Nigerian Research Journal of Engineering and Environmental Sciences 8(1) 2023 pp. 289-295
p ISSN: 2635-3342; e ISSN: 2635-3350

Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

Original Research Article

Analysis of the Effect of Surface and Down Hole Water Contamination on Drilling Fluid Characteristics

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http://doi.org/10.5281/zenodo.8095518

ARTICLE INFORMATION

Article history:
Received 13 Jun. 2023
Revised 28 Jun. 2023
Accepted 29 Jun. 2023
Available online 30 Jun. 2023

Keywords:
Formation
Drilling fluid
Mud program
Contamination
Stability
Fluid loss rheology
Gel strength
Viscosity
Yield point

ABSTRACT

The devastating incidental occurrences experienced in the Oil and Gas industry in the past showed the importance of maintaining integrity of wells and oil facilities. Drilling fluids aids the transportation of cuttings to the surface, cool the bit and control formation pressure thereby preventing blow outs. Millions of barrels of water-based mud are used each year to explore and exploit oil and gas resources both in the onshore and offshore drilling environments. This article evaluated the effect of water contamination on drilling fluids characteristics. Pre-formulated drilling fluid was separately contaminated with 5%, 10%, 15% and 20% of water similar in characteristics to formation water. The hydro-contaminated drilling fluid was then tested for the key parameters [mud weight, emulsion stability, fluid loss and oil - water ratio as well as rheological properties (600, 300, 200, 100, 60, 30, 6 and 3- rpm - revolutions per minutes) and gel strength (10-sec/10-min)]. America Petroleum Institute (API) standards were employed for all the analysis. Complete deviations from the mud program were observed for all the parameters tested except for the mud weights. The 5% water contamination was insignificantly affected while 10% to 20% contamination was entirely intolerable. It is envisaged that sufficient knowledge and attention to muds contamination and its optimization in both offshore and onshore drilling operations will reduce tight hole problems, torque, and drag, and stuck pipe.

1. INTRODUCTION

Crude oil is one of the world's most important natural resources and has had both positive and negative impacts on many nations. As a result of constant demands for energy by the world population, continuous exploration and drilling activities are carried out to produce oil and gas in large quantities. Drilling operations are very expensive and this calls for the use of well formulated drilling fluids to avoid wellbore instability problems. Drilling fluids can either be water based or oil based. These types of fluids are made up of a base fluid, which could be water or diesel, weighting up agents and other chemical additives that help in transporting the cuttings from the wells and keep the drilling mud in a fluid state (Alotaibi et al. 2010).

Generally, the drilling mud by hydrostatic pressure helps to prevent the collapse of unstable strata into the wellbore and causes influx of water from water-bearing strata that are encountered (Hawker, 2016). The water from the water-bearing strata downhole tend to contaminate the drilling fluid and reduce its efficiency. Again, surface water especially wells drilled in marshy or swampy areas also infiltrates the mud during preparation at site and alter its characteristics (Hassiba and Amani, 2013). While circulating the mud, down-hole and returning to the surface, the mud also comes in contact with contaminants (external materials not originally present in the fluids formulation). Drilled solids, cement, salts, and water are very common contaminants. The formation lithology to be drilled influences the type of drilling mud system to be used.

During drilling operations, the mud flows continuously in and out of the wellbore (closed loop) as it performs major functions such as bringing out drilled cuttings from the wellbore to surface, cooling and lubricating the drill bit, removing rock debris and drill cuttings from the site, and providing sufficient hydrostatic pressure against the formation drilled and many others (Nasser et al., 2013; Henaut et al., 2015). The growing need for drilling mud due to very high temperatures and pressures, and the increasing technical demands for regulatory compliance on mud disposal as well as environmental concerns have brought about the evolution of several drilling fluid designs (Khodja et al., 2010). Nevertheless, during drilling operations, the properties of drilling fluids are altered by all kinds of solids and formation liquids (Onojake, and Chikwe, 2019). These contaminants include salts, gypsum/anhydrite, cement amongst others.

The gravity of drilling mud contamination depends majorly on the type of drilling mud used, the type of contaminants and the degree of contamination (Osadolor, 2022). In most drilling operations, cement contamination occurs one or more times when casing strings are cemented (drilling cement after each casing or liner is set) and the plugs are drilled out (Onojake, and Chikwe, 2019). Contaminants alter the chemical and physical properties of the drilling mud which can result in wellbore instability issues. Drilling mud is discarded when contamination is too high such that it is practically unreasonable to treat it out; this situation increases the cost of drilling to operators in the industry. It is therefore important to constantly monitor the properties of drilling mud against contamination to ensure the drilling mud performs optimally. Proper knowledge of drilling mud chemistry, properties, and contaminants is required to perform effective monitoring of drilling mud. This will help oil operators to proffer the right control measures and treatment patterns as drilling progresses.

