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Evaluations of Polyacrylamide Water Based Drilling Fluids for Horizontal Drilling in the Permian Basin

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Abstract

Permian Basin, located in eastern south New Mexico and West Texas, is treated as the largest province of oil and gas production in the U.S. The majority of hydrocarbon production from the Permian Basin is from Wolfcamp shally formation. Drilling horizontal and extended reached wells is continuously increasing day after day in the Permian Basin. There are some technical operational challenges related to increasing lateral section in the horizontal wells such as increasing of torque and drag, the requirement of high circulation rate for hole cleaning, the limitation in surface pump capacity due to the requirement of high circulation rate, and the increase of equivalent circulation density.

The objectives of this research are: (1) to show the capability of using polyacrylamide Anionic Friction Reducer (AFR) with Water Base Drilling Fluid (WBF) as a shale inhibition; (2) to present the effect of different mixing procedures of AFR on both drilling fluid rheological performance and shale inhibition; (3) to show the possibility of using formulated WBF with AFR as a lubricant and (4) to present the possibility of using new formulated WBF with AFR to replace oil based drilling fluids used to drill long lateral sections in the Permian Basin. Lab experiments were conducted to evaluate the performance of the formulated drilling fluid using zeta potential, shale dispersion, roller oven, and rheometer.

The obtained shale recovery from shale dispersion test is 95% when adding 18 pptg (0.72 lbm/ bbl) AFR to the formulated WBF at the end of mixing. It is proven that encapsulation is the shale inhibition mechanism of AFR. The results also reveal different mixing procedures of AFR with WBF affect both thermal stability of mud rheology and shale inhibition. Adding AFR after bentonite directly in the formulated WBF improve thermal stability of the fluid rheology better than adding AFR at the end of mixing in temperature range from 120 to 1800 F. The optimal concentration of AFR to be added after bentonite directly for better hole cleaning and thermal stability is 0.25 to 0.50 lbm/bbl.

Shale inhibition from the formulating WBF by adding AFR after bentonite directly is better than putting AFR at end of mixing as it decreased zeta potential value from -15 mV to -8 mV. The optimum concentration of AFR for shale inhibition is (0.25 lbm/ bbl) if AFR is put after bentonite directly with shale recovery of 98.6%. The torque reduction measured by the lubricity tester for the formulated WBF with 0.5 lbm/bbl AFR is 19% and 20% at 150 F and 180 F, respectively. The steadiness of coefficient of friction calculations with the temperature when using 0.5 lbm/bbl AFR with WBF is another proof of the thermal stability of the formulated WBF.

The formulated WBF with AFR can be used for a shale stabilization in the Permian Basin. Added AFR to WBF helps stability of shear stress versus shear rate with temperature range up to 1800F. Also, AFR cannot be considered as a lubricant additive in WBF. This study presents a promising WBF to replace oil based mud to drill lateral sections in the Permian Basin. This proposed approach is important for the oil and gas industry not only for cost effectiveness, but also to avail environmental concerns.

Introduction

The Permian Basin located in eastern south New Mexico and West Texas is treated as the largest province of oil and gas production in the U.S. with production beginning in 1921(Ward et al., 1986). The Permian Basin is said to be the most oil-productive basin in the US history (Dutton et al., 2005 and Flamm, 2008). The Wolfcamp Formation is the oldest rock layer which deposits in the Permian epoch. The wolf camp Formation is divided into four sections from top to bottom: Wolfcamp A, B, C, and D. The Wolfcamp formation consists of organic shale and carbonates with large amounts of clay minerals (US Energy Information Administration, 2018b). That is why the Wolfcamp shale formation is evaluated as the highest unconventional oil source in the United States. Horizontal wells with 5,000-10,000 ft. lateral length were drilled targeting Wolfcamp A, B, and D benches in 2011. This was followed in 2013 by horizontal wells targeting Wolfcamp Cand Spraberry shale formations (Blomquist, 2016).

Drilling horizontal and extended reached wells is continuously increasing day after day in the Permian Basin (Sharma et al., 2019). The lateral horizontal lengths create some operational obstacles during the operations of drilling such as torque and drag, or high friction, the need of high circulation rate for better hole cleaning, and limiting in surface pumping capacity due to the require of higher circulation rate. Increasing equivalent circulation density may be a result of increasing mud circulation rate which consequently leads to loss of circulation problem if exceeds the formation fracture pressure (Allahvirdizadeh, 2015). Enhancing drilling tools and formulation special drilling fluid were developed to overcome these drilling operation challenges. Oil Based Mud (OBM) was preferred over Water Based Drilling Fluid (WBF) to drill horizontal lateral sections due to its thermal stability of fluid rheology, stabilization of drilled shale formations, higher rate of penetration, and better lubricity (Willis et al., 2018). Conversely, WBF offers better control of loss of circulation problems, lower cost of the formulation mud barrel, better well control during gas kick, and accepted alternative based on the environmental regulations (Hamdan et al., 2020).

It is required to formulate new WBF to surpass the advantages of OBM or at the least have OBM’s advantages. By this way, formulate new WBF can replace the OBM in drilling Wolfcamp formation in the Permian Basin. We focus in this research on formulating new WBF with friction reducers. Friction reducers are high molecular weight additives used to reduce the frictional pressure losses by delaying transition zone between laminar and turbulent flow (Han et al., 2017). These additives may be surfactant or polymers. The oil industry preferred polymer over surfactant due to the need of higher surfactant concentration to initiate drag reduction (Woo Yang et al., 2014). The type of the friction reducer in this paper is anionic polyacrylamide. The polyacrylamide friction reducers are preferred among available polymers due to highest shear and thermal stability (Plank 1992). Sitaramaiah and Smith (1969) showed experimentally adding polyacrylamide, which had molecular weight of 4 to 6 million with concentration of 5 lbm/1000 gallons, to turbulent flow with corresponding shear rates from 20,000 to 30,000 S-1 helps maximize friction reduction.

The design of drilling fluid is one among factor that leads to drilling operation success. Better drilling fluid performance depends on thermal stability of rheological parameters. Based on shally lithology located in Wolfcamp formation in the Permian Basin, it is required to formulate WBF with high capability of shale inhibition. Because if the shale absorbs or interact with water, shale will swell and lead to wellbore instability (O’Brien and Chenever, 1973). Therefore, drilling shale formations with non-inhibitive WBF results in shale swelling which will cause stuck for drilling string (Bybee,1999).

High torque and drag becomes critical and obvious in drilling horizontal wells. This leads to excessive wear and heat to drilling tools. That is why one of drilling fluid functions is to cool and lubricate the drilling string. Improved lubrication enhances the drilling rate and decreases Coefficient of Friction(COF) (Foxenberg et al., 2008). COF is an indication of mechanical interaction between two surface (Veltman, 2008). COF is dimensionless number and defined as a ratio between frictional force to normal load force (Samuel, 2010).

The Objective

The OBM is used to drill horizontal wells in shally Wolfcamp formation in the Permian Basin. It is required to formulate new WBF to be environmentally friendly and have the same advantages of OBM.

