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Universal, High-Performance Wellbore Displacement Spacer System

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Abstract

An effective and efficient wellbore displacement and clean-up is a critical step during well completion operations. An ineffective and poor displacement could lead to increased completion operation cost and reduced oil and gas production.

Traditional displacement spacer systems typically consist of a surfactant spacer or a combination of solvent and surfactant spacers. Many solvents are incompatible with aqueous spacer systems, while surfactant spacers may not be effective in displacing all types of oil-based drilling fluids. As the chemistry of drilling fluid additives becomes more diversified to accommodate various base oils, so too must the chemistry of cleaner/displacement additives to ensure appropriate compatibility.

A universal, high-performance displacement system (TADS-RD) was developed for use in a broad variety of drilling fluid systems, including oil- and synthetic-based muds. It was tested for its ability to effectively remove drilling fluids and water-wet pipe surfaces in the riser, wellbore, and choke, kill, and boost (CKB) lines. Lab test results showed that TADS-RD consistently achieved greater than 98% cleaning efficiency and water-wet pipe surfaces against oil-based invert emulsion drilling fluids.

This paper presents the testing program and lab test results for TADS-RD compared to a traditional displacement system at various conditions and with various oil- and synthetic-based drilling fluid systems. This paper will also include field application recommendations.

Introduction

Drilling fluids play an important role in maintaining wellbore stability, cooling the drill bit, carrying drill cuttings from the well, and maintaining hydrostatic pressure to prevent formation fluids from entering the wellbore. Water-based mud (WBM) is the most widely used system and is less expensive than the oil/synthetic based muds, but its application is limited in highly reactive shale formations. Synthetic-based mud (SBM) is commonly used in offshore drilling areas because of its excellent lubricity and drilling performance, even though the cost per unit is higher than WBM.

Having a clean well to ensure a successful well completion operation is an area of concern[1]. The objectives of wellbore displacements are to remove drilling muds, provide trouble-free completion, and protect the formation by developing a solids-free environment[2]. It requires a combination of proper planning, design, onsite implementation, optimized displacement spacer systems, and correct mechanical downhole cleaning tools.

A wellbore with a properly cleaned production casing increases the ability to set and retrieve downhole tools and enhances production by reducing or eliminating solids that could potentially cause formation damage. It also delivers optimum lifecycle productivity by allowing production fluid access to the entire payzone and by lowering the risk of early water breakthrough and fines migration[3].

The presence of solids can induce a form of concentration cell corrosion, known as crevice corrosion, and possible generation of H_2S or sulfur from additives associated with the mud solids, which may lead to sulfide stress cracking (SSC).

As the chemistry of drilling fluid additives become more diversified to accommodate various base oils, so too must the chemistry of cleaner/displacement additives to ensure appropriate compatibility and performance.

Traditional displacement spacer systems commonly use a surfactant or a combination of a solvent and a surfactant to remove synthetic- and oil-based muds (S/OBM). Both of these spacer systems have their own disadvantages. A surfactant spacer is ineffective in displacing some SBMs, including ester/isomerized-olefin (IO) based systems. On the other hand, a solvent and surfactant spacer system is effective in displacing many SBM; however, it is incompatible in many water-based spacer systems.

The performance of the new, universal, high-performance displacement system (TADS-RD) in displacing various S/OBM will be compared against a traditional surfactant displacement system.

Lab displacement experiments have been designed with consideration of wellbore displacement conditions, i.e., BHT (up to 225˚F), well geometry, spacer volume, and pump time.

Experimental Methods

Drilling Mud Samples:

1. A 13.6 lb/gal ester/IO-based SBM
2. A 14.45 lb/gal internal olefin-based SBM
3. A 14.85 lb/gal alpha and internal olefin (C11-C18) based SBM
4. A 17.0 lb/gal diesel-based OBM

Drilling Mud Preparation:

1. The S/OBM was blended using a Silverson high shear mixer at 6,000 rpm for approximately 10-15 minutes prior to use to ensure a homogeneous mixture.

