DOI: https://dx.doi.org/10.4314/gjpas.v25i1.6

GLOBAL JOURNAL OF PURE AND APPLIED SCIENCES VOL. 25, 2019: 39-44
COPYRIGHT© BACHUDO SCIENCE CO. LTD PRINTED IN NIGERIA ISSN 1118-0579
www.globaljournalseries.com, Email: info@globaljournalseries.com

RHEOLOGICAL PROPERTIES OF SOME OIL BASED MUDS USED IN RESERVOIRS IN THE NIGER DELTA, NIGERIA

ONOJAKE, M. C. AND CHIKWE, T. N

(Received 20 October 2017; Revision Accepted 10 April 2018)

ABSTRACT

Rheological properties of some oil based muds used in oil reservoirs located in the Niger Delta area of Nigeria were analyzed using standard methods (American standard for testing and material. Rheological parameters were obtained with a rotational viscometer by relating the shear stress of the fluid to the shear rate of the equipment. Results obtained from two of the oil based muds labelled OBM_3 and OBM_2; 1st gel strength (8 -9 lb/ft^2), 2nd gel strength (21 — 28 Iblft^2), plastic viscosity (19-23 cP), yield point (6-23 Ib41^2) show that the properties were within mud specification as recommended by American Association of Drilling Engineers (AADE) while results from the third oil based mud (OBM_5); 1st gel strength (171b1f12), 2nd gel strength (35 1b111^2), plastic viscosity (49 cP), yield point (32 Iblft^2) show that the parameters were off mud specification. Plastic viscosity and yield points are flow parameters of drilling fluids determined by their solid concentration and electrochemical forces within the particles of the fluid respectively whereas the gel strengths are time dependent flow parameters hence they are termed thixotropic. Rheological properties maintained within mud specification as specified by AADE are essential for efficient drilling *operations.*

KEYWORDS: Newtonian, Thixotropy, Shear Stress, Shear Rate, Organophillic, Flocculation.

INTRODUCTION

Hydrocarbons beneath the earth crust are globally recovered from reservoirs through a process of drilling with the aid of “complex heterogeneous fluids” known as drilling fluids. Drilling fluids play a significant role in aiding the drilling of borehole into the earth (Bourgoyne et al., 1986). The Egyptian and Chinese cultures used water as the first drilling fluid (Barrett, 2011). The major roles of drilling fluids during drilling operations include provision of gravitational pressure which prevents reservoir fluids from entering into the uncased portion of the well, ensuring that the cleanliness and temperature of the drill bit during drilling operations are maintained and aiding the adequate handling of broken bits of solid materials while drilling apparatus is brought in and out of the well bore during intermittent suspension of drilling activities (Darley and Grey, 1988). Prevention of formation damage and corrosion are the basic criteria for selecting the drilling fluid used for a particular job. Drilling fluids can be pneumatic (air/gas based), oil based or water based depending on the flow properties of the fluid based on applied force (Coussot et al., 2004). Some drilling activities require specific drilling fluid at a particular part of the hole others require a combination of different fluids (Barrett, 2011).

Onojake, M. C., Department of Pure and Industrial Chemistry, University of Port Harcourt, P.M.B 5323, Choba, Port Harcourt, Nigeria.
Chikwe, T. N., Department of Pure and Industrial Chemistry, University of Port Harcourt, P.M.B 5323, Choba, Port Harcourt, Nigeria.

Pneumatic (air/gas based) fluids are employed in drilling depleted zones or areas with abnormally low pressures within the pore spaces of the formation rock. The high penetration rates of pneumatic fluids give them an advantage over liquid mud systems however they are not effective in areas with large volumes of formation fluids (APC, 1975). During the drilling of such formations, the pneumatic fluids are converted to liquid based fluids and this increases the probability of damaging productive zones (Dyke, 2000). Pneaumatic drilling fluids are also not effective for very deep wells below 10 000 ft due to the fact that the volume of air required to lift drill cuttings from the well bore could be greater than what the surface equipment can handle (APC, 1975).