The main objective of this research is to evaluate Water based Fluid (WBF) by using Anionic Friction Reducer (AFR) at optimal pH for enhancing:

1. Shale inhibition
2. Fluid Rheology
3. Thermal Stability
4. Lubrication
5. Capability to Replace oil based mud (OBM) in the Permian Basin

Experimental Preparation

Materials:

<u>The following chemical package was used to formulate the testing fluids:</u>

- Anionic FR (AFR): comprises of anionic acrylamide copolymers and surfactant in mineral oil base.
- Bentonite: used for the initial viscosity, suspension, and fluid loss control
- Starch, and PAC: provided fluid loss reducers
- KCl: salt used for shale inhibition purpose
- Xanthan Gum (XC) polymer: used to provide viscosity
- Soda Ash and caustic soda: Used to control water hardness, and pH, respectively
- Barite: used for controlling drilling fluid density

The standard WBF in this work means that it contains water, bentonite, caustic soda, soda ash, starch, PAC_L, KCl, and barite.

Experimental Apparatus:

The available equipment used in this research are mud mixer, OFITE 900 rheometer, roller oven, a Zeta potential analyzer (Anton Paar Litesizer), shale dispersion test and OFITE lubricity tester to test WBF with the AFR as shown in Fig.1. The pH meter was used to adjust the pH of the formulated WBF. The OFITE 900 rheometer measured automatically shear stress versus different shear speeds at different temperatures and ambient pressure. Roller oven was used to simulate the drilling fluid inside the well as drilling fluid sample was put in a cell and rotated in the oven at any specific temperature.

There are many used techniques to determine shale interaction with the drilling fluids. These techniques are zeta potential, linear swelling test, hot rolling dispersion test, capillary suction test, methylene blue test, and scanning electron microscope (Ahmed et al., 2019). Zeta potential and shale dispersion test are used in this study for study shale inhibition.

Anton Paar Litesizer was used to measure zeta potential by electrophoretic light scattering. The test samples were prepared by mixing chemical additives with water and their pH values were adjusted manually by using pH meter. The samples were then loaded in to an omega cuvette using an inversion method to avoid any trapped air bubbles. Kalliope software was used along with its library of solvent properties such as refractive index, viscosity and relative permittivity for analysis. Water was used as the solvent as it was the base fluid for all formulations. Samples were equilibrated for 3 mins at temperature range from 0 to 900 C and approximated using the Smoluchowski model with a Henry factor of 1.5 (Hiemenz, 1977).

Shale dispersion test is also known as cutting dispersion test. The clay cuttings are ground and sieved by 20-30 mesh screens. According to API recommendations, the weighted sieved clay cuttings are placed in the aging cell with the formulated drilling fluid in the roller oven for 16 hrs (API, 1997). Then shale cuttings are washed and recovered by sieve of 50 mesh. After that, the recovered shale cuttings are heated again in the roller oven for 3 hrs to make sure all water is evaporated. Finally, the recovered shale after heating over the original shale weight is indication of shale recovery percentage. Clearly, higher shale recovery means better shale fluid inhibitor (Jain et al., 2015).

The OFITE lubricity tester was used in this study to measure Coefficient of Friction(COF). In this lubricity tester, the test ring imitates the drill string, where test block simulates the drill hole wall. The torque arm is used to apply load in inch-pounds by test block against the ring. The Lubricity tester measures the frictional force needed to turn the shaft at a specific RPM in presence of drilling fluid. The American Petroleum Institute (API) mentioned the recommended standard conditions for testing lubricity of drilling fluids to be 150 inch-pounds load at 60 RPM (Ekunsanmi, 2012). The temperature was controlled by using thermo cup. Hence, obtaining meter reading of frictional force at a specific temperature become available and easy.

$$COF = \frac{Frictional\ force\ Meter\ Reading\ \times correction\ factor}{100} \qquad (1)$$

$$Correction\ factor = \frac{Standard\ Meter\ Reading\ for\ Deionized\ Water}{Meter\ Reading\ Obtained\ in\ Deionized\ Water\ Calibration}$$

$$Correction\ factor = \frac{34}{Meter\ Reading\ (32\ to\ 36)} \qquad (2)$$

$$Torque\ Reduction\ percentage(\%) = \frac{A - B}{A} \qquad (3)$$

Where

A: Torque reading of untreated mud

B: Torque reading of treated mud

Testing procedure:

The study in this research paper is based on experimental work. All experiments in this work were performed at pH from 8.5 to 9.5 for higher polymers performance and fluid stability (Metwally et al., 2022). The experiments in this paper consist of following steps:

Step 1: WBFs were mixed using the chemicals described in Table 1. Zeta potential measurements were conducted to determine the possibility to use AFR as shale inhibition with water drilling fluid.

Step 2: Determination shale inhibition mechanism based on using shale dispersion test. Shale dispersion test is performed for16 hrs. at 2500F by using Wolfcamp shale cuttings.

Step 3: Using low pressure rheometer (OFITE 900), and roller oven to identify the preferred mixing procedures based on stability of measured shear stress versus shear rate with temperature from 120 to 1800F. Study the effect of different mixing procedure of AFR with WBF on enhancing thermal stability of mud rheology, and shale inhibition.

Step 4: Studying improvement of shale recovery by using shale dispersion tests after determining the preferred mixing procedure.

Step 5: Calculating the COF and torque reduction by using lubricity tester measurements at 80°, 120°, 150°, and 180°F. The torque reduction calculations are based on measured torque of the formulated WBF with AFR in comparison with the formulated WBF without AFR.

Results and discussions

It is pivotal to use inhibitive WBF when drilling shale formations to prevent shale swelling. The zeta potential was used to test the capability of the formulated WBF with AFR as shale inhibitor according to Table 1. It is proved that zeta potential decreased from -39 to -15 mV when increasing AFR concentration from 14 to 18 pptg in the formulated WBF(Fig.2). The measured zeta potential became stable and flat with increasing AFR concentration over 18 pptg (0.72 lbm/bbl) (Mohamed et al., 2022). This decreasing in zeta potential is due to the attraction between negative carboxylate COO^- group on AFR to positive shale edge. The declining in Zeta potential below absolute value of 20 mV is a good indication for shale inhibition (Metwally et al., 2022).

The optimum concentration of AFR for shale inhibition is 18 pptg (0.72 lbm/bbl). Currently, it is needed to know the percentage of shale recovery by using shale dispersion test. Table 2 shows the formulated drilling fluids with and without AFR. Shale recovery of WBF without AFR is less than WBF with AFR as seen in Fig.3. Also, WBF with AFR and with KCl salt has the highest shale recovery (98.6%) as the COO^- negative group attracted to positive edge of the clay and this attraction prevented water from entering between clay particles. But, the author recommended to use AFR with KCl and this is because KCl works as another shale inhibitor by fixation mechanism

It is clear now that AFR enhances shale recovery and prevent shale from swelling. There are many mechanisms of shale inhibition. To know the specific mechanism for AFR as shale inhibitor in WBF, series of shale dispersion test were done. These series were based on firstly on using WBF with 18 pptg with specific weight of shale cuttings. Secondly the recovered shale was calculated and be used again in another dispersion test for new WBF with AFR concentration of 4 pptg. Thirdly, the recovered shale from previous step was calculated and be used again in another dispersion test for new WBF with a new AFR concentration. The Fourth step was to repeat step 3 for different AFR concentrations. The obtained results from these series of shale dispersion tests are illustrated in Fig.4. it is obvious that the recovered percentage of shale increased up to 99.6% with increasing AFR concentration up to 16 pptg. This means that AFR encapsulates the clay surface and prevent water to interact with clay. By this way, encapsulation is the main mechanism of shale inhibition by using AFR with WBF.

