ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 9, Issue 10 , October 2022

Evaluation of the Effect of Clay Contamination on Drilling Mud Characteristics

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ABSTRACT: The article evaluated the effect of clay contamination on drilling mud characteristics. Pre-formulated drilling mud was separately contaminated with 5%, 10%, 15% and 20% of clay then tested for mud weight, emulsion stability, fluid loss and oil - water ratio as well as rheological (600, 300, 200, 100, 60, 30, 6 and 3-rpm) and gel strength (10-sec/10-min) measurements. Plastic viscosity and yield point were estimated from the rheological parameters. All the analysis were carried out in line with America Petroleum Institute (API) standards for testing. The value obtained for the uncontaminated base mud (reference) was 9.5 lb/gal, while 9.8 lb/gal, 10.0 lb/gal, 10.3 lb/gal and 10.5 lb/gal were recorded for 5%, 10%, 15% and 20% clay contaminations respectively. The other results for the control base mud, 5%, 10%, 15% and 20% clay contaminations respectively were; ES values: 405v, 385v, 370v, 292v and 286v, 6-rpm reading: 13cP, 15cP, 18cP, 20cP and 24cP, 10-seconds' gels reading: 17 lb/100ft^2, 19 lb/100ft^2, 20 lb/100ft^2, 25 lb/100ft^2 and 29 lb/100ft^2, 10 minutes' gels reading: 27 lb/100ft^2, 29 lb/100ft^2, 32 lb/100ft^2, 34 lb/100ft^2 and 36 lb/100ft^2, PV value: 25cP, 34cP, 38cP, 40cP and 42cP, YP value: 27 lb/100ft^2, 30 lb/100ft^2, 34 lb/100ft^2, 37 lb/100ft^2 and 38 lb/100ft^2, OWR value: 66/34, 68/32, 69/34, 71/29 and 73/27, HPHT value: 5mls, 5.4ml, 10.6ml, 17.6ml and 20.8ml. Complete deviations from the mud program were observed for all the parameters tested due to the contamination but, 5% to 10% contaminations were insignificantly affected while 15% to 20% contaminations were entirely intolerable.

KEYWORDS: drilling mud, contamination, clay, mud weight, emulsion stability, fluid loss oil - water ratio, Plastic viscosity and yield point

I. INTRODUCTION

Drilling fluid contaminant implied any material that gives an undesirable alteration of the drilling mud properties when introduced into the mud system (Ebikapaye, 2018). Solids are the most dominant of the contaminants and tends to increase in the rheological properties of the mud thereby reducing the rate of penetration especially when excess of it from the formation is allowed into the mud system. Some contaminants are chemical in nature and thus requires specific chemical treatment to recondition the mud to its original properties with high Engineering degree of tolerance. However, it is not always possible to completely remove the contaminants from the mud system but could be reduced to achieve minimum error and management. A drilling fluid is said to be contaminated when there is an intrusion of foreign materials into the drilling fluid system or from excessive treatment of the drilling fluid system with additives thereby causing undesirable changes in the properties and behavior of the drilling fluid (Mahmood and Khaled, 2012).
The primary indication of contamination is a change in the properties of the drilling fluid which often result in difficulty in controlling the essential mud properties like fluid loss, alkalinity, rheology and density. Contamination are usually suspected whenever unexpected change in the properties of the drilling fluid are observed (Ebikapaye, 2018). Drilling fluids contamination can have multiple causes and sometimes these contaminants in the mud system are "masked". A regular and accurate analysis of the properties of the drilling fluid through mud checks/monitoring has been observed to be the most effective method for determining the presence of contaminants. These contaminants could be salt, acid, cement, water or solid but could also be

