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Experimental study on the use of locally produced ester-base fluids at the drilling of shale formation

AhmedWedam AHMED[1], Ekrem KALKAN[1*]

[1]Ataturk University, Faculty of Earth Sciences, Department of Geological Engineering, Oltu-Erzurum, Turkey

Abstract: *Drilling fluids play an important role in the successful drilling applications of oil and gas wells. This role of drilling fluid in oil exploration and exploitation activities is similar to the blood circulation in the human body according to the some researches. The most commonly used drilling fluids are water based fluids in the drilling applications. In this study, to investigate the performance of the ester-based drilling fluid in application of shale occurrence drilling was aimed. This study therefore was undertaken to evaluate the effect of different concentrations of shale occurrence on the rheological properties of ester-based drilling fluid. The fluids used in this study were XB1000 refined from waste cooking oil as ester-based fluid and diesel oil refined from petroleum as oil-based fluid. Within this scope, experimental studies were conducted to obtain some properties such as plastic viscosity, yield point, and gel strength. The results showed that plastic viscosity increased as solid percentage increased in both samples and insignificant shale swelling between the two oil mud fluids shows same tolerance level. Thus, the synthetic-based drilling fluids can be used as a suitable alternative to the oil-based drilling fluids to curb environmental pollution.*

Keywords: *Drilling, Drilling fluid, Ester-based fluid, waste cooking oil, XB1000*

1. Introduction

The drilling fluid, also called drilling mud, is a heavy, viscous fluid mixture used in oil and gasdrilling operations to carry rock cuttings to the surface and also to lubricate and cool the drill bit. The drilling mud, by hydrostatic pressure, also helps prevent the collapse of unstable strata into the borehole and the intrusion of water from water-bearing strata that may be encountered (Anon, 2014a). Three key factors usually determine the type of fluid selected for a specific formation such as cost, technical performance and environmental impact (Anon, 2014b; Ahmed et al., 2019).

Some researchers have gone as far as comparing the role played by drilling fluid in oil exploration and exploitation activities to that of the blood circulation in the human body. In this analogy, the fluid pump functions as the heart; the cuttings that are transferred from the borehole by drilling fluid represent the waste products excreted out of the body through the blood vessels, and the kidney and lungs function as the system for cleaning the mud (Al-Yasiri and Al-Sallami, 2015). It has been estimated that in oil exploratory and extraction activities, the cost of drilling operations is responsible for 50 to 80% of exploration finding costs, and about 30 to 70% of other field development costs (Khodja et al., 2010; Orji et al., 2016).

Drillers use specialised drilling fluids referred to as muds when drilling exploration and production oil and gas wells to help maintain well control and to remove drill cuttings from the drill hole (Burke and Veil, 1995). Recently, in response to the current global environmental challenges in addition to strict international and local regulations on drilling waste discharge requirements, the drilling industry has developed several types of synthetic based muds (SBMs) or synthetic based fluids (SBFs) that combine the desirable operating qualities of OBMs with the lower toxicity and environmental impact qualities of WBMs (Burke and Veil, 1995, Cobby and Craddock, 1999; Thomas, 2001; Chuma, 2011).

Drilling fluids are suspension of solids in either water or oil, which can be mixed with other substances, called additives (Apaleke et al., (2012).The principal functions of the drilling fluids are to: (1) carry cuttings from beneath the bit, transport them up the annulus, and permit their separation at the surface; (2) cool and clean the drilling bits; (3) reduce friction between the drilling string and the side of the hole; (4) maintain the stability of uncased sections of the borehole; (5) prevent inflow of fluids from permeable rocks penetrated; (6) form a thin, low permeable filter cake which seals pores and other openings in formations that penetrated by the bit, and (7) assist in the collection and interpretation of information available from drilling cuttings, cores and electrical logs(Apaleke et al., 2012, Hossain and Al-Majeed, 2015; Behnamanhar et al., 2014).

