AADE-22-FTCE-021

New Rheological Duo System for HTHP Drilling

Brett Cramer and Rick Bennett, BYK USA

Copyright 2022, AADE

This paper was prepared for presentation at the 2022 AADE Fluids Technical Conference and Exhibition held at the Marriott Marquis, Houston, Texas, April 19-20, 2022. This conference is sponsored by the American Association of Drilling Engineers. The information presented in this paper does not reflect any position, claim or endorsement made or implied by the American Association of Drilling Engineers, their officers or members. Questions concerning the content of this paper should be directed to the individual(s) listed as author(s) of this work.

Abstract

High temperature, high pressure (HTHP) environments require drilling fluids with stable rheology through 400° F (204° C). Bentonite-based organoclays, which are the workhorses of the drilling industry, have rheology stability up to 350° F (177° C). This gap has created an unmet need in the industry. Mixed-mineral thixotropes (MMT) have been used traditionally to augment the low-end rheology of drilling fluids, in this study the technology has been applied to solving rheological challenges in HTHP conditions.
A rheology package was developed based on a MMT and a polymeric based liquid rheology modifier (PRM) which complement each other and maintain favorable 6-rpm and yield point values. This paper will present the rheological data after hot rolling 275° F (135° C) and 400° F (204° C).

The data presented in this paper will focus on 6-rpm dial readings, plastic viscosity, and yield point. The paper will additionally discuss the static sag results at 400° F (204° C) in the mineral oil system.

Introduction

High temperature, high pressure (HTHP) wells are drilled in conditions which push the boundaries of the drilling fluid system. These wells may be high temperature, high pressure, or both. This paper will focus on the rheological challenges associated with high temperature wells that exceed 350° F. For nonaqueous drilling fluids, organophilic clays are the main rheological additives providing rheology and suspension (Darley and Gray, 2013). Organo-bentonite products lose rheological properties above 350° F. The theories regarding why this occurs are beyond the scope of this paper. Until the advent of this new technology, organo-hectorite has been the product of choice with few alternatives.

In 2013 the American Petroleum Institute (API) published guidelines to define HTHP conditions. This was published as API TR 1PER15K-1 *Protocol for verification and validation of high-pressure high-temperature equipment*. Within this protocol high temperature is defined as having a flowing temperature greater than 350° F (177° C).

The rheology package is based on a novel MMT (Cornetto and Bennett 2019) plus a liquid PRM (Cornetto and Bennett 2019). MMT are organophilic, wet process clays comprised of combinations of platelet and rod minerals. Figure 1 shows a pictorial depiction of the difference between a standard organo-clay (left) and an MMT (right).

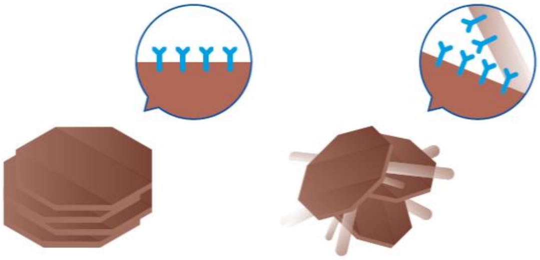


Figure 1: Difference between standard organo-clay and an MMT

The duo system, MMT plus PRM, complemented and balanced each other, maintaining a favorable and stable rheological profile for the test systems. The duo was tested in a mineral oil-based drilling mud and a Gas to Liquid (GTL) oil-based drilling fluid. The scope of this study was a proof of concept focusing on rheological stability in HTHP conditions. As such, the system was not optimized beyond the rheology package for the two test systems.

Testing Protocols

The test methods followed API RP 13B-2 API RP 13-B2 Recommended Practice for Field Testing of Oil-based Drilling Fluids. The rheology package was first evaluated for thermal stability based on systems rheological stability. The method involved the following:

1. The nonaqueous drilling fluids (NADF) were prepared with an overhead mixer for one hour. The fluid was homogenized on a Silverson mixer until the fluid’s temperature reached 150° F.
2. The fluid was transferred to a heating cup and tested with an Ofite 900 viscometer. The rheological properties were measured at 150° F.
3. The fluid was transferred to a stainless cell aging cell and pressurized.
4. The aging cells were placed in a pre-heated roller oven and at 275° F for 16 hours.
5. After rolling overnight, the aging cells were cooled to room temperature and depressurized.

