**AADE-25-NTCE-013**

# Exploring the Improved Performance of PIBSA as an Emulsifier over Traditional Tall Oil Fatty Acid in Drilling Fluids for Fluid Loss Monitoring

Edmund Sandoval, Thomas P Wilson, Scott Shultz and Jennifer Jackson, Lubrizol



## Abstract

This paper explores the use of Polyisobutylene Succinic Anhydride (PIBSA) as an innovative emulsifier in drilling fluids both as primary and secondary emulsifiers. Traditionally, derivatives of tall oil fatty acid have been utilized as an emulsifier in drilling operations. However, this study examines the potential benefits of PIBSA as a direct substitute, with a focus on the PIBSA emulsifier to reduce the need for high-cost fluid loss additives in high temperature drilling applications

The objective of this research is to evaluate the effectiveness of PIBSA in maintaining desirable drilling mud fluid characteristics. The study encompasses laboratory experiments conducted on various drilling fluid formulations using PIBSA as the primary and secondary emulsifier. Fluid loss measurements are taken under controlled conditions to assess the performance of PIBSA compared to tall oil fatty acid-based systems.

Preliminary findings indicate that PIBSA-based emulsifiers demonstrate promising results in terms of creating a stable drilling mud and compatible with other additives under various temperature such as 250°F and 350°F. The use of PIBSA has the potential to significantly reduce the reliance on costly fluid loss additives without compromising fluid performance at the higher temperature. By optimizing the concentration and formulation of PIBSA, drilling operations can achieve improved cost-effectiveness solutions.

In conclusion, this study highlights the innovative use of PIBSA as an emulsifier in drilling fluids, specifically for applications that require more difficult conditions such as higher temperature. The research demonstrates the potential of PIBSA to reduce the dependency on expensive fluid loss additives while maintaining desired fluid properties. The findings of this study contribute to the ongoing efforts in optimizing drilling fluid formulations for cost-effective and efficient drilling operations.

## Introduction

Modern drilling operations demand advanced fluid systems capable of maintaining performance and stability under increasingly challenging wellbore conditions. Invert emulsion muds, a subset of oil-based drilling fluids, are indispensable in these applications due to their ability to provide superior stability in reactive shales, water-sensitive formations, and high-temperature wells. These systems play a crucial role in controlling formation damage, maintaining wellbore stability, and enhancing drilling efficiency. Central to their functionality is the emulsifier, a critical additive responsible for stabilizing the dispersed aqueous phase within the continuous oleaginous phase.

Traditionally, derivatives of tall oil fatty acids (TOFA) have served as the primary emulsifiers in invert emulsion formulations. These emulsifiers are valued for their effectiveness in stabilizing drilling fluids across a range of applications. However, TOFA-based emulsifiers face inherent limitations, particularly when subjected to high-temperature, high-pressure (HTHP) environments encountered in modern drilling. These emulsifiers often require supplementary fluid loss control additives to maintain emulsion stability and mitigate fluid loss under elevated temperatures. The reliance on these additional additives not only increases costs but also complicates fluid formulation and logistics. Furthermore, the fluctuating availability and pricing of TOFA-derived materials have spurred interest in identifying alternative emulsifier chemistries that can address these challenges more efficiently.

Polyisobutylene Succinic Anhydride (PIBSA) represents a novel and promising candidate for emulsifier applications in invert emulsion muds. PIBSA emulsifiers, synthesized from synthetic polymer precursors, offer several advantages over traditional TOFA-based systems. Their synthetic nature enables precise control over molecular properties such as solubility, polarity, and thermal stability, which are critical for ensuring optimal performance in HTHP environments. By leveraging these properties, PIBSA-based emulsifiers have the potential to reduce the reliance on high-cost fluid loss additives while maintaining or improving overall fluid performance.

One of the key benefits of PIBSA-based emulsifiers lies in their enhanced thermal stability. Unlike conventional TOFA emulsifiers, PIBSA exhibits resilience at elevated temperatures, retaining its ability to stabilize emulsions and prevent phase separation even at temperatures as high as 350°F. This thermal stability not only ensures reliable performance during drilling but also minimizes the need for additional additives, thereby reducing costs and simplifying fluid formulations. Furthermore, PIBSA's compatibility with other fluid additives makes it a versatile option for a wide range of drilling fluid systems, enhancing its applicability in diverse operational scenarios.

This study examines the performance of PIBSA as an emulsifier in drilling fluid formulations, with a focus on its role as both a primary and secondary emulsifier. Laboratory experiments were conducted to evaluate the effectiveness of PIBSA in stabilizing emulsions, controlling fluid loss, and maintaining desirable rheological properties under controlled conditions. Key performance metrics, including emulsion stability and fluid loss at temperatures of 250°F and 350°F, were analyzed to assess PIBSA's suitability for high-temperature drilling applications. The study also explores the compatibility of PIBSA with common drilling fluid additives and its ability to maintain fluid performance across varying oil-to-water ratios.

Preliminary findings indicate that PIBSA-based emulsifiers deliver significant advantages in terms of thermal stability, fluid loss control, and overall system performance. These emulsifiers demonstrate the ability to stabilize emulsions under HTHP conditions without the extensive use of supplemental additives, thereby offering a more cost-effective solution for challenging drilling environments. The versatility of PIBSA further enhances its appeal, as it can be tailored to meet specific operational requirements through adjustments in concentration and formulation. This adaptability positions PIBSA as a compelling alternative to traditional TOFA-based emulsifiers, particularly for applications that demand enhanced performance in extreme wellbore conditions.

