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OPTIMIZATION OF THE VISCOSITY AND YIELD POINT OF OIL-BASED MUD PRODUCED USING TREATED OHUBO CLAY ADDITIVE

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Abstract - This work focused on the optimization of the viscosity and yield point ofoil-basedmud (OBM) formulated using Ohubo clay as an additive. The locally sourced Ohubo clay samplewas processed and characterized. As such, elemental compositionsof the untreated and treated clay samples were determined. Then, oil-based mud was formulated, and the viscosity and yield point were evaluated. They were optimized by response surface methodology (RSM). Analysis of the elemental composition of Ohubo clay revealed high values of oxygen (O), aluminum, silicon, calcium, and minor values for other trace elements. Recorded high values of silicon and oxygen show the presence of a silicate compound typical of kaolinitic clay. Variations in percentages of the elements of untreated and treated Ohubo clay samples indicate that the treatment process enhanced the quality of the Ohubo clay.The rheology of the mud, including viscosity and yield point, was displayed as functions of temperature, time, and Ohubo clay dosage.The quadratic equation effectively explained the link between the responses and the considered factors.The optimum viscosity of mud with Ohubo clay additive was revealed as 18.27 cP. Its corresponding optimum yield pointwas recorded as 27.96 lb/100 ft2. These values are within the API standard. As such, the oil-based mud (OBM) formulated is suitable for drilling operations. It is highly recommended that treated Ohubo clay should be applied as a substitute for the usually imported bentonite additive.
Keywords: Ohubo clay, viscosity, yield point. OBM

1. Introduction

Nigeria is the ninth-largest crude oil exporter in the world. Through the drilling of hundreds of oil wells in the Niger Delta region, Nigeria generates more than two million barrels of crude oil every day. To drill any of these oil wells, drilling fluid/mud with the additive of bentonite is often required. It serves the following functions:floats and lifts drilled cuttings out of the well, regulates the down-hole temperature, lubricates the drilling bit, stops corrosion, and stabilizes the hole wall from collapsing. The oil corporations in Nigeria are spending a significant amount of money on importing millions of tons of bentonite from outside to drill oil wells (Chai et al, 2016; Jongs et al, 2018;Udeagbara et al, 2019). The cleaning performance of bentonite is affected by many factors such as fluid viscosity, annular flow velocity, angle of inclination, and drill cutting size and shape (Ahmed et al., 2018). There is a need to process and treat local clay for the replacement of the imported bentonite, as Nigeria is blessed with large clay deposits.

As more researchers looked into how drilling mud affected the formations being drilled, it became evident that drilling mud chemistry was crucial and that drilling muds caused issues like invasion, well bore narrowing, decreased formulation permeability, and general well productivity declines, all of which were then seen in the majority of producing wells. The chemistry of drilling mud is extremely complex and, regrettably, not fully understood. This should not be viewed as a shortcoming specific to this business, as it is true of field surface chemistry in general. As a result, it was discovered that the permeability of the rock surrounding the well bore decreased regardless of the type of mud utilized; this validates the presence of formation damage (Onyemaleze et al, 2016).

There are several research reports on drilling mud (Ibrahim et al, 2017; Vryzas et al, 2017). Most of the reports are of the potential replacement of imported bentonite with local clay. For instance, Omohimoria and Falade (2017) investigated the comparative rheological characteristics of local clay (Afuze) as a potential substitute for imported bentonite in the composition of drilling fluids. The result obtained showed that therewas a slight difference in the rheological properties of the formulated drilling mud when compared to thoseof bentonite. Also,Ameloko et al. (2020) reported the assessment of clay materials for suitability in drilling mud formulation from Ondo State, South-East Nigeria. It was found that the rheological and flow characteristics of mud samples were affected by the addition of polymer (CMC), the beneficiation of local bentonite with sodium carbonate, and an increase in clay concentration. In the available research reports, there is a lack of optimum parameters on drilling mud production using local clay from Ohubo, the southeastern part of Nigeria. Most previousresearchhas primarily focused on bentonite and montmorillonite clays as viscosifiers. This study is therefore aimed at optimizing the viscosity and yield point of oil-based mud produced using treated Ohubo clay additive.

2 Materials and Methods

2.1 Treatment of the clay

The clay used in this studywasobtained from Ohubo in Nkanu-East of Enugu State.Itwas processed through the following treatment steps: crushing of the raw clay, slurry (with addition of water), screening, dewatering, drying, crushing, milling/pulverizing, and packaging. The process followed the standard method used by Nlemedim et al (2023), where the clay was treated using a leaching method with 1.0M H_2SO_4. By this procedure, the powdered clay was sieved into very fine particles (0.05mm). 600.00g of the fine particles was obtained through the screening process. A 250 ml flask with a flat bottom was then filled with 40.00g of the fine clay sample and 180 ml of 1.0M H_2SO_4. For one hour, the mixture was heated to 95 degrees Celsius using a magnetic stirrer. After that, the mixture was repeatedly rinsed with distilled water to entirely remove the acid, which was successfully done by testing it with a blue litmus paper. The resulting slurry was filtered, dried, and ground into powder form. The procedure above, about the clay treatment, was repeated to get a mass of 520g of the treated clay sample.