The formation which is water-sensitive may require oil-based fluid and synthetic-based fluid. A proper formulation of oil-based fluid can prevent water movement from the fluid into the shale occurrence. Despite of its effectiveness, oil-based fluid can give negative impact to environment when the pollutant is discharged and subsequently dispersed to the sea. The cuttings from oil-based fluid do not disperse as much as water-based fluid when it is discharged under water. It will form piles of cuttings that blanket parts of seabed. This condition may affect the bottom-dwelling organisms close to the rig (Seang et al., 2001; Yassin et a., 1991; Sauki et al., 2015).

Synthetic-based drilling fluids are a relatively new class of drilling muds that are particularly useful for deepwater and deviated hole drilling. They are a new class of materials used to provide safe and cost-effective technology for drilling oil and gas wells. Their enhanced drilling performance decreases drilling time and provides advantaged safety, human health, and, in some cases, environmental performance above diesel oil fluids. They were developed to provide an environmentally superior alternative to oil-based drilling fluids (Neff et al., 2000; American Chemistry Council (ACC), 2006).

The rheology of drilling fluid determines its effectiveness in drilling a well (El Fakharanyet al., 2017a). The effectiveness or the performance of the drilling fluid is measured by the capability of the fluid to accomplish its job. The prime use of the drilling fluid is to remove the formation cuttings within the well. The designed fluid should carry and suspend the cuttings while in circulation and transmitted securely through the annulus incurring minimum losses and environmental impact (Walker et al., 2016). The selection and formulation of the fluid is done by the mud engineer, who determines the required viscosity, density, fluid loss control, chemical composition and many other properties of the fluid (Bland et al., 2006). The selection of the type of the drilling fluid is based on three important factors; the cost, technical performance and the environmental impact of the fluid on the formation. The selection of the best suiting type is important as it defines the success of the drilling operation. In recent years, researchers have focused on formulating a biodegradable oil base-mud that would save on cost of disposal, and simultaneously have less of a negative impact on the environment (Hussein and Amin, 2010; El Fakharany et al., 2017b).

An experiment study of the effect of contaminants on the flow properties of oil based drilling by Olufemi and Olalekan (2011) deduced that a 0% drill cutting is allowed in the mud to maintain its viscosity and yield value while 5% drill cuttings are allowed to maintain its fluid loss properties. In addition, as drill cuttings are removed, the plastic viscosity decreases. Decrease in plastic viscosity will increase the low shear rate viscosity, which will bring larger, more easily removable cuttings to the surface. Vice versa; failure to bring cuttings to the surface while they are large enough to be removed by the equipment will increase the plastic viscosity. Weight percentages of oil on cuttings from different solids control equipment during the drilling of a North Sea well with oil base mud exhibited overall value below the UK regulatory limit of 150 g per 1 kg of cuttings, 15 % by weight, (Geehan and McKee, 1994).According to the literature records, the shale content of oil based mud system for shale can be different; depending on mud weight, low gravity solids content, temperature you may observe different behaviors (Gözel, 2015). The main parameter will be the particle size of the shale; smaller particle size distribution will have more effects on the mud properties since the rheology is a surface phenomenon. The general rule for shale content can be defined as maximum 7%.

The objectives of present study are to investigate the performance of locally produced ester-based fluid refined waste cooking oil in the presence of contaminants and compare with the performance of diesel oil refined from petroleum as oil-based fluid. To achieve these objectives some experimental studies were carried out under laboratory condition and the obtained results were discussed.

2. Experimental Procedure

The experimental study was carried out in the Petroleum Engineering Laboratory. In this study, electronic balance, Chandler Engineering Mixer 3060, viscometer (Chandler Engineering Model 3500), turbo hand mixer, measuring cylinder, beaker and spatula were used as laboratory equipment. An electronic balance is a device used to find accurate measurements of weight. It is used very commonly in laboratories for weighing chemicals to ensure a precise measurement of those chemicals for use in various experiments (Anon, 2015b). The Chandler Engineering Mixer 3060 was used in obtaining a uniform and homogeneous mixture of oil based fluids. These mixers are engineered to operate at constant speeds thereby mixing the slurry at an automatically maintained stable shear rate (Anon, 2011). The viscometer use in this study was Chandler Engineering Model 3500. A viscometer also called a viscosimeter is an instrument used to measure the viscosity of a fluid. This equipment was used in obtaining various dial readings at different rpms for plastic viscosity computation. For liquids with viscosities that vary with flow conditions an instrument, called rheometer is used. The viscometers only measure under one flow condition (Anon, 2015c).