The shear stress of the formulated WBF with 18 pptg AFR (0.72 lbm/bbl) was measured at 120, 150, and 180^0F. The measured shear stress versus shear rate was illustrated in Fig.5. It is cleared that the fluid had shear thinning behavior and also, shear stress versus shear rate decreased with increasing temperature from 120 to 180^0 F. This means the formulated WBF with AFR can be degraded with raising temperature.

The formulated WBF with adding AFR at the end of mixing improved the shale inhibition but its rheology degraded with temperature. It is required to improve the AFR mixing procedures with WBF to enhance both shale inhibition and thermal stability of fluid rheology. The chemical engineering preferred that AFR should be mixed with fresh water firstly to obtain highest performance. While the mud engineers preferred bentonite to be mixed firstly to get highest hydration and better rheology. It is required to determine the optimal way for mixing AFR with the WBM. Table 3 shows the test matrix for proposed mixing AFR with drilling fluid for improving drilling fluid rheology. The main deference between fluid 1 and fluid 2 in table 3 is the way of mixing. Fluid 1 was prepared by adjusting PH and then adding AFR and after that adding bentonite and remain additives, while fluid 2 was prepared by adding bentonite and then adjusting PH and after that adding the remain additives as illustrated in table 3.

The measured shear stress versus shear rate for fluid 1 and fluid 2 at temperature 120, 150, and 180^0F were shown in Fig. 6 and Fig. 7. for both fluids with different way of mixing, the shear stress was increased with temperature increase. Fluid 1 had significant increase in shear stress at 180^0F and this resulted in rising apparent viscosity and consequently higher pressure loss. The measured Fluid 2 had higher thermal stability than fluid 1 as there was slightly difference in shear stress measurements.

Fluid 1 and fluid 2 were heated and rolled in the roller oven at 200^0F for 16 hrs and fluid rheology was measured by viscometer OFITE 900 and it was called fluid rheology After Hot Rolling (AHR). Fig. 8 clarifies the measured shear stress at different shear rates for both two fluids. Fluid 2 had less shear stress and apparent viscosity than fluid 1. Furthermore, zeta potential of fluid 2 was decreased with increasing temperature, while measured zeta potential of fluid 1 increased with increasing temperature as appeared in Fig 9. In the fluid 2, the attraction of AFR to the edge of clay or bentonite improved with increasing temperature. This means Fluid 2 is better for shale inhibition than fluid 1. The author recommended prepared WBF by adding bentonite firstly and secondly adding AFR directly and then adding the remain additives because of thermal stability of fluid rheology and better shale inhibition.

The optimal mixing procedure for using AFR with WBF is by adding AFR after bentonite directly at the optimal PH and then adding fluid loss reducers, XC polymer and KCl at the end. The target after knowing the optimal mixing procedures is to determine the optimum concentration for the used AFR. Three WBF samples with different AFR concentrations (0.25, 0.50, and 0.75 lbm/bbl respectively) were prepared by the optimal mixing procedures. The zeta potential was measured for the three WBF samples at different temperatures. The measured zeta potential for the three WBF with different concentrations were declined with increasing temperature as shown in Fig.10 and this means the COO^- on AFR is attracted to positive edge of bentonite. Also, WBF with 0.25 lbm/bbl AFR had the least measured zeta potential if it compared with WBFs with .50 and 0.75 lbm/bbl AFR. Furthermore, fluid rheology of the three formulated WBF with different AFR were measured at different temperatures.Fig.11 through Fig.13 illustrate the shear stress versus shear rate. It was obvious that measured shear stress increased with increased temperature and the reason behind that will be mentioned. Also, WBFs with 0.25 and 0.50 lbm/bbl had more thermal stability than WBF with 0.75lbm/bbl. Thermal stability was based on minor change in the measured shear stress with different temperatures.

According to Mud rheology, it is preferred yield point to be in the optimum range, plastic viscosity to be low as possible, and the Low Shear Yield Point (LSYP) to 1.2-hole diameter (Miswaco Drilling Manual, 2001). LSYP is pivotal for hole cleaning in the deviated or horizontal wells as it gives better carrying cutting capacity. It was shown in Fig.14 that WBFs with AFR with concentrations of 0.25 and 0.50 lbm/bbl had around the same yield point, plastic viscosity, and LSYP. For 8.5-inch hole size, the role of thumb for LSYP should be from 8 to 12 lbf/100 ft^2.Hence, WBFs with 0.25 and 0.50 lbm/bbl AFR had optimum LSYP for all temperature with lowest plastic viscosity. As a result, the optimum concentration for AFR to formulate WBF is (0.25 to 0.50) lbm/bbl to obtain better fluid rheology with thermal stability**.**

As mentioned, it noticed that shear stress and apparent viscosity increasing with increasing temperature. The supposed reason behind that is the interaction between AFR and bentonite. To know exactly this reason, two steps were done based on two mud samples preparation; first sample was prepared without AFR and second sample was prepared without bentonite as demonstrated in table 4. In the first step, the formulate WBF with AFR was compared with one without AFR. The shear stress of formulated WBF without AFR versus shear rate at different temperatures were measured and mentioned in Fig.15. it was found the measured shear stress declined with temperature increase when AFR was not added. When making comparison between Fig.12 and Fig.15, the only difference was the presence of AFR. Currently, it is obvious that interaction between AFR with bentonite is the reason behind increasing measured shear stress and apparent viscosity of the formulated WBF with the temperature.

According to second step, the fluid sample was prepared without adding to bentonite. In this step, the quantity of XC polymer was increased to obtain the same rheology like the one with bentonite. The results of measured shear stress versus shear rate at different temperature was shown in Fig.16. Noticeably, the dose of XC polymer was raised from 0.75 to 2.5 lbm/bbl to achieve the required rheology as WBF with bentonite. Also, the measured shear stress versus shear rate in Fig.16 was declined with rising temperature from 120 to 180^0F. Hence, the formulated WBF with AFR and without bentonite had less thermal stability than the formulated WBF with AFR and with bentonite. Undoubtedly, interaction between AFR with bentonite is the reason behind thermal stability of the formulated WBF.

The interaction between AFR with bentonite are based on attraction between anionic part of the polymer and the positive edge of the clay particles, hydrogen bonds between the surface hydroxyls and the C=O of the polymer, and electrostatic bridges between the anionic part of the polymer and the surface of the clay particles established by divalent ions. As shown in Fig.10, as the temperature increases, zeta potential decreased and this indicates the attraction force between COO^- negative group on AFR positive edge of bentonite increased. Also, hydrogen bonds improved with raising temperature. This attraction lead to thermal stability for the formulated WBF with bentonite and AFR.

