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High-Performance, Seawater-Based Drilling Fluid for High-Temperature Wells

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Abstract

High-performance, water-based fluids are particularly advantageous when compared to conventional water-based systems, as they offer faster penetration rates, enhanced hole cleaning and shale inhibition, and improved wellbore stability. The temperature stability of high-performance, water-based fluid systems is typically limited to 300°F owing to the use of biopolymers. To support operations in high-temperature environments, a new clay-free, seawater-based fluid that is stable in 400°F environments has been developed.

This new system exhibits good shale inhibition and is environmentally acceptable for offshore drilling. The use of a novel synthetic polymer that functions as both a viscosifier and a filtration-control agent enhanced the temperature stability of the fluid, allowing for the replacement of the biopolymers. The polymer functions well in seawater, which can help reduce water transportation costs.

This paper presents a detailed study of the seawater-based fluid formulated with 12.0–16.0-lb/gal densities and adequate suspension, shale stability, and filtration control. The fluid remains highly flowable at temperatures as low as 40°F and exhibits a stable rheological profile after exposure to 150 to 400°F aging conditions. For example, a 14.0-lb/gal formulation aged at 150°F for 16 hours gave a plastic viscosity of 33 cp and a yield point of 32 lb/100 ft^2; after static aging for 16 hours at 400°F, the plastic viscosity was 37 cp and the yield point was 32 lb/100 ft^2. The new formulation provides reliable thermal stability that can readily function in high-temperature wells, while preserving the benefits of high-performance, water-based drilling fluids.

Introduction

High-performance water-based muds (HP WBMs) offer a variety of advantages compared to conventional water-based muds, including improved shale stability, improved clay and cuttings inhibition, increased rate of penetration (ROP), reduced bit balling and accretion, torque and drag reduction, and high temperature stability (Rodriguez et al. 2010; Morton et al. 2005). However, HP WBMs have typically been limited to wells with temperatures up to 300°F. The temperature limitation for HP WBMs is largely due to the dependence on biopolymers, such as xanthan gum, starches, and modified cellulose, for both viscosity and filtration control. The biopolymer-based products used in the HP WBMs undergo thermal decomposition via fragmentation, hydrolysis, and oxidation (Seright and Henrici 1990).

Synthetic polymers have a greater propensity towards thermal stability owing to the presence of a carbon-carbon backbone, and significant efforts have been directed towards the development of synthetic-based viscosifiers and filtration-control agents (Perricone et al. 1986; Fernandez 2005). While significant progress has been made in the development of high-temperature stable viscosifiers and filtration-control agents, the products lack fluid suspension properties. Fluids that use synthetic polymers for viscosity and filtration control often rely on clays, such as bentonite, for suspension properties (Deville et al. 2011; Thaemlitz et al. 1999). The use of clay overcomes concerns of thermal decomposition, yet introduces the potential for thermal flocculation and gelation of the clay (Elward-Berry and Darby 1997). Moreover, the introduction of clays increases the colloidal content of the fluid, which reduces the ROP.

A new clay-free, high-temperature, high-performance, water-based mud (HT HP WBM) was recently developed (Galindo et al. 2015). The new HT HP WBM relies on a novel high-temperature (HT) polymer in place of biopolymers and clays. The work presented in this paper extends the use of the new HT polymer to seawater-based HT HP WBMs. Expanding the scope of the HT HP WBM can reduce water transportation cost and improve logistics, while also providing thermal stability up to 400°F.

Experimental

The HT HP WBM was formulated using a multimixer. The formulations were then conditioned by dynamically aging the fluid sample at 150°F for 16 hours. The conditioned fluids were then statically aged at 400°F under a nitrogen gas cap of 300 psi. The fluids were cooled to room temperature and stirred for 10 minutes with the multimixer. The aged fluid viscosity was determined with a direct-indicating viscometer, and the pH was determined with a pH meter. The fluid loss of each formulation was determined with LT/LP and HT/HP filtration according to the API recommended practice (API RP 13B-1 2014). The shear strength of the aged seawater formulations was determined using the shearometer tube according to the API recommended practice.

Results and Discussion

Temperature Stability

The use of a new high-temperature (HT) polymer improved the temperature stability of the HT HP WBM to 400°F, which is a significant improvement over the 300°F limitation imposed by the use of biopolymers (**Fig. 1**). The HT polymer was used in combination with the remaining system components, including water as the continuous phase, pH buffer for pH control, potassium chloride for shale stabilization, a rheology modifier and thinner for viscosity adjustment, and barite as the weighting agent. The HT polymer in the HT HP WBM formulation provided excellent viscosity and HT/HP filtration control in the fluid formulation both after hot rolling (AHR) and after static aging (ASA) conditions (**Fig. 2**).

