

Integrated Real-Time Surface Wetting Characterization for Optimized Wellbore Spacer Design

Shannon Bryant, Tad Nott, OFI Testing Equipment Inc.

Copyright 2026, AADE

This paper was prepared for presentation at the 2026 AADE Fluids Technical Conference and Exhibition held at the Marriott Marquis Hotel, Houston, Texas, April 7-8, 2026. This conference is sponsored by the American Association of Drilling Engineers. The information presented in this paper does not reflect any position, claim or endorsement made or implied by the American Association of Drilling Engineers, their officers, or members. Questions concerning the content of this paper should be directed to the individual(s) listed as author(s) of this work.

Abstract

Scope: In cementing operations following non-aqueous drilling fluids (NADFs), achieving a water-wet surface is critical for strong cement bond integrity. Current methods for evaluating spacer effectiveness are subjective and lack real-time feedback. This paper addresses this limitation by developing a novel instrument for measuring and correlating spacer performance with wellbore cleaning efficiency. **Methods:** An integrated testing instrument was developed to dynamically measure a spacer's ability to transition an oil-wet surface to a water-wet state. The system utilizes electrical conductivity as a real-time proxy for wetting characteristics. The system simultaneously acquires and logs relevant operational parameters, including motor RPM, torque, and spacer volume added. Laboratory tests were conducted using various NADFs and commercially available spacer and surfactant packages. **Conclusions:** Comparative testing demonstrated significant differences in wetting performance across various spacer formulations. Real-time conductivity data objectively captured the transition from oil-wet to water-wet conditions, while torque monitoring provided complementary insight into cleaning dynamics. Combining these parameters yielded a more complete evaluation than either alone, enabling quantitative comparison of spacer effectiveness. **Novelty-Contribution** This paper introduces a comprehensive method for evaluating and comparing spacer and surfactant performance in a laboratory setting. The use of real-time, correlated data acquisition provides an objective and more reliable characterization of the wetting transition, which can lead to optimized spacer design and improved primary cementing success. This innovative approach offers a practical tool for practicing engineers to mitigate the risks of poor cement bonding due to NADF contamination.

Introduction

Non-aqueous drilling fluids (NADFs) leave oil-wet residues on casing and formation surfaces that must be converted to a water-wet condition for effective primary cementing. Spacer and pre-flush systems are therefore designed not only for hydraulic displacement efficiency but also for their ability to invert NADF-based emulsions and restore water-wet conditions

at the wellbore interface. API RP 10B-2 Section 13 (API - American Petroleum Institute 2024). includes a spacer surfactant screening test (aka wettability test) to assess this behavior; however, existing implementations have historically relied on manually operated devices with limited data capture and significant operator subjectivity.

This work describes the design and evaluation of an upgraded wettability test device that integrates controlled mixing, automated timing, and digital acquisition of conductivity, temperature, motor speed, spacer volume, and motor power. The objective is to provide a more quantitative and repeatable laboratory basis for spacer selection when NADFs are used, using a plateau conductivity criterion defined by both an electrical reading ($\sim 100 \mu\text{A}$) and a practical spacer-to-mud volumetric limit ($\leq 1:1$). The performance of multiple spacer systems was evaluated against several NADF's at 100°F (37.8°C) and 150°F (65.6°C). Results from this testing were used to illustrate device capability and repeatability.

Mud and cement slurry designs are generally established before the compatibility tests are performed. A spacers density and viscosity are designed to fit within the wellbore fluid hierarchies. Both density and viscosity of the spacer should be higher than the mud and lower than the cement. A basic spacer system with these characteristics will be sufficient to displace the mud and keep it from commingling with the cement. If the spacer does not clean the wellbore surfaces, then the cement process may not be successful. For the spacer to be effective with the NADF, a 'surfactant package' (blend of surfactants and supporting chemicals designed to control wetting, emulsification, cleaning, and interfacial behavior in drilling fluids) is needed. Each NADF may require different spacer surfactant packages. The wettability tester helps determine the most efficient surfactant package and the ability of the spacer to make a water-external (or water-wet) phase emulsion with the NAF.