The introduction of PIBSA into drilling fluid formulations also addresses critical industry concerns related to cost-efficiency and operational reliability. By reducing the dependency on high-cost fluid loss additives, PIBSA-based systems contribute to a more streamlined and economically viable approach to drilling fluid design. Additionally, the thermal stability and compatibility of PIBSA ensure that these systems can withstand the rigors of HTHP wells, providing a reliable solution for operators seeking to optimize performance in increasingly complex drilling scenarios.

## Experimental

### *Polyisobutylene Succinic Anhydride (PIBSA)*

The stability of invert emulsion wellbore compositions formulated with various PIBSA-based emulsifiers was evaluated under simulated downhole conditions. The characteristics of the PIBSA-based emulsifiers are summarized in Table 1 were prepared from polyisobutylene (PIB) acylated with maleic anhydride to form succinated polyisobutylene (PIBSA). The resulting PIBs is then reacted with alcohols and/or amines to form esters, amides, imides, and combinations thereof. Incomplete conversion of the succinate resulted in formation of ester/acids which then react with pendant amines to form ester/acid salts. The resulting emulsifiers are characterized by total base number (TBN) and total acid number (TAN)).

**Table 1 Materials Utilized in Experimental Testing**

| Emulsifier | Type | PIB Mn | Amine/alcohol | Head Group | TBN | TAN |
|---|---|---|---|---|---|---|
| Emul-1 | PIBSA | 1000 | Amine Type 1 | Ester/acid salt | 25 | 25 |
| Emul-2 | PIBSA | 1000 | Amine Type 1 | Ester/acid salt | 50 | 30 |
| Emul-3 | PIBSA | 1000 | Amine Type 2 | Imide | 40 | 30 |
| Emul-4 | PIBSA | 1000 | Amine Type 3 | Ester/acid salt | 30 | 3 |
| Emul-7[2] | Conven-tional | NA | Diethylene triamine | Acid / amide | NA | NA |
| Emul -8 | Conven-tional | NA | Modified Tall Oil | | NA | NA |

1.TBN and TAN are approximate
2.Mixture of tall oil fatty acid (TOFA) and amides of TOFA and diethylene triamine
3. Modified Tall Oil (MTO)
4. NA = not applicable

### *Drilling Mud Composition - Primary Emulsifiers*

The primary emulsifiers, both PIBSA-based and conventional TOFA-based, were formulated as invert emulsions with a 70:30 oil-to-water ratio utilizing the specified recipes outlined below. The preparation of the primary emulsifier involves the following steps: No. 2 diesel fuel and organophilic clay (Bentone 150 for the 250°F conditions and Bentone 38 for the 350°F conditions) were combined with the primary emulsifier (10 ml) and lime (8 g) in a sample cup. This mixture was then subjected to medium-speed mixing for 5 minutes using a Hamilton Beach 3-speed mixer. Following this, an aqueous solution containing 30% CaCl2 (70 g) was added to the mixture, which was then mixed at medium speed for an additional 10 minutes. Finally, barite (200 grams) was introduced into the mixture, and the resultant blend was mixed at high speed for 30 minutes. This comprehensive mixing procedure ensures that all components are thoroughly blended. The detailed formulations and conditions can be found in Tables 2.

**Table 2 Primary Emulsifier Drilling Mud Formulation**

| | Mud 1 | Mud 2 | Mud 3 | Mud 4 | Mud 5 |
|---|---|---|---|---|---|
| Diesel (mL) | 280 | 280 | 280 | 280 | 280 |
| Organo Clay<br>- Bentone 150 (g)<br>- Bentone 38 | 6 | 6 | 6 | 6 | 6 |
| Primary emulsifier (mL) | | | | | |
| Emul-1 | 10 | | | | |
| Emul-2 | | 10 | | | |
| Emul-3 | | | 10 | | |
| Emul-4 | | | | 10 | |
| Emul-8 | | | | | 10 |
| Lime (g) | 8 | 8 | 8 | 8 | 8 |
| CaCl2 - 30% (mL) | 70 | 70 | 70 | 70 | 70 |
| Barite (g) | 200 | 200 | 200 | 200 | 200 |
| Hot Roll - Temp (℉) | 250/ 350 | 250/ 350 | 250/ 350 | 250/ 350 | 250/ 350 |
| Hot Roll – Time (Hrs) | 16 | 16 | 16 | 16 | 16 |

### *Secondary Emulsifiers*

The PIBSA-based products were formulated to evaluate their ability to function as secondary emulsifiers. The preparation of these muds followed the same procedure described above for the primary emulsifier, with the exception that lime was omitted from the formulation. The drilling mud recipe for the 250°F conditions remained the same as for the primary emulsifier and is outlined in Table 3. For the secondary emulsifier testing at

350°F, the sample list was streamlined to include only one PIBSA-based emulsifier, specifically Emul-1, which was compared against the conventional emulsifier. This focused approach was intended to provide a clear comparison of performance between the PIBSA-based and traditional emulsifiers under higher temperature conditions. The test mud recipes for the 350°F testing conditions are summarized below in Table 4.