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
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combinations of two or more of these. Salt contamination are usually from drilling of salt formations, encroachment of formation water or application of salty makeup water. This is commonly detected by an increase in chlorides content of the filtrate in water based mud and chloride content of the mud for oil based mud systems (SIEP, 2003). This could also be attributed to increase in yield point, fluid loss and decrease in pH (alkalinity). Decrease in the mud density is also observed if the source of salt is a flow of saltwater. However, if saltwater mud is used to drill large quantity of salt formation, it is not regarded as a contaminant. Evaporated salts includes the chlorides of sodium, potassium, calcium and magnesium. ($NaCl$, KCl, $CaCl_2$ and $MgCl_2$). Acid Gases Contaminants include carbon dioxide (CO_2) and hydrogen sulfide (H_2S) and are usually produced from natural gas. These gases form weak acid solutions when added to water, causing the clays to flocculate and increase in the polymer viscosifying effect (SIEP, 2003). Formations that have component of H_2S or/and CO_2 can be drilled safely with the aid of oil-based mud, provided the formations are drilled with an overbalance. Again, cement contamination results from well cementing process as a result of calcium hydroxide (CaOH) formation that causes flocculation of the clays in the drilling fluid. It is usually indicated by increase in the level of calcium or hardness. It also results in the mud's viscosity and pH increment (SIEP, 2003). However, this contaminants can be removed by the application of soda ash or sodium bicarbonate. If a low pH is required sodium bicarbonate is preferred to soda ash (Shadravon 2012). Carbonate/Bicarbonate are also formed due to encroachment of CO_2 when drilling with alkaline drilling fluids (Shadravon, 2012). Seeping of CO_2 into an alkaline mud system reacts with OH- ions resulting in formation of soluble carbonates. Similarly, overtreatment of mud system contaminated by other sources with soda ash or sodium bicarbonate contributes to the problem known as "carbonate alkalinity" (Ebikapaye, 2018). This type of contamination results into high gels and yield point, and decreased pH. Ebikapaye, 2018 also reported that solid contaminants encountered during drilling operations are classified into reactive solids (clays and shales) and non-reactive solids (sands, limestone, etc), There are however some solids that are intentionally incorporated into in drilling fluids to condition the mud. These solids could be bentonite, barite and other polymers (smectite, illite, chlorite, kaolinite etc). This causes a reduction in the liquid phase of the mud thereby increasing the effective viscosity of the mud (SIEP, 2003). Generally, increased mud plastic viscosity, gel strengths and poor response to deflocculants as well as high retort solids volumes, high MBT (Methylene Blue Test) values and high D/B ratio (Drill Solids/Bentonite) with thick filter cake and high fluid loss, slow rate of penetration, difficulty during trips with tight hole, swab and surge are all possible signs that the mud system is loaded with solids.

II. MATERIALS AND METHOD

This section covered the materials and equipment used for the study, as well as the various experimental procedures employed to achieve the aim of the investigation.

A. Materials

The materials used for the study includes: clay, water and pre- formulated drilling mud.

B. Equipment

The equipment used for the various measurements and experiments consists of the following, Hamilton beach mixer and its accessories, Thermo cup and sticks, Mud balance, Weighing balance, Retort, Meters (Electrical stability and viscosity) and High temperature high pressure filter press.

C. Sample Preparation

The pre-formulated drilling mud was contaminated with clay similar to clay around the drill location. The physical characteristics of the clay employed for the contamination is presented in Table 1. Samples of fluid was contaminated with 5%, 10%, 15% and 20% of clay were prepared separately.

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Table 1: Characteristics of clay used for drilling fluid contamination

Parameter	Results
Appearance	Powder
Colour	Light or Pale (Gray)
Odour	Almost Odourless
Relative density	$2.6 g/cm^3$
Solubility	Insoluble in water
Stability	Stable at normal ambient temperature

D. Experimental Procedures

D.i Determination of Mud Weight

The mud balance was calibrated with water then replaced with a pre- formulated mud. The mud balance cup was filled to brim with mud and covered with the cap (firmly seated) to ensure that some mud samples expelled through the hole in the cap to remove any trapped air or gas, then a thumb was placed over the hole in the cap, and held firmly on the cup before wiping the outside of the cup dry with a napkin. The balance arm of the mud balance was placed on the support base and balanced by moving the rider along the graduated scale until the level bubble was centered (under the center line). The weight of the mud was displayed at the left- hand edge of the rider and reported to the nearest 0.1 lb/gal. The process was repeated for all the mud samples (with 5%, 10%, 15% and 20% water contamination.)