This paper presents an experimental study on the effects of surface and downhole water contamination on some physical properties of a synthetic oil- based mud (SOBM) system.

2. MATERIALS AND METHODS

2.1. Materials and Equipment

The materials used for the study includes water and pre- formulated drilling mud while the equipment employed include Hamilton beach mixer and its accessories, balance (mud and weighing) meters (Electrical stability and viscosity) and high temperature high pressure filter press.

2.2. Sample Preparation

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

2.3. Determination of Mud Weight, Emulsion Stability, Rheological properties, Gel Strength, Fluid Loss and Oil- water ratio

The procedure for the determination of mud weight, emulsion stability, rheological properties, gel strength, fluid loss and oil- water ratio followed those methods specified in the study conducted by Osadolor et al. (2022)

and Achadu and Osadolor (2023). The processes were repeated for all the mud samples (with 5%, 10%, 15% and 20% water contamination).

Table 1: Characteristics of water used for drilling fluid contamination (Osadolor, 2022)

Parameters	Value
pH	7.41
Electrical conductivity (µs/cm)	460.00
Total dissolved solids (mg/l)	220.00
Total alkalinity (mg/l)	80.00
Bicarbonate alkalinity (mg/l as $CaCO_3$)	80.00
Total hardness (mg/l)	150.00
Calcium hardness (mg/l as $CaCO_3$)	92.00
Magnesium hardness (mg/l as $MgCO_3$)	52.00
Sodium (mg/l)	32.50
Potassium (mg/l)	2.50
Calcium (mg/l)	38.20
Magnesium (mg/l)	13.00
Iron (Fe) (mg/l)	0.06
Fluoride (mg/l)	0.40
Chloride (mg/l)	42.78
Bromide (mg/l)	0.22
Nitrate (mg/l)	9.90
Phosphate (mg/l)	2.12
Sulphate (mg/l)	50.30
Silicates as SiO_2 (mg/l)	3.60

3. RESULTS AND DISCUSSION

The results of the drilling fluid contaminated with water 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.

3.1. Mud Density

Drilling fluid density is usually called mud weight and barite, calcium carbonate or hematite are the agents employed in increasing it, hence the value depends on the amount of these substances present. Mud density 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 base mud (control) was 9.5 lb/gal, while 9.42 lb/gal, 9.4 lb/gal, 9.33 lb/gal and 9.3 lb/gal were recorded for 5%, 10%, 15% and 20% water contaminations respectively. The values for mud density obtained in this study showed a slight decrease in mud density values, which corroborates values obtained by Ebikapaye, (2018), where the effect of temperature caused a decrease in the density of water-based drilling mud, but a disparity in mud density values reported by Broni-Bediako et al (2019) and Biwott et al (2019). It can be observed that the mud weight of the base mud was greater than all the values obtained after contamination. However, from the specified mud program, mud weight range (9.0 lb/gal – 10.0 lb/gal), 5%, 10%, 15% and 20% water contaminations had no significant impact on the mud weight. The results showed a pattern of slight decrease in the mud weight with increase in water incorporated into the system. This implied that as drilling progresses, a constant check of the mud weight is important as a continuous increase in the water contamination can lead to a reduction in the weight of the mud system out of specification.

3.2. 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 value obtained for base mud (control) was 405v, while 360 V, 297 V, 252 V and 240 V were recorded for 5%, 10%, 15% and 20% contaminations respectively. The values for emulsion stability obtained in this study showed a trend similar to that obtained by Kumapayi et al. (2014) and Shadravon (2012), where the effects of extreme high pressure high temperature (HPHT) conditions on invert emulsion drilling fluid caused a decrease in the ES values of the mud after hot rolling at 250 ºF and 400 ºF, it however showed a disparity in ES values obtained by Adekomaya (2013) where an increase in temperature and magnesium saltwater caused an increase in ES values of the mud.

Table 2: Characteristics of water contaminated drilling fluid

Parameters		Base mud	Percentage water contamination				Control (Mud program)
			5% water	10% water	15% water	20% water	
Mud weight (lb/gal)		9.5	9.42	9.4	9.33	9.3	9.0 – 10.0
ES (volts)		405	360	297	252	240	> 350
Shear stress (N/m^2)							
Rheological properties	600 rpm	77	97	111	117	125	
	300 rpm	52	64	73	77	83	
	200 rpm	44	52	58	62	66	
	100 rpm	33	38	41	44	45	
	60 rpm	27	33	34	37	38	
	30 rpm	17	20	23	24	27	
	6 rpm	13	14	17	18	20	12 – 14
	3 rpm	13	14	16	17	20	
	10 (s)	17	19	21	22	25	17 – 20
	10 (m)	27	29	31	32	35	24 – 27
PV (cP)		25	33	38	40	42	15 – 25
YP ($lb/100ft^2$)		27	31	35	37	41	24 – 28
Rs (%)		21	18	15	13	11	
Ro (%)		52	52	52	52	52	
Rw(%)		27	30	33	35	37	
OWR		66/34	63/37	61/39	60/40	58/42	65/35 – 70/30
HTHP FLmls		5 ml	9.2 ml	9.8 ml	10.8 ml	12.0 ml	5 ml