6. The cells were opened, then mixed with moderate sheer for 10 minutes on an overhead mixer.
7. Rheology was taken at 150° F. The untreated fluids were then transferred back to the aging cells.
8. The cells were hot rolled at 400° F for 16 hours.
9. 5. After cooling the cells and mixing the muds, rheology taken again.

After verifying these NAFD systems maintained stable rheological properties through 400° F, we investigated their performance against weight-material sag (Zamora and Bell 2004; Zeng and Bouguetta 2016.) The NADF were prepared as previously described and static aged at 400° F for 24 and 72 hours respectively. The following method was used to determine how much sag occurred.

1. Transfer 350-ml fluid to a stainless-steel aging cell and pressurize to 300 psi nitrogen.
2. Cells were placed in a pre-heated oven in the vertical position.
3. Cells were removed after 24 or 72 hours and cooled undisturbed with a fan.
4. A glass beaker was tared and filled with 233 grams of deionized water. The meniscus level was marked on the beaker. This volume represents the top 2/3's of a 350 ml lab barrel.
5. The cells were depressurized before opening.
6. Free oil was removed by transfer pipette to a 25-ml graduated cylinder. Volume recorded, then transferred to the previously marked beaker.
7. Continued removing drilling fluid by spatula until the 233 ml volume is reached.
8. The remaining fluid in the cell (bottom third) was mixed under low mixing speed for 5 minutes.
9. Fluid was transferred by pipette to a 10-ml BYK-Gardener pycnometer and weighed.
10. All the fluid were combined into a mixing cup and mixed at low speed for 5 minutes.
11. Density of the re-combined fluid taken by pycnometer as before.

Equation 1

Δ Bottom, ppg = density of the bottom - density of the full mud

We found describing sag performance using Δ Bottom advantageous. The free oil is recorded, but not part of the calculation. Always removing the same amount of fluid (top 2/3) has fewer steps compared to taking the top, middle, and bottom layers. The calculation is intuitive; as the density increase (Δ Bottom) approaches zero, the fluid remains more homogenous.

Experiment

The following outlines the data from the mineral oil system (Formula 1), and the GTL oil system (Formula 2). Additionally, a 3-day static sag at 400° F was performed on Formula 1.

Formula 1: Mineral Oil

The test formula used for the mineral oil system is shown in the table 1. The system was a 14.0 ppg 80/20 nonaqueous drilling fluid (NADF).

Table 1: Mineral Oil Formula 1

Formula 1	
	lb/bbl
Mineral oil	**154**
MMT	**6**
Liquid PRM	**1**
Lime	**6**
Combination emulsifier	**8**
25% $CaCl_2$ brine	**65**
API barite, 4.1	**329**
Ocma clay	**20**

The rheology duo demonstrated exceptional rheology from 275° F through 400° F highlighted by the stable 6-rpm dial reading, plastic viscosity, and the yield point. The electrical stability remained above 500 volts demonstrating the emulsion stability remained stable through the testing range. Of note, the 600-rpm dial readings were likewise within acceptable ranges. The full rheology data is captured in Table 2 in the Appendix. The 6-rpm dial readings, plastic viscosity and yield point results are highlighted in Table 3 in the Appendix. Of note, the 6-rpm results were 8-11 over the temperature gradient and yield point was 8-12 lbs./100ft^2 over the temperature gradient with 600-rpm reading not exceeding 71.

Formula 2: GTL

The test formula used for the GTL based drilling fluid was formulated to match the mineral oil-based fluid so that a comparison could be easily accomplished. Formula 2 was matched to Formula 1, being a 14.0 ppg 80/20 nonaqueous drilling fluid. The test system formula is in Table 4.

Formula 2	lb/bbl
GTL fluid	**152**
MMT	**6**
Liquid PRM	**1**
Lime	**6**
Combination emulsifier	**8**
25% $CaCl_2$ brine	**65**
API barite, 4.1	**333**
Ocma clay	**20**

Table 2: GTL oil Formula 2

The rheology duo demonstrated comparable marked rheology from 275° F through 400° F as was in the mineral oil-based formula. This performance was highlighted by the stable 6-rpm dial reading, plastic viscosity, and the yield point. The full rheology data is captured in Table 5 in the Appendix. The 6-rpm dial readings, plastic viscosity and yield point are highlighted in table 6 in the Appendix. The 6-rpm reading at 400° F with the GTL fluid was 11 with a yield point of 14 lbs./100ft^2. In the GTL system the 600-rpm was 96.

