AADE-24-FTCE-048

Innovative High-Performance Spacer Fluid: A Breakthrough for Ensuring Precise Zonal Isolation in Complex Reservoir Drilling and Completion

Mootasem Chtay, Kai He, Humberto Soto, Chad Gilmer and Youseffi Crick, ChampionX; Thomas Sodhi and Xiangyu Liu, Formerly ChampionX

Abstract

To tackle the industry's challenges of drilling hotter and deeper wells in harsh reservoir conditions, there is a demand for advancements in drilling and cement fluid technologies. This paper focuses on spacer technology and demonstrates how spacers can perform multiple functions to ensure successful completion of these wells. Four topics that influence the performance will be discussed: 1). Chemical requirements of the new spacer and its rheological properties up to 300°F; 2). Spacer stability and solid carrying capability up to 300°F 3). Spacer mud displacement properties and efficiency; and 4). Spacer's ability to act as a wellbore strengthening fluid in depleted conditions.

In this work, a solution capable of maintaining its rheological properties at temperatures as high as 300°F was developed, without the need for pH adjustments. This innovative solution is compatible with Synthetic/Oil based mud (S/OBM), Water Based Mud (WBM) and cement. Moreover, it exhibits a rapid hydration rate and can be mixed-on-the-fly, facilitating efficient use in operations.

The paper will further discuss the performance of the spacer to enhance formation integrity prior to pumping the cement. A key advantage of the new spacer is minimizing the solids in the spacer and thus reducing operational complexity. Notably, the new spacer fluids were implemented in the field with favorable results.

In conclusion, this paper presents an innovative spacer fluid as a transformative multifunctional solution for achieving precise zonal isolation in drilling and completing challenging wells. The documented attributes and real-world performance of this fluid underscore its potential to significantly improve operations and ensure the success of reservoir drilling projects.

Introduction

Drilling and completion fluids play a large part in the safe and successful drilling of wells, and ensuring the well has a long and productive lifespan. For the well to have a long well life, it is imperative that the cement job is designed as per best engineering practices. Notably, the success does not only rely on the properties of the cement, but also extends to the mud removal process. In fact, utilizing spacers is perhaps even more important than the actual composition of the cement slurry. (API, 2003).

A spacer is a viscous fluid that is used to displace drilling fluid and prepare the newly drilled well section for the primary cementing operations. A well-engineered spacer is critical to the success of proper cement placement and achieving zonal isolation. Chemically, a spacer should be compatible with both the drilling fluid and the cement. The spacer should act as a barrier between these fluids, not allowing them to mix. Contamination of cement by drilling fluids will cause poor cement bonding to the casing and the formation and can lead to inadequate zonal isolation. Rheological hierarchy optimization is also critical during fluid displacement in horizontal sections of a well. Obtaining density hierarchy to avoid fluid intermixing, as well as viscous fingering, is essential for effectively cleaning drilling fluid inside the tubing/casing and in the annulus. (Matthews et al., 2021) Proper fluid displacement provides effective zonal isolation and proper cement placement. The subsequent sections of this paper will delve into the multifaceted benefits of utilizing spacer fluids, including their impact on zonal isolation and overall cement job effectiveness.

The proper utilization of spacer systems in well completion has been understood for decades. Spacers have been formulated to adhere to the industry's primary function mentioned previously of spacer fluids; however, the last fifteen years has seen the focus shift to multifunctional spacer formulations to play a bigger part in preparing weak formations for potentially high equivalent circulation densities (ECD) during primary cementation. (Brandl et al., 2008), (Quintero et al, 2008), (Ilesanmi et al, 2014), and (Shine et al, 2023).

The strive for a more comprehensive spacer system is becoming increasingly complex as we target higher pressure and higher temperature reservoirs. This, coupled with the industry's requirements for simpler, safer, and more sustainable operations, is enabling new technology to challenge aspects of the standard spacer systems. As the energy industry continues the path towards more sustainable solutions, we are technically challenged to look at the minute details of various systems to accomplish the targets. This requires us to look for additives and products that require less loading to achieve the functional specifications for the fluids. This drive will also require us to look at products that can have multiple functionalities to reduce the number of products required to formulate a complete system. Finally, finding ways to reduce horsepower and equipment requirements in drilling and completion operations by identifying the right chemistry that meet the required specification with minimal energy use.

