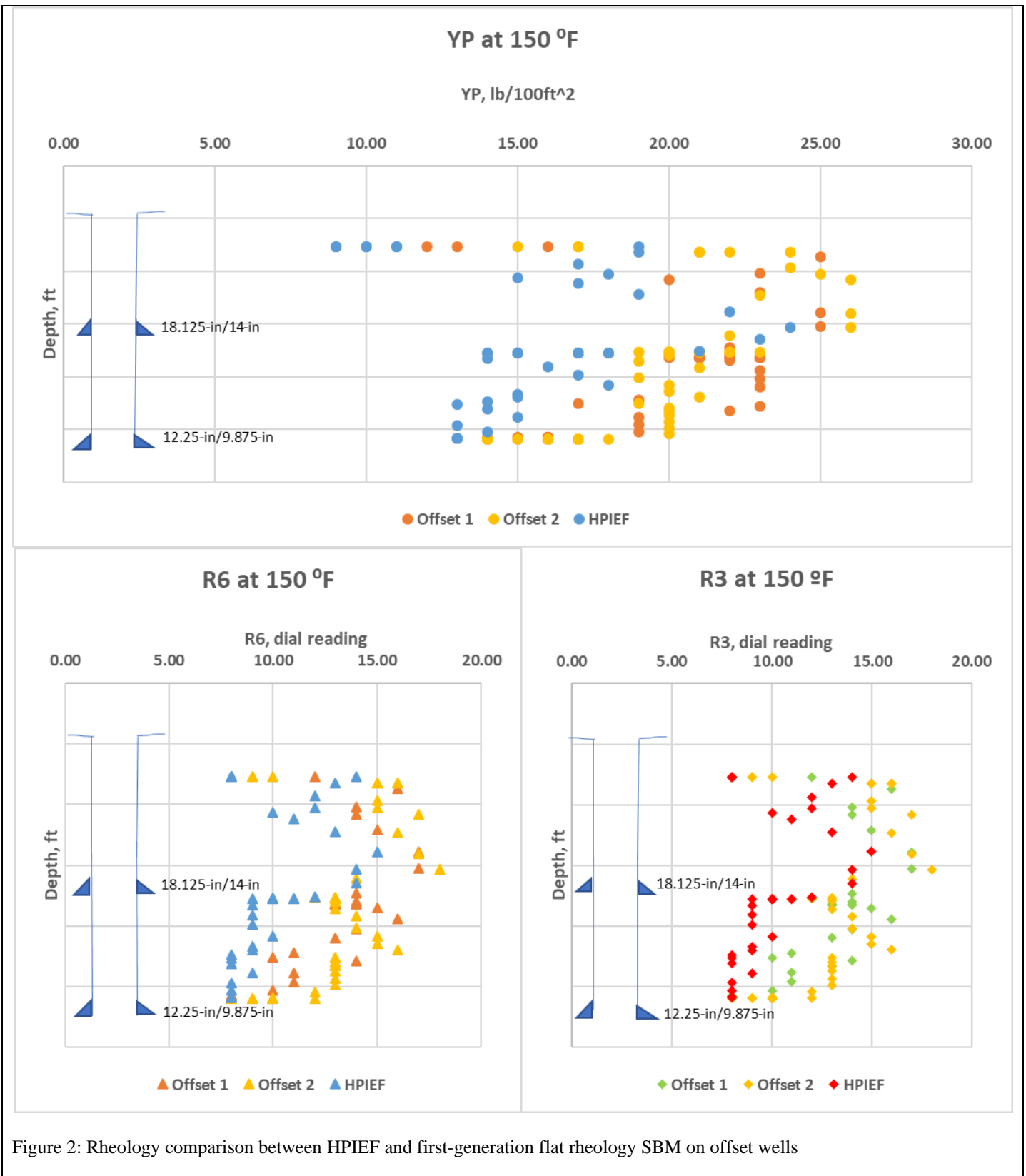


Figure 2: Rheology comparison between HPIEF and first-generation flat rheology SBM on offset wells