Formula 1: Static Sag Performance

As noted, the base systems were optimized only for rheology. However, for a more comprehensive evaluation of the system, static sag was included in the workplan. A 3-day static sag was evaluated for the mineral oil formula (Formula 1). The acceptable value for this project was set to be less than 4 pounds per gallon.

The testing procedure was outlined in the testing protocol section of this paper. Due to the size of the tables, tables 7-9 are in the Appendix. The full set of rheological data for the MMT plus PRM is reported in table 7. In table 8, the static sag is captured, focusing on the 6-rpm dial readings, plastic viscosity, and yield point. The table shows the results over the 3 time periods at 400° F. The results demonstrate the yield point and 6-rpm were within acceptable values.

These results allowed for the calculation of the Δ bottom static sag calculation. The data is captured below in table 9. The MMT plus the PRM system had a consistent static sag of 3.57 pounds per gallon in the 1-day and 3-day evaluations. These results met the acceptable values we had targeted.

Conclusions

HTHP drilling conditions demand robust systems for successful, on-time drilling campaigns. This necessitates higher performing products to meet the challenges. The MMT matched with the high-temperature stable PRM focused on in this paper, met these needs. The combination of products provided a stable rheological profile throughout the HTHP temperature gradients with an inherently low 3-day static sag.

Acknowledgements

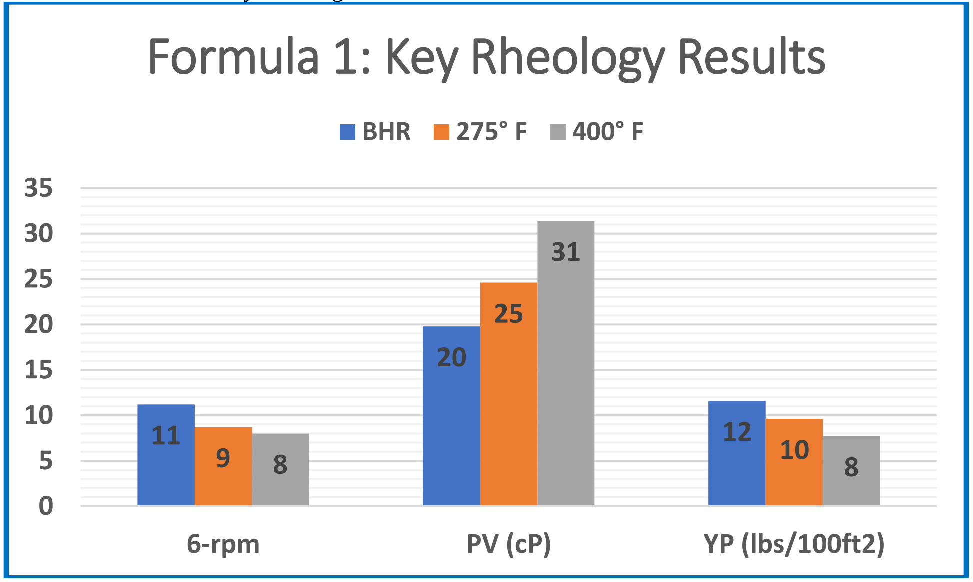
Thanks to AADE for permitting Byk the opportunity to share this technology. Thanks also to BYK USA for the opportunity to present.

Appendix

1. Table 2: Formula 1 rheological data set

	Dial reading at 150° F						cP	lbs/100ft^2			Volts
	600-rpm	**300-rpm**	**200-rpm**	**100-rpm**	**6-rpm**	**3-rpm**	**PV**	**YP**	**10" gel**	**10' gel**	**ES**
BHR	51	31	25	18	**11**	11	**20**	**12**	11	14	**473**
AHR @ 275° F	59	34	27	19	**8.7**	7.8	**25**	**10**	9	10	**548**
AHR @ 400° F	71	39	30	19	**8.0**	7.0	**31**	**8**	8	9	**529**