The fluid was prepared to an oil-water ratio of 75/25. The base fluids (continuous phase) used are refined waste cooking oil (XB 1000) and Diesel Oil (DO) for comparison. Water was added as discontinuous phase, other mud additives are calcium chloride ($CaCl_2$), forming brine with water and acting as the internal phase of the emulsion (the emulsified phase). This was used for osmotic dehydration of water wet formation. The Primary emulsifiers and secondary emulsifiers and organophilic clay were added as well. The 10 oil mud samples were prepared using all the materials with different percentages of shale cuttings (Table 1).

The muds were mixed according to the procedures recommended by API. Turbo hand mixer was used to mix the two types of oil mud of different shale concentrations. A rotational viscometer was used to measure the rheological properties of mud samples at 600rpm, 300rpm, 200rpm, 100rpm, 6rpm and 3rpm as recommended by API to measure the rheological properties of drilling mud samples. The properties were measured at 120 ^oF at 0 hour of ageing, 16 hours of ageing, 32 hours of ageingand 48 hours of ageing.

Table 1. Formulation of Drilling Fluids

Additives	**XB1**	**XB2**	**XB3**	**XB4**	**XB5**	**DO1**	**DO2**	**DO3**	**DO4**	**DO5**
Specific Gravity, ppg	8	8	8	8	8	8	8	8	8	8
Oil, ml	245	245	245	245	245	245	245	245	245	245
Water, ml	70	70	70	70	70	70	70	70	70	70
Primary Emulsifier, ml	5	5	5	5	5	5	5	5	5	5
Secondary Emulsifier, ml	2	2	2	2	2	2	2	2	2	2
Lime, g	3	3	3	3	3	3	3	3	3	3
$CaCl_2$, g	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
Clay, g	2	2	2	2	2	2	2	2	2	2
Shale, %	5	10	15	20	25	5	10	15	20	25

The rotational viscometer was also used to measure the gel strength at 10 seconds and 10 minutes' gel strengths. The 10 seconds gel strength reading was taken at 3rpm after 10 seconds while the 10 minutes' gel strength reading was taken at 3rpm after 10 minutes. These were taken by recording the maximum deflection of the dial reading recorded.
There is the American Petroleum Institute (API) standard for drilling fluids rheology requirements (Table 2). API was formed in 1919 as a standards-setting organization and is the global leader in convening subject matter experts across segments to establish, maintain, and distribute consensus standards for the oil and gas industry.

Table 2. API (13B) specifications for oil-base drilling fluids (Darley and Gray, 1988; Mohammed, 2012)

Parameter	**Numerical Value Requirement**
Basic Oil Characteristics Requirements	
Flash Point	150 °F (66 °C)
Fire Point	200 °F (93 °C)
Aniline Point	140 °F (60 °C)
Fluid Properties	
Density	7.5 to over 22.0 (lb/gal)
Plastic Viscosity	< 65 (cP) or ALAP
Yield Point	15-45 (lb/100 ft^2))
PV/YP Ratio	0.8-1.5
Gel Strength 10 seconds	3-20 (lb/100 ft^2)
Gel Strength 10 minutes	8-30 (lb/100 ft^2)
Calcium Chloride	20-25 % by weight
Excess Lime	1-3 ppg
Electrical Stability	> 400 (volts)
HPHT Filtrate before rolling	10-25 Millilitres (ml)
HPHT Filtrate after rolling (350 ^oF -500 ^oF)	< 10 (ml/30 min)
API Fluid loss	15.0 ml (maximum)
Oil/Water Ratio	65/35 to 95/5
EPA Mysid Shrimp Test	30 000 ppm LC_{50} (minimum)
pH	8.5-10

3. Results and Discussion

The oil-based fluids prepared for this study were measured by using viscometer under laboratory conditions. The dial readings were carried out at 80 °F(room temperature) and at 120 °F for curing period of fluids at 0 hour, 16 hours, 32 hours and 48 hours. The results obtained for 0%, 5%, 10%, 15%, 20% and 25% of shale contents were illustrated in Tables 3-8, respectively.