Currently, the industry standards for spacer systems additives utilizes biopolymers, cellulose-derived polymers, or clays. All these current options have limitations including instability and thinning at high temperatures, high loading requirements, and mixing issues. Many of these additives need to be hydrated for up to 8 hours before use, subject to the availability of a mixing tank.

In this work, various lab testing was conducted to evaluate the newly developed polymer and to understand its properties. The product was formulated by following API testing protocol for rheology (API RP 10B-2, 2013), mud compatibility, dynamic settling, and fluid loss. The data presented in this paper will showcase the system design to achieve specific targets, including mixability and hydration, solid carrying capability and system stability, rheological fluid/fluid compatibility with water-based (WBM) and oil-based (OBM) drilling fluids as well as cement, and dual functionality with great fluid loss characteristics to potentially aid wellbore strengthening without solids.

Experimental Procedures

Materials

Table 1 shows the spacer formulation used in order of addition and duration for mixing.

Table 1: Spacer System Designs

Component	Fluid #1: Spacer	Fluid #2: Spacer + Surfactant	Fluid #3: Enhanced Spacer
Test Type	Rheology Settling	Compatibility	Fluid Loss
Water	36 gal/bbl	36 gal/bbl	36 gal/bbl
Spacer Additive #1	3 – 5 lb/bbl	3.8 lb/bbl	
Spacer Additive #2			3-5 lb/bbl
Surfactant		2.5 gal/bbl	
Mutual Solvent		2 gal/bbl	
Barite	205 lb/bbl	214 lb/bbl	205 lb/bbl
Weight	12ppg	12ppg	12ppg

The spacer additive was allowed to hydrate for 5 minutes before adding the other additives. Total mixing time did not exceed 15 minutes.

Drilling fluids used for compatibility testing were obtained from customer field mud. 11ppg WBM contains brine, viscosifier, fluid loss, lubricant and weighing agent. 11ppg OBM contains diesel, organophilic clay, lime, primary emulsifier, secondary emulsifier, brine, fluid loss additive and weighting agent.

Cement recipe used for compatibility testing is 14ppg cement containing Class G cement, silica flour, bentonite gel, cement retarder, anti-settling additive, and fresh water.

Rheology Measurements

Rheological data was measured using OFITE 900 rotational viscometer (Figure 1) at various speeds (300, 200, 100, 60, 30, 5 and 3 RPM) and at different temperatures with R1 rotor and B1 bob.

Figure 1: OFITE 900 Rotational Viscometer

Static and Dynamic Settling Measurements

The static and dynamic settling tests are conducted to simulate events at which the fluid is either static due to sudden stops due to surface issues or moving at a slow speed due to reduction in flow rates. The static test was performed by preparing 600-ml of spacer and conditioning it for 30 minutes at the required temperatures (150°F and 180°F) following API RP 10B-2 standard. Subsequently, 100-mL of spacer was then poured into a 100-mL graduated cylinder and placed in a preheated oven (150°F and 180°F) for 2 hours, after which the free fluid volume was recorded after aging. A 10-mL sample of spacer from the top and bottom of the cylinder was obtained using a pre-weighted syringe (M_{empty}), and the weight of the top and bottom sample, M_{top} and M_{bottom}, respectively, was measured. The change in density (% ρ) between the top and bottom of the spacer was then calculated using the Equation 1:

$$\% \rho = 2 \times \frac{M_{bottom} - M_{top}}{M_{bottom} + M_{top} - 2 \times M_{empty}} \qquad \textit{Equation 1}$$

Dynamic settling test was conducted to indicate how solid settling occurs while the fluid system is in motion at low speed. (Doan et al., 16). Dynamic settling at 300°F of the new product was tested utilizing the 12 ppg spacer formulation at 3 lb/bbl with barite as the weighing agent. The test was performed at 300°F by preparing 500-ml of spacer and pouring the spacer into a consistometer slurry cup with a modified paddle as shown in Figure 2.

