AADE-24-FTCE-030

A New Shale Stabilizer for Water Based Muds to Meet the Highly Faceted Demands of Drilling

Chris Waller, Youseffi Crick, Mootasem Chtay, Chad Gilmer, Mehrnoosh Moradi, ChampionX

Abstract

Water-based mud (WBM) systems have gained significant traction over the years as drilling systems require a more ESG centered approach. To meet these demands, new shale stabilizer chemistry development within the drilling additive space is critical for the industry. Specifically, work has been completed to develop a shale stabilizer to meet the rigorous demands of drilling in highly reactive shale formations. The new approach was not to focus on one individual chemistry, but rather, to create a multifunctional shale stabilizer for cuttings recovery, stabilization, and reactivity.

Performance tests conducted included bulk hardness, cuttings recovery, linear swell, accretion, and fines control. The results demonstrate the formulation's ability to maintain rock properties of the borehole and reduce clay reactivity. Pierre Shale formation outcrop material was used for testing due to its high clay content and reactivity. The additive was tested in tap water as well as a general water-based mud formulation for compatibility. The new technology combines different chemistries, which work well for individual requirements, and together to produce a singular additive to meet drilling requirements.

In conclusion, the new shale stabilizer performs well at shale inhibition and stabilization mechanisms to achieve a solution that allows the industry to continue its transition from oil-based muds (OBM) to WBM in water sensitive zones. While a high demand formation was tested, the formulation can be tailored to meet the individual needs seen when drilling through different formations.

Introduction

The move to a more ESG conscious industry has led to a transition towards more WBM drilling fluids. To help meet the high demands of such systems, particularly when drilling through high reactivity shales, new shale stabilizers need to be developed.

The interactions of water-based fluids with argillaceous shales can have negative effects on drilling that need to be prevented (Allen D. Garrison, 1938) (M.J. Wilson, L. Wilson, 2014). Chemistries which help limit such issues as dispersion of cuttings and the formation into the drilling mud should be used in water-based muds to better prevent these (S. Mettath, E. Stamatakis, S. Young, G. De Stefano, 2011). This should not include just a singular chemistry, but rather a combination of several agents such as a polymeric agent to help encapsulation, ammonium salts for cationic exchange, and amine salts for swelling control (J. Finks, 2015). These chemical agents help to limit or stop the onset of osmotic swelling (M.J. Wilson, L. Wilson, I. Patey, 2014), which can lead to dispersion of the clay particles and problems within the mud such as gelation, negatively impacting rheology. These issues may create problems affecting hole cleaning, cuttings agglomeration, rate of penetration, wellbore instability, or tight holes just to name a few (R.I. Anderson, I. Ratcliffe, H.C. Greenwell, P.A. Williams, S. Cliffe, P.V. Coveney, 2009). Due to the overwhelming presence of shale formations drilled globally, a very high cost is associated with these borehole instability issues (Borehole Instability, 2012-2024 Petrowiki, Society of Petroleum Engineers).

The purpose of this work was to formulate a shale stabilizer that aids in cuttings recovery, bulk hardness, and clay reactivity. The proposed shale stabilizer incorporated multiple chemistries rather than focusing on a singular chemistry to help achieve this multifunctional capability.

Experimental

Methods and Materials

Four well known chemistries were chosen to make up the new Shale Stabilizer Y. Each chemistry was selected based on their individual functionalities relative to shale stabilization. Included were a polymeric agent, a polymeric amine, an ammonium salt, and a salted amine. The final formulation combined each component to create a singular product. Compatibility was tested in a generic water-based mud using an OFITE Model 900 for dial readings PV, YP, and GS.

The mineralogy of the Pierre Shale, conducted by Premier Oilfield Group, was selected for the tests. Table 1 shows X-ray Diffraction results from the out-crop material used. Three samples were randomly taken from the bulk material to establish the makeup of the Pierre Shale. As can be seen, the Pierre Shale is a rock high in both reactive and dispersive clays. To draw out the reactive and dispersive properties of the clays, tap water was used throughout the test protocols. A 3% KCl solution was also used a functional benchmark to test against.

Table 1: Pierre Shale mineralogy by Wt. %, 3 samples run.