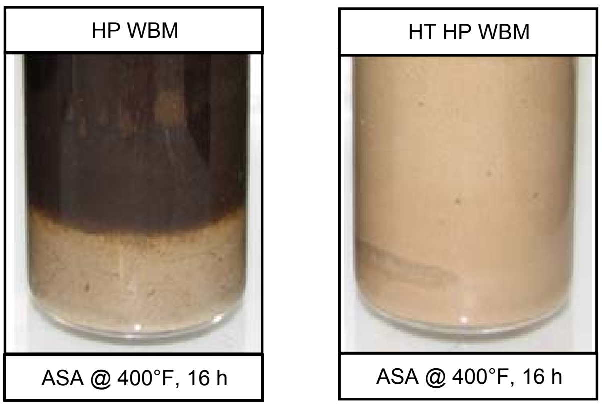

Fig. 1—Comparison of high-performance water-based muds

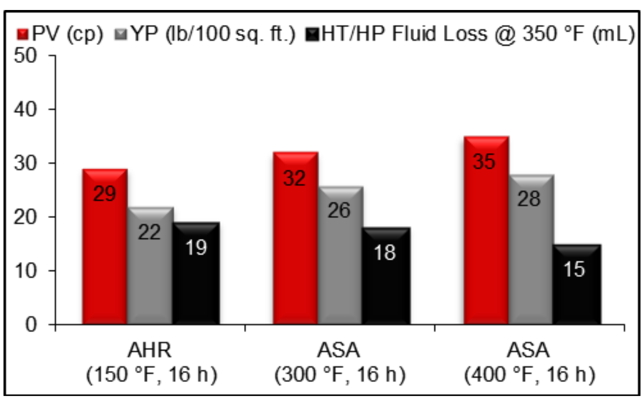

Fig. 2—Representative performance of 14.0-lb/gal HT HP WBM

The seawater-based HT HP WBM was formulated with densities ranging from 12.0 to 16.0 lb/gal (Table 1). The formulations were readily adjusted by increasing the quantities of the HT polymer and rheology modifier with increasing fluid density in conjunction with increased loadings of barite. The remaining system components include seawater as the continuous phase, pH buffer for pH control, and a thinner for viscosity adjustment.

Table 1—Representative Seawater Formulations

Density	12.0 lb/gal	14.0 lb/gal	16.0 lb/gal
Material	**Quantity**		
Seawater (bbl)	0.83	0.79	0.72
pH buffer (lb/bbl)	4.5	4.5	4.5
Rheology modifier (lb/bbl)	0.3	0.6	1.5
HT polymer (lb/bbl)	7.0	7.0	7.5
Thinner (lb/bbl)	1.5	1.5	3.0
Barite (lb/bbl)	191.9	311.0	421.0

The 12.0-lb/gal seawater-based HT HP WBM provided excellent viscosity and thermal stability before fluid conditioning and after static aging at 400°F for 16 hours (**Table 2**). For example, the 12.0-lb/gal formulation gave a plastic viscosity of 28 cp and a yield point of 25 lb/100 ft^2 before conditioning. After static aging at 400°F for 16 hours, the fluid viscosity remained stable with a plastic viscosity of 32 cp and a yield point of 31 lb/100 ft^2. The LT/LP fluid loss was 2.5 mL, and the HT/HP fluid loss at 350°F was 14.4 mL. The low-end rheology also remained relatively stable.

Table 2—Performance of 12.0-lb/gal Seawater Formulation

Dynamic Aging at °F for 16 h	—	150	—
Static Aging at °F for 16 h	**—**	**—**	**400**
Direct Indicating Viscometer Rheology			
Plastic viscosity (cp)	28	31	32
Yield point (lb/100 ft^2)	25	25	31
600 rev/min	81	87	95
300 rev/min	53	56	63
200 rev/min	43	46	51
100 rev/min	30	32	36
6 rev/min	11	12	13
3 rev/min	10	11	11
10 sec gel (lb/100 ft^2)	11	11	11
10 min gel (lb/100 ft^2)	14	12	12
Fluid Loss			
LT/LP fluid loss (mL)	—	—	2.5
HT/HP fluid loss @ 350°F (mL)	—	—	14.4

The density was increased to 14.0 lb/gal without consequence (**Table 3**). The seawater-based HT HP WBM remained stable before and after high-temperature aging. The 14.0-lb/gal formulation had a plastic viscosity of 33 cp and a yield point of 31 lb/100 ft^2 before aging. The viscosity was well maintained after fluid conditioning and static aging at 400°F for 16 hours, giving a plastic viscosity of 37 cp and a yield point of 32 lb/100 ft^2 with 2.0 mL and 16.4 mL of LT/LP and HT/HP fluid loss, respectively. The low shear readings remained high between 150°F and 400°F aging, which further signifies that the fluid retains suspension capabilities even after high temperature exposure.