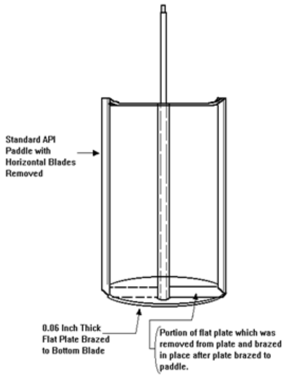

Figure 2: Modified Cup Paddle for Dynamic Settling Test

The cup was placed in a consistometer programed to ramp up to 300°F and 10,000 psi within 60 minutes. Once the target temperature and pressure were reached, the spacer was kept at test conditions for 15 minutes and then allowed to cool to ambient temperature, and the pressure was released. Subsequently, a syringe was used to collect samples from the top, middle and bottom sections of the cup and the densities of each sample were measured. % ρ was determined by calculating the change in density between the top and bottom samples. Additionally, the bottom of the paddle was also observed for any settling or segregation, and as well as for the presence of solid packing.

Rheological Fluid/Fluid Compatibility Measurements

The compatibility between the various fluids is assessed by calculating the R-Index Value (R) (Elochukwu, 2022), to establish that the rheological properties of the pure fluid is not affected by mixing with another fluid at various concentration. The R-Index is calculated using the Equation 2:

$$R\ Index\ (RPM) = \theta_m - \theta_i \qquad \text{Equation 2}$$

Where θ_m is the highest 100 RPM reading from spacer/mud mixture or spacer/cement mixture obtained from OFITE 900 viscometer, and θ_i is the highest reading from the individual fluid. Testing was conducted at 100% drilling fluids (or cement) and then mixed with the spacer at the ratios of 95:5, 75:25, 50:50, 25:75, 5:95 and 0:100.

Fluid Loss Measurements

Fluid loss testing was performed with 100 mesh sand packed in HTHP cell equipped with a 325-mesh screen at the bottom end cap. The spacer was mixed and then aged in an atmospheric consistometer at 150°F for 30 minutes. The fluid loss was performed at 150°F with 1000 psi top pressure and results were collected at various intervals. Based upon the fluid loss data collected at the 15 minutes and 30 minutes, the sealing factor fluid loss is calculated by:

$$Fluid\ loss = (FL_{30min} - FL_{15min})/15 \qquad \text{Equation 3}$$

The passing criterion for performance rating based upon the sealing factor fluid loss number calculated by equation 3 is:

- Less than 0.5/min = Excellent+ Sealing
- Less than 0.75/min = Excellent Sealing
- Less than 1/min = Good Sealing
- Greater than 1 = Poor sealing

Results and Discussion

In response to the challenge of replacing the current spacer formulation to meet a wider range of well conditions, our primary objective was to develop a new spacer viscosifier that met key performance criteria. These criteria included excellent mixability and rapid hydration, robust solid carrying capacity with minimal loading requirements, adaptability for achieving viscosity and density hierarchy, and compatibility with WBM, SBM/OBM and cement. Additionally, the system needed to exhibit stability at temperatures up to 300°F and form a thin film with exceptional fluid loss control.

To address these requirements, an innovative spacer viscosifier was developed with the aim of surpassing current industry standards and establishing clear technical distinctions from existing products. Notable improvements were observed in mixability and hydration speed, allowing for mix-on-the-fly operations. This capability not only reduces equipment footprint but also enables real-time adjustment of spacer rheology based on observed mud returns and rheological data, aligning with the industry's push for more sustainable solutions.

Mixability and Hydration

For the viscosifier to readily dissolve in solution, it must exhibit quick viscosity development and avoid fisheyes, which occurs due to the poor dispersion of partly hydrated polymers, leading to the formation of globules. This issue often arises from adding the polymeric product too fast to the desired solution. However. The current solution can be added at any rate without the formation of fisheyes. To understand viscosity buildup at different times, viscosity measurements were conducted at various intervals to construct the hydration curve (Figure 3). The hydration curve, along with vortex closure images (Figure 4) highlights the quick viscosity development using this product and underscores the positive impact of this robust and quick hydration on mix-on-the-fly operations. Further data will demonstrate that this quick hydration will not compromise the solid carrying capabilities of the fluid.