2.2 Determination of the elemental composition of the Ohubo clay

The clay sample was subjected to quantitative analysis utilizing energy-dispersive X-ray fluorescence (EDXRF) spectroscopy. The elemental contents of the sample were determined by chemical analysis (Igwilo et al, 2020). The sample was placed in the spectrometer's sample holder and exposed to high-energy X-ray radiation from the controlled X-ray tube. In the spectrum graph of X-ray intensity as a function of the peaks, XRF peaks of different intensities were revealed. Additionally, percentage concentrations of various components of the sample's overall concentration were used to express its chemical composition.

2.3 Formulation of the muds

The techniques used for manufacture and the assessment of the drilling mud's rheological characteristics were performed using API drilling mud production standards (API, 2000;Nlemedim et al, 2023; Omotioma et al, 2024). Measured raw materials were poured, one after the other, with an interval of 5 minutes, into the steel cup of the single-spindle mixer. The addition of the raw materials was performed in the order of 200 mL diesel, 10g clay, 0.3g xanthium gum biopolymer, 0.5g high viscosity polyanionic cellulose, and13.0g barite. After the materials were fully incorporated into the steel mixer cup, it was left to mix for 35 minutes while being stirred.

On the optimization process, interactive effects of the factors of dosage of the Ohubo clay, time, and temperature onplastic viscosity(V) and yield point of the mud were determined by response surface methodology (RSM) as shown in Table 2. In the process, Design Expert software version 11 was used to design the experiment. The plastic viscosity and yield point of the mud were calculated using Equations (1) and (2), respectively (Omotioma et al, 2014; Nlemedim et al, 2023):

V = 600 RPM reading - 300 RPM reading (1)

YP = 300 RPM reading –V (2)

3. Results and Discussion

3.1 Elemental composition of the clay samples as determined by XRF

Elemental compositions of the untreated and treated Ohubo clay samples, as determined by XRF (X-Ray Fluorescence),are shown in Table 1. In it, Ca, Ti, V, Cr, O, Cu, Zn, Al, Si, S, Cl, K, Mn, Fe, Co, Rb, Sr, Zr, Nb, Ag, Ta, and Ba are predominant elements revealed in the form of percentages. High values of oxygen (O), aluminum (Al), silicon (Si), calcium (Ca), and a minor value for other trace elements were shown. The high values of silicon and oxygen show the presence of a silicate compound typical of kaolinitic clay. Variations in percentages of the elements of untreated and treated Ohubo clay samples show that the treatment process enhanced the quality of the clay. This assertion is in line with the report of Igwilo et al(2020).

Table 1: XRF results (Elemental compositions)

Element	Untreated Ohubo clay	Treated Ohubo clay
Ag	0.036	0.014
Al	7.089	7.278
Ba	0.092	0.087
Ca	0.227	0.209
Cl	0.906	0.774
Co	0.013	0.011
Cr	0.049	0.049
Cu	0.035	0.033
Fe	1.933	1.921
K	2.353	2.349
Mg	- - - - -	- - - - -
Mn	0.021	0.022
Mo	- - - - -	0.002
Na	- - - - -	0.846
Nb	0.011	0.011
Ni	0.002	- - - - -
O	49.717	49.484
P	0.030	- - - - -
Rb	0.017	0.016
S	0.032	0.071
Si	36.002	35.394
Sn	- - - - -	- - - - -
Sr	0.008	0.007
Ta	0.034	0.039
Ti	1.037	1.026

V	0.048	0.044
W	- - - - -	- - - - -
Zn	0.011	0.008
Zr	0.300	0.302

3.2 RSM results of the rheological properties (viscosities and yield point) of the mud

The RSM result of Table 2 demonstrates how the process variables interact to affect the mud's viscosity and yield point. The viscosities and yield point of the mud are shown in the RSM findings as a function of temperature, time, and dosage of Ohubo clay. For more thorough information on the link between the variables and the viscosity/yield point of the mud, additional analyses, including mathematical modeling, diagnostic analysis, and graphical plots,were utilized as revealed in thenextsection.