Adding AFR after bentonite directly at optimal PH and then adding the remain additives help improve fluid rheology with thermal stability. Also, this way of mixing can improve shale inhibition. As Adding 0.25 lbm/bbl AFR after bentonite directly had zeta potential of -8 mV, while adding this amount of AFR at the end of mixing had -15 mV zeta potential. This means Adding 0.25 lbm/bbl AFR after bentonite directly is perfect for shale inhibition and decreases the required AFR for shale inhibition from 0.72 to 0.25 lbm/bbl. Furthermore, shale dispersion tests were done to determine percentage of shale recovery when using formulated WBF with 0.25 and 0.50 lbm/bbl of AFR. The obtained shale recovery was illustrated in Fig.17.The shale recovery were 98.7 and 99.7% when using AFR of .25, and 0.50 lbm/bbl, respectively. This indicates that Adding AFR after bentonite directly enhanced shale inhibition than adding AFR at the end of mixing as shown in Fig.18.Besides, this way of mixing and formulation WBF decrease the required amount of AFR to be used as a shale inhibitor.

During the drilling operation of horizontal well, there an increase in the torque because of mechanical friction between the drill string and hole. Therefore, mechanical friction plays a significant role in extend reach wells in comparison with vertical wells. Therefore, the lubricant additives are required to decrease torque when drilling long horizontal wells. Lubricants are chemical additives that form the thin film between contacted surfaces and this film is the responsible for decreasing wear and friction. COF is critical measurement to test the lubricity of any drilling fluid. In general, OBM has lower COF than WBF as the COF value for OBM is (0.16 to 0.20) and for WBF is (0.25 to 0.35) (Samuel, 2010). That is why it is pivotal that WBF should have a lower COF if it is require to be used in horizontal wells.

The measured COF of WBF with and without AFR at temperature range from 80° to 180°F is shown in Fig.19. It is appeared that COF of WBF without AFR increased from 0.32 to 0.4 with increasing temperature. This is due to degradation of its viscosity when raising temperature and becoming unable to form thin film to reduce friction. On the other hand, the formulated WBF with 0.25 and 0.50 lbm/bbl had constant COF value to be equal 0.3 and this value did not change with raising temperature. This means the thin film of WBF with (0.25 and 0.50 lbm/bbl) AFR is stable with increasing temperature up to 180 °F. When AFR concentration changed from 0.50 to 0.75 lbm/bbl in the WBF, there was slight increase in COF. This happened due to increasing viscosity of the WBF with 0.75 lbm/bbl and this results in increasing COF.

The torque reduction calculations of WBF with AFR using Equation 3 are illustrated in Fig.20. The WBF with 0.50 lbm/bbl AFR has the highest torque reduction amount of all concentrations at different temperatures. Adding 0.5 lbm/bbl to the Formulated WBF and decreased torque with 19% and 20% at 150° F and 180° F, respectively in comparison with WBF without AFR. It is clear that using WBF with AFR higher than 0.50 lbm/bbl leads to more friction and less torque reduction.

The new formulated WBF with AFR added after bentonite directly provides stable shear stress versus shear rate at temperature up to 180°F. This means that AFR helps in thermal stability of the fluid rheology. Also, when AFR is added to WBF, this prevents interaction between water and shale surface of Wolfcamp cuttings from the Permian Basin and also avoid swelling of these shale cuttings. This results in increasing shale recovery and stability of wellbore. Furthermore, AFR in WBF has stable thin film that increase torque reduction when temperature rise up to 180^{0}F. This will enhance rate of penetration. The formulated WBF with AFR has almost the advantages of OBM. Due to the environmental regulation for limiting the use of OBM, the new formulated WBF with AFR may be considered as a promising alternative to replace OBM in the Permian Basin.

Conclusion

This paper focused experimentally on investigating the ability of using AFR with WBF as a shale inhibition. Also, it concentrated on the preferred mixing procedures of AFR with WBF for enhancing mud Rheology with thermal stability, shale inhibition, torque reduction, and replacing oil based mud in Permian Basin. The following conclusions are drawn from the study:

- Encapsulation is the shale inhibition mechanism of AFR
- The preferred Mixing procedure of AFR in WBF is adding it directly after bentonite
- Adding AFR (0.25 - 0.50 lbm/bbl) after bentonite directly enhance thermal stability and mud rheology
- Shale inhibition of the formulating WBF by adding AFR after bentonite directly is 98.5% and 99% when using 0.25 and 0.5 lbm/bbl, respectively
- The Formulated WBF with 0.5 lbm/bbl enhanced the mud lubrication and decreased Torque with 19% and 20% at 150 F and 180 F, respectively
- The formulated WBF could be used to replace oil based drilling fluids when drilling long lateral sections

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Nomenclature

FR = Friction Reducer
WBF = Water Based Fluid
API =American Petroleum Institute
Ibm =Pound mass
Ibf =Pound force
YP =Yield Point
PV =Plastic Viscosity
LSYP =Low Shear Yield Point
XC =Xanthan gum
mV =millivolt
ml = millilitter
bbl = Barrel
pptg =Pound per thousand gallon
PAC =Polyanionic Cellulose
RPM =Revolution Per Minute

Conversions

Lbm/bbl = 0.04 x pptg
1/S = 1.703 x RPM

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Tables

Table 1: test matrix of using AFR in drilling fluid as a shale inhibitor (Metwally et al, 2022)

STEP 1			STEP 2		
pH(8.5-9.5)			pH(8.5-9.5)		
Additives	Quantities	Unit	Additives	Quantities	Unit
Water	350	ml	Water	350	ml
Bentonite	10	lbm/bbl	Bentonite	10	lbm/bbl
NaOH	0.5	lbm/bbl	NaOH	0.5	lbm/bbl
Starch	3	lbm/bbl	Starch	3	lbm/bbl
XC polymer	1	lbm/bbl	XC polymer	1	lbm/bbl
PAC-L	1	lbm/bbl	PAC-L	1	lbm/bbl
KCl	0	lbm/bbl	KCl	17.5	lbm/bbl
AFR	different	pptg	AFR	Different	pptg
Measuring zeta potential versus AFR concentrations			Measuring zeta potential versus AFR concentration		

Table 2: Test matrix of the formulated WBF with and without AFR

	Step 1	Step 2	Step 3	
	pH (8.5 – 9.5)	pH (8.5 – 9.5)	pH (8.5 – 9.5)	
Additives	Quantities	Quantities	Quantities	Unit
Water	350	350	350	ml
Bentonite	8	8	8	lbm/bbl
Soda ash	0.5	0.5	0.5	lbm/bbl
Caustic soda	0.3	0.3	0.3	lbm/bbl
Starch	3	3	3	lbm/bbl
KCl (Salt)	17.5	17.5	0	lbm/bbl
AFR	0	18	18	pptg
PAC-L	1	1	1	lbm/bbl
XC polymer	1.25	1.25	1.25	lbm/bbl

Table 3: New mixing procedures to formulated WBF with AFR.