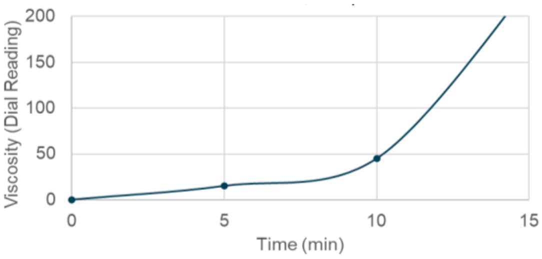

Figure 3: Hydration Curve of New Product using Waring Blender @ RT. Viscosity measurements @ RT using OFITE 900


1-min 5-min 10-min

Figure 4: Hydration Progression for 10 Minutes of New Product

Despite differences in mixing time, the hydration of the newly developed viscosifier utilizing various mixing procedures, including API RP 10B-2, Waring Blending mixing, and overhead mixing blending, demonstrates robust and fast hydration within 10 minutes, yielding consistent results (Table 2). Specifically, API mixing procedure, which involves mixing at 4000rpm for 15 seconds followed by 12000 rpm for 35 seconds, revealed that hydration occurred approximately at 1 minute under high shear conditions, yielding comparable results as slower lab mixing. This leads to the conclusion that at high shear rate, hydration occurs within 1 minute. Operators in Eagle Ford, South Texas and DJ Basin, Wyoming have seen this positive impact on mixing and have reported reduction in total operation cost due to the fast hydration of the new viscosifier.

Table 2: Rheological Data @ 80F with Different Mix Techniques

Mixing Procedure (12ppg Spacer)	Rheology Dial Readings @ 80°F							PV	YP
	300	200	100	60	30	6	3	cP	lb/100 ft^2
API RP 10B-2	55	49	36	28	21	10	7	29	26
Waring Blender	54	46	35	29	23	13	11	29	26
Stirrer	55	47	36	30	24	14	12	28	27

The rheological data at 80°F and 180°F of the new product, in comparison to the incumbent products (Figure 5) showed that the required dosage for the new product is less than 50% of what is currently being used to achieve similar rheological properties.

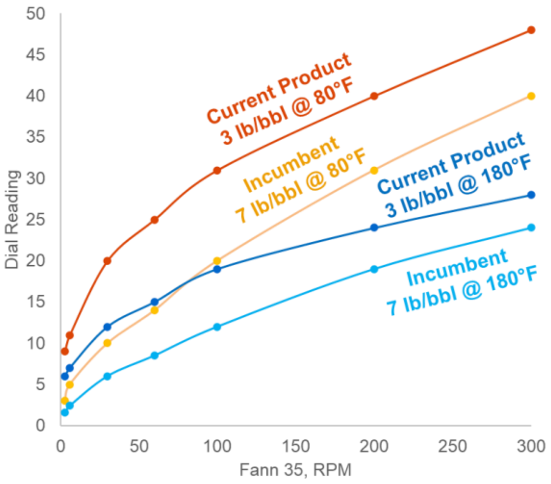

Figure 5: Viscosity Reading of New Product and Incumber Product @ 80F and 180F

These results demonstrate that achieving the necessary rheological hierarchy for efficient cleanout of drilling fluids is readily attainable. The ability of the spacer to viscosify rapidly, coupled with its low dosage requirement, provides operators with the flexibility to mix a spacer system on-the-fly without significant adjustments to the rheological properties of the mud through multiple circulations. This advantage reduces the time required to develop the appropriate yield point (YP) of the spacer fluid without significantly reducing the YP of the drilling fluid.

Solid Carrying Capability & Stability

In addition to rapid hydration, modifying rheology properties while ensuring solid carrying capability is crucial, i.e. the quick development in rheological properties does not compromise the solid carrying capacity of the spacer. This important performance metric is governed by the final rheological properties after the spacer fluid is fully hydrated. As a result, laboratory dynamic settling tests were conducted to assess the stability that contributes to the slurry's effective placement. Results showed that the new technology improved the dynamic settling at less than half the concentration of the incumbent product. Furthermore, static settling tests were conducted, and result showed similar performance between incumbent and new product at half the concentration. Passing the static test indicates that the density of the slurry at the top of a certain zone is comparable to the slurry at the bottom.

Table 3: Static Settling Test New Product and Incumbent Product @ 150F and 180F

	Current Product 3.5 lb/bbl		Incumbent Product 9 lb/bbl	
Temp	150°F	180°F	150°F	180°F
Free Fluid (%)	0	0	0	0
% ρ (Static Settling)	1%	5%	1%	2%

In table 3, the spacer is considered stable at these specific temperatures when % ρ is less than 5% and the volume of free fluid is less than 2%. Accordingly, both spacers are considered stable at both temperatures.