Drilling fluids that are liquid in nature are also called drilling mud as such water and oil based fluids fall under this category. Water based muds are sub classified into inhibitive, non inhibitive and polymer fluids depending on their impact on clay swelling (Coussot et al., 2004). Clay swelling is a damage of the formation caused by the reduction of formation permeability arising from the change in clay equilibrium. The clay equilibrium is altered when water-base filtrates from stimulation fluids, completion, drilling activities, work over permeate into the reservoir (Darley and Grey, 1988). The inhibitive fluids have an appreciable impact on clay swelling due to the presence of cations such as Sodium (Na^+), Calcium (Ca^{++}) and Potassium (K^+). Generally, K^+ or Ca^{++}, or a combination of the two, whereas non inhibitive fluids do not have significant impact on clay swelling examples are commercial bentonites (APC, 1975). The mud properties of polymer fluids on the other hand depends on large molecules with or without clay interactions, they could either be inhibitive or non inhibitive (ASME, 2005). Water based muds are the most widely used drilling muds because they are easy to build, cost of maintenance is relatively low and can be formed to outwit most challenges associated with drilling operations (Azar and Samuel, 2007).

Oil based muds are composed of dearomatized oil, wetting agent, filtrate reducer, lime, emulsifier, organophilic clay, viscosifyer and brine at various concentrations (Dyke, 2000). Oil based fluids are primarily used in the drilling of problematic shales and highly deviated holes because of their ability to reduce friction and prevent hydration of clays (Barrett, 2011). Oil based muds can also be chosen because of their ability to resist contaminants such as anhydrite, salt, carbondioxide and hydrogen sulphide gases (ASME, 2005). In choosing oil based fluids, cost is a major consideration, initially a barrel of an oil based mud is very expensive compared to a conventional water based muds however the fact that oil based fluids can be recycled makes its cost in a multi-well operation comparable to the cost of a water based fluid. Recently, due to the environmental concern associated with the use of oil based fluids, their use is either restricted or prohibited to certain locations (Hanson et al., 1990).

Most drilling problems are related to drilling fluids as such drilling engineering is one of the challenging disciplines in the petroleum industry. The drilling fluid itself is not very expensive however the maintenance of the right properties during drilling operations profoundly influence the total well cost. Rheological properties are properties related to flow and deformation of materials under applied forces. The nature of the internal structure of these drilling fluids is usually very complicated and subject to modification depending on the flow shears conditions that can lead to heterogenous phenomena (HWU, 2009). It is vital to characterize the internal structure of the drilling fluid, and this is analogous to the evaluation of the rheological properties (ASME, 2005). This study is therefore aimed at evaluating the physical and rheological properties of some oil based muds used in an oil rich formation located in the Niger Delta area of Nigeria. An in-depth knowledge of these properties will enable mud scientists and engineers have a better understanding of the proper usage of the fluids for successful and economical completion of an oil well, proper disposal to curb environmental concerns as well as modification of the fluid where and when necessary for product optimization.

MATERIALS AND METHODS
SAMPLE COLLECTION AND ANALYSIS

Three samples of drilling fluids were obtained from three (3) different drilling companies in the industrial area of Port Harcourt. The samples were all Oil Base Muds (OBM) labeled OBM_1, OBM_2 and OBM_3 respectively. Rheology and emulsion stability test were carried out using a rotational viscometer based on American Standard for testing and Materials (ASTM) methods. Each parameter reading is obtained twice and the average reading recorded.

Rheological Test for Oil Based Muds

The sample of the mud to be tested was poured into a thermal cup approximately two-third (2/3) full with mud sample. The thermal cup was placed on viscometer stand and raised up until rotary sleeve is immersed to scribe lid on sleeve and it was turned locked. It was heated to the temperature of 120 ^{0}F which was measured using a thermometer. The red knob on top of the viscometer was turned to 600rpm (revolutions per minutes) speed, to take the readings. The experiment was repeated to obtain readings for 300rpm, 200rpm, 100rpm, 6rpm, 3rpm. The shear stress (τ) was obtained by adding 1.067 to the dial reading as shown in equation 1. The dial readings were recorded as shear stress in Table 1. The gel strength was obtained at 10 seconds and 10 minutes respectively. Plastic viscosity (*Pv*) and yield point *(Yp)* were calculated from the rheology at 600rpm and 300rpm as shown in equations 2 & 3.