**Table 3 Secondary Emulsifier at 250°F Mud**

| | Mud 6 | Mud 7 | Mud 8 | Mud 9 |
|---|---|---|---|---|
| No. 2 Diesel (mL) | 280 | 280 | 280 | 280 |
| Organo Clay - Bentone 150 (g) | 6 | 6 | 6 | 6 |
| Secondary emulsifier (mL) | | | | |
| Emul-1 | 10 | | | |
| Emul-2 | | 10 | | |
| Emul-3 | | | 10 | |
| Emul-7 | | | | 10 |
| CaCl2 - 30% (mL) | 70 | 70 | 70 | 70 |
| Barite (g) | 200 | 200 | 200 | 200 |
| Hot Roll - Temp (℉) | 250 | 250 | 250 | 250 |
| Hot Roll - Temp (Hrs) | 16 | 16 | 16 | 16 |

**Table 4 Secondary Emulsifier at 350°F Mud**

| | Mud 10 PIBSA | Mud 11 Conventional |
|---|---|---|
| No. 2 Diesel (mL) | 280 | 280 |
| Organo Clay - Bentone 38 (g) | 6 | 6 |
| Secondary emulsifier (mL) | | |
| Emul-1 | 10 | |
| Emul-7 | | 10 |
| CaCl2 - 30% (mL) | 70 | 70 |
| Barite (g) | 200 | 200 |
| Hot Roll - Temp (℉) | 350 | 350 |
| Hot Roll - Temp (Hrs) | 16 | 16 |

### *Primary/Secondary Combination*

The emulsifiers, both PIBSA-based and conventional tall-oil-based, were tested in the presence of secondary emulsifiers to create three distinct systems for comparison:

- PIBSA-based primary and secondary emulsifiers
- Conventional primary emulsifier with a PIBSA-based secondary emulsifier
- Conventional primary and secondary emulsifiers

The formulations for these systems followed a similar recipe to those used in previous testing phases as detailed in Table 5. Specifically, the primary emulsifier was included at 10 mL, and the secondary emulsifier was incorporated at 4.5 mL. To increase the challenge of the testing conditions, the brine composition was changed from calcium chloride to calcium bromide. In this adjusted formulation, 70 mL of a 54% calcium bromide solution was used to replace the calcium chloride. This change in brine composition necessitated a reduction in barite levels to 150 parts to account for the increased density of the calcium bromide solution. Hot rolling was conducted exclusively at 350°F to simulate high-temperature conditions.

**Table 5 Combination Drilling Mud Compositions**

| | Mud 12 PIBSA/ PIBSA | Mud 14 Conventional/ Conventional |
|---|---|---|
| Diesel (mL) | 280 | 280 |
| Organo Clay - Bentone 38 (g) | 6 | 6 |
| Primary emulsifier (mL) | | |
| Emul -3 | 10 | |
| Emul-8 | | 10 |
| Secondary emulsifier (mL) | | |
| Emul-1 | 4.5 | |
| Emul-7 | | 4.5 |
| Lime (g) | 8 | 8 |
| CaBr2 - 54% (mL) | 70 | 70 |
| Barite (g) | 150 | 150 |
| Hot Roll - Temp (℉) | 350 | 350 |
| Hot Roll – Time (Hrs) | 16 | 16 |

### *Test Conditions*

Prepared mud samples were placed into high-temperature-resistant rolling or aging cells. The oven was set to the specified test temperature of 250°F or 350°F, depending on the testing requirements. The cells were pressurized and aged for 16 hours. The test muds were evaluated according to the American Petroleum Institute (API) standards for drilling muds. The viscosity at 600, 300, 200, 100, 6, and 3 rpm was recorded, along with plastic viscosity (PV), yield point (YP), 10-second and 10-minute gel strengths, and emulsion stability (ES). For applicable tests, high-temperature/high-pressure (HTHP) fluid loss measurements were obtained both before hot rolling (BHR) and after hot rolling (AHR). Rheological and electrical stability properties were measured at 150°F before hot rolling. The samples were then subjected to hot rolling for 16 hours in aging cells at 250°F or 350°F under a constant pressure of 100 psi. After hot rolling, the samples were cooled, transferred to sample cups, and remixed for 15 minutes. The rheology and ES properties were measured again at 150°F HTHP fluid loss of the samples was evaluated under conditions of 350°F and 500 psi using an HTHP filter press. For this test, the prepared drilling mud sample was placed in the testing cell, and controlled pressure was applied. The filtrate was collected and measured over a 30-minute period to determine fluid loss control. Filter cake thickness was measured using a slide ruler and recorded in millimeters after conversion from 32nds of an inch. Key parameters assessed include shear stress across various rotational speeds, PV, YP, 10-second and 10-minute gel strengths, and ES. These metrics are essential for evaluating the drilling mud's capacity to suspend solids, maintain optimal flow properties, and stabilize emulsions under operational conditions. When evaluating key drilling mud properties, the following target ranges were used as benchmarks:

- Plastic viscosity (PV): 8–35 cP
- Yield point (YP): Minimum of 5 and less than three times the PV
- 10-second gel strength: 2–5 lb/100 ft²
- 10-minute gel strength: 2–35 lb/100 ft²
- Electrical stability (ES): Greater than 400 V
- Filter cake thickness: Thinner is better, measured in millimeters, converted to 32nds of an inch

## Results and Discussion

### *Primary Emulsifiers*

The rheological properties and emulsion stability of diesel-based drilling muds formulated with PIBSA-based emulsifiers were systematically evaluated in comparison to those containing conventional TOFA-based emulsifiers, both before and after aging at 250°F.

In the detailed comparison between the conventional product Emul-8 TOFA-based and the four PIBSA-based products (Emul-1, Emul-2, Emul-3, and Emul-4), three of the PIBSA-based emulsifiers demonstrated performance that was comparable to that of the conventional TOFA-based emulsifier. However, Emul-4 did not form a stable emulsion, indicating that not all PIBSA-based products offer the potential for application as diesel-based drilling mud additives.