Overall Makeup

Mineral Groups				
Fwk %	Clay %	Carb %	Other %	Total %
43.0	53.8	1.6	1.1	99.6
40.3	54.7	1.6	2.7	99.3
44.0	53.3	1.4	1.2	99.9

Clay Breakdown

Clay Minerals					ML I/S
ML I/S %	Ill+Mic %	Chl %	Kao %	Total %	Avg Exp %
26.0	25.1	0.0	2.7	53.8	25-35
29.4	22.6	0.0	2.7	54.7	25-35
23.5	27.3	0.0	2.4	53.3	35-45

Loading for Shale Stabilizer Y during tests was set at 3% by volume of the solution. The loading of each individual shale stabilizer mentioned above was set to achieve the same active loading in solution as Shale Stabilizer Y when tested. Prior to each test stock solutions were made in tap water for each stabilizer tested.

Cuttings Recovery

For Cuttings Recovery, the Pierre Shale was processed down to obtain 6/12 mesh cuttings size. Each test used 20g of cuttings. The cuttings were then placed in a roller cell with 1 lab barrel of fluid, sealed and hot rolled for 16 hrs. at 200°F and ambient pressure (see Figures 1 and 2). After hot roll aging, and cooling, the cuttings were recovered and washed with de-ionized water using a 12-mesh screen for recovery. They were then placed in an aluminum drying pan and dried in a 158°F oven overnight. Once dried they were cooled in a desiccator and weighed in the pan.

% Cuttings Retention= (W2/W1) *100

W1=Initial Cuttings Weight of 20g
W2=Retained Cuttings Weight (Weight of Dried Pan - Total Weight)

Figure 1: OFITE roller oven used for cuttings recovery, bulk hardness, and accretion tests. Photo: Courtesy of https://www.ofite.com/products/drilling-fluids/aging/5-roller-oven.

Figure 2: Aging cell used for cuttings recovery, bulk hardness, and accretion. Photo: Courtesy of https://www.ofite.com/products/drilling-fluids/aging.

Bulk Hardness

For Bulk Hardness, the Pierre Shale was processed down to obtain 6/12 cuttings size. Each test used 40g of the processed cuttings. The cuttings along with 1 lab barrel fluid were added to the roller cell and then sealed. Hot roll aging was done for 16 hours at 200°F and ambient pressure. After hot roll aging, the cuttings were recovered using a 30-mesh sieve and excess fluid was washed off with tap water. The recovered cuttings from the sieve were placed into the extrusion chamber of the tester. The cuttings were lightly packed, and a plastic disk was placed in the chamber and lightly pressed down until in contact with the cuttings. The top plate with the extrusion piston was then secured. The piston was slowly screwed down until contact with the plastic disk was made. A torque wrench was secured at the top of the piston bolt connected to the extrusion cup and zeroed (see Figure 3). The torque wrench was slowly screwed down until 100-inch pounds was reached and the number of turns was recorded.

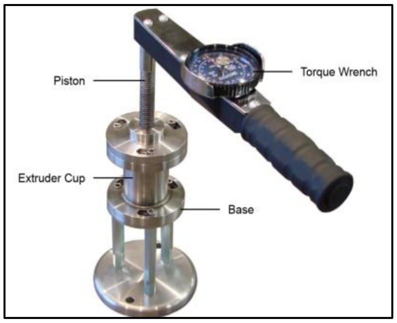

Figure 3: OFITE bulk hardness tester. Photo: Courtesy of https://www.ofite.com/products/drilling-fluids/swelling/bulk-hardness-tester.

Linear Swell

Bentonite API Calibration Grade was used for all tests. The volume of fluid prepared for each test was 100 mL in tap water with and without stabilizers. Each test used 11.5g of bentonite powder compressed for 15 minutes at 2500 psi in a Grace pelletizer (see Figure 4). Then, the pellet was removed from the pelletizer with gloves carefully to avoid any moisture uptake. A volume of 75-80 mL of the fluid was poured into the cup of the Grace M4600 equipment. The bentonite pellet was then secured in the pellet holder. The pellet holder assembly was then screwed into the Grace M4600 and prepared to run a 24-hour test at 500 psi. Then, the cup was secured onto the tester, pressurized and the program started.