Table 4: Dynamic Settling Test Results @ 300F

	Current Product 3 lb/bbl	Incumbent Product 7 lb/bbl
Temp	300°F	300°F
% ρ (Dynamic Settling)	5%	21%
Cone Height	5mm	10mm
Cone Height on paddle		

As shown in table 4, spacer is considered stable at temperatures above 250°F when % ρ is less than 10% and there is no evidence of settlement at the bottom of the cup (formation of cone). Cone formation indicates settling of particles which indicates poor solid carrying capabilities at the low pump rates. The current product outperformed the incumbent product and stayed within the pass criteria at 300°F. There was little indication of a cone formation, and the spacer did not show segregation or packing with the new additive. This represents a significant performance advantage over the incumbent product.

It was observed that the carrying capacity at the low dosage of spacer fluid, utilizing barite as the weighing agent, is as efficient as using at least double the concentrations with the other polymers. Furthermore, the polymer exhibited excellent stability at 300°F. Future studies will explore the possibility of increasing the stability to as high as 400°F, to try and expand the utilization window of this technology.

Rheological Fluid/Fluid Compatibility

The spacer system must be compatible with both the drilling fluid system and the cement system, as it interacts with both during pumping operations. For WBM, compatibility is straight forward since the spacer is a water-based system; however, when drilling with OBM, modifications to the spacer recipe are necessary by adding surfactants and mutual solvents to achieve the proper compatibility with the oil-based fluids. Displacing OBM by water-based fluid presents challenges due to the increased pressures observed as a result of the thick emulsion formed at the interface of the two fluids (Quintero et al., 2008). It is important to note that adding surfactants and mutual solvent did not influence the hydration rate or final viscosity of the polymer. The compatibility between the various fluids is assessed by calculating the R-Index Value (R) (Elochukwu, 2022), to establish that the rheological properties of the pure fluid is not affected by mixing with another fluid at various concentration. Table 5 shows the viscosity and R Index value for mud/spacer mixture and table 6 shows these values for spacer/cement mixture, respectively. PV and YP values were calculated based on best fit to a Bingham Plastic Model.

Table 5: Mud/Spacer Compatibility Data with R-Index Value

Fluid Mix								
Mud %		100	95	75	50	25	5	0
Spacer %		0	5	25	50	75	95	100
Dial Reading	300	24	26.5	44	50	42	37.5	44
	200	18.5	20	38	41	36	31	37
	100	13	13.5	32	30	27	21	28.5
	60	10	11	28	24	23	15	23.5
	30	8	8	24	19	18	8	18
Plastic Viscosity (cP)		18.5	22	23.5	38	31	36	34
Yield Point (lbs/100ft2)		6	5	22	14	13	13	13
R Index Value		3						
Remarks		Compatible						
Testing done at 180°F using 11ppg OBM and 12ppg spacer.								

Table 6: Spacer/Cement Compatibility Data with R-Index Value

Fluid Mix								
Spacer %		100	95	75	50	25	5	0
Cement %		0	5	25	50	75	95	100
Dial Reading	300	41	42	43	52	62	107	79
	200	36	37	37	43	51	88	63
	100	28	28	28	32	38	65	46
	60	23	23	24	26	31	55	37
	30	18	18	18	21	25	44	30
Plastic Viscosity (cP)		32	33	33	40	47	78	59
Yield Point (lbs/100ft2)		13	13	13	15	18	34	22
R Index Value		19						
Remarks		Compatible						
Testing done at 180°F using 12ppg spacer and 14ppg Cement.								

For a fluid to be considered compatible, the R-Index criteria are listed in table 7 below:

Table 7: R-Index Criteria

R-Index Value	Result
R < 0	Compatible
0<R<40	Compatible, check friction pressure
41<R<70	Slightly incompatible
R>71	Incompatible

As per the criteria outlined in table 7, both OBM and cement are compatible with the fluid. However, hydraulic simulation must be performed to assess friction pressure at the proposed pump rate and the overall pumping procedure.

The new developed spacer additive has shown better rheological properties with lower PV and higher YP than the incumbent product. The lower PV will allow a larger pumping operation window due to potential lower friction pressures. Higher YP, as is also evident by the settling testing at 300°F, provides for more fluid stability. Figure 6 below shows the rheological characteristics of the new and the incumbent fluids at various temperatures and shows the advantage of using the newly developed spacer system across the different temperature ranges.

