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Research Paper

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Effects of Contaminants on the Rheological Properties of Oil Based Muds

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Abstract- Oil based muds obtained from the Niger Delta area of Nigeria were contaminated with various concentrations of salt and cement contaminants. Molar concentrations of 1.0 M, 3.0 M, 5.0 M, 7.0 M and 10.0 M of salt as well as those of cement were introduced into 10.0 Liters of the Oil based mud respectively with the molar concentrations corresponding to 10.0%, 30.0%, 50.0 %, 70.0% and 100.0 % of the contaminated mud system. The Rheological properties of the contaminated Oil base muds were determined with the use of a Fann Model 35 Viscometer. Results obtained showed that the Plastic viscosity and the Gel strengths of the Oil based mud contaminated with 30.0 % salt solution were within American Association of Drilling Engineers (AADE) specification while only 10.0 % of the cement contaminated Oil based mud fell within AADE specification in terms of Plastic viscosity and Gel strengths, also 50.0 % of both salt and cement contaminated Oil based mud were within AADE specification in terms of Yield point. The salt used as contaminant was sodium chloride (NaCl) while the cement used was portland cement with chemical composition $3CaO.SiO_2$, $2CaO.SiO_2$, $3CaO.Al_2O_3$ and $4CaO.Al_2O_3FeO_3$ and the rheological properties (Plastic Viscosity, Yield point and Gel strengths) generally increased with increase in concentration of the contaminants however results obtained from Pearson's correlation coefficient analyses showed that the rate of increase was higher with the cement contaminant indicating that cement has a more devastating effect on the mud properties compared to salt.

Keywords- Plastic viscosity; yield point; gel strength; drilling; salt; cement.

I. INTRODUCTION

The ultimate success of any drilling operation is highly dependent on the ability to meet certain key requirements. Crude oil exploration which basically involves drilling operations were achieved in the nineteenth century with the use of continuous circulation systems using water however, the use of water alone as a drilling fluid was only partially successful at removing drill cuttings because of its limitations in accessing Well depth of several kilometers. While these drilling fluids were suitable for early exploration works, they suffer negative interactions with some formations as they go deeper in to the Wells due to poor temperature stability and lack of lubricity to drill at an incline [1, 2]. Drilling muds or fluids are complex heterogeneous fluids that consists of several additives, employed in drilling oil and natural gas wells [3]. The transportation of drill cuttings to the surface were the original use of drilling muds however progress in drilling Engineering demanded more sophistication from the drilling mud in order to enhance its functions to include prevention of well-control challenges, wellbore stability, reduction of damage to formation, lubricating and cooling of drill string as well as providing information about the wellbore [4]. The physical and chemical properties of drilling muds are highly dependent on the type of solids in the mud, these solids are categorized as either active or inactive depending on their level of interaction with the continuous phase of the fluid [5]. Drilling fluids are classified into water based muds (which was initially used during the early years of drilling operation) and oil based mud depending on the nature of the continuous phase of the fluid. Water is the continuous phase for water based muds while oil is the continuous phase for oil based muds [6].