$$\tau = Dial\ reading + 1.067 \quad (1)$$

$$Pv = 600rpm - 300rpm \quad (2)$$

$$Yp = 300rpm - Pv \quad (3)$$

RESULTS

Table 1 shows the rheological properties of three different oil based muds. All the rheological parameters were measured in Ib/100ft^2 except the plastic viscosity which is measured in centipoise. 1st and 2nd gel strengths are measured at 10 seconds and 10 minutes respectively.

Table -1, Rheological Properties Of Oil Based Muds

	Shear Stress			
Rheology @ 120 ^{0}F	**OBM_1**	**OBM_2**	**OBM_3**	**Specification**
600 rpm	52	61	130	50.00-65.00
300 rpm	29	42	81	25.00-45.00
200 rpm	35	24	62	15.00-35.00
100 rpm	22	15	41	10.00-25.00
6 rpm	7	5	24	7.00-12.00
3 rpm	6	4	16	5.00-7.00
1st Gel strength	8	9	17	7.00-12.00
2nd Gel strength	21	28	35	15.00-30.00
Plastic viscosity	23	19	49	15.00-30.00
Yield point	6	23	32	5.00-30.00

Pearson's correlation analysis was adopted to analyze the relationship between the rheological properties of the different oil based muds considered in this study. An average of each of the properties of the drilling mud is represented as X while the upper limit of the AADE specification for drilling muds is represented as Y as shown in Table 2

Table 2. Correlation of the Rheological Properties of Oil Based Muds

Rheology @ 120 ^{0}F	**(X)**	**Spec. (Y)**	$X-\bar{X}$	$Y-\bar{Y}$	$(X-\bar{X})^2$	$(Y-\bar{Y})^2$	$(X-\bar{X})(Y-\bar{Y})$
600 rpm	81.000	65.000	50.134	35.900	2513.418	1288.810	1799.811
300 rpm	50.670	45.000	19.804	15.900	392.198	252.810	314.884
200 rpm	40.330	35.000	9.464	5.900	89.567	34.810	55.838
100 rpm	26.000	25.000	-4.866	-4.100	23.678	16.810	19.951
6 rpm	12.000	12.000	-18.866	-17.100	355.926	292.410	322.609
3 rpm	8.670	7.000	-22.196	-22.100	492.662	488.410	490.532
1st Gel strength	11.330	12.000	-19.536	-17.100	381.655	292.410	334.066
2nd Gel strength	28.000	30.000	-2.866	0.900	8.214	0.810	-2.579
Plastic viscosity	30.330	30.000	-0.536	0.900	0.287	0.810	-0.482
Yield point	20.330	30.000	-10.536	0.900	111.007	0.810	-9.482

$\bar{X}$: Mean of X = 30.866, $\bar{Y}$: Mean of Y = 29.100, $\sum (X-\bar{X})(Y-\bar{Y})$ = 3325.144,
$\sum (X-\bar{X})^2$ = 4368.614, $\sum (Y-\bar{Y})^2$ = 2668.900
*Pearson correlation coefficient **(R)** = 0.9738, Coefficient of determination **(R^2)** = 0.9483.*

$$R = \frac{\sum (X-\bar{X})(Y-\bar{Y})}{\sqrt{\sum (X-\bar{X})^2 \sum (Y-\bar{Y})^2}} \quad \ldots\ldots \quad (4)$$

Table 3 illustrates the Pearson's correlation coefficient matrix for the rheological properties of the drilling muds (OBM_1, OBM_2 and OBM_3).