The comprehensive analysis revealed only minimal deviations in performance across the evaluated parameters, including viscosity over different rotational speed, PV, YP, 10s and 10min gel strength, and emulsion stability. The detailed data supporting these findings are located in Table 5. It was observed that the PIBSA-based products maintained equivalent performance to the TOFA-based emulsifier at a temperature of 250°F

The subsequent evaluation of performance at 350°F will be critically important to determine the potential for significantly improved mud stability at higher temperatures. This will further elucidate the advantages of PIBSA-based emulsifiers in maintaining emulsion stability and overall drilling fluid performance under HTHP conditions

**Table 6 Results of Primary Emulsifiers at 250°F**

| | Emul-1 | | Emul-2 | | Emul-3 | | Emul-8 | |
|---|---|---|---|---|---|---|---|---|
| | BHR | AHR | BHR | AHR | BHR | AHR | BHR | AHR |
| at 600 rpm (cP) | 39.1 | 43.5 | 36.9 | 40.8 | 37.9 | 44.4 | 49.1 | 30.5 |
| at 300 rpm (cP) | 25.6 | 29.1 | 24.4 | 26.9 | 25.4 | 30.9 | 25 | 16.5 |
| at 200 rpm (cP) | 17.5 | 21.4 | 18.6 | 20.5 | 17.2 | 20.6 | 17.7 | 11.7 |
| at 100 rpm (cP) | 11.5 | 14.2 | 12.4 | 13.7 | 11.9 | 14.8 | 11.6 | 7.2 |
| at 6 rpm (cP) | 3.9 | 5.0 | 4.4 | 4.8 | 4.6 | 6.5 | 5.1 | 2.7 |
| at 3 rpm (cP) | 3.4 | 4.3 | 3.9 | 4.2 | 3.9 | 5.8 | 4.9 | 2.6 |
| | | | | | | | | |
| Plastic Viscosity (PV) (cP) | 14.3 | 15.0 | 12.9 | 14.3 | 13.2 | 14.0 | 20.5 | 13.7 |
| Yield Point (YP) (lbf/100ft2) | 9.2 | 11.7 | 10.2 | 11.1 | 10.3 | 13.9 | 4.4 | 2.1 |
| 10 s Gel strength (lb/100ft2) | 4.8 | 5.5 | 5.0 | 5.5 | 5.5 | 6.9 | 8.5 | 5.2 |
| 10 min Gel strength (lb/100ft2) | 5.5 | 5.7 | 6.2 | 5.9 | 6.6 | 7.3 | 16.2 | 7.4 |
| Emulsion Stability (ES) (V) | 1080.3 | 962.7 | 922.0 | 1312.0 | 1125.7 | 1143.0 | 1295 | 573.67 |

*Emul -4 DNR (Did not roll)

The primary emulsifiers were tested at 350°F in drilling mud, with an emphasis on evaluating their performance in terms of shear stress across various ranges PV, YP, 10s and 10min gel strength, and emulsion stability. These results are presented in Table 7. As shown in the table below, the viscosity over different rotational speed values over a range Emul-1, Emul-2, and Emul-3 closely align with those of the conventional emulsifiers demonstrating comparable performance under these higher temperature conditions. Furthermore, the rheology properties for the new emulsifiers exhibit remarkable consistency with the values recorded for conventional treatment. These findings indicate that the PIBSA-based emulsifiers can effectively replicate the desired rheological properties of traditional TOFA- based emulsifiers in diesel conditions.

A minor difference was observed in emulsion stability, where the conventional emulsifier exhibited a slightly higher stability compared to the PIBSA based emulsifiers, but all ES values were well above the API recommendation of 400V.

**Table 7 Primary Emulsifiers at 350F**

| | Emul-1 | | Emul-2 | | Emul-3 | | Emul-8 | |
|---|---|---|---|---|---|---|---|---|
| | BHR | AHR | BHR | AHR | BHR | AHR | BHR | AHR |
| at 600 rpm (cP) | 32.9 | 31.4 | 32.0 | 28.8 | 31.0 | 31.4 | 35.2 | 35.2 |
| at 300 rpm (cP) | 19.5 | 19.2 | 20.4 | 17.6 | 19.0 | 20.1 | 18.6 | 18.6 |
| at 200 rpm (cP) | 13.9 | 13.9 | 15.2 | 12.6 | 13.8 | 15.2 | 13.1 | 13.1 |
| at 100 rpm (cP) | 8.6 | 8.7 | 10.1 | 8.1 | 8.7 | 10.3 | 7.7 | 7.7 |
| at 6 rpm (cP) | 2.5 | 2.8 | 3.6 | 2.6 | 2.7 | 3.8 | 1.7 | 1.7 |
| at 3 rpm (cP) | 2.2 | 2.6 | 2.9 | 2.2 | 2.4 | 3.4 | 1.4 | 1.4 |
| | | | | | | | | |
| Plastic Viscosity (PV) (cP) | 13.6 | 12.4 | 11.9 | 11.8 | 12.2 | 11.8 | 14.5 | 12.3 |
| Yield Point (YP) (lbf/100ft2) | 5.1 | 5.6 | 6.9 | 4.7 | 5.3 | 7.7 | 4.6 | 1.4 |
| 10 s Gel strength (lb/100ft2) | 3.1 | 3.5 | 4.0 | 3.0 | 3.4 | 4.2 | 2.1 | 0.4 |
| 10 min Gel strength (lb/100ft2) | 4.7 | 4.4 | 4.8 | 3.1 | 4.4 | 4.9 | 8.1 | 0.5 |
| Emulsion Stability (ES) (V) | 1161.3 | 960.7 | 832.7 | 1003.0 | 944.7 | 1171.0 | 1583.0 | 1262.0 |
| **HTHP Fluid Loss*** | | **4.8** | | **6.0** | | **6.8** | | **62** |