II. RELATED WORK

The use of oil based fluid instead of water not only increases the lubricity of the crude but also significantly eliminates the problems of shale interactions during deeper drilling operations. Initially, diesel was the continuous phase of the base fluid for oil based muds but with increasing awareness of the health risks there has been a move to replace diesel with low toxicity oils like highly refined petroleum based oils, synthesized oils and non-petroleum oils [7]. Drilling muds either oil or water based is essential in the drilling program of every successful drilling operation. Factors that negatively affect the rheological properties of the drilling mud are capable of impairing the down hole performance of the mud thereby resulting in serious drilling problems. The physical properties of the mud as well as its rheological properties must be consistently monitored to optimize the drilling process [8]. Rheology is the science of deformation and flow of matter, it is primarily concerned with the relationship between shear rate / stress and their impact on the flow characteristics of the mud inside tubular and annular spaces [2]. The most prevalent problem affecting drilling muds is the potential destruction of the mud properties under elevated temperatures and pressures as well as the presence of contaminants [9]. Due to the presence of contaminants as well as temperature and pressure effect, the rheology, visco- elastic and physical properties of the drilling muds changes and as a result the performance of drilling fluids are negatively affected [8]. Contaminants are foreign bodies or impurities that alter the properties of a substance. In drilling fluids, a contaminant is any substance that causes undesirable changes in the drilling mud properties [10]. In general, solids are by far the most dominant contaminant in drilling fluids. When these solids are in abundance whether from the formation or from drilling mud building process, the rheological properties are greatly affected hence, slowing the drilling process [6]. During drilling operation, the drilling mud picks up contaminants such as salts, drilled solids, and cement. Instability in drilling mud properties arises due to various contaminants incorporated in the mud system, hence a high concentration of contaminants in a drilling mud causes detrimental effects on its performance [11]. The aim of this study is to determine the effects of various concentrations of contaminants (salt and cement) on the rheological properties of oil based muds, this will be critical in developing ways of minimizing their exposure with the muds considering the fact that contact between drilling muds and some of these contaminants during drilling operations is inevitable.

III. METHODOLOGY

Sample Collection and Preparation

Oil based mud (OBM) was obtained from the mud tank in a drilling site in Delta State, Nigeria. The salt and cement solution used as contaminants were prepared in the Laboratory at different molar concentrations of 1.0M, 3.0M, 5.0M, 7.0M and 10.0M respectively and then used to contaminate 10 Liters of the oil based mud (OBM) at a mixing ratio of 10%, 30%, 50%, 70% and 100% corresponding to each molar concentration. The contaminated OBM was left for two hours, thereafter introduced into a Fann Model 35 Viscometer. The salt used as contaminant was sodium chloride (NaCl) while the cement used was portland cement with chemical composition $3CaO.SiO_2$, $2CaO.SiO_2$, $3CaO.Al_2O_3$ and $4CaO.Al_2O_3FeO_3$ representing tricalcium silicate, dicalcium silicate, tricalcium aluminate and tetra-calcium aluminoferrite respectively. The dial readings of the various samples were obtained by the use of a Fann Viscometer at readings 600, 300, 200, 100, 60, 30 and 3 rpm (revolutions per minute) as indicated by American Association of Drilling Engineers (AADE) determine the rheological properties of mud samples.

Determination of Plastic Viscosity (PV) of OBM

Each of the different salt and cement contaminated OBM was introduced into the thermal cup of the viscometer respectively and placed on a viscometer stand. The thermal cup which was two third filled with contaminated OBM was heated to a temperature of 120 ^{0}F and the red knob on top of the viscometer was adjusted to a speed of 600 rpm to obtain readings. The experiment was repeated to obtain readings for 300rpm, 200rpm, 100rpm, 6rpm, and 3rpm. The difference between 600 rpm and 300 rpm dial readings is the Plastic viscosity (Pv) in centipoise as calculated in equation 1 below:

$$Pv = \theta 600 - \theta 300 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where: Pv = Plastic Viscosity (centipoise)
θ600 = Dial reading at 600 rpm
θ300 = Dial reading at 300 rpm

Determination of Yield Point (YP) of OBM

The same procedure employed in the determination of PV was also employed for the determination of YP however the red knob of the viscometer was turned to a speed of 300 rpm and then subtracted from the PV to obtain the YP which is measured in lb/100ft^2 as calculated in equation 2:

$$YP = \theta 300 - Pv \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where: YP = Yield Point (Ib/100ft2)
θ300 = Dial reading at 300 rpm
Pv = Plastic Viscosity (centipoise)

Determination of Gel Strength (GS) of OBM

Each of the sample from the previous procedure was stirred at 600 rpm for about 15 seconds, the knob was turned to the STOP position and the mud sample was allowed to rest at 10 seconds and 10 minutes after which the knob was switched to the gel position. The maximum deflection of the dial before the gel breaks is recorded as the GS in lb/100ft^2. The 1st and 2nd GS were obtained at 10 seconds and 10 minutes respectively

All the dial readings were recorded as shear stress (τ) by adding 1.067 to the dial reading as shown in equation 3:

$$\tau = Dial\ reading + 1.067 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3)$$

A typical viscometer used in determining the rheological properties of drilling muds is shown in figure 1.