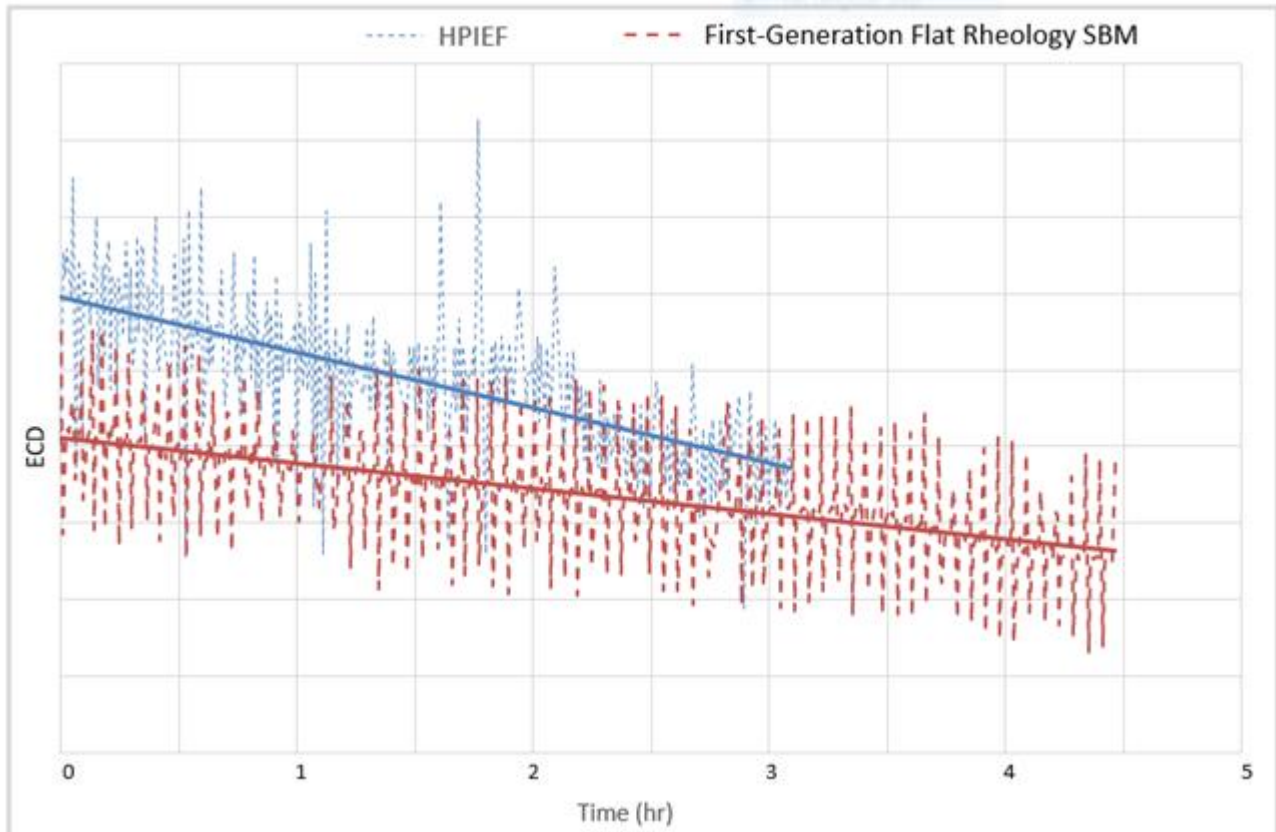


Figure 3: ECD Reduction Rates at Section TD (Clean-up Cycles) 18 1/2 x 22"

Table 3: Formation losses comparison during casing/liner running

9-7/8" casing/liner running and cementing losses summary			
Well	HPIEF	Offset 1	Offset 2
Water depth, ft	4987	4986	4987
Hole size, inch	12.25	12.25	12.25
Interval length, ft	8724	8170	8905
Running casing and landing string, bbl.	0	19	6
Washing to bottom, bbl.	0	0	0
Attempting to circulate, bbl.	0	174	26
Pumping cement, bbl.	0	173	99
Displacing with SBM, bbl.	0	76	977
Total volume lost, bbl.	0	442	1108

Table 4: HPIEF rheological profile for 18.125-in section

<b>Mud Weight, lb/gal</b>	<b>11.4</b>		
<b>Mud Temp, °F</b>	<b>70</b>		
<b>Rheology Temp, °F</b>	<b>40</b>	<b>100</b>	<b>150</b>
<b>R600, °VG</b>	97	61	50
<b>R300, °VG</b>	56	38	33
<b>R200, °VG</b>	41	29	26
<b>R100, °VG</b>	26	21	20
<b>R6, °VG</b>	10	9	10
<b>R3, °VG</b>	8	8	10
<b>PV, cP</b>	41	23	17
<b>YP, lb/100 ft<sup>2</sup></b>	15	15	16
<b>LSYP, lb/100 ft<sup>2</sup></b>	6	7	10
<b>10-sec Gel, lb/100 ft<sup>2</sup></b>	12	14	15
<b>10-min Gel, lb/100 ft<sup>2</sup></b>	21	21	24