Table 3. Viscometer Readings for 0% Shale Content in Oil-Base Fluids

Shale Content (0%)	XB1000				Diesel Oil			
	Dial Readings				Dial Readings			
	0 hours		16 hours		0 hours		16 hours	
RPM	80 °F	120 °F	80 °F	120 °F	80 °F	120 °F	80 °F	120 °F
600	60	46	60	46	60	35	60	35
300	37	25	37	25	35	20	35	20
200	25	18	25	18	27	15	27	15
100	15	10	15	10	15	10	15	10
6	5	4	5	4	6	5	6	5
3	3	3	3	3	5	3	5	3
10'	3	3	3	3	5	3	5	3
10"	5	4	5	4	6	5	6	5
PV	23	21	23	21	25	15	25	15
YP	14	4	14	4	10	5	10	5

RPM:

Table 4. Viscometer Readings for 5% Shale Content in Oil-Base Fluids

Shale Content (5%)	XB1					DO 1				
	Dial Readings					Dial Readings				
	16 hrs		32 hrs		48 hrs	16 hrs		32 hrs		48 hrs
RPM	80 °F	120 °F	80 °F	120 °F	120 °F	80 °F	120 °F	80 °F	120 °F	120 °F
600	70	45	70	45	50	61	42	65	50	50
300	37	25	38	20	29	36	25	37	28	27
200	27	17	28	15	21	28	20	26	19	20
100	16	10	16	10	13	19	13	15	12	12
6	5	4	5	4	4	9	6	4	4	4
3	4	3	4	3	3	8	5	3	3	3
10'	4	3	4	3		8	5	3	3	
10"	5	4	5	4		9	6	4	4	
PV	33	20	32	25	21	25	17	28	22	23
YP	4	5	6	-5	8	11	8	9	6	4

Table 5. Viscometer Readings for 10% Shale Content in Oil-Base Fluids

Shale Content (10%)	XB2					DO 2				
	Dial Readings					Dial Readings				
	16 hrs		32 hrs		48 hrs	16 hrs		32 hrs		48 hrs
RPM	80 °F	120 °F	80 °F	120 °F	120 °F	80 °F	120 °F	80 °F	120 °F	120 °F
600	75	50	75	58	60	60	40	65	50	55
300	42	25	42	32	35	35	23	37	32	30
200	31	17	31	22	24	25	18	26	23	23
100	18	10	18	13	15	15	12	16	13	15
6	5	4	5	4	5	5	5	5	4	5
3	4	3	4	3	4	4	4	4	3	4
10'	4	3	4	3		4	4	4	3	
10"	5	4	5	4		5	5	5	4	
PV	33	25	33	26	25	25	17	28	18	25
YP	9	0	9	6	10	10	6	9	14	5

Table 6. Viscometer Readings for 15 % Shale Contents in Oil-Base Fluids

Shale Content (15%)	XB3					DO 3				
	Dial Readings					Dial Readings				
	16 hrs		32 hrs		48 hrs	16 hrs		32 hrs		48 hrs
RPM	80 °F	120 °F	80 °F	120 °F	120 °F	80 °F	120 °F	80 °F	120 °F	120 °F
600	80	55	85	55	57	60	45	65	50	50
300	43	30	47	30	29	35	30	35	30	32
200	31	20	34	20	20	25	20	24	20	21
100	18	13	20	12	13	15	15	15	14	15
6	5	4	5	5	5	7	6	6	6	6
3	4	3	4	4	4	6	5	5	5	5
10'	4	3	4	4		6	5	5	5	
10"	5	4	5	5		7	6	6	6	
PV	37	25	38	25	28	25	15	30	20	18
YP	6	5	9	5	1	10	15	5	10	14