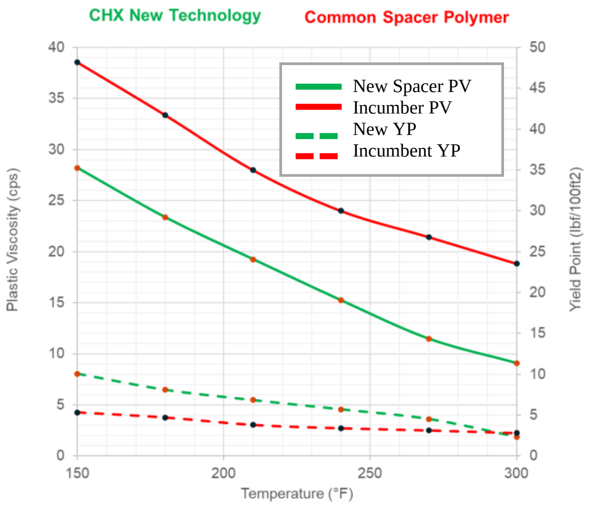

Figure 6: PV and YP Values at Various Temperatures (Up to 300F)

Dual Functionality

Another challenge that the industry faces is the need for the spacer to have good fluid loss characteristics, and to be able to build a thin film on the formation to reduce fluid loss. Current technologies have shown that the viscosifier can potentially be used without pairing LCM to control the losses at 1000 micron. (Shine et al, 2023). However, at 3000 microns, there was a significant increase in leak-off during performance testing, necessitating the use of LCM at 5000-micron level. A second generation of the proposed product has excellent fluid loss capabilities with barite, as the only solid additive, which is used as a weighing agent. As shown in table 8, increasing the dosage of new product from 3lb/bbl to 5 lb/bbl (other products required more than 12 ppb polymer) resulted in a fluid loss volume decreases by more than 50% (from 67mL to 27.5mL).

Table 8: Fluid Loss Data at Different Concentrations

	Fluid Loss (mL)/minute		
Time (min)	3lb/bbl New Product	4lb/bbl New Product	5lb/bbl New Product
0	33	17	13
1	37	22	16
2	40	24	17
5	46	28	19
10	51	32.5	22
15	57	37	24
20	61	40	25.5
25	64	43	26
30	67	46	27.5

Previous work has shown that the formation of thin film can prevent fluid loss into the formation, thereby slowing down total fluid loss in weak formations. The ability of the spacer to strengthen the wellbore and enable effective cementing in a single stage reduces rig time, simplifies the operation, lowers costs and improvs quality. (Brandl et al., 2008). Having a spacer system that performs well in the fluid loss category without having any solids may facilitate either a reduction in LCM solids, or potentially, can lead to a solids free approach utilizing new technologies.

An industry criterion used to evaluate the effective sealing characteristics of the spacer fluid is to calculate fluid loss per minute for the last 15 minutes of the test. This gives the fluid enough time to build a filter cake and assesses the true fluid loss post filter cake formation without initial spurt loss. Based on the difference in fluid collected over the 15 minutes interval, the value obtained per minute is used to determine how well the fluid can seal the formation. The results obtained for the various concentrations tested are presented in Table 9.

Table 9: Fluid Loss Results at Different Concentrations

Spacer Formula	**Fluid loss, cc/min**
New Product @3 lb/bbl	0.53
New Product @4 lb/bbl	0.6
New Product@5 lb/bbl	0.23

Industry standards specify that the fluid loss, calculated in the last 30 minutes as per equation 3 in cc/min, of less than 0.5 cc/min earns an Excellent+ rating for sealing the reservoir prior to the cement. Notably, the same rating has previously required the addition of fiber and LCM to the spacer However, further work including slot test with various widths and field trial, is necessary to confirm the ability of the solids free spacer to achieve the same results observed. It is worthwhile to mention that as per the same criteria, any value <0.75 m./min is considered Excellent. As such, modifications to achieve the required fluid loss can be easily made with as little as 3 lb/bbl loading of the product to meet the required sealing criteria.

Conclusions

When compared to commercial viscosifiers, the new and innovative technology demonstrates excellent solid carrying capability in both static and dynamic settling tests. The spacer system has been successfully deployed in many jobs in Eagle Ford, South Texas and DJ Basin, Wyoming, resulting operation cost reduction due to the fast hydration of the new viscosifier, eliminating the need for batch-mixing the spacer.