Figure 4: Grace M4600 LSM and Pelletizer. Photo: Courtesy of https://www.gic.com/M4600.php.

Capillary Suction Time (CST)

The Pierre Shale was processed using a mortar and pestle to obtain a -200-mesh powder. The solutions for each test were prepared ahead of time in tap water with and without the additive mixed in. One gram of the Pierre Shale powder was added to 4 mL of solution in a 15 mL centrifuge tube, capped, and placed on a vortex mixer for 30 seconds. After mixing, it was placed in a rack still for 1 hour and then placed back on the vortex mixer for 30 seconds. The cap was then removed, and the slurry was poured into the funnel on the CST tester (see Figure 5). Once the tester signaled the end of the test the capillary suction time in seconds was recorded from the screen. Tests were repeated in triplicate and averaged.

Figure 5: Capillary suction timer. Photo: Courtesy of https://www.ofite.com/products/wastewater/meters-52/capillary-suction-timer.

Accretion

Accretion tests were modeled from previous work (S. Cliffe, S. Young, 2008). For this test, the Arne Clay was processed to create 6/12 mesh cuttings size and the moisture content was obtained using a heated moisture balance. Each test used a total of 40g of processed Arne Clay. Prior to beginning the test, a blank steel rod was prepared by removing any surface oxidation with a wire wheel brush on a bench grinder. After removing the surface oxidation, it was then scuffed using 400 mesh sandpaper and double rinsed with both Isopropyl Alcohol and Acetone. While awaiting the test the metal rods were stored in a desiccator and weighed. In a roller cell, the cuttings were placed with 1 lab barrel of the fluid (Table 3) to be tested. The roller cell was then sealed and placed in a roller oven. The test was conducted at room temperature and the cells were rolled for 20 minutes. After rolling the steel rods were removed from the cell and carefully leaned against a clamped rod and allowed to drip dry overnight. After drying overnight, the steel rods with the accreted material were placed in a 200°F oven for 2 hrs. to remove any remaining moisture. They were then weighed and the accretion percents were calculated with the equation below.

Accretion = [(W2-W1)/(WC*(100 - MC)/100]*100

WC=Weight of Cuttings
W1=Weight of Blank Steel Rod
W2=Weight of Steel Rod With Accretions
MC= % Moisture Content of Sized Arne Clay Cuttings

Table 3: Mud compositions used for both Accretions Tests and Compatibility.

Additive	**Mud without Stabilizer (g)**	**Mud with Stabilizer (g) unless stated by volume**	**Time on HB Mixer Min.**
Tap Water	273.46	273.46	N/A
KCl	14.39	14.39	5
Sodium Thiosulfate	1.17	1.17	3
Lubricant	7.813	7.813	2
Starch	1.56	1.56	10
Xanthan Gum	1.41	1.41	15
Shale Stabilizer Y	-	3% v/v	5
Caustic	To pH 9.5	To pH 9.5	5
Calcium Carbonate	15.626	15.626	5
Barite	159.39	159.39	10

Fines Control Test

For this test, the Pierre Shale was processed in a mortar and pestle down to achieve a -200-mesh powder. A volume of 20 mL of the testing solution with stabilizer or without stabilizer (blank tap water) were added to a 20 mL scintillation vial. Then, 1g of the processed Pierre Shale powder was added. The scintillation vial was capped, and hand shaken vigorously for 30 seconds to disperse the solids throughout the solution. After 30 seconds of shaking, the vial was placed against a background and allowed to sit static. The bottles were photographed as the solids settled at 0.50, 1, 3, 5, and 10 minutes.

Water-based Mud (WBM) Compatibility

For the compatibility assessment, the same mud formulations shown in Table 3 was used. The test was done using an OFITE Model 900 for Dial Readings (DR), PV, YP, and GS.

It is fully recognized that compatibility is also dependent on the mud type, which will vary across different providers within the industry. This was considered when developing Shale Stabilizer Y.