Table 7. Viscometer Readings for 20 % Shale Content in Oil-Base Fluids

Shale Content (20%)	XB4					DO 4				
	Dial Readings					Dial Readings				
	16 hrs		32 hrs		48 hrs	16 hrs		32 hrs		48 hrs
RPM	RT	120 °F	RT	120 °F	120 °F	RT	120 °F	RT	120 °F	120 °F
600	85	60	95	70	77	60	42	65	55	55
300	48	35	53	35	43	35	25	36	29	30
200	35	25	38	25	30	25	18	27	20	21
100	20	15	22	15	19	15	12	20	15	14
6	6	5	10	5	7	7	5	8	6	6
3	5	4	6	4	5	6	4	7	5	5
10'	6	4	6	5		6	4	7	5	
10"	7	5	11	7		7	5	9	6	
PV	37	25	42	35	34	25	17	29	26	25
YP	11	10	11	0	9	10	8	7	3	5

Table 8. Viscometer Readings for 25 % Shale Content in Oil-Base Fluids

Shale Content (25%)	XB5					DO 5				
	Dial Readings					Dial Readings				
	16 hrs		32 hrs		48 hrs	16 hrs		32 hrs		48 hrs
RPM	80 °F	120 °F	80 °F	120 °F	120 °F	80 °F	120 °F	80 °F	120 °F	120 °F
600	100	60	105	80	85	65	40	68	55	60
300	55	40	58	43	51	38	25	40	30	32
200	40	25	42	30	35	28	15	29	22	22
100	23	15	25	18	22	17	10	18	15	15
6	8	7	8	6	7	7	5	8	6	7
3	6	6	7	5	6	6	4	6	5	6
10'	8	7	7	6		6	4	6	5	
10"	9	8	8	7		7	5	9	6	
PV	45	20	47	37	34	27	15	28	25	28
YP	10	20	11	6	17	11	10	12	5	4

From Tables 3 to 8, similar rheological dial readings were observed for both XB1000 and DO. This may be as a result of increasing shale particles content, increasing the solids concentration therefore increasing the resistance to flow. The low dial readings from the initial prepared mud with shale contaminates may prove that the shale might be one of a hard one. An experiment conducted by Chenevert and Osisanya (1989), on swelling tests of native shales showed that, hard shale swells to a total value of 2 % after about 400 minutes and remains intact while the soft shale fails in 10 minutes after it swells to 0.75 % using fresh water as reference fluid.

It was shown from Tables 5 and 6 that the same trend with slight increase in dial reading at 32 hours of curing period. The minimal increase in dial readings compare to the 16 hours curing period may be due to minimal solid break down or geothermal expansion of the shale particles increasing the surface area thus increased dial readings.

In the Tables 7 and 8 for curing period of samples at 48 hours exhibited same characteristics of increasing dial reading as RPM increased, but insignificant shale swelling as well for both oil fluid samples. The maximum percentage of the shale allowed in a typical non aqueous drilling fluid is to help control or to maintain the weight of the fluid in carrying cuttings up and not because it (shale) has a swelling factor in the oil base fluids as reported byOlufemi and Olalekan (2011) and Geehan and McKee (1994). This behaviour was confirmed in the results obtained for both XB1000 and DO.

The graphs of plastic viscosity and yield point for the various oil samples were compared in Figs.1and for curing period of samples at 16 hours, 32 hours and 48 hours, respectively. All temperatures were taken at 120 ^{o}F with the help of an electrically controlled thermos-cup.