Fig. 1: Fann Model 35 Viscometer

IV. RESULTS AND DISCUSSION

Table-1, Rheological Properties of Contaminated OBM at Different Salt Concentrations

Rheology @ 120 ^{0}F	1.0 M	3.0 M	5.0 M	7.0 M	10.0 M	AADE Specification
600 rpm	52	68	79	99	118	50.00-65.00
300 rpm	27	39	47	66	80	25.00-45.00
200 rpm	22	34	40	56	62	15.00-35.00
100 rpm	15	21	33	43	55	10.00-25.00
6 rpm	7	11	20	29	38	7.00-12.00
3 rpm	6	7	11	18	20	5.00-7.00
1st Gel strength (Ib/100ft2)	8	12	15	18	21	7.00-12.00
2nd Gel strength (Ib/100ft2)	17	28	37	46	55	15.00-30.00
Plastic viscosity (cP)	25	29	32	33	38	15.00-30.00
Yield point (Ib/100ft2)	2	10	15	33	42	5.00-30.00

Table-2, Rheological Properties of Contaminated OBM at Different Cement Concentrations

Rheology @ 120 ^{0}F	1.0 M	3.0 M	5.0 M	7.0 M	10.0 M	AADE Specification
600 rpm	58	72	85	105	125	50.00-65.00
300 rpm	32	40	52	70	84	25.00-45.00
200 rpm	25	37	44	61	73	15.00-35.00
100 rpm	19	23	37	48	60	10.00-25.00
6 rpm	10	16	21	33	45	7.00-12.00
3 rpm	8	12	20	28	37	5.00-7.00
1st Gel strength (Ib/100ft2)	11	15	19	22	25	7.00-12.00
2nd Gel strength (Ib/100ft2)	22	33	40	49	62	15.00-30.00
Plastic viscosity (cP)	26	32	33	35	41	15.00-30.00
Yield point (Ib/100ft2)	4	12	19	35	43	5.00-30.00

Table-3, Correlation of the Rheological Properties of Salt Contaminated OBM

Rheology @ 120°F	10.0 M (X)	1.0 M (Y)	X - M_X	Y - My	$(X - M_X)^2$	$(Y-My)^2$	$(X - M_X)(Y-My)$
600 rpm	118.000	52.000	65.100	33.900	4238.010	1149.210	2206.890
300 rpm	80.000	27.000	27.100	8.900	734.410	79.210	241.190
200 rpm	62.000	22.000	9.100	9.900	82.810	15.210	35.490
100 rpm	55.000	15.000	2.100	-3.100	4.410	9.610	-6.510
6 rpm	38.000	7.000	-14.900	-11.100	222.010	123.210	165.390
3 rpm	20.000	6.000	-32.900	-12.100	1082.410	146.410	398.090
1st Gel strength	21.000	8.000	-31.900	-10.100	1017.610	102.010	322.190
2nd Gel strength	55.000	17.000	-2.100	-1.100	4.410	1.210	-2.310
Plastic viscosity	38.000	25.000	-14.900	6.900	222.010	47.610	-102.810
Yield point	42.000	2.000	-10.900	-16.100	118.810	259.210	175.490

Mx: Mean of X = 52.900, My: Mean of Y = 18.100, $\sum(X - Mx)(Y - My) = 3433.100$, $\sum(X - Mx)^2 = 7726.900$, $\sum(Y-My)^2 = 1932.900$
Pearson correlation coefficient (R) = 0.8883, Coefficient of determination (R^2) = 0.7891.