Table 3. Pearson's Correlation Coefficient Matrix for the Rheological Properties Of Oil Based Muds

Rheology @ 120 ^{0}F	2nd Gel Strength	200rpm	100 rpm	Plastic Viscosity	1st Gel Strength	6 rpm	3 rpm	300 rpm	Yield Point
2nd Gel Strength	1								
200 rpm	0.97	1							
100 rpm	0.97	1	1						
Plastic Viscosity	0.92	0.99	0.99	1					
1st Gel Strength	0.91	0.98	0.99	1	1				
6 rpm	0.91	0.98	0.99	1	1	1			
3 rpm	0.93	0.99	0.99	1	1	1	1		
300 rpm	0.72	0.86	0.87	0.93	0.94	0.94	0.92	1	
Yield Point	0.34	0.55	0.57	0.68	0.7	0.7	0.66	0.9	1

DISCUSSION

Rheological models used in characterizing fluid flow in the oil industry are classified into Newtonian or non Newtonian model. Newtonian model describes the simplest fluid flow behavior in which the fluid viscosity is a linear constant of proportionality between shear stress and shear rate under constant temperature and pressure. Fluids characterized by the Newtonian model are called Newtonian fluids examples are water, oil, gasoline, alcohol etc (Barett, 2011). For non Newtonian model however, no linear constant proportionality exists between the shear rate and the shear stress, the viscosity changes as the shear rate changes. Fluids characterized by this model are called non Newtonian fluids, most drilling fluids especially the oil based muds fall under this category (Dyke, 2000). Non Newtonian fluids are further characterized into sub models. The sub models of most interest in drilling fluid technology are Bingham plastic, power-law and Herschel-Bulkley models. Most drilling fluids are not described by a single model rather a combination of models (ASME, 2005). There is a linear relationship between the shear stress and the shear rate for drilling fluids that exhibit Bingham plastic behavior as can be seen in Table 1, such fluids do not flow until the shear stress supersedes a critical value known as the yield point. All the oil base muds considered in this study show Bingham plastic behavior. Shear rate is the rate at which layers of the fluid move past each other per unit distance and it is measured in reciprocal seconds. However, it can be converted to revolution per minute (rpm) as typical for most rotational viscometer (Olatunde and Usman, 2011). Shear stress is expressed in units of force per unit area and it is a function of the shear rate (Menzel, 1973). A rotational viscometer measures the shear rate and shear stress of a drilling fluid which enables the direct calculation of Bingham Plastic parameters such as plastic viscosity and yield Point as shown in Table 1.

Plastic viscosity (Pv) is the resistance to flow caused by mechanical friction resulting from solids concentration, size and shape of solids as well as viscosity of the fluid phase. Pv increases with increasing percentage volume of solid. It also increases at constant percentage volume of solid at decreasing particle size of the fluid; this is because decreased particle size increases surface area which in turn increases the frictional drag of the fluid (Moore, 1974). The Pv of a mud is by theory the lowest viscosity a mud can have as such it is the effective viscosity as the shear rate approaches infinity (Olatunde and Usman, 2011). The shear rate of drilling mud is at its maximum as it passes through the bit nozzles. The Pv is therefore approximately the mud's viscosity at the nozzles (Menzel, 1973). The Pv is one of the major parameters that enables the transporting capacity of the mud, suspension of weighting materials as well as pressure surges at the reservoir through hydrostatic pressures in the annulus. It is certain that drilling fluids with high Pv will exert so much pressure on the annulus in addition to jeopardizing the transport capacity of the mud (Dyke, 2000). There must be a balance therefore between the Pv and the mud density. The American Association of Drilling Engineers (AADE) specifies a Pv in the range of 15 to 30 *$Ib/100ft^2$* for oil based muds (ASME, 2005). Table 1 show that the Pv of OBM_1 and OBM_2 are within specification while that for OBM_3 is off specification. The apparent viscosity is half of the 600rpm dial reading and it is a measure of resistance to flow caused by solids in the mud, solids and liquids as well as upon the shearing layers of the mud (Menzel, 1973).

Yield Point (Yp) is the initial flow resistance which results from the electrochemical forces between the particles of the fluid due to surface charges dispersed in the fluid phase (Dyke, 2000). Yield point depends on the surface properties and volume concentration of the mud solids as well as ionic environment of the liquid surrounding the solids (Moore, 1974). AADE specifies Yp in the range of 5 to 30 *$Ib/100ft^2$*. Table 1 show that Yp for OBM_1 and OBM_2 are within specification while that for OBM_3 is off specification. The Yp can be controlled by proper chemical treatment which reduces the attractive forces thereby reducing the yield point (Fink, 2003).