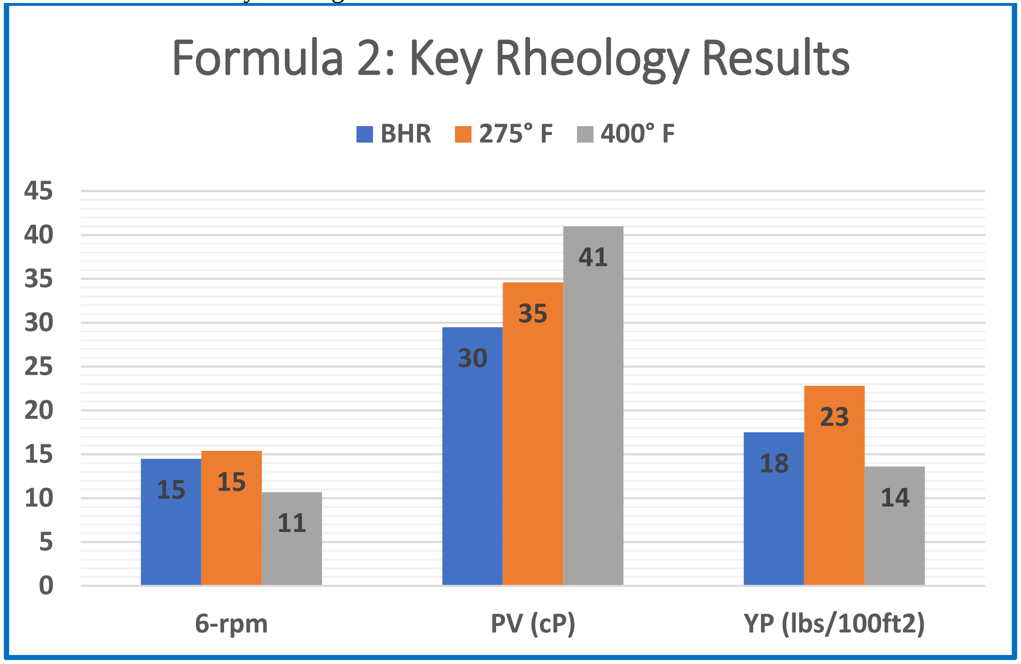
2. Table 3: Formula 1 key rheological results



3. Table 5: Formula 2 rheological data set

	Dial reading at 150° F						cP	lbs/100ft^2			Volts
	600-rpm	**300-rpm**	**200-rpm**	**100-rpm**	**6-rpm**	**3-rpm**	**PV**	**YP**	**10" gel**	**10' gel**	**ES**
BHR	77	47	37	28	**14.5**	14.0	**30**	**18**	15	19	716
AHR @ 275° F	92	57	45	32	**15.4**	14.7	**35**	**23**	16	22	880
AHR @ 400° F	96	55	40	27	**10.7**	9.9	**41**	**14**	11	12	387

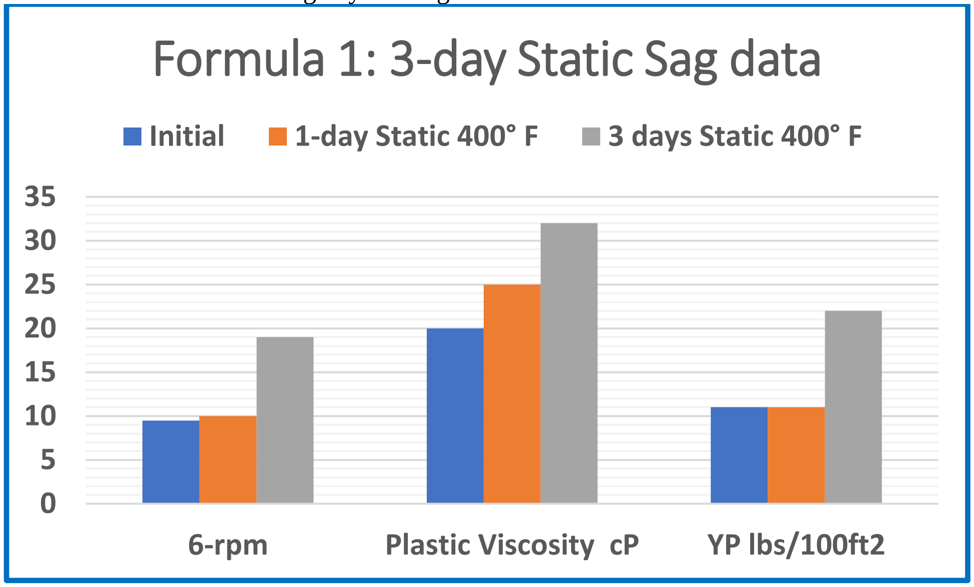
4. Table 6: Formula 2 key rheological results