Table-4, Correlation of the Rheological Properties of Cement Contaminated OBM

Rheology @ 120°F	Ave. (X)	Spec. (Y)	X - M_X	Y - My	$(X - M_X)^2$	$(Y-My)^2$	$(X - M_X)(Y-My)$
600 rpm	125.000	58.000	65.500	36.500	4290.250	1332.250	2390.750
300 rpm	84.000	32.000	24.500	10.500	600.250	110.250	257.250
200 rpm	73.000	25.000	13.500	3.500	182.250	12.250	47.250
100 rpm	60.000	19.000	0.500	-2.500	0.250	6.250	-1.250
6 rpm	45.000	10.000	-14.500	-11.500	210.250	132.250	166.750
3 rpm	37.000	8.000	-22.500	-13.500	506.250	182.250	303.750
1st Gel strength	25.000	11.000	-34.500	-10.500	1190.250	110.250	362.250
2nd Gel strength	62.000	22.000	2.500	0.500	6.250	0.250	1.250
Plastic viscosity	41.000	26.000	-18.500	4.500	342.250	20.250	-83.250
Yield point	43.000	4.000	-16.500	-17.500	272.250	306.250	288.750

Mx: Mean of X = 59.500, My: Mean of Y = 21.500, $\sum(X - Mx)(Y - My) = 3733.100$, $\sum(X - Mx)^2 = 7600.500$, $\sum(Y-My)^2 = 2212.500$
Pearson correlation coefficient (R) = 0.9104, Coefficient of determination (R^2) = 0.8288.

$$R = \frac{\sum(X - Mx)(Y - My)}{\sqrt{\sum(X - Mx)^2 \sum(Y - My)^2}} \qquad (4)$$

The rheological properties of drilling muds are essential in evaluating the suitability of the muds in carrying out its functions. It is critical to ensure that the rheological properties of drilling muds are within specification based on international standards as a failure to do so could lead to loss of money, time and in extreme cases abandonment of the Well [8]. Rheological properties of drilling muds such as Plastic viscosity and yield point are obtained from the relationship between the shear rates of the rotational viscometer in revolutions per minute (rpm) and the shear stress of the dial readings which can be calculated using equation 3. 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 common for most rotational viscometer while shear stress is a function of the shear rate expressed in units of force per unit area [12]. Oil based muds (OBM) are non-Newtonian fluids because no linear constant proportionality exist between the shear rate and the shear stress. Non Newtonian fluids are further classified into sub models, the sub models of most interest in drilling fluid technology are Bingham plastic, power-law and Herschel-Bulkley models, it is worthy to note that most drilling fluids are not described by a single model rather a combination of models, however the OBM properties (Plastic viscosity, Yield point and Gel strength) in this study are Bingham Plastic parameters [1]. Table 1 shows the impact of various salt concentrations on the rheological properties of drilling mud while Table 2 shows the impact of various