Figure 4: ROP and ECD comparison during 18.125-in section

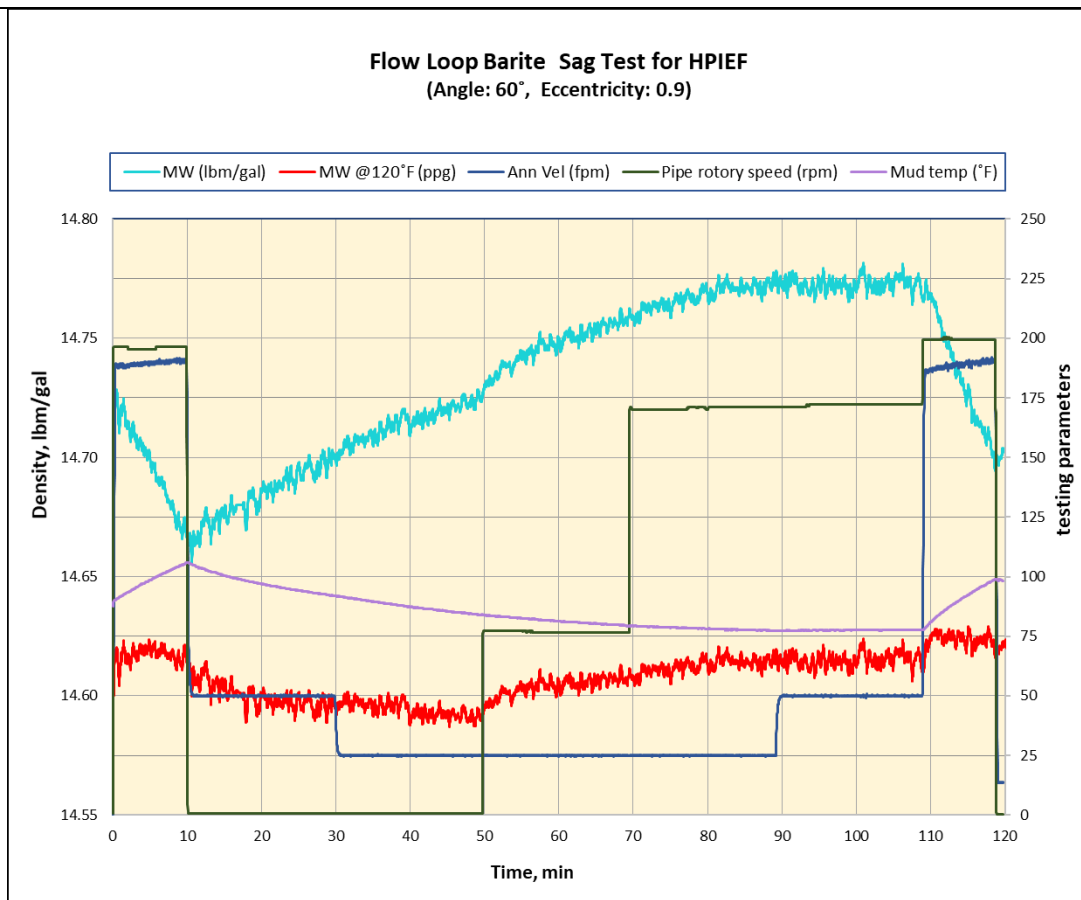


Figure 5: Sag Flow Loop test with HPIEF showing minimal density drop and short pick up time