Fluid 1			Fluid 2		
pH(8.5-9.5)			pH(8.5-9.5)		
Additives	Quantities	Unit	Additives	Quantities	Unit
Water	350	ml	Water	350	ml
NaOH	0.5	lbm/bbl	Bentonite	8	lbm/bbl
AFR	0.72	lbm/bbl	NaOH	0.5	lbm/bbl
Bentonite	8	lbm/bbl	AFR	0.72	lbm/bbl
Starch	3	lbm/bbl	Starch	3	lbm/bbl
PAC-L	1	lbm/bbl	PAC-L	1	lbm/bbl
XC polymer	0.75	lbm/bbl	XC polymer	0.75	lbm/bbl
KCl	17.5	lbm/bbl	KCl	17.5	lbm/bbl
Barite	As required	lbm/bbl	Barite	As required	lbm/bbl

Table 4: Test matrix for determination reason behind thermal stability of the new formulated WBF.

Step 1			Step 2		
pH(8.5-9.5)			pH(8.5-9.5)		
Additives	Quantities	Unit	Additives	Quantities	Unit
Water	350	ml	Water	350	ml
Bentonite	8	lbm /bbl	Bentonite	0	lbm /bbl
NaOH	0.5	lbm/bbl	NaOH	0.5	lbm/bbl
AFR	0	lbm/bbl	AFR	0.5	lbm/bbl
Starch	3	lbm/bbl	Starch	3	lbm/bbl
PAC-L	1	lbm/bbl	PAC-L	1	lbm/bbl
XC polymer	0.75	lbm/bbl	XC polymer	As required	lbm/bbl
KCl	17.5	lbm/bbl	KCl	17.5	lbm/bbl
Barite	As required	lbm/bbl	Barite	As required	lbm/bbl

Figures

Figure 1: Apparatuses used in this research paper

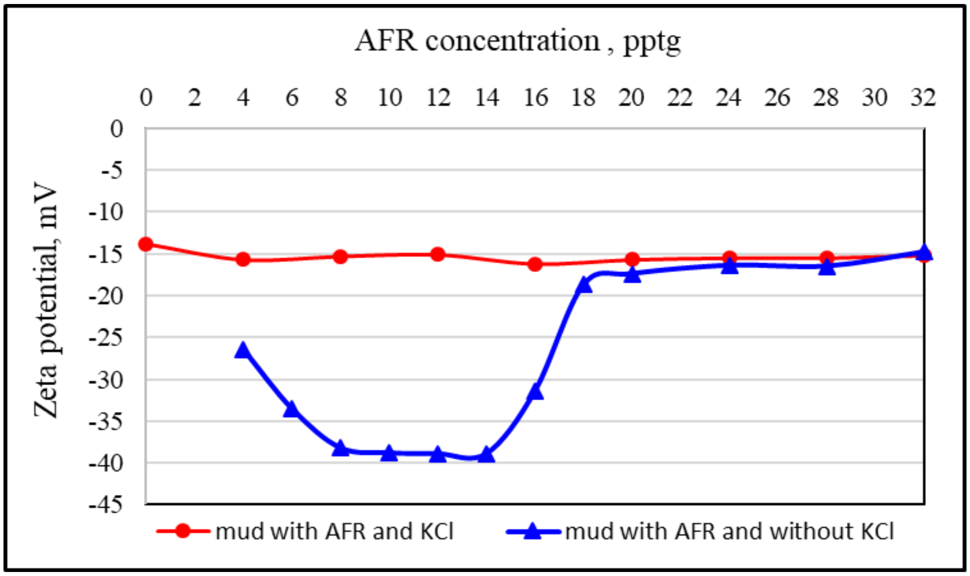

Figure 2: Zeta potential of the formulated drilling fluids with and without KCl salt at different AFR concentrations (Metwally et al, 2022)

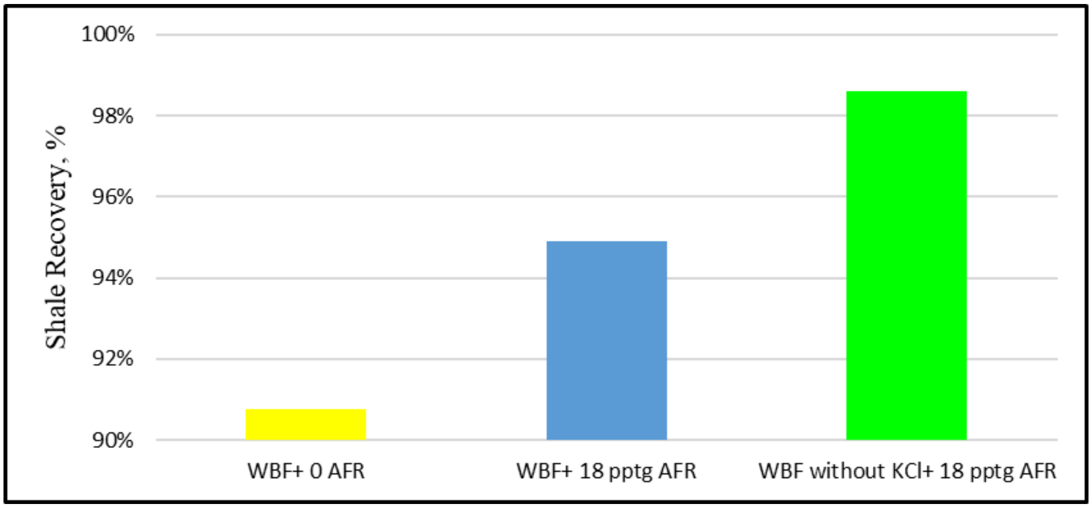

Figure 3: Results of shale dispersion test of the formulated drilling fluids

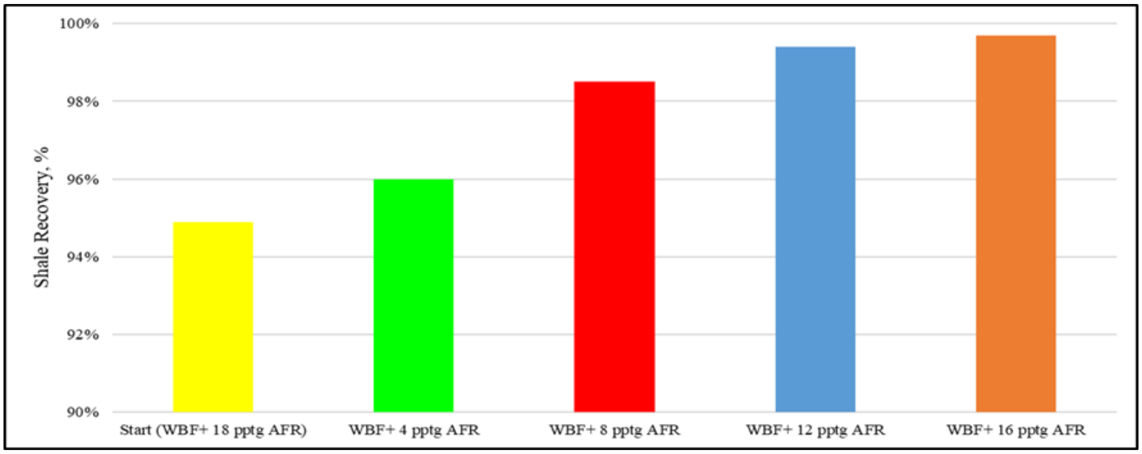

Figure 4: percentages of shale recovery from the formulated drilling fluid with different AFR concentrations