*30 minutes @ 300F/500 psi

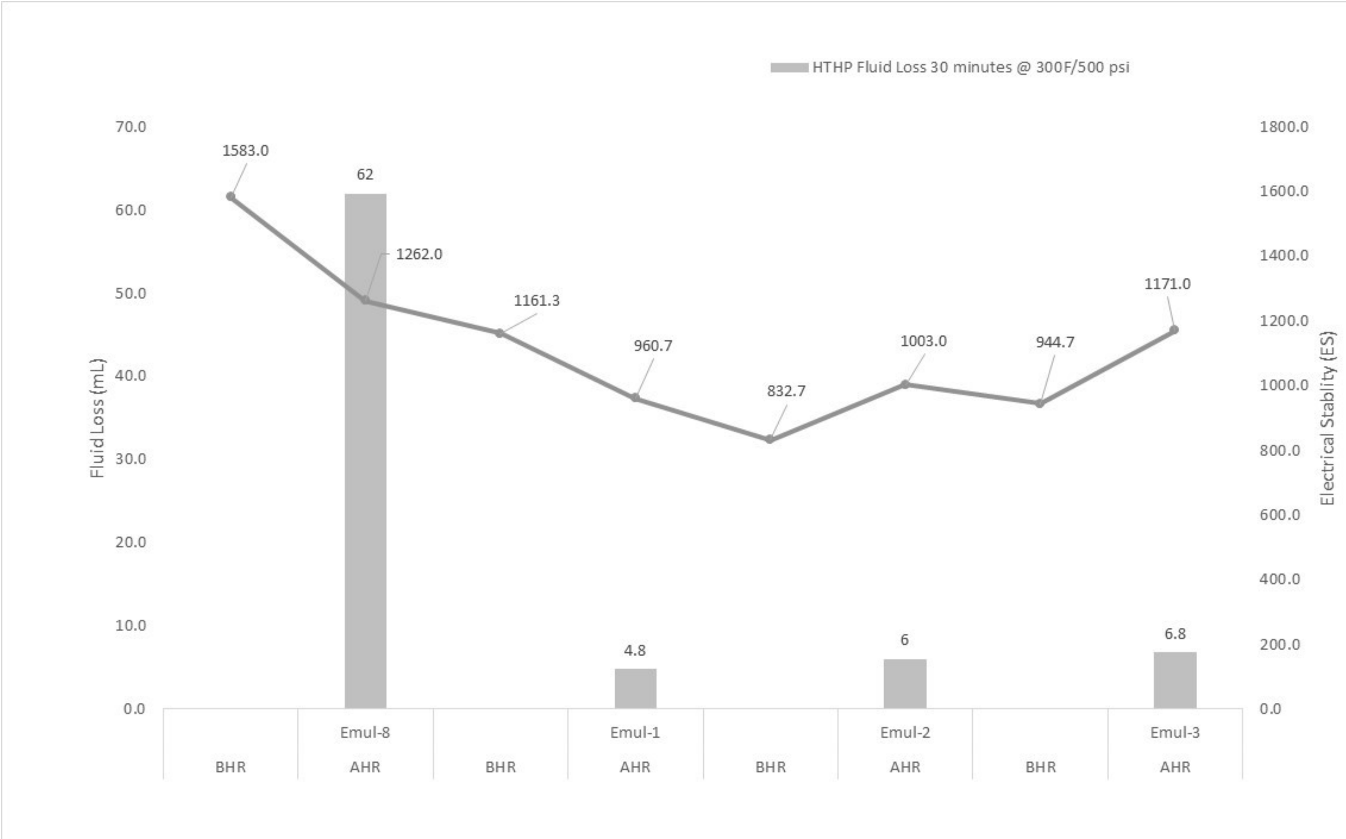


**Figure 1 Primary Emulsifiers HTHP Fluid Loss vs ES**

As highlighted in the introduction, the value of using PIBSA-based emulsifiers is that under high-temperature conditions, they can offer more stability and potentially reduce overall fluid loss. If fluid loss can be minimized with these products, the need to add additional fluid loss additives is significantly reduced, thereby saving the considerable expense of incorporating extra additives into the drilling mud. By comparing the performance of HTHP fluid loss at 30 minutes at 300°F and 500 psi, as detailed at the bottom of Table 7 and in Graph 1, the conventional emulsifier versus the PIBSA-based emulsifier highlights the significant benefits of the PIBSA-based products. Specifically, the fluid loss result for the conventional product was measured at 62 mL, while the PIBSA-based emulsifiers achieved significantly reduced values of 4.8 mL for Emul-1, 6.0 mL for Emul-2, and 6.8 mL for Emul-3. These results clearly underscore the exceptional ability of the PIBSA emulsifiers to maintain fluid retention under highly challenging conditions, marking a substantial improvement over conventional systems. This improvement not only enhances the efficiency of the drilling process but also contributes to overall cost savings and operational effectiveness

## Secondary Emulsifiers

Following the initial testing of primary emulsifiers against the conventional tall-oil-based emulsifier, the evaluation was subsequently modified to focus on secondary emulsifiers (Emul-1, Emul-2, and Emul-3) under conditions that excluded lime and initially operated at a lower temperature of 250°F. The detailed experimental results are summarized in Table 8, which highlights the performance metrics of the three PIBSA-based emulsifiers in comparison to the conventional tall-oil-based emulsifier, both before and after hot rolling as secondary emulsifiers.