2. The S/OBM density and rheology values were checked against the expected values. An OFITE Model 900 viscometer was used to check the S/OBM rheology at 120 ˚F. An OFITE pressurized fluid density scale (part # 100-70) was used to measure the mud density.

Viscometer for Cleaning Test:

An OFITE Model 800 or 900 Viscometer

Spacer Temperature, Pipe Analog Rotation, and Contact Time

Wellbore displacement conditions for wells in the Gulf of Mexico, i.e., BHT, well geometry, spacer volume, and pump time, were used to calculate spacer temperature, contact time, and pipe analog rotation for lab testing.

To simulate downhole conditions, where pipes have been exposed with SBM at an elevated temperature, a pipe analog was baked in a 13.6 lb/gal ester/IO-based SBM for 3 days at 225 ˚F and pressurized to 400 psi prior to a displacement test.

To simulate a 13.6 lb/gal ester/IO-based SBM displacement in the riser line, the pipe analog was rotated at 100 rpm (Table 1). This rotation speed is equivalent to a pumping/flow rate of ~40 ft/min. No base oil was used during experiment in order to simulate a displacement system efficacy when a base oil was not used during displacement operations.

The spacer fluids were heated for at least 2-3 hours and kept at a constant temperature of 170˚F throughout the duration of displacement test. This was the predicted spacer temperatures provided through modeling software for a well with BHT of 225˚F.

Table 1. Lab displacement conditions to displace a 13.6 lb/gal ester/IO-based SBM for riser displacement

	Pipe Analog Rotation (rpm)	Spacer Temperature (˚F)	Contact Time (min)
SBM	-	170	Pre-baked for 3 days at 225˚F
Base oil	Not used		
Weighted push pill	100	170	9.8
Surfactant pill	100	170	13.5
Viscous pill	100	170	7.5
CBF	100	170	15

To simulate a 13.6 lb/gal ester/IO-based SBM displacement in the wellbore line, the pipe analog was rotated at 450 rpm. This rotation speed is equivalent to a pumping/flow rate of ~180 ft/min (Table 2). The pipe analog rotation and contact time were previously calculated by the applied engineering group using CV-Pro™ displacement modeling software.

The spacer fluids were kept constant at 170˚F throughout the duration of displacement test.

Table 2. Lab displacement conditions to displace a 13.6 lb/gal ester/IO-based SBM for wellbore displacement

	Pipe Analog Rotation (rpm)	Spacer Temperature (˚F)	Contact Time (min)
SBM	-	170	Pre-baked for 3 days at 225˚F
Base oil	450	170	9
Weighted push pill	450	170	10.5
Surfactant pill	450	170	15
Viscous pill	450	170	10
CBF	450	170	22.5

To simulate exposure of pipes with SBM at mud line condition for long period of time, a pipe analog was chilled in a 13.6 lb/gal SBM at 170˚F for 2 days prior to a displacement test.

To simulate a 13.6 lb/gal ester/IO-based SBM displacement in the CKB line, the pipe analog was rotated to 1,000 rpm (Table 3). This was the best lab representation of displacement in the CKB line due to limitation of OFITE 900 viscometer.

Table 3. Lab displacement conditions to displace a 13.6 lb/gal ester/IO-based SBM for CKB displacement

	Pipe Analog Rotation (rpm)	Spacer Temperature (˚F)	Contact Time (min)
SBM	-	RT	Pre-chilled for 2 days at 40˚F
Base oil	Not used		
Surfactant pill	1,000	RT	1.75
CBF	1,000	RT	7.75

To simulate a 14.45 lb/gal internal olefin-based SBM displacement, a pipe analog rotation of 100 rpm was used. This simulated a displacement in the riser line, which was the most difficult area to clean due to much lower annular velocity in comparison to wellbore and CKB.

Both SBM and spacer fluids were kept constant at 40˚F to simulate mud line condition (Table 4). The 15-min SBM contact time was applied to provide a fair amount and even coating of SBM to the pipe analog surfaces. The efficacy of a displacement system was determined by analyzing spacer cleaning efficiency results after the surfactant pill stage only. This was a common way of looking at efficacy of a displacement system by some operators.