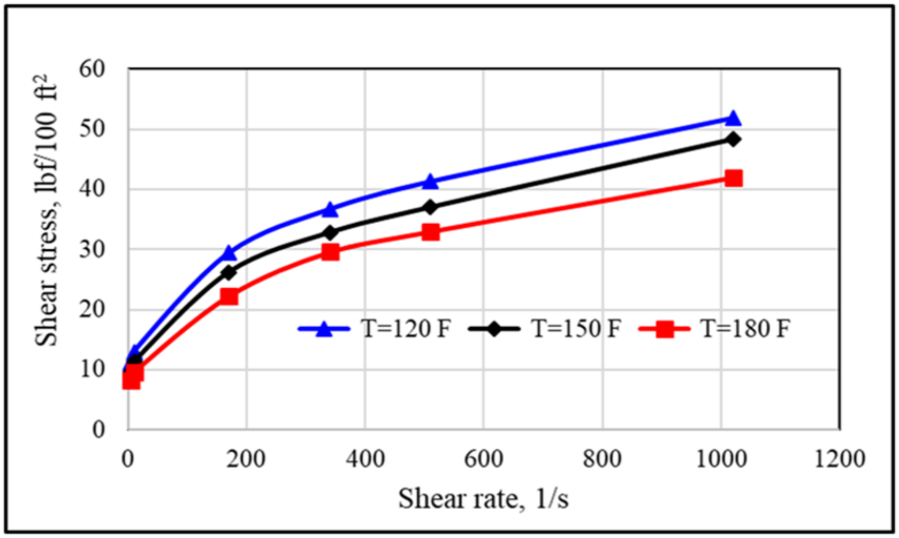

Figure 5: Shear stress of the formulated WBF with 18 pptg (0.72 lbm/bbl)

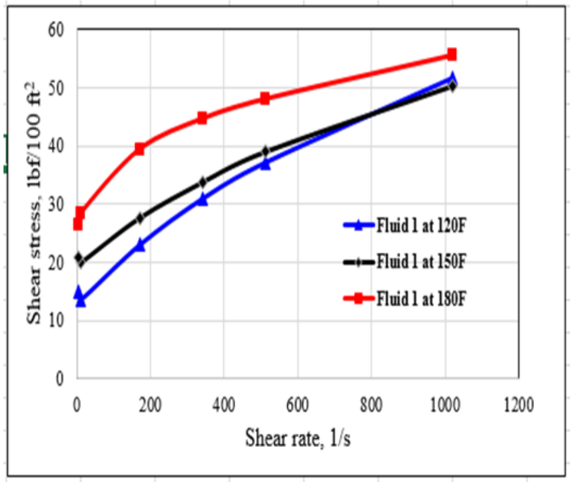

Figure 6: Shear stress vs. Shear rate of Drilling Fluid 1

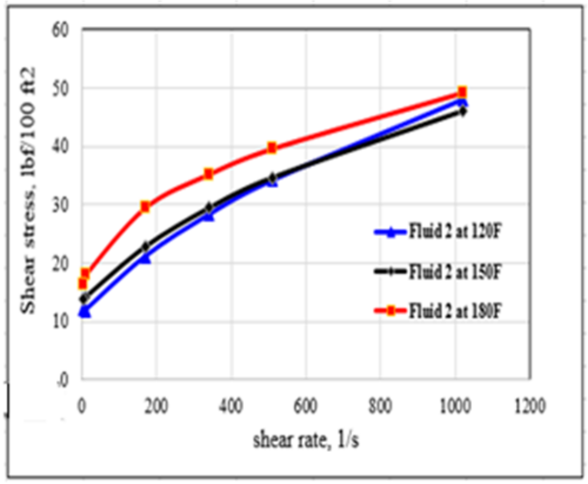

Figure 7: Shear stress vs. Shear rate of Drilling Fluid 2

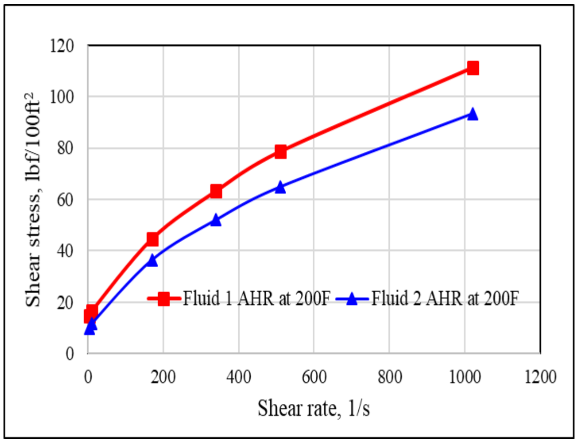

Figure 8: Fluid rheology AHR for Fluid 1 and Fluid 2

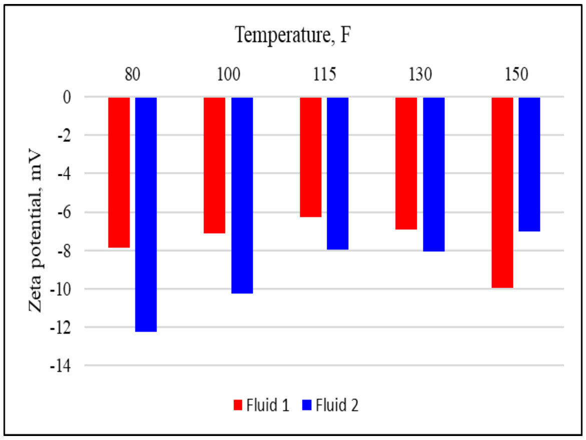

Figure 9: Zeta potential for Fluid 1 and Fluid 2

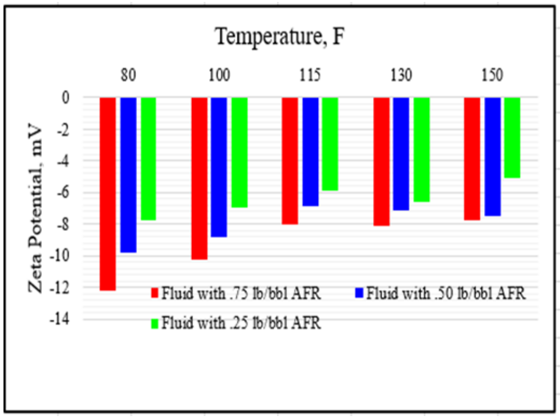

Figure 10: Zeta potential measurement for the formulated WBFs with different AFR concentrations