As shown in Table 8, the PIBSA-based secondary emulsifiers maintained consistent performance across several key rheological parameters No significant differences were observed in these rheological properties, regardless of whether the measurements were taken before or after hot rolling. This consistency indicates that the experimental emulsifiers are comparable to the conventional formulation in terms of meeting API drilling mud standards under the tested conditions. Notably, a closer examination of emulsion stability revealed that all formulations produced stable emulsions, with emulsion stability values exceeding 600 V even after hot rolling. This high level of stability was expected at the lower temperature of 250°F, further validating the reliability and effectiveness of the PIBSA-based emulsifiers under moderate thermal conditions as secondary emulsifiers. These findings underscore the potential of PIBSA-based secondary emulsifiers to serve as reliable alternatives to conventional formulations, offering comparable performance while maintaining stability and consistency

### Table 8 Results Secondary Emulsifiers at 250°F

| | Emul-1 | | Emul-2 | | Emul-3 | | Emul-7 | |
|---|---|---|---|---|---|---|---|---|
| | BHR | AHR | BHR | AHR | BHR | AHR | BHR | AHR |
| at 600 rpm (cP) | 37.6 | 38.8 | 33.6 | 28.3 | 34.1 | 36.6 | 36.9 | 35.3 |
| at 300 rpm (cP) | 24.5 | 25.4 | 21.0 | 15.6 | 21.1 | 23.4 | 20.5 | 19.1 |
| at 200 rpm (cP) | 18.1 | 16.2 | 15.4 | 10.5 | 15.1 | 17.2 | 15.6 | 14.3 |
| at 100 rpm (cP) | 11.8 | 10.6 | 9.7 | 5.7 | 9.5 | 10.5 | 10.7 | 9.6 |
| at 6 rpm (cP) | 3.7 | 3.0 | 2.9 | 1.1 | 2.7 | 2.5 | 4.4 | 3.6 |
| at 3 rpm (cP) | 3.1 | 2.5 | 2.5 | 0.7 | 2.1 | 2.0 | 3.9 | 3.2 |
| | | | | | | | | |
| Plastic Viscosity (PV) (cP) | 13.7 | 13.9 | 13.6 | 11.9 | 13.4 | 14.5 | 12.5 | 12.4 |
| Yield Point (YP) (lbf/100ft2) | 9.1 | 8.9 | 5.5 | 2.4 | 6.1 | 6.4 | 9.5 | 8.0 |
| 10 s Gel strength (lb/100ft2) | 4.5 | 3.2 | 3.6 | 0.6 | 3.2 | 2.7 | 5.1 | 4.3 |
| 10 min Gel strength (lb/100ft2) | 5.1 | 3.5 | 4.0 | 0.5 | 3.8 | 3.4 | 5.6 | 5.0 |
| Emulsion Stability (ES) (V) | 1096.7 | 919.7 | 727.0 | 808.0 | 824.3 | 626.7 | 723.3 | 705.7 |

The next phase of testing focused on evaluating the secondary emulsifiers at a higher temperature of 350°F. For this phase, Emul-1 was selected for comparison against the conventional tall-oil-based emulsifier. The results of this comparison, including measurements taken before and after hot rolling, are summarized below in Table 9.

An analysis of key rheological properties, including plastic viscosity, yield point, 10-second gel strength, and 10-minute gel strength, again showed similar characteristics between the PIBSA-based and conventional emulsifiers. Additionally, emulsion stability measurements indicated no substantial differences between the two formulations, with both maintaining robust stability at 350°F.

### Table 9 Secondary Emulsifier at 350 °F

| | Emul-1 | | Emul-7 | |
|---|---|---|---|---|
| | BHR | AHR | BHR | AHR |
| **at 600 rpm (cP)** | 32.80 | 26.30 | 29.60 | 42.10 |
| **at 300 rpm (cP)** | 17.20 | 16.60 | 19.60 | 27.50 |
| **at 200 rpm (cP)** | 12.00 | 12.00 | 15.00 | 20.30 |
| **at 100 rpm (cP)** | 7.70 | 7.50 | 10.00 | 13.30 |
| **at 6 rpm (cP)** | 1.90 | 1.20 | 3.80 | 4.60 |
| **at 3 rpm (cP)** | 1.60 | 1.00 | 3.30 | 4.00 |
| | | | | |
| **Plastic Viscosity (PV) (cP)** | 12.80 | 11.80 | 10.10 | 16.00 |
| **Yield Point (YP) (lbf/100ft2)** | 4.70 | 3.40 | 7.80 | 8.90 |
| **10 s Gel strength (lb/100ft2)** | 2.10 | 0.60 | 4.60 | 5.70 |
| **10 min Gel strength (lb/100ft2)** | 3.30 | 2.80 | 5.30 | 6.40 |
| **Emulsion Stability (ES) (V)** | 951.00 | 609.00 | 1096.00 | 782.00 |
| **HTHP Fluid Loss*** | | **28** | | **34** |

*30 minutes @ 350F

When evaluating high-temperature, high-pressure (HTHP) fluid loss at 30 minutes, no significant variation was observed between the two emulsifiers. The primary fluid loss values were recorded as 34 mL for the conventional emulsifier and 28 mL for Emul-1, indicating that under the conditions tested, the use of PIBSA did not significantly impact fluid loss, unlike the primary emulsifiers.