A plot of shear stress (y axis) against shear rate (x axis) gives Pv as the slope of the graph and Yp as the intercept. For non Newtonian fluids described by the Bingham Plastic model, such graphs are called the Bingham plastic curve. This is illustrated in

Figure 1:

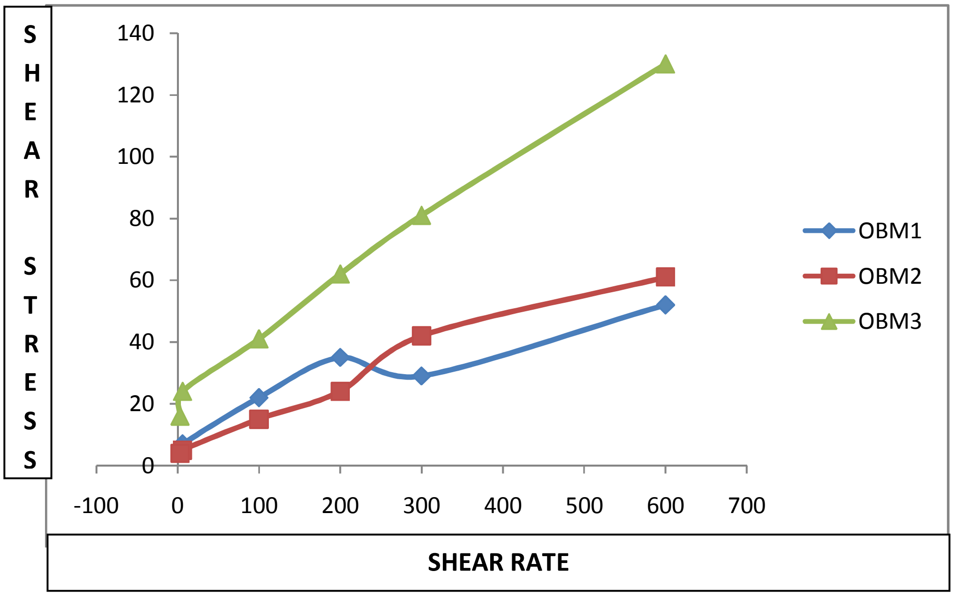

Figure 1. Bingham Plastic Curve for Oil Based Muds

Gel strength of a fluid is a thixotropic property of the fluid which indicates the strength of forces of attraction (gelation) in a drilling fluid under inactive conditions (Darley and Grey, 1988). The gel strength is the shear stress measured at low shear rate after a mud has remained in an inactive state for a period of time (10 seconds and 10 minutes in the standard API procedure) hence they are termed thixotropic. The viscosity of drilling muds with thixotropic properties are time dependent (Clark et al., 1976). High solids concentration leading to flocculation gives rise to high gel strength. Rheological problems in the mud system are often reflected by a mud's gel strength development with time. Progressive gels are formed when there is a wide range between the 1st and 2nd gel readings. High flat gels are formed when the 1st and 2nd gel readings are high without an appreciable difference. Low flat gels are formed when the 1st and 2nd gel readings are low without a wide range of difference and this is the most desirable gel strength for drilling fluids (Barette, 2011; Bourgoyne et al., 1986). Table 1 shows that OBM_1 and OBM_2 formed low flat gels as their 1st and 2nd gel readings were within AADE specification, whereas OBM_3 can be said to form a high flat gel and it is off specification. In order to perform the function of suspension of cuttings and weight material, the gel strength of a drilling fluid must not be allowed to be higher than necessary (Olatunde and Usman, 2011). High gel strengths could result in swabbing during the pulling of pipes, surging when pipe is lowered, logging tools to bottom difficulty, entrapped air or gas, sand and cuttings being retained in the mud during drilling operations (HWU, 2009). Some amount of gelling however is important in drilling fluids to keep cuttings from setting to the bottom of the hole (Hanson et al., 1990). Gel strengths and yield point are both a measure of the forces of attraction in a mud system. A reduction in one usually results in a reduction in the other; therefore, similar chemical treatments are used to modify them (Haaland et al., 1976).