Figure 1: Wettability Tester



Equipment

The wettability tester (figure 1) is built around a insulated stainless-steel mixing container and an overhead variable-speed motor, rather than a modified constant-speed cement mixer. This configuration eliminates leakage around mixer blades during extended tests and allows conditioning and titration of NADF's and spacer systems for long periods of time at temperatures up to approximately 200 °F (93.3°C) while maintaining safe handling of the cup exterior. Leaking is an

ever-present problem with standard cement mixers, even when the blades are brand new, leaks will occur after constant mixing of more than 10 minutes. Since constant speed mixers are intended for short duration and high-speed mixing and wettability tests will be run for 20 to 30 minutes or longer and the mixing speed much lower, the overhead mixing method is preferred. The mixing container accommodates up to 800 mL of fluid, which is sufficient for typical starting NADF volumes of 200–300 mL and spacer additions up to and beyond a 1:1 spacer-to-mud ratio.

Three electrical contacts are mounted on the wall of the mixing container to measure temperature and electrical conductivity of the fluid. A motor with integrated digital control provides adjustable mixing speed and records both the speed and power required. Motor power (amperage) is tracked and can act as a surrogate for torque, to indicate changes in fluid resistance during mixing. All variables—conductivity, temperature, motor speed, motor power, elapsed test time, and cumulative spacer volume—are recorded through an integrated data acquisition system and displayed on a touch-screen controller.

The touch screen controller provides several functional screens. A real-time display shows instantaneous conductivity, temperature (in °F or °C), motor speed, elapsed time, and setpoints for temperature and speed. A graph screen plots conductivity as a function of spacer volume during titration for correlation with visual features such as the phase inversion point and plateau behavior. Calibration and utilities screens are used to verify temperature measurement, document blade weight and motor RPM in accordance with API RP 10B-2, set and adjust test timers, and archive individual test files for export.

To remove operator subjectivity, an automated timing sequence was added to standardize the sequence, duration of mixing, and measurement following each spacer addition. Three user-defined timers—wait time, stop time, and condition time—govern, respectively, the mixing period after addition, the pause interval with the motor stopped, and the subsequent conditioning time before conductivity is recorded and plotted. If the timer sequence is not required, they can all be set to zero. This automated timing sequence, combined with recorded motor speed, reduces operator subjectivity and improves the repeatability of the spacer screening test.

Methods

Test fluids

A single NADF was used for the initial evaluation followed by a lab mud and then two field muds. Several spacer systems were formulated with surfactant packages intended to invert the NADF to a water-external, conductive emulsion. For each spacer we used tap water, barite, and diutan as the base. Then for the surfactant package a store-bought surfactant and D-Limonene was used for a solvent.

Test procedure

For each test, the spacer (or spacer plus surfactant package) was first conditioned in the wettability mixing container and heated to the target test temperature. Conductivity was adjusted to a reference value (~100 μ A), and the spacer was then transferred to a heated external vessel while the mixing container was cleaned and loaded with the prescribed volume of NADF. The NADF was brought to the same target temperature under agitation, with motor speed adjusted to establish and maintain a consistent surface vortex in the fluid.

Once the NADF reached the target temperature, the spacer was titrated into the mixing container in predefined increments while the motor speed was adjusted as needed to preserve the vortex and ensure effective dispersion. After each addition, the automated timer sequence was initiated: the fluid was mixed for the designated wait time, stopped for the stop time, then re-mixed during the condition time, after which the conductivity measurement was recorded and plotted. This titration procedure was repeated until the conductivity response indicated that a stable plateau had been achieved or until spacer additions exceeded a 1:1 spacer-to-mud volumetric ratio.

Plateau conductivity definition and efficiency

Plateau conductivity was defined as the minimum spacer volume V_s at which all of the following criteria were met:

Measured conductivity was stable and no longer increasing with the additional spacer titrations.

Conductivity remained within a stability band of approximately $\pm 5 \mu\text{A}$ over at least the next two titration steps at constant test conditions.