D.ii Determination of Emulsion Stability

The mud sample to be tested was stirred with the Hamilton beech mixer for 30 minutes, then transferred to a thermal cup and heated to 48.9ºC. The emulsion stability **(**ES) meter was calibrated to 1999v, then the clean electrical probe was inserted into the mud sample and stirred again with the probe for about 10 seconds (without allowing the probe to touch the bottom or sides of the container). The knob on the meter was pushed, then the highest value obtained was noted as the first reading, then the mud sample was stirred again with the probe for another 10 seconds and the knob pushed down for a second reading. The process was repeated for a third reading. The mean of the three readings was noted as the ES value for the mud sample. The process was repeated for all the mud samples (with 5%, 10%, 15% and 20% water contamination.)

D.iii. Rheological Measurements

The thermo cup containing the mud sample was placed on the viscometer stand, then the stand was raised until the rotary sleeve was immersed in the mud sample to scribe line, then locked into place by turning the locking mechanism. The mud sample in the thermo cup was heated to 48.9ºC, then a thermometer was inserted into the mud sample to confirm the temperature. At 48.9ºC, a flipped meter knob located on the top of viscometer was used to stir position for about 10 seconds, then the knob was positioned on 600-rpm speed, until the dial reading stabilized, then 600-rpm reading displayed was recorded, the knob position was switched to 300-rpm, 200-rpm, 100-rpm, 60-rpm, 30-rpm, 6-rpm and 3-rpm and the corresponding readings recorded. The process was repeated for all the mud samples (with 5%, 10%, 15% and 20% water contamination.)

The Plastic Viscosity (PV) and Yield Point (YP) were calculated from the 600-rpm and 300-rpm dial readings according to Equations 1 and 2

$$PV = 600\text{-rpm} - 300\text{-rpm} \quad (1)$$

$$YP = 300\text{-rpm} - PV \quad (2)$$

D.iv. Gel Strength (10-sec/10-min) Measurement

In line with the arrangement above, (Rheology measurement), the viscometer knob was moved to the stir position and stirred for 10 seconds, then the knob was placed at the 3-rpm and the meter turned off, then the mud was allowed to stand undisturbed for 10 seconds, then the viscometer was turned on and the maximum dial

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International Journal of Advanced Research in Science, Engineering and Technology
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reading noted. This maximum dial deflection was recorded as the 10-seconds (initial) gel strength. Meter knob was then moved to stir position and the mud was stirred for 10 seconds, then the knob was re-positioned to the 3-rpm speed and the meter was turned off, as mud was allowed to stand undisturbed for 10 minutes. The viscometer was turned on and the maximum dial reading noted. This maximum dial deflection is noted as the 10-minutes gel strength. The process was repeated for all the mud samples (with 5%, 10%, 15% and 20% water contamination.)

D.v. Oil- water ratio determination

Retort equipment (Fig 3.5) was used to measure the oil water ratio. The retort assembly and condenser was cleaned and dried then the mud sample was poured into the mud cup. The side of the cup was lightly tapped to avoid air entrapment then the lid of the cup was placed and rotated to ensure proper fit (ensuring that excess mud flowed out of the hole on the lid), then the body of the retort cup was gently wiped, thereafter the retort body was packed with a steel wool and the thread of the retort cup greased. The retort body was then hand tightened unto the retort cup. Retort stem was then attached to the condenser and the assembly placed into the heating jacket then closed. A clean dry measuring cylinder was placed under the condenser discharge tube, and heating jacket was then connected to a power supply and retort allowed to run for 45 minutes, then the power indicator automatically went off, the measuring cylinder was removed and values for solids, oil and water percentages were recorded. The process was repeated for all the mud samples (with 5%, 10%, 15% and 20% water contamination.)