## Combination Primary/Secondary

In the final phase of testing, we evaluated drilling mud formulations containing both primary and secondary emulsifiers. This included comparing a PIBSA-based primary and secondary emulsifier system against a conventional TOFA-based primary and secondary emulsifier system. These tests were conducted at only 350°F, and the results are summarized in Table 10.

The findings indicate that the two scenarios demonstrated similar performance, with consistent viscosity values observed across the systems at different rotational speeds. The plastic viscosity, yield point, 10-second gel strength, and 10-minute gel strength values also showed comparable results, with the PIBSA-based system slightly outperforming the conventional. Specifically, the PIBSA-based system maintained higher 10-second gel strength compared to the conventional system, which experienced a slight decrease. In contrast, the mixed system exhibited decreases in both 10-second and 10-minute gel strengths.

### Table 10 Combination Primary/Secondary Results

| | Emul-3/Emul-1 | | Emul-8/Emul-7 | |
|---|---|---|---|---|
| | BHR | AHR | BHR | AHR |
| **at 600 rpm (cP)** | 30.30 | 31.10 | 30.80 | 37.50 |
| **at 300 rpm (cP)** | 18.00 | 19.20 | 19.40 | 21.00 |
| **at 200 rpm (cP)** | 13.00 | 14.40 | 14.20 | 13.80 |
| **at 100 rpm (cP)** | 7.80 | 9.00 | 8.90 | 7.20 |
| **at 6 rpm (cP)** | 2.20 | 2.80 | 2.70 | 0.80 |
| **at 3 rpm (cP)** | 1.90 | 2.40 | 2.40 | 0.60 |
| **Plastic Viscosity (PV) (cP)** | 12.50 | 12.40 | 12.30 | 16.70 |
| **Yield Point (YP) (lbf/100ft2)** | 4.60 | 5.90 | 5.30 | 2.50 |
| **10 s Gel strength (lb/100ft2)** | 2.70 | 3.50 | 3.30 | 0.60 |
| **10 min Gel strength (lb/100ft2)** | 3.90 | 3.80 | 5.10 | 6.90 |
| **Emulsion Stability (ES) (V)** | 977.00 | 1236.00 | 969.67 | 1791.67 |
| **HTHP Fluid Loss*** | | 4.8 | | 17.4 |