Spacer efficiency η was calculated for each test as:

$$\eta = \frac{V_s}{V_s + V_{mud}} \times 100\%$$

where V_{mud} is the initial NADF volume and V_s is the spacer volume at plateau conductivity. A spacer was considered successful (or efficient) if plateau conductivity was achieved at or below a 1:1 spacer-to-mud ratio and if tests at the same conditions produced plateau volumes at $\sim 100 \mu\text{A}$.

Conductivity increased from near-zero values for the neat NADF to stable plateau values above $90 \mu\text{A}$ as spacer was titrated into the system and the emulsion inverted to a water-external phase. For all tests that met the plateau definition, final plateau conductivities were approximately 95–

100 μA , with no significant dependence on spacer type or temperature within the range evaluated. Differences between spacers and test conditions were therefore assessed primarily based on plateau spacer volume and calculated efficiency.

Test matrix

The initial evaluation comprised four tests using two different spacer systems and a single laboratory NADF. Spacer 1 was tested at 150 °F with an initial NADF volume of 300mls and two tests were conducted to assess repeatability. Spacer 2 was tested at 100 °F with initial NADF volumes of 250mls.

A clean lab mud and two different field muds were then tested with multiple spacer designs. Three tests were run on the lab mud at 100 °F. The first test (with Spacer 4) was run without adding the surfactant package, then the next test was run with the surfactant package. The third test was run on Spacer5 to look for a difference in efficiency.

Four tests were run on two muds brought in from the field. Two tests run at 150 °F and two at 100 °F. Both muds required a different spacer (and surfactant package) to reach conductivity above $90 \mu\text{A}$. Results from these tests, with different fluids and temperatures, will demonstrate the device's ability to distinguish between different spacers effectiveness.

Table 1: Results Summary

Description	Temperature	Volume Efficiency	Rheology	Comments
Test 1) BaseOil-Sp1-11/03	150 °F (65.6 °C)	200ml (44%) to 99 µA	-n/a-	{Figure.2}
Test 2) BaseOil-Sp1-11//04-repeat	150 °F (65.6 °C)	200ml (44%) to 99 µA	-n/a-	{Figure.3}
Test 3) BaseOil-Sp2-11/25	100 °F (37.7 °C)	175ml (41%) to 97 µA	-n/a-	{Figure.4}
Test 4) BaseOil-Sp2-12/01-repeat	100 °F (37.7 °C)	175ml (41%) to 95 µA	-n/a-	{Figure.5}
Lab Mud Testing				
Test 5) LabMud-Sp4-12/17 W/O Surfactant Package	100 °F	200ml (44%) to 90 µA	-n/a-	{Figure.6}
Test 6) LabMud-Sp4-12/17	100 °F	225ml (47%) to 99 µA	-n/a-	{Figure.7}
Test 7) LabMud-Sp5-12/18-repeat {Figure.8}	100 °F	200ml (44%) to 97 µA	Mud: YP 10, Pv 15, 300rpm 25 Spacer: YP 13, Pv 15, 300rpm 28 Combined: YP 39, Pv 80, 300rpm 118	
Field Mud Testing				
Test 8) FieldMud1-Sp5-12/18	150 °F	325ml (FAIL) ~12 µA	-n/a-	{Figure.9}
Test 9) FieldMud1-Sp6-12/22 {Figure.10}	150 °F	250ml (50%) to 97 µA	Mud: YP 13, Pv 32, 300rpm 44 Spacer: YP 17, Pv 42, 300rpm 59 Combined: YP 35, Pv 63, 300rpm 98	
Test 10) FieldMud2-Sp6-12/22	100 °F	300ml (FAIL) ~79 µA	-n/a-	{Figure.11}
Test 11) FieldMud2-Sp7-12/23-repeat	100 °F	200ml (40%) to 98 µA	-n/a-	{Figure.12}

Results

All tests were conducted at nominal temperatures of either 100 °F or 150 °F, representative of typical spacer design temperatures for NADF cementing operations. Spacer 1 at 150°F exhibited excellent repeatability. Both tests reached plateau at a spacer volume of 200 mL for an initial 300 mL of NADF, corresponding to a spacer efficiency of approximately 40%, and maximum conductivities of 99 μA. Spacer 2 at 100°F with 250 mL NADF also showed consistent behavior, with both replicate tests reaching plateau at 175 mL spacer (~ 41% efficiency) and maximum conductivities of 95–97 μA. In both cases, the variation in plateau volume between replicates was within the targeted ±5% band, supporting the repeatability of the upgraded test method and timing protocol.