Table 2 shows that a strong positive correlation was obtained from the statistical analyses carried out on the rheological properties of the oil based mud. A positive correlation means that a high value on X variable will go with a high value on Y variable and a low value on X variable will go with a low value on Y variable. On the other hand, a negative correlation means that a high value on X variable will go with a low value on Y variable (vice versa) which means that a high X variable went with a high Y variable, this is also evident from the positive value of the Pearson's correlation coefficient (R) which is calculated using equation 4.

The Pearson's correlation coefficient matrix as shown in Table 3 unveils that each of the rheological properties of the drilling mud is positively correlated to each other which infers that high value of a specific property for instance plastic viscosity will result in high values of another property such as yield point.

CONCLUSION

Mud specification depends on a number of parameters ranging from the nature of the well, soil condition, true depth of the well and well performance, this is extremely important in determining the application of the mud in a particular well. Rheology of oil based muds and indeed all drilling fluids depend on the relationship between the shear stress of the mud and the shear rate of the rotational viscometer. Rheological parameters of oil based muds such as the plastic viscosity, yield point and the gel strength of the mud are determined by the solid concentration and electrochemical charges present in the drilling mud, these parameters are essential in solids build up, flocculation or deflocculating of solids within the mud. For the drilling mud to optimally perform its functions such as maintaining hydrostatic pressure, transportation and suspension of drill cuttings, these rheological parameters must be within specification based on international standard.

REFERENCES

Amoco Production Company APC 1975. Drilling Fluid Manual, Pp 1-5.

American society of mechanical engineers (ASME), 2005. Drilling fluids processing handbook, shale shaker committee, Gulf publishing company, 10-40

Azar, J and Samuel G. R., 2007. Drilling Engineering Pennwell Corporation, 1-6.

Barette, M. L., 2011. Drilling mud, 20th century History, 161-168.

Bourgoyne Jr, A. T., Millein, K. K., Chenevert, M. E and Young Jr, F.,1986. Applied drilling engineering Richardson, TX: society of petroleum engineering, 2-17

Clark, R. K., Scheuerman, R. F., Rath, H and Van Laar H. G., 1976. Polyacrylamide-potassium -chloride mud for drilling water-sensitive shales, paper SPE 5514, journal of petroleum technology, 719-727.

Coussot, P., Bertrand, F and Herzhaft, B., 2004. Rheological Behavior of Drilling Muds, Characterization Using MRI Visualization Oil & Gas Science and Technology Rev. IFP, Vol. 59, 23-29.

Darley, H. C. H and Grey, G. R., 1988. Compositions and properties of drilling and completion fluids. 5thEdn, Gulf Publishing Company, Houston De, 1-10.

Dyke, K.V., 2000. Drilling fluids. Rotary drilling series (unit II). Austin, TX: The University of Texas.

Fink, J., 2003. Oil Field Chemicals. Gulf professional pub. 25-30

Haaland, E., Pettersen, G and Tuntland, O. B., 1976.Testing of iron oxides as weight material for drilling mud (unsolicited). Society of petroleum engineers, 330

Hanson, P., Trigg Jr., T., Racheal, G and Zamora M.,1990. Investigation of Barite "sag" in weighted drilling fluids in highly deviated wells. Society of petroleum engine engineers inc. 230-233.

HWU, 2009. Drilling engineering, lecture material institute of petroleum engineering. Herriot Walt university, Edinburg; UK. 358-363.

Menzel, D., 1973. A new weighting material for drilling fluids based on synthetic iron oxide. American Institute of Mining, Metallurgical and Petroleum Engineers, Inc, 4517-ms.

Moore, D., 1974. Drilling Practice Manual. Pennwell Pub. Co. 100-120.

Olatunde, A. O. and Usman M. A., 2011. Improvement of rheological properties of drilling fluids using local based materials/chemicals.