cement concentrations on these rheological properties. The choice of salt (NaCl) and cement as contaminants of the OBM was borne out of the fact that they form part of the components easily encountered by the muds during drilling operations. Sodium chloride (NaCl) is the major constituent of brine which is usually found during drilling of oil wells and it is the most common salt encountered during drilling operations while the chemical components of portland cement is similar with those in down- hole well casings [10, 13]. Plastic viscosity of a drilling mud is theoretically the minimum viscosity a mud could have as the shear rate approaches infinity, it relates to the resistance to flow due to inter-particle friction caused by the quantity of solids in the mud, size and shape of those solids as well as the viscosity of the continuous liquid phase [14]. The Yield point of a drilling mud is the yield stress extrapolated to a shear rate of zero, it practically means the minimum stress that must be applied to a material to enable it flow, on the other hand the Gel strength is the shear stress measured at low shear rate after the drilling mud is static for a certain period of time, it is one of the important drilling fluid properties because it demonstrates the ability of the drilling mud to suspend drill solids and weighting material when circulation is ceased [15]. At least two readings were obtained for the gel strength as shown in Tables 1 and 2, the first reading was recorded after the mud has been static for 10 seconds while the second reading was recorded after 10 minutes.
Table 1 and 2 show that the Plastic viscosity, Yield point and Gel strength of the OBM increased with increase in the salt and cement concentrations. The higher the concentration of the salt and cement contaminants, the higher the rheological properties of the OBM. From Table 1 it can be deduced that only a maximum of 30% salt contaminated OBM corresponding to 3.0 M (molar concentration) fell within AADE specification in terms of Plastic viscosity whereas only 10% salt contaminated OBM were within AADE specification in terms of 1st and 2nd gel strengths. Table 1 also showed that up to 50% salt contaminated OBM corresponding to 5.0 M fell within AADE specification with respect to Yield point. From Table 2 it can be deduced that only a maximum of 10 % cement contaminated OBM corresponding to 1.0 M (molar concentration) fell within AADE (American Association for Drilling Engineers) specification in terms of Plastic viscosity whereas only 10 % cement contaminated OBM were within AADE specification in terms of 1st and 2nd gel strengths. From Table 2 it can be deduced just like Table 1 that only a maximum of 50 % cement contaminated OBM corresponding to 5.0 M fell within AADE specification with respect to Yield point [16]. In order to appreciate the impact of the salt contaminants on the OBM, the rheological properties of 100 % salt contaminated OBM corresponding to 10.0 M were correlated with the rheological properties of 10 % salt contaminated OBM as shown in Table 3, this correlation was based on the fact that all the rheological properties of the 10 % salt contaminated OBM were within AADE specification. The same correlation was done between 100 % cement contaminated OBM and 10 % cement contaminated OBM as shown in Table 4. Results obtained from both Table 3 and 4 showed a very strong correlation between both properties however a stronger correlation was observed in the cement contaminated OBM as shown by the value of the Pearson's correlation coefficient (R) which is higher than that for the salt contaminated OBM. A positive correlation depicted by the value of R as calculated using equation 4 implies that an increase in the molar concentration of the contaminants led to an increase in the rheological properties of the OBM with the strength of the increase determined by the numerical value of R. Comparing Tables 3 and 4 it can be concluded that the impact of cement contaminants on the rheological properties of the OBM is higher than the impact of the salt contaminants considering the fact that both contaminants were introduced to the OBM at equal concentrations. Salt (NaCl) and cement can cause a lot of damage to the OBM ranging from lowering the pH to flocculating the mud system thereby reducing the drilling rate and the higher the concentration of these contaminants the more devastating their impacts. The harmful effect of salt on a drilling mud is due to the increased ionic concentration which changes the charge distribution at the clay surfaces on the other hand it is the calcium ions in cement reacting with solids that causes most difficulties involved in cement contamination [7, 9].

V. CONCLUSION AND FUTURE SCOPE

The impact of contamination on the characteristics of an Oil based mud and indeed all drilling muds is highly dependent on the type of solid as well as the concentration of the contaminants. In order for drilling muds to perform functions such as transportation of cuttings to the surface, cooling and lubrication of drill bit, exert hydrostatic pressure, prevent corrosion etc such drilling muds must be free from contaminants. The presence of salt and cement contaminants in oil based muds increases the rheological properties such as plastic viscosity, yield point and gel strengths of the drilling mud which ultimately results in flocculation of the mud system, lowering of mud pH etc. The higher the concentration of the salt and cement contaminants the higher the negative impacts on the mud system with the cement contaminant having a more devastating impact on mud properties. Future research will focus on reducing the negative impacts of these inevitable contaminants on mud properties in other to save the life of the wells.

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