Results and Discussion

To evaluate the performance of the new shale stabilizer formulation, primary focus was given to the following test methods: cuttings recovery, bulk hardness, linear swell, and capillary suction time (CST). Secondary focus was on the performance from a qualitative fines control bottle test and accretion (S. Cliffe, S. Young, 2008). The proposed Shale Stabilizer Y was formulated with four distinct chemistries in water. Tests were run with Shale Stabilizer Y at a 3% v/v loading in tap water. Each individual chemistry, used to make up Shale Stabilizer Y, was tested side by side at equivalent activity loadings for relative performance as standalone products as indicated in the Methods and Materials section. The four individual chemistries were selected to perform different functions relative to shale stabilization on their own. For example, one component may be beneficial for controlling fines but not good enough at controlling reactivity.

Performance tests were conducted with Bentonite for linear swell, and the balance of the tests used Pierre Shale. The Pierre Shale, taken from outcrops, was chosen for its high clay content, which showed both dispersive and reactive clays.

The tests mentioned above are well known to practitioners within the industry. Bulk hardness and cuttings recovery provide a reference to how the rock properties of the formation are maintained after exposure to water-based fluids. Linear swell provides a reference to how the clays within the formation react when exposed to water-based fluids and is a measure of their swelling capacity. CST and fines control tests give a general picture of fines dispersion and control arising from formation exposure to water-based fluids. Accretion (S. Cliffe, S. Young, 2008) tests, on the other hand, give insight into how the shale stabilizer will help control dispersion and accretion of ball type clays found in formation mineralogy. In the following paragraphs we present a comparison of the results obtained with Shale Stabilizer Y and its individual components compared with tap water and 3% KCl.

The results from ***Cuttings Recovery,*** summarized in Figure 7, show how well the formation material, Pierre Shale, was protected by each stabilizer component. Each component present in Shale Stabilizer Y was tested individually at equivalent active loadings. While some of the components showed slightly better performance, such as the salted amine (71.8%), shale stabilizer Y performed competitively at 66.9% recovery. When compared to 3% KCl solution (34%) and the polymeric agent (1.3%), performance was substantially better.

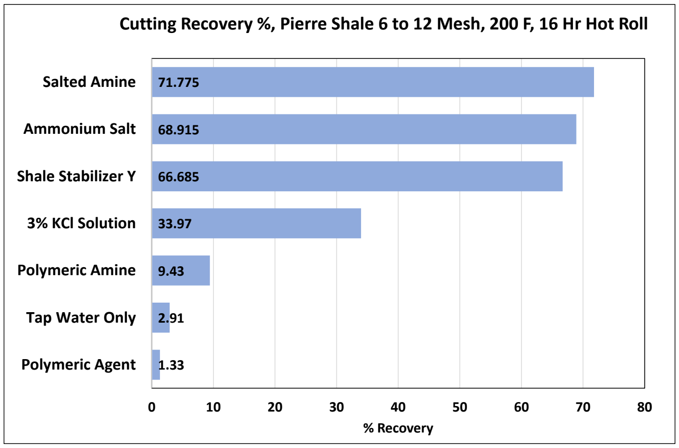

Figure 7: Results from Cutting Recovery tests.

Bulk Hardness results, shown in Figure 8, were complimentary to those seen in Cuttings Recovery. Bulk hardness was used as a measure of how well the rock properties of the Pierre Shale were maintained when using the shale stabilizers. Like cuttings recovery, it is desirable for the cuttings to remain as discreet particles while retaining their hardness. Shale Stabilizer Y showed to be comparable to the ammonium salt, and the benchmark 3% KCl. Performance of the polymeric agent, tap water, and polymeric amine lagged due to loss during hot roll, and extrusion of the cuttings before reaching 100-inch lbs. In the case of the polymeric agent, there were so few cuttings left that the piston of the bulk hardness tester nearly bottomed out on the slotted extrusion plate after only two turns.