Table 4. Lab displacement conditions to displace a 14.45 lb/gal internal olefin-based SBM

	Pipe Analog Rotation (rpm)	Spacer Temperature (˚F)	Contact Time (min)
SBM	6	40	15
Base oil	Not used		
Weighted push pill	100	40	10
Surfactant pill	100	40	12

To simulate a 17.0 lb/gal diesel-based OBM displacement in the wellbore line, a pipe analog rotation of 450 rpm was used (Table 5). No base oil was used to evaluate the efficacy of a displacement system because base oil was used only to thin the OBM.

The pipe analog rotation and contact time were previously calculated through modeling software by the applied engineering department. Spacer fluids were kept constant at RT throughout the duration of experiment.

Table 5. Lab displacement conditions to displace a 17.0 lb/gal diesel based OBM

	Pipe Analog Rotation (rpm)	Spacer Temperature (˚F)	Contact Time (min)
SBM	3	RT	15
Base oil	Not used		
Weighted push pill	450	RT	5.8
Surfactant pill	450	RT	14.5
Viscous pill	450	RT	5.8
CBF	450	RT	15

To simulate a 14.85 lb/gal alpha and internal olefin (C11-C18) based SBM displacement in the riser line, a pipe analog rotation of 100 rpm was used. No base oil was used to evaluate the efficacy of a displacement system (Table 6).

No specific well condition was used in this experiment. The efficacy of a displacement system was evaluated by analyzing the spacer cleaning efficiency after the surfactant pill stage at 4- and 10-min intervals.

Table 6. Lab displacement conditions to displace alpha and internal olefin-based SBM

	Pipe Analog Rotation (rpm)	Spacer Temperature (˚F)	Contact Time (min)
SBM	3	RT	15
Base oil	Not used		
Weighted push pill	100	RT	5
Surfactant pill	100	RT	10

Cleaning Test Procedure:

Submerged a pipe analog in CBF or surfactant pill-based fluid (without additives), removed it from the fluid, and recorded the weight as W1 and W2 respectively. Dried the pipe analog, and submerged it in S/OBM. Removed the pipe analog from S/OBM, and recorded the weight (W3). Cleaned, and dried the pipe analog prior to displacement tests. Submerged the pipe analog in S/OBM, base oil (if used), weighted push pill, surfactant pill, viscous pill, and CBF at pipe analog rotation and contact time showed in Tables 1-6. Recorded the pipe analog weight after surfactant pill and CBF stages, and labeled them W4 and W5 respectively.

% Spacer Cleaning Efficiency Calculation:

1. % removal calculation after surfactant pill

% cleaning efficiency = [1 – {(W4-W2)/(W3-W2)}] x 100

2. % removal calculation after CBF

% cleaning efficiency = [1 – {(W5-W1)/(W3-W1)}] x 100

Fluid Compatibility

Fluid compatibility of S/OBM and TADS displacement spacer system was evaluated by performing a visual observation for emulsion formation after 4 hours. A 17.0 lb/gal diesel-based OBM and a 17.4 lb/gal TADS-RD weighted push pill were mixed well to create a homogeneous mixture at ratios of 75:25, 50:50, and 25:75.

Results and Discussions

The riser section is the most difficult section to clean due to much lower annular velocity in comparison to wellbore and CKB annular velocities. It is recommended to use riser condition as a way to measure the efficacy and efficiency of a displacement system.

Displacement Test Results for 13.6 lb/gal Ester/IO-Based SBM – Riser Displacement

Incubating a pipe analog in an ester/IO-based SBM for 3 days at 225˚F resulted in a higher amount of SBM deposited on surfaces than observed in conventional displacement modeling procedures (rotating the analog at 3 rpm and RT for 15 min). This test resulted in much more challenging displacement modeling conditions.