*30 minutes @ 300F/500psi

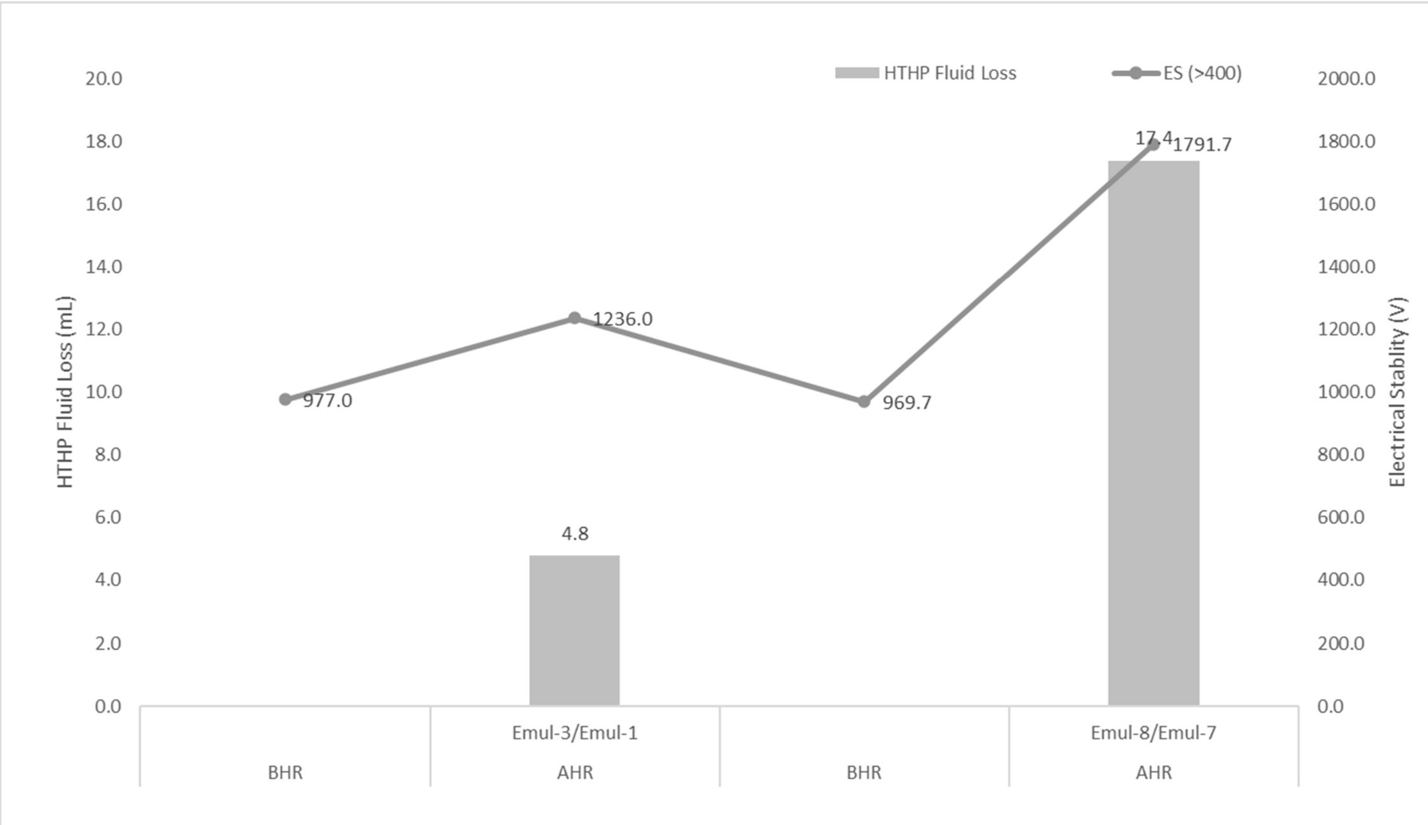


**Figure 2: Combination Systems HTHP Fluid Loss vs ES**

Both systems met the target for plastic viscosity, but notable differences emerged in yield point and 10-second gel strength after hot rolling. The conventional system failed to meet the target range for yield point and 10-second gel strength, while the PIBSA-based system maintained the correct physical properties, demonstrating superior rheological stability.

Electrical stability was another critical parameter, with both systems achieving values greater than 400 V, thus meeting the target criteria. However, the most significant differences were observed during the high-temperature, high-pressure (HTHP) fluid loss testing conducted at 30 minutes under 300°F and 500 psi conditions, as illustrated in Figure 2. The fluid loss values recorded were as follows:

- PIBSA-based system: 4.8 mL
- Conventional system: 17.4 mL

The results clearly demonstrate that the PIBSA-based system significantly outperformed the other system in terms of fluid retention under HTHP conditions. Furthermore, the PIBSA-based system produced a notably thinner filter cake, which is advantageous for maintaining wellbore stability and reducing formation damage. If fluid loss can be minimized with these products, the necessity for adding additional fluid loss additives is significantly reduced, thereby saving the considerable costs associated with incorporating extra additives into the drilling mud.

The PIBSA-based emulsifier system demonstrated superior performance in maintaining vital drilling mud properties, particularly under high-temperature, high-pressure conditions. This makes it a highly viable alternative to conventional tall-oil-based systems, offering enhanced fluid retention and stability while reducing the need for extra additives, ultimately leading to cost savings and improved efficiency in drilling operations.

## Conclusions

The findings presented in this study underscore the potential of PIBSA based emulsifiers as an improved alternative to conventional tall-oil fatty acid (TOFA)-based systems in diesel based drilling fluids. PIBSA emulsifiers demonstrated exceptional thermal stability, enhanced fluid loss control, and consistent rheological properties under HTHP conditions. These characteristics position PIBSA as an alternative solution for modern drilling operations, which demand robust and cost-efficient fluid systems capable of withstanding extreme wellbore environments.

Compared to TOFA-based emulsifiers, PIBSA systems showed significant improvements in HTHP fluid loss, particularly at elevated temperatures of up to 350°F, with fluid loss values reduced by nearly 90% in some cases. This reduction not only enhances wellbore stability but also minimizes the necessity for additional fluid loss additives, offering substantial cost savings and simplifying fluid formulations. The versatility of PIBSA-based emulsifiers, evidenced by their compatibility with a variety of additives and adaptability across different oil-to-water ratios, further enhances their appeal for diverse drilling scenarios.

Moreover, the ability of PIBSA emulsifiers to maintain stable emulsions and achieve superior rheological properties across both primary and secondary applications highlights their reliability and efficacy. By delivering comparable or superior performance to conventional systems without the associated material limitations or high costs, PIBSA emulsifiers represent an advancement in drilling fluid technology.

In conclusion, the integration of PIBSA emulsifiers into drilling fluid formulations not only addresses critical industry challenges such as thermal stability, reduction on volatile raw materials and cost-efficiency but also aligns with the growing need for innovative, high-performance solutions in increasingly complex drilling environments. Further studies and field trials will be instrumental in unlocking their full potential and accelerating their implementation on a broader scale.

## Nomenclature

Define acronyms used in the text here unless they are explained in the body of the text. Use units where appropriate. Note there is a tab before the "BHA" to make the first term right justified.

*PV= Plastic Viscosity*
*HTPH = High Temperature, High Pressure*
*API= American Petroleum Institute*
*PIBSA = Polyisobutylene Succinic Anhydride*
*TOFA = Tall Oil Fatty Acids*

## References

Please note that the format for references is now based on Chicago Style (Author-Date) for compatibility with other scientific publications. References should be in alphabetical order and referred to in the text by (Author, Date), not superscripted numbers. This Reference section is 9 pt New Times Roman with 0.2-inch hanging indent.

Ali, S.A., Luyster, M.R., and Patel, A.D. 2006. "Dual Purpose Reversible Reservoir Drill-In Fluid Provides the Perfect Solution for Drilling and Completion Efficiency of a Reservoir." SPE/IADC Indian Drilling Technology Conference, Mumbai, India, Oct 16-18, 2006. SPE-104110-MS. https://doi.org/10.2118/10410-MS

Dunn, M.D., Crane, L.R. and Thomas, R.L. 2005. "North Slope Drilling Practices – Ever Adapting to New Challenges." AADE-05-NTCE-07, AADE National Technical Conference, Houston, April 5-7, 2005. Available from www.aade.org