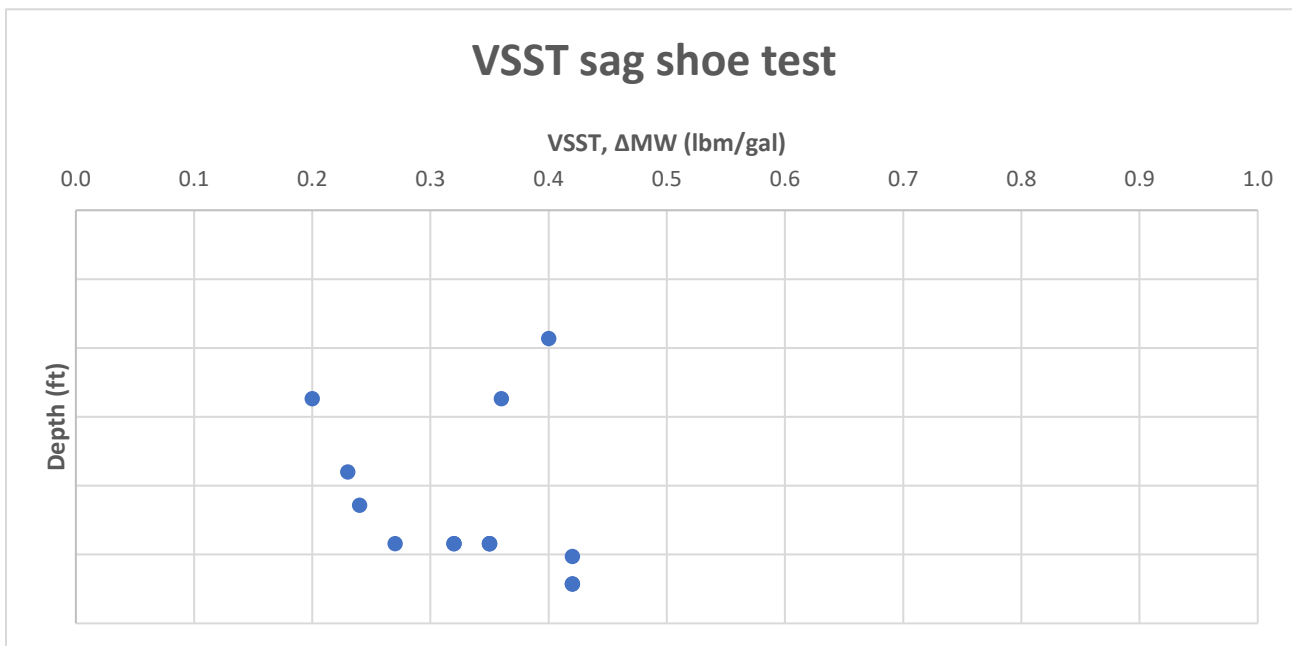


Figure 6: VSST results showing low VSST dynamic sag results

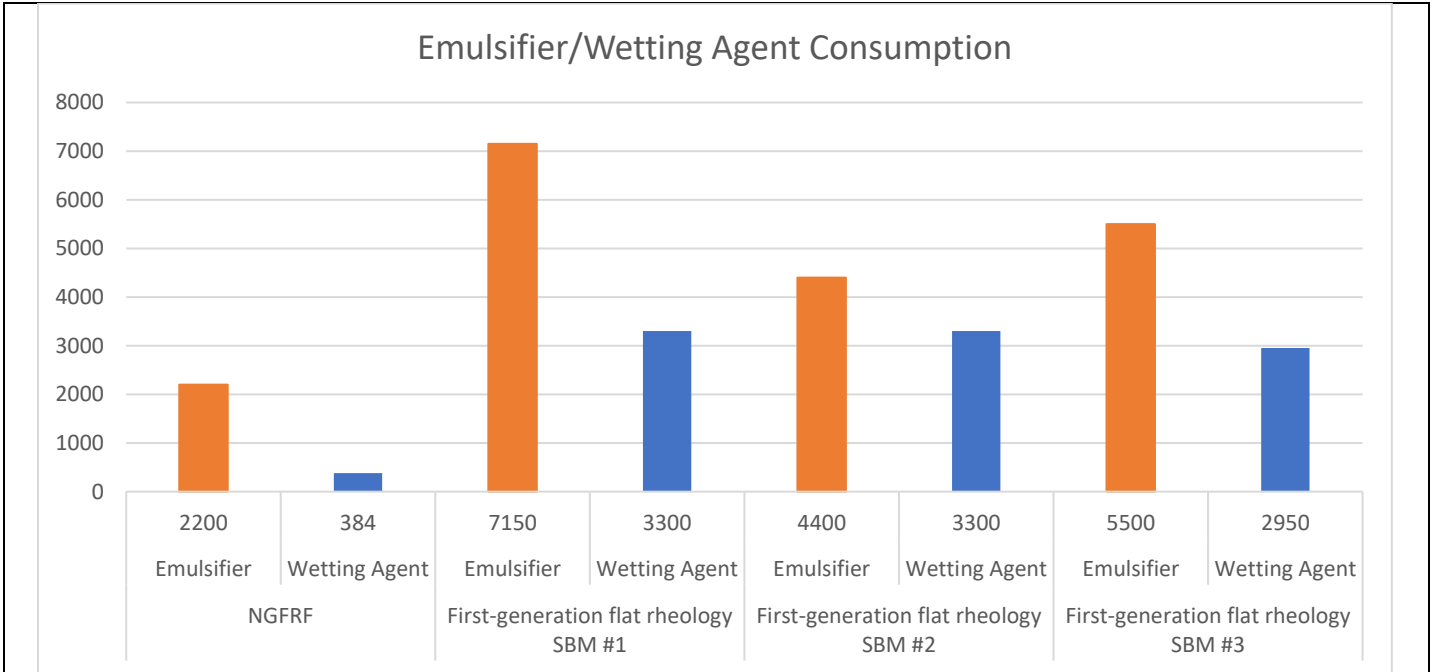