Fig.2- Test 1_BO_Sp1 {%Ef-44}

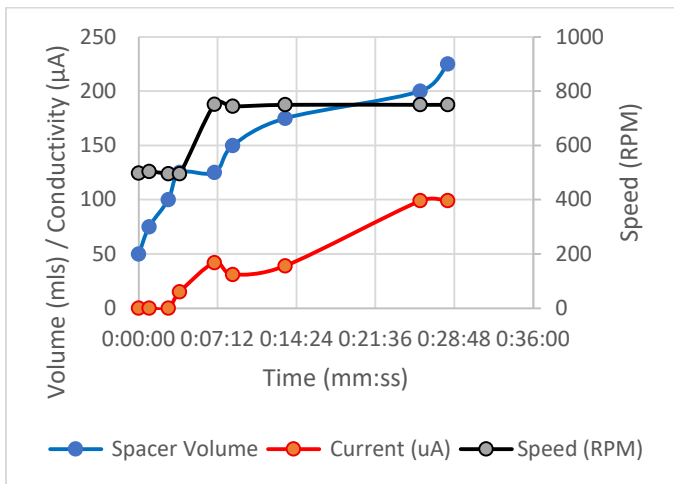


Fig.3- Test 2_BO_Sp1repeat {%Ef-44}

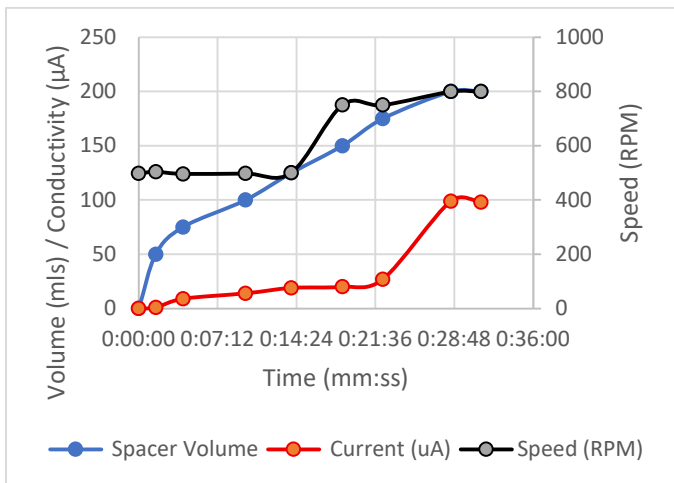


Fig.4- Test 3_BO_Sp2 {%Ef-41}

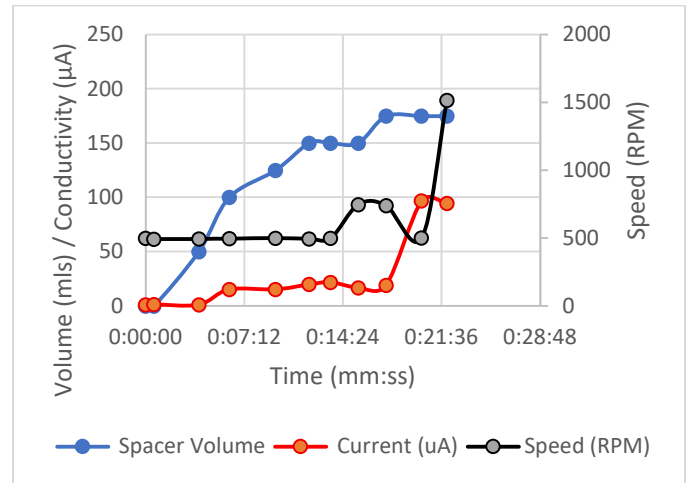
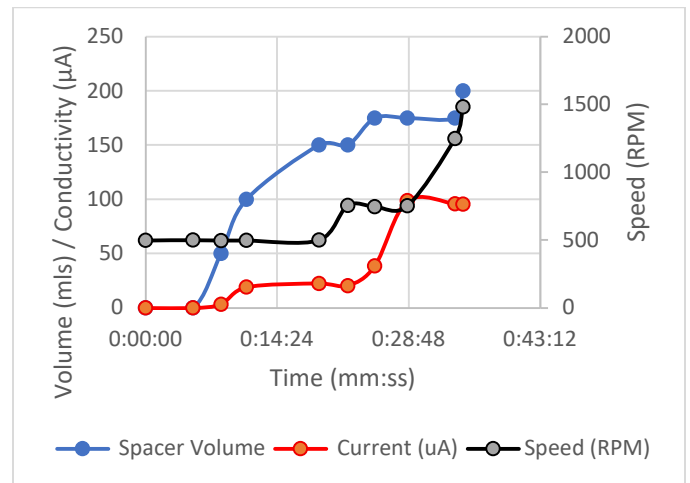


Fig.5- Test 4_BO_Sp2repeat {%Ef-41}



Results from the mud tests demonstrated the importance of selecting the right spacer design for each NADF. The first two tests on the lab mud shows the effect of the surfactant package. Test 4 did not have the surfactants added to the spacer, and the conductivity just reached the criteria for a successful cleaning of the NADF. When surfactants were added the spacer, full conductivity was achieved. Another spacer was tested on the same mud and achieved conductivity with less spacer, making it slightly more efficient.

This last spacer (Spacer 5) that worked well on the lab mud would not work at all when tested on the first field mud. This mud was tested again with Spacer 6. While it worked in this mud, it would not work with the second field mud. Redesigning the spacer again, Spacer 7 was able to successfully clean the mud.