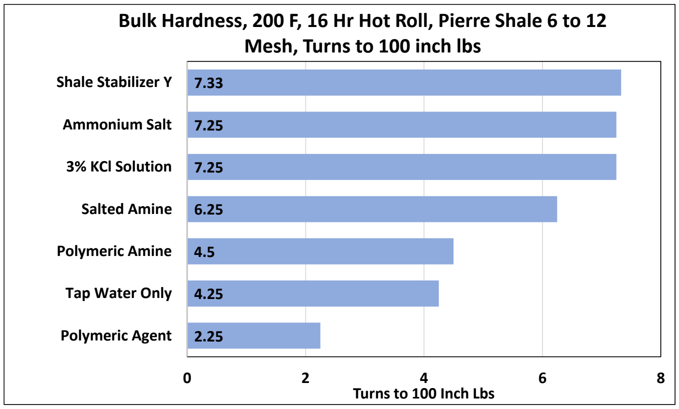

Figure 8: Cumulative results from all bulk hardness tests.

Example pictures, for reference, show an ideal puck like tablet formed from well stabilized cuttings and the extrusion of softened cuttings from inadequate stabilization of a failed test.

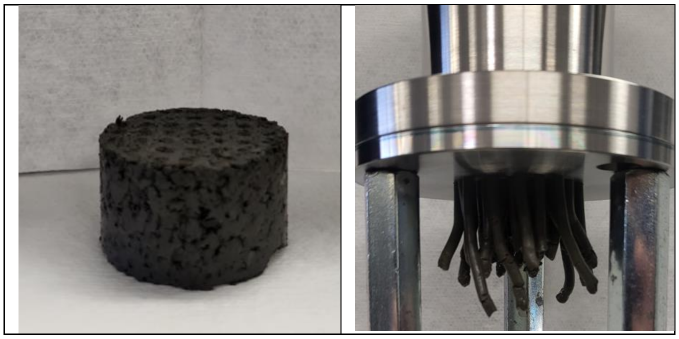

Figure 9: For reference: example pictures of an ideal result from bulk hardness on the left and a failed result right.

Linear Swell Meter results shown in Figure 10 for Shale Stabilizer Y show a slight reduction in swelling over 24 hours relative to the tap water only test. The amine-based compounds appeared to exacerbate swelling possibly due to their surfactant character helping to wet out the bentonite material. When used individually, the concentrations of each may need further optimization.

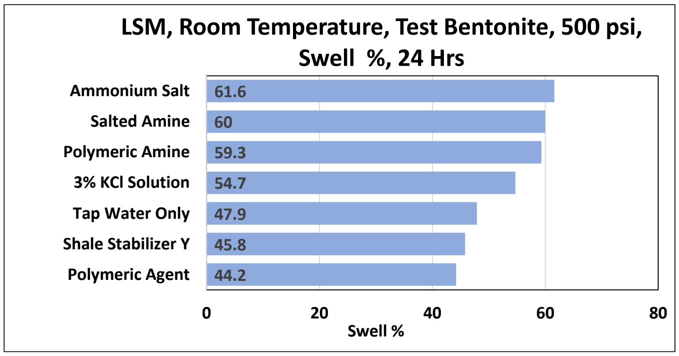

Figure 10: Linear swell meter results.

Fines control tests such as ***CST*** provide an insight into the coagulation properties of the stabilizing agent. Figure 11 shows good control of fines by most of the stabilizers tested. In this test, Shale Stabilizer Y somewhat lagged the individual components. Despite this, it still showed substantial gains in Capillary Suction Times when compared to the tap water blank. The Polymeric agent showed poor performance since it added viscosity to the solution and its functionality as a dispersant hindered it. Because of long CST times, the tests with the polymeric agent were stopped at 1000 seconds and reported as such. It is believed that the other tests such as Cuttings Recovery and Bulk Hardness better reflect the functionality of shale stabilizers while drilling.

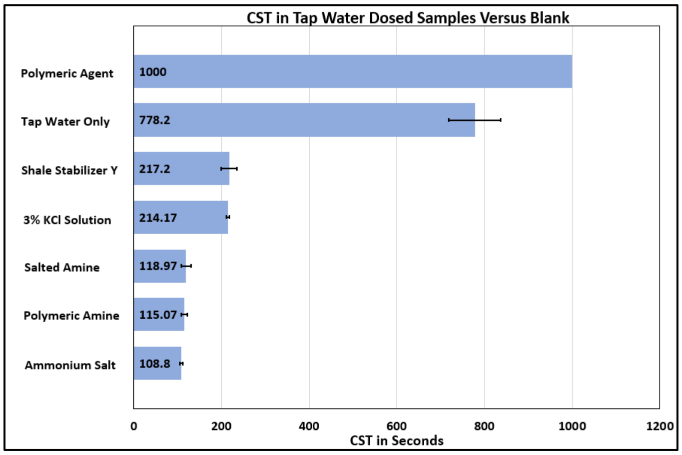

Figure 11: CST tests run comparing Shale Stabilizer Y to each component, 3% KCl benchmark, and blank.