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

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 > 350 V, 5% water contaminations had no significant impact on the ES of the mud performance. The deviations from the values recorded in the control sample were observed in the samples contaminated with 10%, 15% and 20% water. The 20% water contamination had highest deviation. These low values observed in 10%, 15% and 20% contaminations are significant and need attention for the mud to function optimally. The decrease in ES values resulting from increase in water contamination implied that water weakens the emulsion of the mud system. This leads to increase in surface area of the water and makes the water droplets larger, thereby easing the mud system's ability to conduct electricity similar to what was observed in the clay contamination reported by Osadolor et al., (2022). Inferentially, as water contaminants increased (5% - 20%) in the mud system, the emulsion stability of the mud decreased, with no detrimental effect on the emulsion stability until 10% and above in water contaminations.

3.3. 6-rpm Reading

6-rpm is the rheological representation of the mud closest to the formation which indicates the cleanliness of the drilled hole. The values recorded for the base mud (uncontaminated sample) was observed to be 13 cP, while values for 5%, 10%, 15% and 20% contaminations were 14 cP, 17 cP, 18 cP and 20 cP respectively. It was observed that the values of 6-rpm reading displayed similar pattern with mud weight i.e., it increased with increase in the mud contamination. Biwott et al (2019) in an attempt to improve the rheological properties of water-based mud using Moringa oleifera leaves reported that 6-rpm reading of fluid increased with increased concentration of material and Shadravon (2012) recorded an increase in 6 - rpm values, a trend observed in this study. The acceptable reading for 6-rpm is (12-14cP), hence the base mud and 5% water contaminations were on specification while others were off spec. The increase of the 6-rpm reading of the mud system could be attributed to the thickening effect of water which made the mud more viscous thereby causing an up rise in the rheological values of the mud. The intrusion of water in form of contamination also leads to increase in the volume of the mud system and affects the rheological properties of the drilling fluid thereby reducing its efficiency.

3.4. Gel Strength

The measure of the strength of attractive force in drilling mud is referred to gel strengths and are 10-seconds and 10-minutes.

3.4.1. 10- seconds gels

10-seconds of gels reading for the base mud was 17 lb/100ft^2, while those for 5%, 10%, 15% and 20% water contaminated samples were 19 lb/100ft^2, 21 lb/100ft^2, 22 lb/100ft^{2}and 25 lb/100ft^2 respectively. The values for 10-second gels obtained in this study corroborates with the values reported by Biwott et al. (2019), Shadravon (2012) and Broni - Bediako et al. (2019), but greater than values reported by Yunita, et al. (2017), where increase in temperature led to decrease in 10- seconds gels of the mud samples. Like was observed in the clay contamination, the values of 10-seconds gels increased progressively from 17 lb/100ft^2 (0% contamination) to 29 lb/100ft^2 after 20% contamination. The focus range for 10- second gels was (17 lb/100ft^2- 20 lb/100ft^2) as specified in the mud program. Hence, the base mud and 5% water contamination were within specification. The 10%, 15% and 20% water contamination 10- seconds gels value of 21 lb/100ft^2, 22 lb/100ft^2 and 25 lb/100ft^2 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 water 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.

3.4.2. 10 minutes' gels

10- minutes gels reading for base mud (control sample) was 27 lb/100ft^2, while 29 lb/100ft^2, 31 lb/100ft^2, 32 lb/100ft^{2}and 35 lb/100ft^2 were obtained for 5%, 10%, 15% and 20% water contamination respectively. The mud program values for 10- minute gels were 24 lb/100ft^2- 27 lb/100ft^{2}showed that only the base mud (27 lb/100ft^2) was within specified range, just as observed in the clay contamination. All the other values for the various contaminations were higher than the recommended range of values. The values for 10-minute gels showed a similar trend with 10-second gels values and corroborates the works of Biwott et al (2019), Shadravon (2012) and Broni- Bediako et al. (2019), but greater than values obtained by Yunita et al. (2017).