Fig.6- Test 5 LM_Sp4 w/o SurfPkg {%Ef-44}

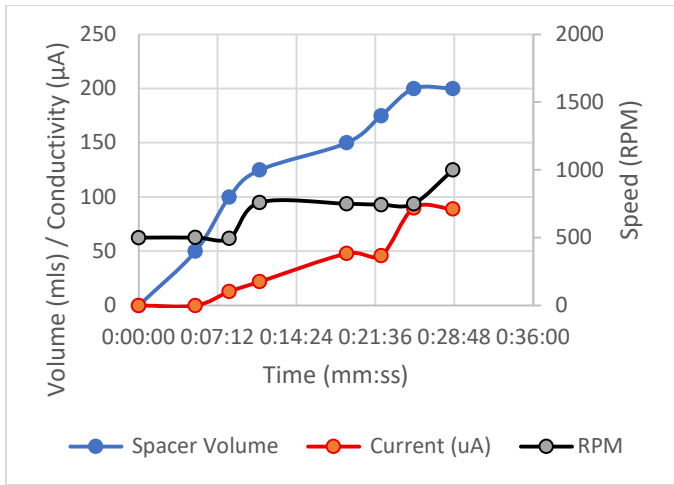


Fig 9- Test 8 FM1_Sp5 {fail}

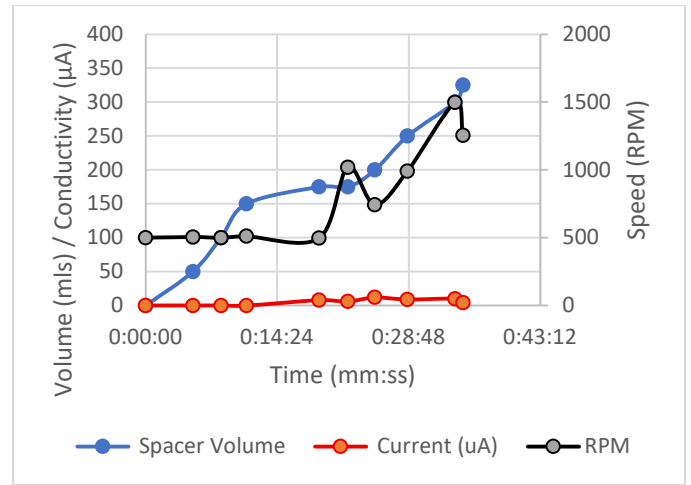


Fig.7- Test 6 LM_Sp4 w/ surfPkg {%Ef-47}

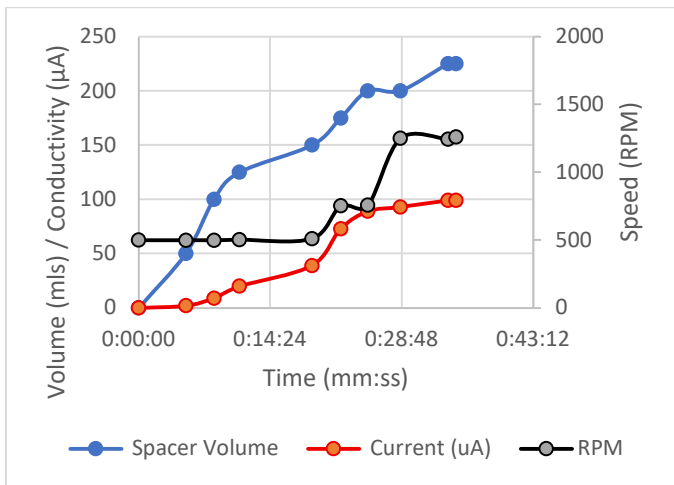


Fig 10- Test 9 FM1_Sp6 {%Ef-50}

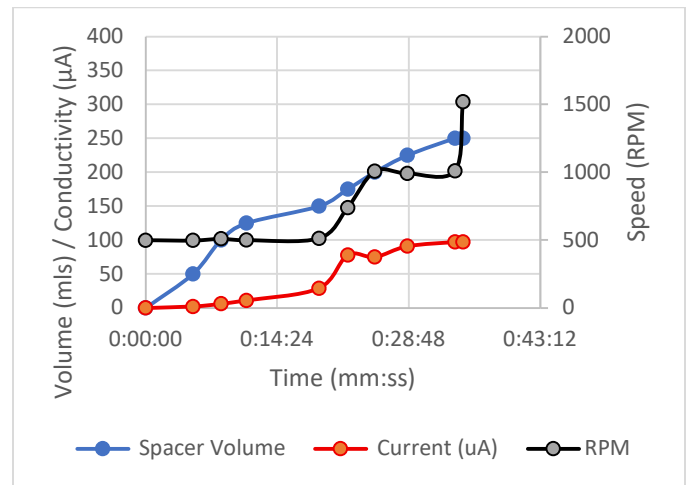


Fig 8- Test 7 LM_Sp5 {%Ef-44}

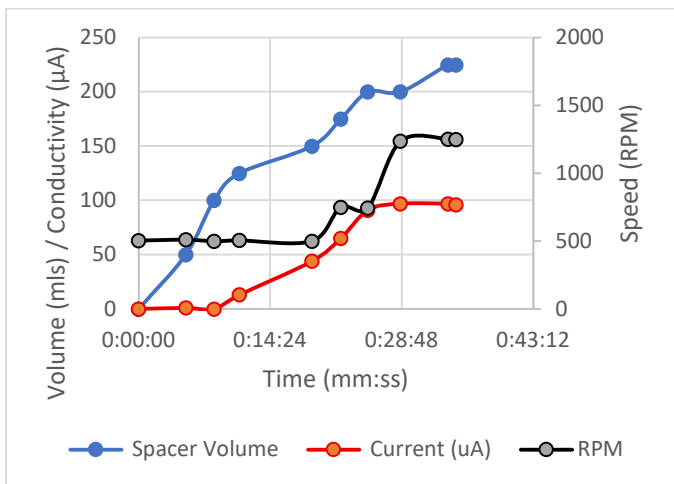


Fig 11- Test 10 FM2_Sp6 {fail}

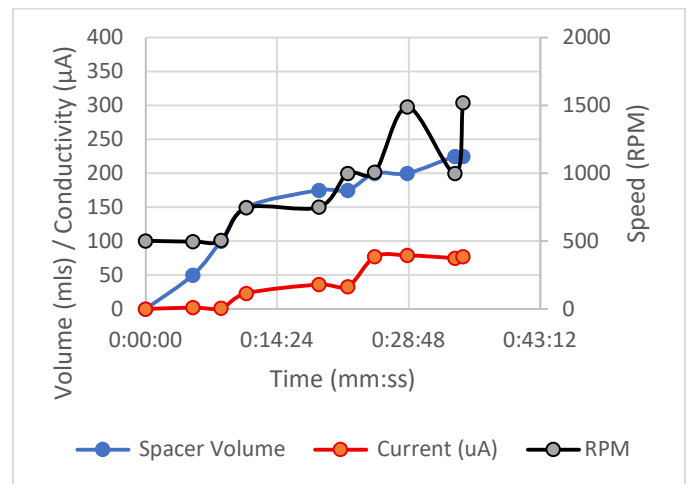
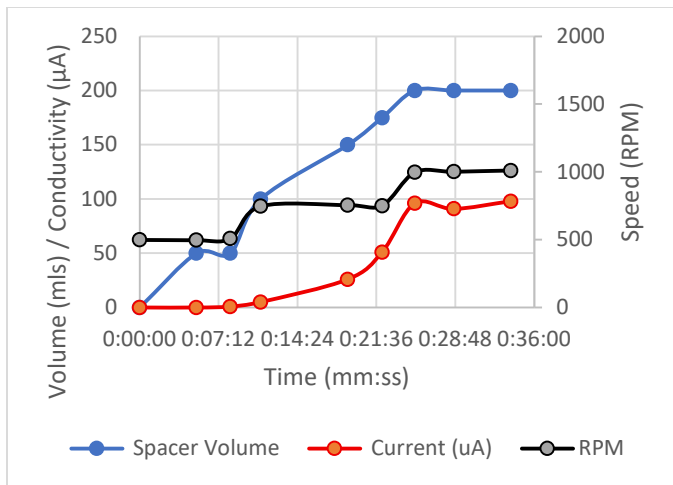


Fig 12- Test 11 FM2_Sp7 {%Ef-40}



Nomenclature

NADF = Non Aqueous Drilling Fluid
 API = American Petroleum Institute
 RP = Recommended Practice

References

API - American Petroleum Institute. (2024). *API 10B-2 Recommended Practice for Testing Well Cements*. Washington, D.C.: API - American Petroleum Institute.

Conclusions

An upgraded wettability tester was developed and evaluated for spacer surfactant screening in NADF cementing applications, incorporating overhead mixing, controlled heating, automated timing, and digital acquisition of conductivity, temperature, motor speed, motor power, and spacer volume. The device enables wettability tests without leakage and provides full conductivity–volume response curves rather than single end-point measurements.

Using a plateau conductivity definition based on a $\geq 90 \mu\text{A}$ threshold, a spacer-to-mud ratio and stability of the conductivity signal, six spacers were screened against different NADF's. Spacers 1 and 2 demonstrated good repeatability at 150 °F and 100 °F, respectively, with repeated plateau volumes within the targeted $\pm 5\%$ tolerance.

The results indicate that the upgraded device provides a more quantitative and reproducible implementation of the API RP 10B-2 spacer screening test and can resolve the effects of spacer formulation and temperature on wettability performance. Ongoing and future work will extend the test matrix to multiple field NADFs, examine correlations between torque signatures, conductivity response, to establish robust acceptance criteria for spacer selection.

Acknowledgments

The authors would like to acknowledge contributions and help from the OFITE team and specifically Doanh Ba Ho and Alejandro Hinojosa. We would also like to thank Genesis Fluids for their expertise and steady supply of field mud.