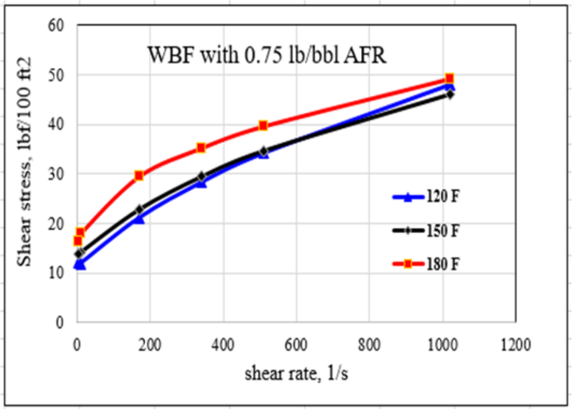

Figure 11: Shear stress vs. Shear rate of WBF with 0.75 lbm/bbl AFR

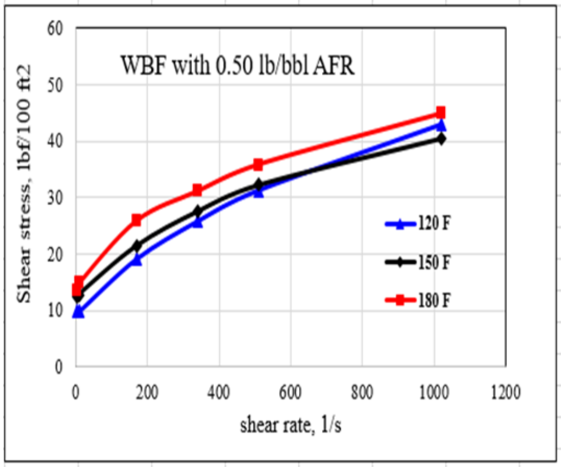

Figure 12: Shear stress vs. Shear rate of WBF with 0.50 lbm/bbl AFR

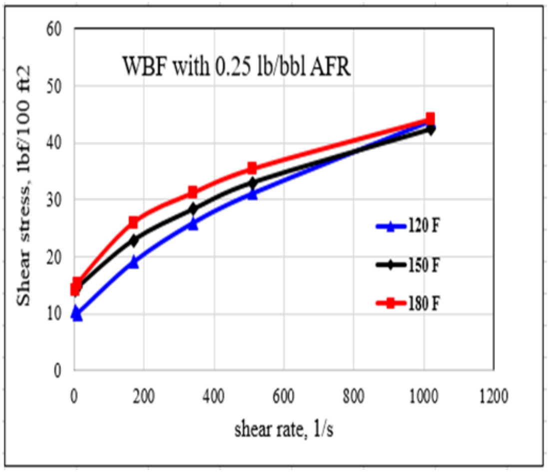

Figure 13: Shear stress vs. Shear rate of WBF with 0.25 lbm/bbl AFR

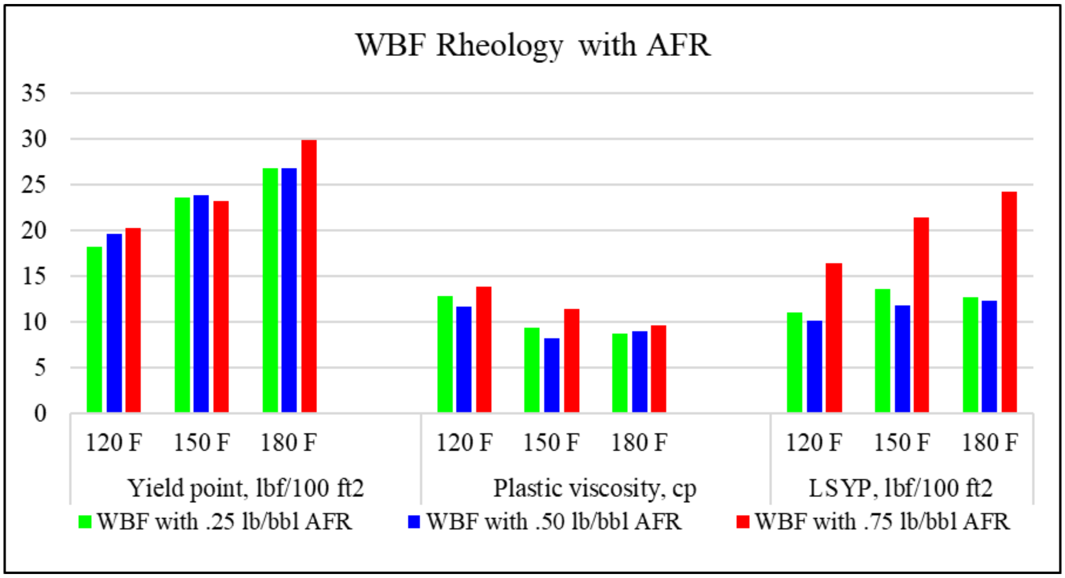

Figure 14: Yield point, plastic viscosity, and LSYP of the formulated WBF with different AFR concentrations

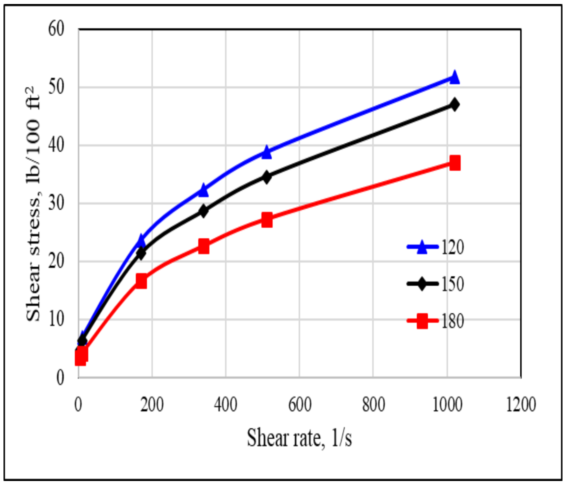

Figure 15: Shear stress vs. Shear rate of WBF of the formulated WBF without AFR

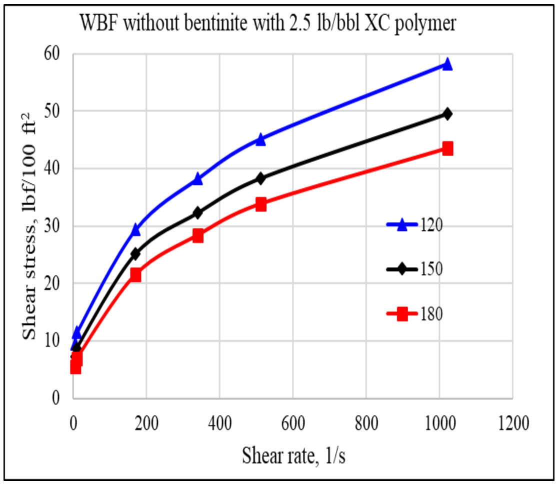

Figure 16: Shear stress vs. Shear rate of WBF of the formulated WBF without bentonite