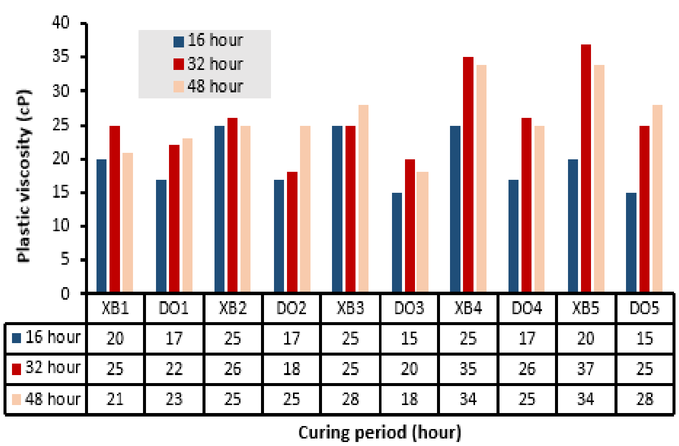

Fig. 1. The effect of curing period on the plastic viscosity at 120 ^{o}F

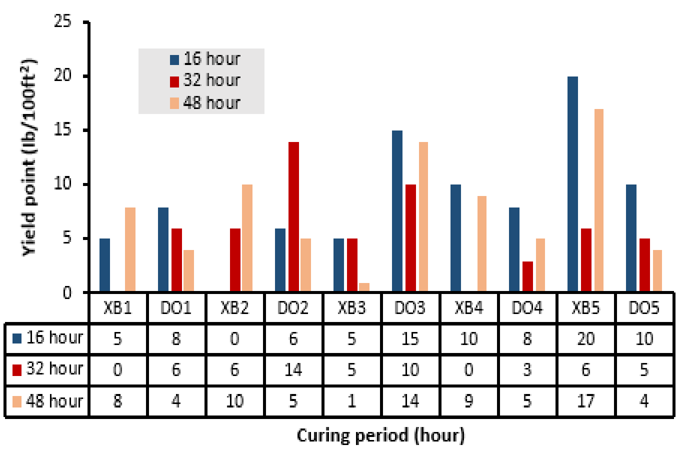

Fig. 2. The effect of curing period on the yield point at 120 ^{o}F

It is seen from Fig. 1that, the plastic viscosities for XB increased steadily as the shale percentage increased, stabilised from XB2 (10 % shale cuttings) to XB4 (20 % shale cuttings) and then finally dropped at XB5 (25 % shale cuttings). This steady and constant value for plastic viscosity shows the insignificant swelling of the shale and only showed the increased in plastic viscosity as a result of increase in solid concentration. The API standard for the plastic viscosity for an oil-based fluid is less than 65cP and thus all fluid samples passed the test.

It is seen from Fig. 2that, the yield point also increased from X3 to XB5 after a drop at XB2. The yield point exhibited an increase in that trend as solid particles increased. On the contrary, all samples did not meet the range for the API specification for yield point of 15-45 lb/100ft^2. The values were not high because there were no any soluble contaminants such as salt or anhydrite to increase the force of attraction between the clay particles; also the absence of barite in the system resulted in decreased yield points.

At the same shale percentages for 32 hours and 48 hours of curing period shows an increased plastic viscosity which was as result of decreased shale sizes increasing surface area, which increased the frictional drag.
Both oil-base fluids depicted the same tolerance characteristics to shale swelling. They both satisfied the required API standard for plastic viscosity which is less than 65 cp, but without a weighting agent inclusive. This gives an idea that, even though shale swelling is insignificant in oil based fluids, their tolerance to carry cuttings up from the subsurface limits the shale contaminants to a max range of 5 % to about 11 % depending on the type of shale and solids contents present in the oil-base fluid.

4. Conclusion

In this study, performance of the ester-based drilling fluid in application of shale occurrence drilling was investigated. This study therefore was undertaken to evaluate the effect of different concentrations of shale occurrence on the rheological properties of ester-based drilling fluid. According to the obtained results, the both of oil-base fluids depicted the same tolerance characteristics to shale swelling. They satisfiedthe required API standard for plastic viscosity which is less than 65 cP, but without a weighting agent inclusive. At the end of the research, it was obtained that plastic viscosity increased as shale percentage increased in both samples and insignificant shale swelling between the two oil-based fluids showed same tolerance level.

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