Key benefits have been identified in utilizing this spacer through laboratory testing and field implementations, as discussed in the paper. These benefits include 1). Fast hydration at low dosage, reducing the need for additional mixing units on the rig and eliminating extra circulations to reduce mud yield point. 2). Excellent temperature stability with impressive solid carrying capacity, with ongoing effort to increase the temperature tolerance above 300°F. 3). Easy attainment of fluid/fluid compatibility with drilling fluids and cement, simplifying the mixing process for required additives. 4). Sealing potential, possibly eliminating the need for additional lost circulation materials (LCM) solids.

Spacers have undergone significant improvements within the industry over the past decade with companies improving their functionalities to help with formation sealing prior to primary cement jobs. The new product brings in a new approach to looking at specific additives within any fluids system and challenges us to provide more sustainable solutions that require less energy to mix on location. These improvements will allow the industry to achieve sustainability by reducing chemical products required to deliver functional specifications of each product. The new product not only met the functional requirements of spacers, but also offers potential optimizations that yield positive results upon application.

Acknowledgments

The authors would like to acknowledge Dominique Matthews and Jesse Lee for their contribution and to ChampionX for supporting and permission to publish the data.

Nomenclature

API RP = *American Petroleum Institute Recommended Practice*
BHA = *Bottom Hole Assembly*
BHCT = *Bottom Hole Circulating Temperature*
HTHP = *High Temperature, High Pressure*
LCM = *Lost Circulation Material*
OBM = *Oil Based Mud*
Ppb = *Pounds per Barrel*
Ppg = *Pounds per Gallon*
PV = *Plastic Viscosity (cP)*
SBM = *Synthetic Based Mud*
WBM = *Water Based Mud*
YP = *Yield Point (lbf/100ft^2)*

References

1. API Recommended Practice 10B, Recommended Practice for Testing Well Cements, 2nd edition, American Petroleum Institute, (2013).
2. API Recommended Practice 65, Cementing Shallow Water Flow Zones in Deepwater Wells, 1st edition, American Petroleum institute, (2003).
3. Brandl, A., Bray, S., Magelky, C., Lant, K., Martin, R. and St.-Clergy, J. 2011. "An Innovative Cement Spacer with Biodegradable Components Effectively Sealing Severe Lost Circulation Zones." 10th Offshore Mediterranean Conference and Exhibition. Ravenna, March 23-25, 2011. Available from http://onepetro.org/OMCONF/proceedings-pdf/OMC11/All-OMC11/OMC-2011-067/1684835/omc-2011-067.pdf/1
4. Doan, A.A., Kellum, M.G. and Cardenas, I. 2016. "Using Large Cellulose Particles to Improve Hight-Temperature Cement Slurry Stability." AADE-16-FTCE-44, AADE National Technical Conference, Houston, April 12-13, 2016. Available from www.aade.org.
5. Elochukwu, H., Samansu Douglas, E. and Chikere, A.O. 2022. "Evaluation of Methyl Ester Sulphonate Spacer Fluid Additive for Efficient Wellbore Clean-Up." Energy Geosci 3(1): 73-79. Available from https://doi.org/10.1016/j.engeos.2021.11.002.
6. Matthews, D.L., Lee, J., Liu, X and P. Street. 2021. "How to Mitigate Methane Leaks with Cementing Chemical Technology" E&P Newsletter. Available from https://www.hartenergy.com/ep/exclusives/how-mitigate-methane-leaks-cementing-chemical-technology-197042
7. Ilesanmi, O., Gill, S., Hilal, B., and Kulakofsky, D. "Cement Spacer Technology Eliminates Costly Remedial Jobs While Providing Excellent Bond Logs." SPE-172377-MS, SPE Nigeria Annual International Conference and Exhibition, Lagos, August 05-07, 2014. Available from https://doi.org/10.2118/202418-MS
8. Quintero, L., Christian, C., Halliday, W. and Dean, D. "New Spacer Technology for Cleaning and Water Wetting of Casing and Riser." AADE-08-DF-HO-01, AADE Fluid Conference and Exhibition, Houston, April 8-9, 2008. Available from www.aade.org.
9. Shine, J.M., Sowailem, A., Gbemiga, I., and Bermudez, F. "Improved Well Integrity Using A Novel Fluid Technology o Overcome Large Fracture Networks and Permeable Formations." SPE-215140-MS, SPE Annual Technical Conference and Exhibition, San Antonio, October 16-18, 2023. Available from https://doi.org/10.2118/215140-MS.