Fines Control tests provide information about the coagulation properties of the stabilizing agents used. Although the bottle tests results shown in Table 4 tend to be more qualitative, they still give a good pictorial representation of the individual stabilizers potential ability to coagulate and rapidly drop out fines from the water column. Results in the tables below have been arranged to show the tap water blank, then in descending order based on performance. Shale Stabilizer Y performed well showing good coagulation of the fines followed by good settling of coagulated particles and was substantially better than the tap water only sample. The salted amine and ammonium salt samples also performed relatively well, while the polymeric types of stabilizers along with the KCl showed the poorest performance. The poor performance of the polymeric agent is attributed to its dispersant functionality and viscosifying effect that may enable fines to remain dispersed throughout the water column.

Table 4: Pictorial results from Fines Control Test.

Chemical	**Time**				
	0.5 min	**1 min**	**3 min**	**5 min**	**10 min**
Tap Water					
Shale Stabilizer Y					
Salted Amine					
Ammonium Salt					
Polymeric Amine					
3% KCl					
Polymeric Agent					

The ***Accretion*** results presented in Table 12 showed some nominal gains when Shale Stabilizer Y was added, but both muds performed well showing little accretion of the Arne Clay onto the carbon steel rod. If desired, adjustments can be made to the formulation to increase its capability respective to accretions problems. Accretion results can be seen in Tables 5 and 6 below. The accretion portion of the tests was limited to only Shale Stabilizer Y due to our limited ability to obtain Arne Clay. Future tests will be conducted with cuttings specific to the region in which the well is drilled and based on the mineralogy.

Table 5: Accretion results using water-based mud and Arne Clay.

Mud	**WC (g)**	**W1 (g)**	**W2 (g)**	**MC (%)**	**Accretion %**
Blank	**40**	**600.90**	**604.4**	**8.24**	**9.54**
With Shale Stabilizer Y 3%	**40**	**601.44**	**604.34**	**8.24**	**7.90**

Table 6: Images obtained before and after accretion.

Steel Rods Before	**Accretion After**
Rods Before Test	**Left Blank** **Right w/ Stabilizer Y**
	

For ***Water-based Mud Compatibility,*** a generic mud was used for testing which did not utilize any customer-based additives. During the development of the formulation special attention was paid to the activity and types of chemistry used to avoid compatibility issues with water-based muds. It is fully recognized that compatibility would have to be assessed based on the unique mud formulation to be used with Shale Stabilizer Y. Results, depicted in Table 7, showed minimal impact on the mud when Shale Stabilizer Y was added at 3% by volume. A slight reduction in YP was also observed.

Table 7: Results from water-based mud compatibility of Shale Stabilizer Y.

Rheology @ 120° F	Blank	With Shale Stabilizer Y at 3%
600 rpm DR	59.2	51.5
300 rpm DR	55.1	42.1
200 rpm DR	45.9	38.5
100 rpm DR	33.2	28.9
6 rpm DR	15.7	13.2
3 rpm DR	13.7	11.5
10 Sec. GS	14.1	12.4
10 Min. GS	18	14.9
PV (cp)	4.1	9.4
YP (lb./100 ft^2)	51	32.7

Results presented previously from the different testing methods showed that Shale Stabilizer Y had in general better comprehensive performance than any individual additive used in the formulation. Furthermore, it was shown that from bulk hardness and cuttings recovery, the Pierre Shale was able to maintain cohesiveness, while maintaining its presence as discreet well preserved rock particles. It needs to be mentioned that for the water-based mud compatibility a very general mud formulation was used. When formulating Shale Stabilizer Y, compatibility with a wide variety of mud formulations was kept in mind. It is recognized, however, that individual mud providers have their own formulations and further compatibility studies with unique mud systems would have to be tested on a case-by-case basis.