The traditional surfactant system proved to be ineffective and inefficient in displacing a 13.6 lb/gal ester/IO-based SBM (Fig. 1). After the surfactant pill stage, with a treatment loading of 20% v/v, it only provided ~6% spacer cleaning efficiency. SBM residue and barite residue from the weighted push pill remained adhered to the pipe analog surfaces. After the CBF stage, the spacer cleaning efficiency was only ~30%, with barite and SBM residues still adhered on surfaces. The barite residue adhered strongly to surfaces and was found to be nearly impossible to remove chemically.

SBM	Base Oil	Surfactant Pill	CBF
	No Base Oil		
% Removal	-	5.8%, Oil wet	30.2%, Oil wet

Fig. 1. Traditional surfactant displacement system against a 13.6 lb/gal ester/IO-based SBM – Riser Line

In comparison, the TADS-RD displacement system, with treatment loading of only ~4% v/v, was effective and efficient in displacing a 13.6 lb/gal ester/IO-based SBM (Fig. 2). The spacer cleaning efficiency after surfactant pill and CBF stages was >99%, which exceeded the typical acceptance criteria of 95% spacer cleaning efficiency. Surfaces were completely water-wet, with no SBM or barite residue. In addition, visual observation of the pipe analog indicated that the TADS-RD system was able to completely displace the SBM in less than 5 min, even though the surfactant pill stage total contact time was 13.5 min.

SBM	Base Oil	Surfactant Pill	CBF
	No Base Oil		
% Removal	-	99.8%, Water-wet	99.9%, Water-wet

Fig. 2. TADS-RD displacement system against a 13.6 lb/gal ester/IO-based SBM – Riser Line

Displacement Test Results for 13.6 lb/gal Ester/IO-Based SBM – Wellbore Displacement

The TADS-RD system showed superior cleaning efficiency in displacing a 13.6 lb/gal ester/IO-based SBM in wellbore line. The spacer cleaning efficiencies after surfactant pill and CBF stages were >98% and 99%, respectively, leaving water-wet surfaces without any residues (Fig. 3). These results were expected as annular velocity used to simulate wellbore displacement was 4.5 times higher than a displacement in the riser line.

Lab experiments also showed that a base oil could displace SBM efficiently when wellbore displacement conditions were used. However, a barite residue was deposited back to surfaces after the weighted push pill stage. The TADS-RD system removed this barite residue efficiently without any problems. In contrast, the traditional surfactant system was not able to remove the barite residue effectively.

SBM	Base Oil	Weighted Push Pill
		
% Removal	95.43%	-
Surfactant Pill	**Viscous Pill**	**CBF**
		
98.8%, Water-wet	-	99.9%, Water-wet

Fig. 3. TADS-RD displacement system against a 13.6 lb/gal ester/IO-based SBM – Wellbore Line

Displacement Test Results for 13.6 lb/gal Ester/IO- Based SBM – CKB Displacement

CKB displacement lab tests showed similar results to the riser and wellbore tests. A >99% spacer cleaning efficiency was achieved after both surfactant pill and CBF stages (Fig. 4). Surfaces were completely water-wet, with no residue.

SBM	Surfactant Pill	CBF
		
% Removal	99.5%, Water-wet	99.6%, Water-wet

Fig. 4. TADS-RD displacement system against a 13.6 lb/gal ester/isomerized olefin SBM – CKB Line

Displacement Test Results for 14.45 lb/gal Internal Olefin-Based SBM

The efficacy of both systems were analyzed by looking at spacer cleaning efficiency of the surfactant pill stage only. This was a common way of looking at spacer efficiency by some operators, where both the viscous pill and the CBF are not evaluated as they typically did not contain displacement chemicals.

The traditional surfactant system, with a treatment loading of 20% v/v, was ineffective and inefficient in displacing a 14.45 lb/gal internal olefin-based SBM at a mud line temperature of 40˚F. The spacer cleaning efficiency after the surfactant pill was only 80% (Fig. 5). Some SBM residue still adhered on surfaces, and surfaces were not completely water-wet.