The oil water ratio was estimated using Equation 3.

$$OWR = \frac{Ro}{Ro+Rw} \quad 3$$

Rw = Ratio of water, Ro = Ratio of oil

D.vi. Determination of Fluid Loss

The fluid loss was determined using the High Temperature High Pressure (HTHP) filter press. The HTHP heating jacket was connected to a power source then a thermo stick was inserted into the side of the jacket to monitor temperature. Jacket was heated to a temperature of 260ºF (121.1ºC), 10ºF above test temperature. As the heating was ongoing, the HTHP cell was prepared and mud sample to be tested was transferred to the cell to $3^{1}/_{4}$ full to allow for expansion. The cell was then placed into the heating jacket, then the top and bottom pressure unit were set and locked. A thermo stick was inserted into the cell to monitor the temperature within the cell. Pressure units at the top and bottom was pressurized to 100psi and the top valve half turned. Temperature of the cell was monitored until selected temperature, 250ºF (121.1ºC) was obtained, then the pressure in the upper pressure unit was set to 600psi, and the bottom valve half turned clockwise to start filtration. A timer was set for 30 minutes, and the pressure and temperature maintained, thereafter, both valves (top and bottom) were closed, the T-screws backed off, and bled off pressure in both regulators. Filtrate were then collected and real value estimated as in Equation 4.

Real filtrate volume recorded = 2 x volume obtained 4

The process was repeated for all the mud samples (with 5%, 10%, 15% and 20% clay contamination.)

III. DISCUSSION OF RESULTS

The results of the drilling fluid contaminated with clay are presented in Table 2 and discussed under the following headings: Mud weight (Mud density), emulsion stability, 6-rpm reading, gel strength (10- seconds and 10- minutes gels), plastic viscosity, yield point, oil- water ratio and high temperature high pressure fluid loss.

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Table 2: Characteristics of clay contaminated drilling fluid

Parameters		Base Mud	5% Clay	10% Clay	15% Clay	20% Clay	Control (Mud Program)
Mud weight lb/gal		9.5	9.8	10.0	10.3	10.5	9.0 – 10.0
ES volts		405v	385v	370v	292v	286v	> 350v
Rheological Properties	**600**	77	98	110	117	122	
	300	52	64	72	77	80	
	200	44	52	59	62	66	
	100	33	37	42	45	49	
	60	27	32	35	38	42	
	30	17	20	22	27	29	
	6	13	15	18	20	24	12 – 14
	3	13	15	17	20	24	
	10s	17	19	20	25	29	17 – 20
	10m	27	29	32	34	36	24 – 27
PV (cP).		25	34	38	40	42	15 – 25
YP lb/100ft^2		27	30	34	37	38	24 – 28
Rs (%)		21%	23%	25%	27%	29%	
Ro (%)		52%	52%	52%	52%	52%	
Rw (%)		27%	25%	23%	21%	19%	
OWR		66/34	68/32	69/34	71/29	73/27	65/35 – 70/30
HTHP FL mls		5mls	5.4mls	10.6mls	17.6mls	20.8mls	5mls

ES= Emulsion Stability, PV= Plastic Viscosity YP= Yield Point, Rs=Ratio of solids Ro= Ratio of oil, Rw= Ratio of water, OWR= Oil- water ratio. HTHP FL= High Temperature High Pressure Fluid loss

A. Mud Density:

Drilling fluid density also referred as mud weight is dependent on the amount of barite, calcium carbonate or hematite it contains. It increases the hydrostatic gradient within the wellbore to enable the pressure in the wellbore to be higher than formation pressure (Samuel and Leon, 2020). The value obtained for the uncontaminated base mud (reference) was 9.5 lb/gal, while 9.8 lb/gal, 10.0 lb/gal, 10.3 lb/gal and 10.5 lb/gal were recorded for 5%, 10%, 15% and 20% clay contaminations respectively. The values for the contaminated mud densities obtained in this study showed a similar trend with values reported by Broni- Bediako et al (2019) but greater than values noted by Ebikapaye, (2018). The mud weight of the reference base mud was less than all the values obtained after contamination. However, from the specified mud program with mud weight range of 9.0 lb/gal – 10.0 lb/gal, 5% and 10% clay contaminations had no significant impact on the mud weight. The deviations from the values recorded in the control was observed in 15% and 20% contamination, with 20% contamination having the highest deviation. These values noted with 15% and 20% contaminations are significant and therefore needs some levels of treatment for the mud to serve its purpose. The results showed a pattern of progressive increase in the mud weight with increase in clay incorporated into the system. This implied that as drilling progresses, a constant check of the mud weight is important as formation clay can lead to a creep up in the weight of the mud system, especially if solids control equipment is not functioning optimally.