Table 3—Performance of 14.0-lb/gal Seawater Formulation

Dynamic Aging at °F for 16 h	—	150	—
Static Aging at °F for 16 h	—	—	400
Direct Indicating Viscometer Rheology			
Plastic viscosity (cp)	33	34	37
Yield point (lb/100 ft^2)	31	30	32
600 rev/min	97	98	106
300 rev/min	64	64	69
200 rev/min	54	51	55
100 rev/min	37	35	37
6 rev/min	14	13	11
3 rev/min	13	11	10
10 sec gel (lb/100 ft^2)	13	12	10
10 min gel (lb/100 ft^2)	19	16	14
Fluid Loss			
LT/LP fluid loss (mL)	—	—	2.0
HT/HP fluid loss @ 350°F (mL)	—	—	16.4

Compared to the 12.0- and 14.0-lb/gal formulations, the performance of the 16.0-lb/gal seawater-based HT HP WBM was slightly reduced (**Table 4**). The fluid retained good plastic viscosity and yield point; however, the low shear readings were reduced, yet remained at serviceable levels. The HT/HP fluid loss at 350°F remained low, giving only 21.0 mL of fluid loss after 400°F aging.

Table 4—Performance of 16.0-lb/gal Seawater Formulation

Dynamic Aging at °F for 16 h	—	150	—
Static Aging at °F for 16 h	—	—	400
Direct Indicating Viscometer Rheology			
Plastic viscosity (cp)	47	41	38
Yield point (lb/100 ft^2)	37	29	19
600 rev/min	131	111	95
300 rev/min	84	70	57
200 rev/min	66	54	43
100 rev/min	43	35	27
6 rev/min	14	10	6
3 rev/min	12	9	5
10 sec gel (lb/100 ft^2)	13	9	5
10 min gel (lb/100 ft^2)	22	14	8
Fluid Loss			
LT/LP fluid loss (mL)	—	—	2.0
HT/HP fluid loss @ 350°F (mL)	—	—	21.0

The shear strengths of the seawater formulations were low (**Table 5**). The shear strength of the 12.0-lb/gal formulation was so low that a measureable value could not be obtained. Whereas, the shear strengths of the 14.0- and 16.0-lb/gal formulations were ≤ 10 lb/100 ft^2. The low shear strengths of the statically aged samples corresponds to the low gel strengths observed in the fluids that were mixed after aging, indicating that the gels are non-progressive even after high temperature exposure. This is in stark contrast to water-based muds that have shear strength values up to > 100 lb/100 ft^2.

Table 5—Shear Strength of Seawater Formulations

Density	12.0 lb/gal	14.0 lb/gal	16.0 lb/gal
Shear strength (lb/100 ft^2)	0	5	10

[a] Shear strength determined after sample was aged at 400°F for 16 h.

Low-Temperature Viscosity

It is crucial that the drilling fluid remains highly flowable while circulating, especially when passing through the riser during offshore drilling operations. The temperature of the drilling fluid may reach as low as 40°F when passing through the riser. The viscosity of a 14.0 lb/gal HT HP WBM was measured at 40, 77, and 120°F (**Table 6**). The plastic viscosity and viscosity increased with decreasing temperature, yet the low shear readings remained relatively consistent across the temperatures studied. Overall, the HT HP WBM remains flowable even at 40°F, giving a plastic viscosity of 65 cp and yield point of 47 lb/100 ft^2.

Table 6—14.0 lb/gal HT HP WBM Low-Temperature Rheology

Temperature (°F)	40	77	120
Direct Indicating Viscometer Rheology			
Plastic viscosity (cp)	65	45	36
Yield point (lb/100 ft^2)	47	36	35
600 rev/min	177	126	107
300 rev/min	112	81	71
200 rev/min	86	63	56
100 rev/min	56	42	39
6 rev/min	14	13	14
3 rev/min	12	12	13
10 sec gel (lb/100 ft^2)	12	12	14
10 min gel (lb/100 ft^2)	16	18	20

Environmental Compliance

Environmental testing was also conducted on the HT polymer. The HT polymer passed the ecotoxicity tests for the Gulf of Mexico and the North Sea (**Table 7**). The polymer also passed land toxicity tests. Thus, the HT polymer in the HT HP WBM is suitable for land and offshore drilling.

Bioassay Test	Species	HT Polymer
Gulf of Mexico	*A. bahia*	Passed
North Sea invertebrate	*A. tonsa*	Passed
North Sea fish	*C. variegatus*	Passed
North Sea algae	*S. costatum*	Passed

Conclusions

The following conclusions are drawn based on the laboratory test results:

- The HT polymer can be used both in land and offshore drilling operations, and the use of seawater as the continuous phase can significantly improve logistics when using a water-based drilling fluid.
- The HT HP WBM remains highly flowable even at temperatures as low as 40°F.
- The gel strengths remain non-progressive even after exposure to high-temperature static-aging conditions.
- The HT HP WBM provides excellent thermal stability with stable viscosity and HT/HP fluid loss after fluid conditioning to static aging at 400°F when formulated with seawater.

Acknowledgments

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