SBM	Base Oil	Surfactant Pill
	No Base Oil	
% Removal	-	80.0%, Partial water-wet

Fig. 5. Traditional surfactant displacement system against a 14.45 lb/gal internal olefin based SBM

In contrast, the new TADS-RD displacement system, with a treatment loading of ~7% v/v, was effective and efficient in displacing the internal olefin-based SBM. The spacer cleaning efficiency after surfactant pill stage was >99%, leaving water-wet surfaces without any residues (Fig 6).

BM	Base Oil	Surfactant Pill
	No Base Oil	
% Removal	-	99.9%, Water-wet

Fig. 6. TADS-RD displacement system against a 14.45 lb/gal internal olefin-based SBM

Displacement Test Results for 14.85 lb/gal Alpha and Internal Olefin (C11-C18) Based SBM

The traditional surfactant system showed poor spacer cleaning efficiency in displacing a 14.85 lb/gal alpha and IO (C11-C18) based SBM. The spacer cleaning efficiency was only ~67% after the surfactant pill stage, and surfaces were oil wet (Fig. 7), which failed to the minimum spacer cleaning efficiency of 95%. Barite and SBM residues clearly adhered on surfaces, which showed that the surfactant system is ineffective and inefficient in displacing alpha- and internal olefin-based SBM.

SBM	Base Oil	Surfactant Pill (After 4 Min)	Surfactant Pill (After 10 Min)
	No Base Oil		
% Removal	-	56.2%, Oil-wet	66.7%, Oil-wet

Fig. 7. Traditional surfactant displacement system against a 14.85 lb/gal alpha and internal olefin (C11-C18) based SBM

The TADS-RD system surpassed the >95% spacer cleaning efficiency requirement, offering >99% efficiency and leaving water-wet surfaces with only after 4 min contact time (Fig. 8), compared to the 10 minutes programmed into the CV-Pro™ modeling software.

SBM	Base Oil	Surfactant Pill (After 4 Min)	Surfactant Pill (After 10 Min)
	No Base Oil		
% Removal	-	99.2%, Water-wet	99.5%, Water-wet

Fig. 8. TADS-RD displacement system against a 14.85 lb/gal alpha and internal olefin (C11-C18) based SBM

Displacement Test Results for 17.0 lb/gal Diesel Based OBM

The traditional surfactant system demonstrated ineffectiveness in displacing a 17.0 lb/gal diesel based OBM. This system was only able to achieve a partial OBM displacement, even though it was an improvement over alpha- and IO-based SBM displacements (Fig. 7). OBM residue was clearly visible on surfaces after the surfactant pill stage (Fig. 9). The spacer cleaning efficiency after surfactant pill and CBF stages were ~82% and ~88%, respectively, and leaving oil-wet surfaces.

SBM	Base Oil	Surfactant Pill	CBF
	No Base Oil		
% Removal	-	82.3%, Oil wet	88.4%, Oil wet

Fig. 9. Traditional surfactant displacement system against a 17.0 lb/gal diesel-based OBM

In contrast, the TADS-RD system demonstrated effective and efficient cleaning in the diesel-based OBM (Fig. 10). The spacer cleaning efficiency after the surfactant pill and CBF was >99%, leaving water-wet surfaces with no residue on the pipe surface.

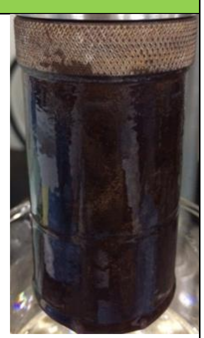
SBM	Base Oil	Surfactant Pill	CBF
	No Base Oil		
% Removal	-	99.4%, Water-wet	99.7%, Water-wet

Fig. 10. TADS-RD displacement system against a 17.0 lb/gal diesel-based OBM

Temperature Stability and Fluid Compatibility Results

The TADS-RD system was temperature stable with no sign of degradation at 170˚F.