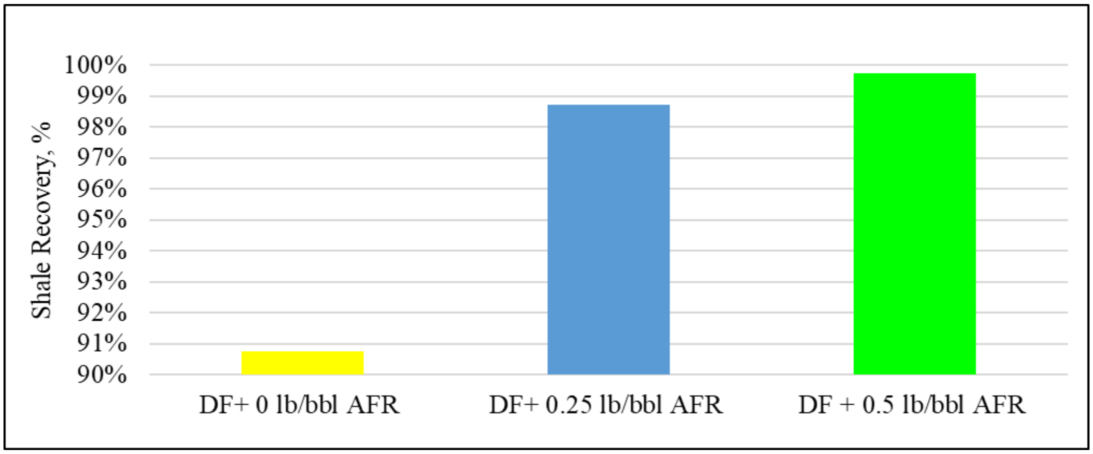

Figure 17: Shale dispersion test of formulated WBF with AFR

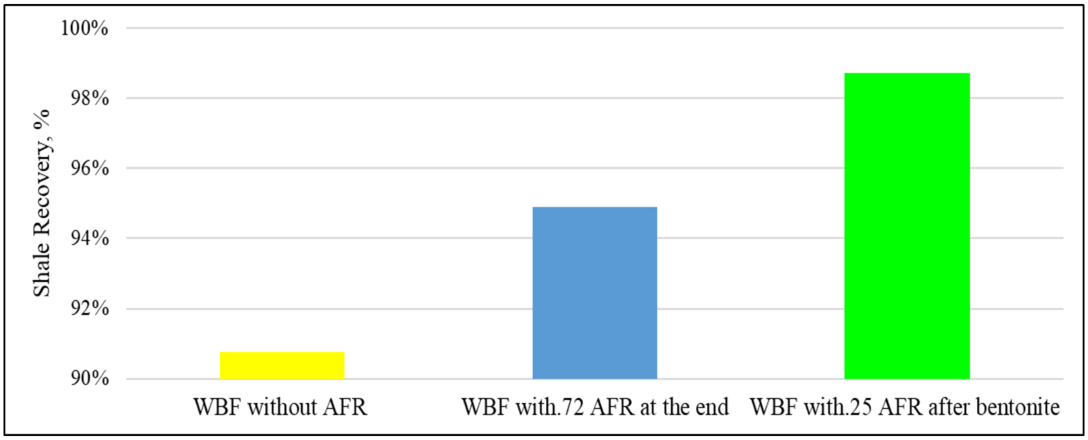

Figure 18: Shale recovery from WBF with different ways of mixing AFR

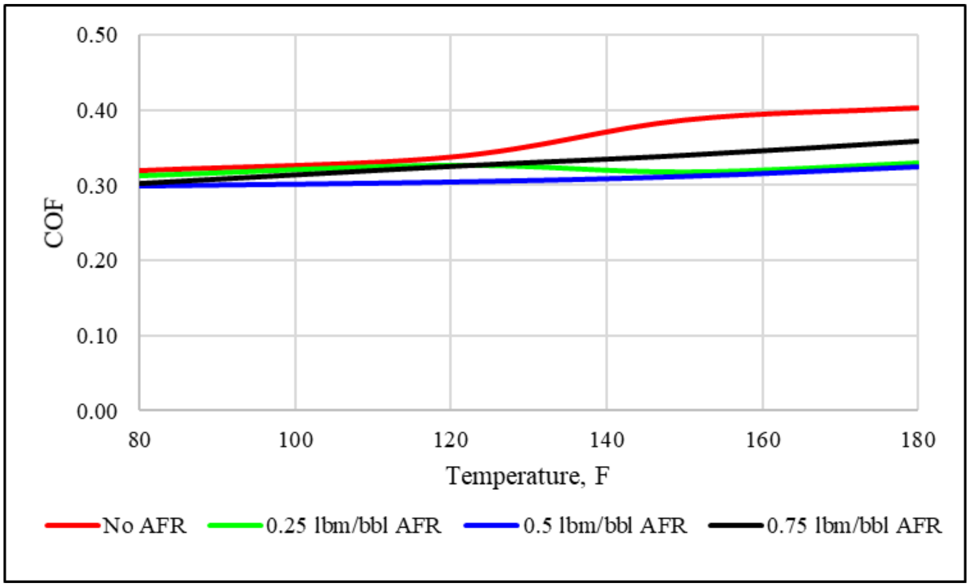

Figure 19: COF of the formulated WBF with and without AFR

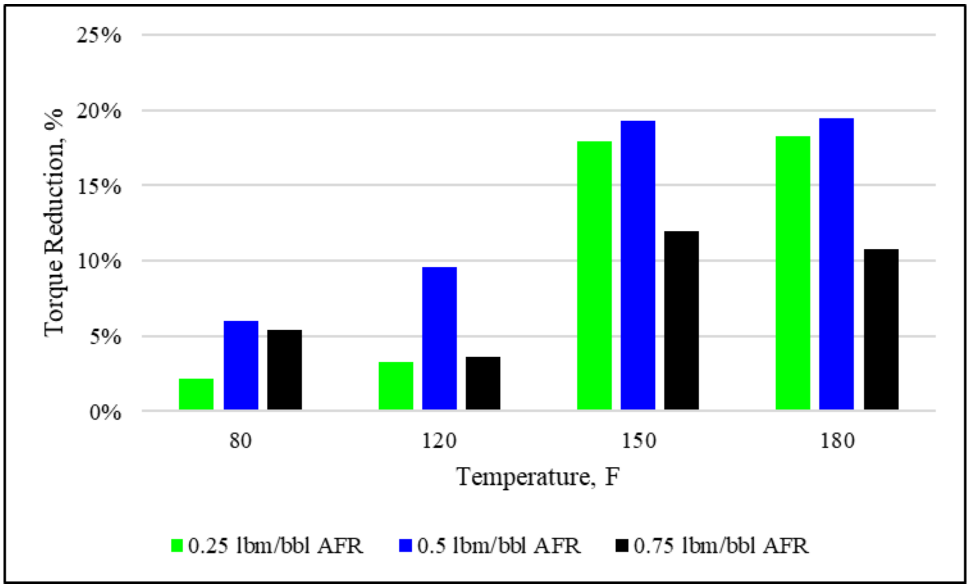

Figure 20: Torque reduction of the formulated WBF with and without AFR