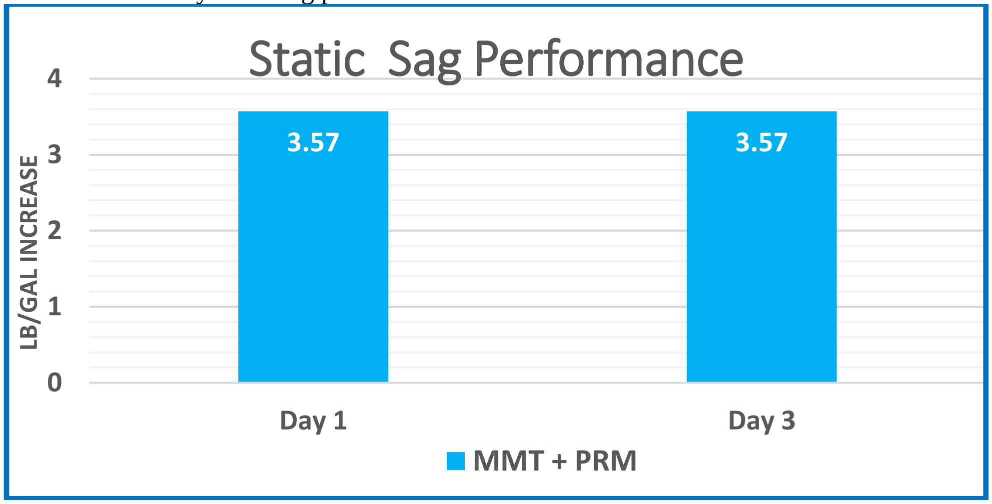
5. Table 7: 3-day static sag data Formula 1

400° F	Dial reading at 150° F						cP	Lbs./100ft^2			Volts
Static Sag	**600-rpm**	**300-rpm**	**200-rpm**	**100-rpm**	**6-rpm**	**3-rpm**	**PV**	**YP**	**10" gel**	**10' gel**	**ES**
Initial	**51**	**31**	**24**	**17**	**10**	**9**	**20**	**11**	**10**	**12**	**521**
16 hour	**60**	**36**	**26**	**18**	**10**	**10**	**25**	**11**	**12**	**17**	**589**
3 days	**87**	**55**	**44**	**33**	**19**	**18**	**32**	**22**	**18**	**20**	**710**

6. Table 8: Formula 1 static sag key rheological data



7. Table 9: 1 to 3-day static sag performance



References

1. Cornetto C., Bennett R.: “Mixed Mineral Thixotrope Suspension Aid in Oil-based Drilling Fluids for ECD Management”, AADE National Technical Conference, AADE-19 NTCE-028, Denver Colorado April 9-10, 2019.
2. Cornetto C., Bennett R.: “Polymers for Temperature Independent Viscosity”, AADE National Technical Conference, AADE-19 NTCE-013, Denver Colorado April 9-10, 2019.
3. Darley, H. C. H., Gray, G.R.: Composition and Properties of Drilling and Completion Fluids, 5th ed., Butterworth Heinemann. 1988.
4. Maghrabi, S., et al: “Making good HTHP Invert Emulsion Drilling Fluids Great and Green” AADE-13-FTCE-16, AADE National Technical Conference, Oklahoma City, February 26-27, 2013.
5. Zamora, M. Bell, R.: “Improving Wellsite Test for Monitoring Barite Sag” AADE Drilling Fluids Technical Conference, AADE-04-DF-HO-19, Houston, Texas April 6-7, 2004.
6. Zeng, W, Bouguetta: “A comparative assessment of barite sag evaluation methods” SPE 2016 Deepwater Drilling and Completions Conference, SPE-180348-MS Galveston, Texas 14-15 September 2016.