Fluid compatibility results between TADS-RD system and diesel-based OBM showed that TADS-RD system was fully compatible with a diesel-based OBM. No sign of emulsion was formed after 4 hours. It is expected that there will no compatibility issues between TADS-RD system and various SBMs.

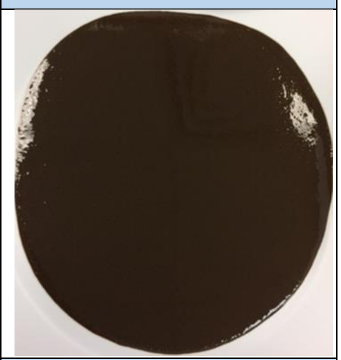
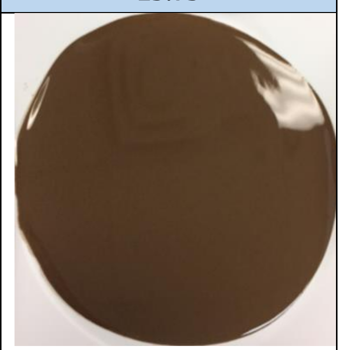
OBM:TADS-RD 100:0	OBM:TADS-RD 75:25
	
OBM:TADS-RD 50:50	**OBM:TADS-RD 25:75**
	

Fig. 11 TADS-RD:OBM Compatibility Results in Ratios of 100:0, 75:25, 50:50, and 25:75

Conclusions

The traditional surfactant displacement system was ineffective in displacing various S/OBMs. It performed the poorest in displacing an ester/internal olefin-based SBM. It did not achieve the minimum acceptance criteria of 95% spacer cleaning efficiency nor of leaving water-wet surfaces (Fig. 12).

The new TADS-RD displacement system is indeed a universal, non-specific, and high-performance displacement system that could be used to displace various S/OBMs effectively and efficiently at various fluid densities. It is proven to be effective and efficient in displacing ester/IO, internal olefin, and alpha and internal olefin (C11-C18) based SBM and a diesel-based OBM with an average of >99% spacer cleaning efficiency, yielding water-wet surfaces.

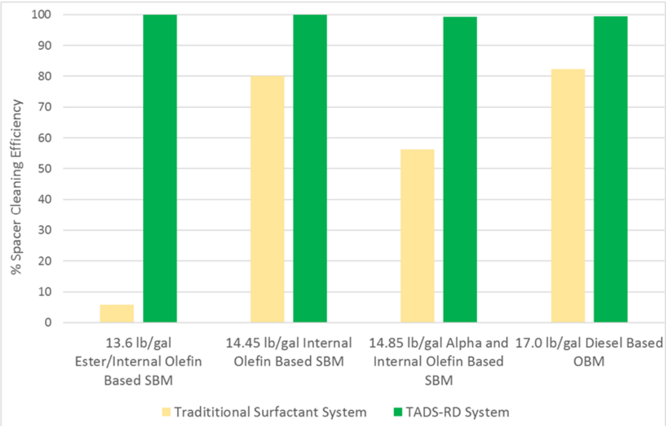


Fig 12. Spacer cleaning efficiency comparisons between traditional surfactant system and TADS-RD system

The TADS-RD system is fully compatible with S/OBMs and high-density non-zinc brines, and no special mixing equipment is required to prepare the spacer system. It is more economical in comparison to the traditional surfactant spacer system, as it requires lower treatment levels to effectively and efficiently displace S/OBMs.

The TADS-RD system has demonstrated comparable performance in the field by successfully displacing a 17.0 lb/gal diesel-based OBM for an offshore well in GOM.

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Nomenclature

BHT = Bottomhole Temperature
SBM = Synthetic-Based Mud
OBM = Oil-Based Mud
WBM = Water-Based Mud
IO = Isomerized Olefin
CBF = Clear Brine Fluid
CKB = Choke, Kill, Boost
GOM = Gulf of Mexico
RT = Room Temperature
Bbls = barrels
Lb/gal = pounds per gallon
V/v = volume per volume
Ft/min = feet per min
˚F = temperature in Fahrenheit

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