Figure 7: Emulsifier/Wetting Agent Consumption Comparison

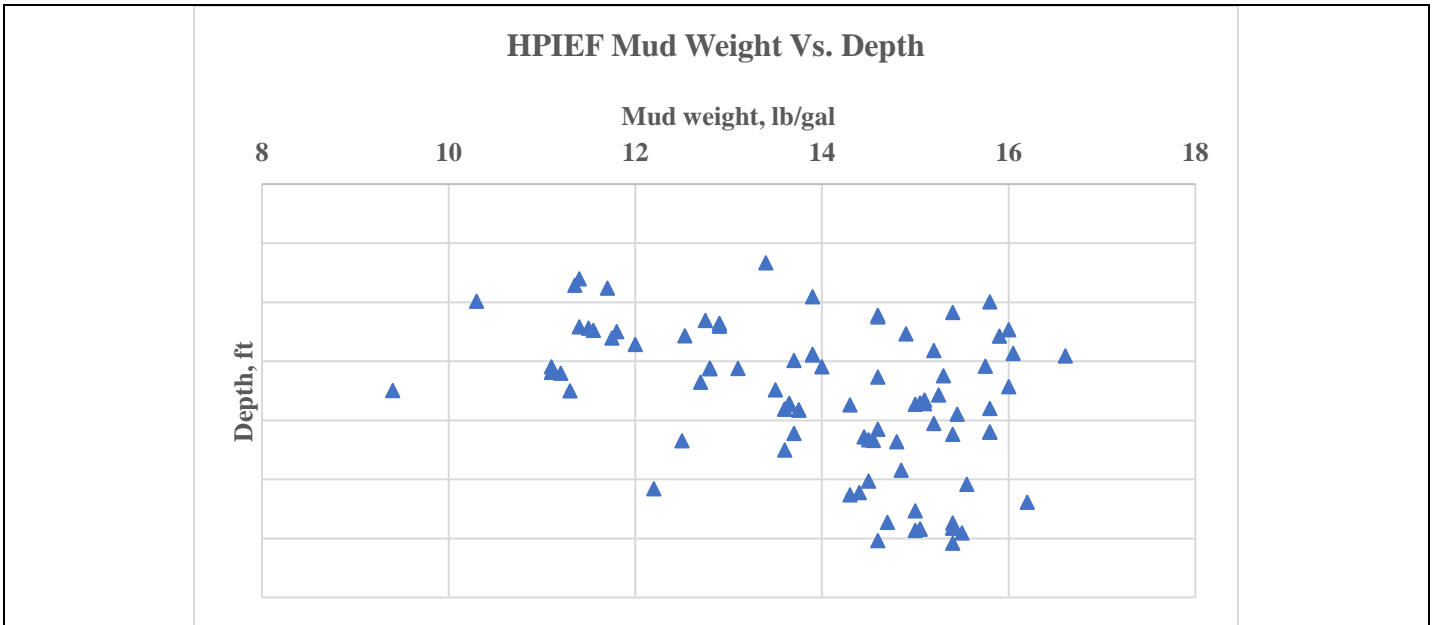


Figure 8: Graph showing the mud weight distribution of the HPIEF for North America Offshore