B. Emulsion Stability (ES)

The relative stability of a water-in-oil emulsion mud is indicated by the breakdown voltage at which the emulsion becomes conductive. ES is the increase in voltage across a probe until the emulsion breaks and current is established. The ES value obtained for base mud (control) was 405v, while 385v, 370v, 292v and 286v were recorded for 5%, 10%, 15% and 20% clay contaminations respectively. The obtained levels showed a decrease in values with increase in clay contamination similar to that reported by Kumapayi et al. (2014) and Shadravoin (2012). The values recorded were however at variance with the result by Adekomaya (2013). The result showed that the emulsion stability of the base mud was greater than all the values obtained after contamination. However, from the specified mud program, ES of > 350v, 5% and 10% clay contaminations may not have significant

ISSN: 2350-0328

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impact on the mud performance. The decrease in ES value with increase in the clay contamination implied that clay weakens the emulsion of the mud system, a disadvantage to the mud performance. Formation clay (water loving) usually dissolves in the dispersed phase thereby increasing the surface area of the water, making the water droplets larger and the mud system ease of electricity conduct. The presence of conductive solids affects the E.S. readings. Inferentially, as clay contaminants increased (5% - 20%) in the mud system, the emulsion stability of the mud decreased, however with no detrimental effect on the emulsion stability until about 15% and above in clay contaminations.

C. 6-rpm reading

6-rpm reading is a representation of the rheology of the mud at the closest point of the formation, it gives an idea of how well the hole is been cleansed. The reading recorded for base mud (uncontaminated sample) was 13cP, while values for 5%, 10%, 15% and 20% contaminations were 15cP, 18cP, 20cP and 24cP respectively. It was observed that the values of 6-rpm reading displayed similar pattern with mud weight: increased with increase in the mud contamination. These values corroborates with the works of Biwott et al (2019) and Shadravon (2012). The acceptable reading for 6-rpm is (12-14cP), hence the base mud of value 13 was within specification while others were off the recommended values specified in the mud program. The increase in clay contamination also results in increase in the solids content of the mud system and leads to increase in the rheological value of the mud system.

D. Gel strength

Gel strengths, (10 - seconds and 10 - minutes), indicates strength of attractive forces (gelation) in a drilling fluid under static conditions.

D.i 10 - seconds gels:

10-seconds gels reading for the base mud was 17 lb/100ft^2, while 19 lb/100ft^2, 20 lb/100ft^2, 25 lb/100ft^2 and 29 lb/100ft^2 were for 5%, 10%, 15% and 20% clay contaminated samples respectively. These values agrees with the values reported by Biwott et al (2019) and Broni- Bediako, et al (2019), but at variance (greater) than level noted by Yunita, et al. (2017).

The focus range for 10- seconds gels was (17 lb/100ft^2 - 20 lb/100ft^2) as specified in the mud program. Like the trend observed in the mud weight and ES, 5% and 10% clay contamination were within specification while 15% and 20% contaminations values of 10 seconds gels were higher than the values specified in the mud program. The result showed that 10- seconds gels value for the mud system increased with an increase in clay contamination and could be attributed to excessive gelation resulting from high solids concentration. The result implied that the strength of the attractive forces (gelation) in the mud system under static condition increased with increase in the solids concentration of the mud system.

D.ii. 10 Minutes' gels

10 minutes' gels reading for base mud (control sample) was 27 lb/100ft^2, while 29 lb/100ft^2, 32 lb/100ft^2, 34 lb/100ft^2 and 36 lb/100ft^2 were recorded for 5%, 10%, 15% and 20% clay contaminations respectively. The Mud program specified 24 lb/100ft^2 - 27 lb/100ft^2 for 10 - minute gels, hence it's only the base mud that met the recommended value for 10 minutes' gels reading, all the other values for the various contaminations were higher. These values were also similar with the results of Biwott et al (2019) and Shadravon (2012) but at variance with the result reported by Yunita et al. (2017).