Conclusions

The proposed Shale Stabilizer Y was developed to meet the needs of water-based muds in a more ESG centered industry. Different chemistries, each with their own unique functionality, were combined to create a multifunctional stabilizer. Harsh performance tests utilizing fresh water as well as a highly reactive Pierre Shale were used to test the functionality of the proposed Shale Stabilizer Y

Shale Stabilizer Y showed consistent comprehensive performance when compared to the individual components also tested at equivalent loadings. Even though some tests, such as CST, showed some lagging of the new stabilizer, it still showed marked gains when compared to the freshwater blank. While it performed well in fines control tests, it more relevantly exceeded at cuttings erosion and bulk hardness. Accretion also showed some gains when using the new formulation. In addition, Water-Based Mud Compatibility tests demonstrated that Shale Stabilizer Y had minimal impact when added to the mud.

Based on all the results it is believed that Shale Stabilizer Y can help effectively stabilize water sensitive formations during drilling. While work on the current version has been completed, future work to refine and improve the formulation will be taken on as the product is tested against mineralogy from different formations. Further research will be conducted to enhance the different functionalities on an as needed basis.

Acknowledgments

I would like to acknowledge ChampionX for providing the necessary resources and time which made this research possible.

Nomenclature

Chl = Chlorite
CST = Capillary Suction Time
DI = De-Ionized
DR = Dial Reading
ESG = Environmental Social Governance
Fwk = Framework Silicates
Ill = Illite
Kao = Kaolinite
KCl = Potassium Chloride
LSM = Linear Swell Meter
Mic = Mica
ML I/S = Mixed Layer Illite Smectite
OBM = Oil-Based Mud
PV = Plastic Viscosity, cp
v/v = volume / volume
YP = Yield Point, lb/100 ft^2
GS = Gel Strength
WBM = Water-Based Mud

References

1. Allen D. Garrison., December 1939, "Surface Chemistry of Clays and Shales", Volume 132, Petroleum Development and Technology 1939, Petroleum Division Papers and Discussions Presented before the division at meeting held at San Antonio, October 5-7. https://doi.org/10.2118/939191-G
2. Chapter 3 - Clay stabilization, Editor(s): Johannes Fink, Petroleum Engineer's Guide to Oil Field Chemicals and Fluids (Second Edition), Gulf Professional Publishing, 2015, Pages 121-145, https://doi.org/10.1016/B978-0-12-803734-8.00003-5
3. M.J. Wilson, L. Wilson, "Clay Mineralogy and shale instability: an alternative conceptual analysis", Received: 15 March 2012, Mineralogical Society of Great Britain, and Ireland, https://doi.org/10.1180/claymin.2014.049.2.01
4. S. Cliffe, S. Young, "Agglomeration and Accretion of Drill Cuttings in Water-Based Fluids", AADE-08DF-HO-10, AADE 2008 Fluids Conference and Exhibition, Houston, TX, April 8-9, 2008, Available from www.aade.org
5. S. Mettath, E. Stamatakis, S. Young, G. De Stefano, "The Prevention and Cure of Bit Balling in Water-Based Drilling Fluids", AADE-11-NTCE-28, AADE 2011 Fluids Conference and Exhibition, Houston, TX, April 7-9, 2011, Available from www.aade.org
6. M. J. Wilson, L. Wilson, I. Patey; "The influence of individual clay minerals on formation damage of reservoir sandstones: a critical review with some new insights". Clay Minerals 2014;; 49 (2): 147–164. https://doi.org/10.1180/claymin.2014.049.2.02
7. Petrowiki, "Borehole Instability", Society of Petroleum Engineers, 2012-2024, Borehole instability - PetroWiki (spe.org), Accessed 01/30/2024
8. R.L. Anderson, I. Ratcliffe, H.C. Greenwell, P.A. Williams, S.

Cliffe, P.V. Coveney, Clay swelling — A challenge in the oilfield, Earth-Science Reviews, Volume 98, Issues 3–4, 2010, Pages 201-216, https://doi.org/10.1016/j.earscirev.2009.11.003