3.5. Plastic Viscosity (PV)

PV is defined as flow resistance occasioned by mechanical friction and is estimated by subtracting the 300-rpm reading from that of 600-rpm reading. The PV value of the base mud was 25 cP, while values for 5%, 10%, 15% and 20% water contamination were 33 cP, 38 cP, 40 cP and 42 cP respectively. The increase in PV occasioned by the increase in clay contamination is in line with the results reported by Biwott et al. (2019), Kumapayi et al. (2014) and Mahmud (2016) who reported that an increase in cement concentration led to an increase in PV value, but greater than results reported by Adekomaya (2013) and Yunita, et al. (2017). The recorded values were also outside the range specified in the mud program (15 - 25 cP), implying that the PV values of all the water contaminated mud samples were outside the acceptable range. The values confirmed that an increase in water intrusion into mud system leads to increase in plastic viscosity.

3.6. Yield Point (YP)

Yield point is the effect of electrochemical forces between the particles that results in resistance to flow and are usually obtained from rheological measurements. The YP value for base mud was 27 lb/100ft^2, while 31 lb/100ft^2, 35 lb/100ft^2, 37 lb/100ft^2 and 41 lb/100ft^2 were recorded for 5%, 10%, 15% and 20% contaminations respectively. Kumapayi et al, (2014)'s YP values also corroborates values obtained in this study but greater than values recorded by Adekomaya (2013) and Yunita, et al. (2017) where a decrease in YP with an increase in contaminations was observed. The values followed similar trend like other parameters. The acceptable value for YP was the range (24 lb/100ft^2- 28 lb/100ft^2), implying that all the values obtained after contamination were greater than the specified range of values. It can therefore be inferred that an increase in water infiltration results to increment in the attractive forces which aggregates or flocculates particles thereby raising the overall number of charges that in turn increases in the yield point.

3.7. Oil-Water Ratio (OWR)

OWR stipulations the various fractions of oil and water in a drilling mud system. This fraction provides the basic information that influences the drilling mud characteristics. This parameter is also critical for evaluating the performance of solids control equipment. The OWR of the base mud was 66/34, while after 5%, 10%, 15% and 20% water contaminations were 63/37, 61/39, 60/40 and 58/42 respectively. These values are less than OWR values recorded after clay contamination reported by Achadu and Osadolor (2023). The OWR values recorded in this study confirmed that as water contamination of the drilling mud increases, OWR decreases accordingly because additional water into the mud system increases the volume and the percentage of water present and this reduces the drilling fluid performance in terms of bringing the drill cuttings to the surface.

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

Regular adjustment of drilling fluid's filtration characteristics is critical to lowering drilled hole conditions and fluid loss into voids in formations. The HPHT often referred to static filtration tests are important for show casing the filter cake properties and filtrate volume loss for drilling fluid under specified testing conditions. The HPHT value of base mud was 5 ml, while the values for 5%, 10%, 15% and 20% water contaminations were 9.2 ml, 9.8 ml, 10.8 ml and 12 ml respectively, this corroborates values obtained after clay contaminations. HPHT values of water contamination showed an increase after water contamination, with loose water present in the filtrate. This was indicated in HPHT FL values recorded in Table 2. The mud program specified the acceptable value of HPHT FL to be ≤ 5 ml, but the values after 5%, 10%, 15% and 20% contaminations were greater than the specified value. This could be attributed to water increment that resulted in the breaking down of the mud emulsion thereby precipitating free water droplets in the mud system. This phenomenon causes a fluid loss rise in the mud system. This was in line with the works of Mahmud (2016), Broni-Bediako et al. (2019), Kumapayi et al. (2014), Shadravon (2012) and Adekomaya (2013) where an increase in temperature led to an increase in the fluid loss, but a disparity in fluid lost after contamination with magnesium saltwater.

4. CONCLUSION

Water can be incorporated into the mud system from surface or sub-surface, thereby causing detrimental effects on the drilling mud properties. A reduction in mud weight was observed, although from 5% - 20% water contamination, the mud weight remained in the acceptable range. Water incorporated into the mud system led to a decrease in the stability of the mud out of acceptable range, which can lead to swelling clay under gauged hole, and could lead to tight hole problems, torque and drag and stuck pipe, increasing operation cost. Increase in rheological properties in the mud out of specification was observed as contamination was increased. Water incorporated into the system from 5% - 20% caused a reduction in the oil- water ratio, i.e., a reduction in the oil volume and an increase in the water volume of the mud system, this can lead to problems like loose water interacting with formation clays, which leads to tight hole problems, reduced lubricity, that could lead to torque and drag. The fluid loss of the mud system increased with an increase in contamination (5% - 20% water) this can lead to too much fluid loss into the formation resulting in thick filter cake, which can cause tight hole problems, torque, and drag, and stuck pipe.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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