E. Plastic Viscosity (PV)

PV is the resistance to flow caused by mechanical friction. It is the difference between the 600-rpm reading and 300-rpm reading. The PV value of the base mud was 25cP, while values for 5%, 10%, 15% and 20% clay contamination were 34cP, 38cP, 40cP and 42cP respectively. The increase in PV occasioned by the increase in clay contamination is in line with the results reported by Kumapayi et al., (2014) and Kassim Mahmud (2016) but higher than levels noted by Adekomaya (2013) and Yunita, et al (2017). The results showed that the PV values of the contaminated samples were higher than the range specified in the mud program and therefore unacceptable. This implied that increase in clay contamination will result in corresponding increase in plastic viscosity because of the solid nature of clay which has the tendency of making the mud system more viscous.

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F. Yield Point

Yield point (YP) is the initial resistance to flow caused by electrochemical forces between the particles. YP is usually obtained from rheological measurements. The YP value for the control base mud was 27 lb/100ft^2, while 30 lb/100ft^2, 34 lb/100ft^2, 37 lb/100ft^2 and 38 lb/100ft^2 were recorded for 5%, 10%, 15% and 20% contaminations respectively. The values were contrary to values reported by Adekomaya (2013) but corroborates the results of Kumapayi et al, (2014). It can therefore be substantiated that an increase in clay contamination leads to a corresponding increase in the attractive forces thereby bringing the particles together and increasing the total number of charges which in turn leads to an increase in the yield point.

G. Oil - water ratio

Oil - water ratio (OWR) is the ratio of the oil to water present in a mud system and this provides vital information for control of mud properties and is also essential for evaluating solids control equipment. The OWR value of the base mud was 66/34, while after 5%, 10%, 15% and 20% clay contaminations the ratios were 68/32, 69/34, 71/29 and 73/27 respectively. The mud program specified 65/35 – 70/30 as acceptable OWR for the formation under study, therefore, the ratio recorded after 5% and 10% clay contamination were within specification while the values for 15% and 20% had more oil and less water compared to the mud program which implied that an increase in the clay contamination leads to a corresponding increase in the oil - water ratio. This could also be linked to the water loving attributes of clay that makes it dissolve in the water phase thereby leading to an increase in the solids content and causing a decrease in the water value.

H. High Pressure High Temperature Fluid Loss (HPHT FL)

Control of filtration properties of drilling fluids are useful in reducing tight hole conditions and fluid loss to formations. The value of this parameter is used to express filter cake quality and filtrate volume loss for a drilling mud under specific testing conditions. The HPHT value of obtained for the base mud was 5mls, while the values for 5%, 10%, 15% and 20% clay contaminations were 5.4ml, 10.6ml, 17.6ml and 20.8ml respectively. However, the mud program specified $\leq$ 5ml for HPHT FL, this implied that none of the HPHT FL values after contamination were within the acceptable limit. This could be linked to the increase of clay which leads to a resulting breakdown in the emulsion of the mud thereby leaving free water droplets in the mud system, which causes an increase in the fluid loss of the system. The result corroborates the values reported by Yunita et al (2016), Mahmud (2016), Broni- Bediako et al (2019) and Kumapayi et al., (2014).

IV. CONCLUSION

The mud weight of the reference base mud was less than all the values obtained after contamination. The results showed a pattern of progressive increase in the mud weight with an increase in the contamination of clay incorporated into the system. 5% and 10% clay contaminations had no significant impact on the mud weight but values noted with 15% and 20% contaminations were of significance. Emulsion stability of the mud decreased with increase in clay contamination while 6-rpm reading, solids content and rheological value of the mud system as well as the 10-seconds gels reading and plastic viscosity increases with increase in clay contamination. Also, an increase in clay contamination leads to a corresponding increase in the attractive forces; bringing the particles together and increasing the total number of charges which in turn leads to an increase in the yield point. Oil - water ratio for 15% and 20% clay contamination had more oil and less water which was linked to the water loving attributes of clay that makes it dissolve in the water phase thereby leading to an increase in the solids content and decrease in the water value.

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