Table 2: RSM result of OBM with Ohubo clay

Std	Run.	Factor1 A: C. dosage, wt%	Factor 2 B: Temp, K	Factor 3 C: T, min.	Response 1 V, cP	Response 2 YP, lb/100 ft2
7	1	5	323	40	14.63	24.14
17	2	7	313	35	18.37	28.13
6	3	9	303	40	12.49	22.01
15	4	7	313	35	18.37	28.13
3	5	5	323	30	11.38	20.88
2	6	9	303	30	13.42	23.02
20	7	7	313	35	18.37	28.13
13	8	7	313	30	16.39	25.97
4	9	9	323	30	10.33	19.37
12	10	7	323	35	16.15	25.69
10	11	9	313	35	15.51	25.03
5	12	5	303	40	14.98	24.47
18	13	7	313	35	18.37	28.13
9	14	5	313	35	15.79	25.31
16	15	7	313	35	18.37	28.13
8	16	9	323	40	11.29	20.79
14	17	7	313	40	18.31	27.69
11	18	7	303	35	16.52	25.99
1	19	5	303	30	12.69	22.17
19	20	7	313	35	18.37	28.13

3.2.1 Mathematical models of the viscosity and yield point

Equations3 to 4 are the viscosity and yield point mathematical models, which expresses the relationship between the dependent and independent variables. The largest index of the variables is two, making the model a quadratic one. It is possible to anticipate the reaction for specific levels of each element using the model expressed in terms of coded factors. By comparing the factor coefficients, the coded Eqn. can be used to determine the relative importance of the variable under consideration (Omotioma et al, 2024). The positive sign in each mathematical model symbolizes synergic effect, while the negative sign means an antagonistic effect.

Mathematical model of viscosity (V) of OBM with Ohubo clay:

$$V = +18.36 - 0.6430A - 0.6320B + 0.7490C - 0.3288AB - 0.6888AC + 0.3562BC - 2.70A^2 - 2.01B^2 - 0.9995C^2 \quad (3)$$

Mathematical model of yield point (YP) of OBM with Ohubo clay:

$$YP = +28.05-0.6750A-0.6790B+0.7690C-0.4063AB-0.6438AC+0.4237BC-2.77A^2-2.10B^2-1.11C^2 \quad (4)$$

3.2.2 Diagnostic Reports of the RSM analysis

The Diagnostic Report of the RSM analysis is shown in Table 3. It shows how the actual experimental value compares with the predicted value. This was based on the values of residual, leverage, Cook's distance, and difference of fits (DFFITS). The results show that the predicted viscosities and yield points are highly correlated with the experimental ones. This is an indication that the model generated by the RSM effectively explained the relationship between the response and the considered factors.

Table 3: Diagnostic report of OBM with Viscosity of Ohubo clay

Actual Value (cP)	Predicted Value (cP)	Residual	Leverage	Internally Studentized Residuals	Externally Studentized Residuals	Cook's Distance	Influence on Fitted Value DFFITS
14.63	14.78	-0.1519	0.793	-0.908	-0.900	0.316	-1.762
18.37	18.36	0.0082	0.118	0.024	0.022	0.000	0.008
12.49	12.67	-0.1799	0.793	-1.076	-1.085	0.444	-2.125
18.37	18.36	0.0082	0.118	0.024	0.022	0.000	0.008
11.38	11.19	0.1861	0.793	1.112	1.127	0.475	2.208
13.42	13.26	0.1581	0.793	0.945	0.939	0.342	1.840
18.37	18.36	0.0082	0.118	0.024	0.022	0.000	0.008
16.39	16.61	-0.2233	0.491	-0.851	-0.838	0.070	-0.823
10.33	10.63	-0.2979	0.793	-1.781	-2.045	1.217	-4.005
16.15	15.72	0.4347	0.491	1.657	1.845	0.265	1.812
15.51	15.02	0.4907	0.491	1.870	2.200	0.337	2.160
14.98	14.68	0.3041	0.793	1.818	2.108	1.267	4.127
18.37	18.36	0.0082	0.118	0.024	0.022	0.000	0.008
15.79	16.31	-0.5153	0.491	-1.963	-2.376	0.372	-2.333
18.37	18.36	0.0082	0.118	0.024	0.022	0.000	0.008
11.29	11.46	-0.1709	0.793	-1.022	-1.024	0.400	-2.006
18.31	18.11	0.1987	0.491	0.757	0.740	0.055	0.727
16.52	16.98	-0.4593	0.491	-1.750	-1.993	0.295	-1.957
12.69	12.51	0.1771	0.793	1.059	1.066	0.430	2.087
18.37	18.36	0.0082	0.118	0.024	0.022	0.000	0.008

Table 3: Diagnostic report of OBM with yield point of Ohubo clay

Actual Valuelb/100 ft2	Predicted Valuelb/100 ft2	Residual	Leverage	Internally Studentized Residuals	Externally Studentized Residuals	Cook's Distance	Influence on Fitted Value DFFITS
24.14	24.32	-0.1763	0.793	-0.907	-0.898	0.315	-1.759
28.13	28.05	0.0765	0.118	0.191	0.181	0.000	0.066
22.01	22.19	-0.1793	0.793	-0.922	-0.915	0.326	-1.792
28.13	28.05	0.0765	0.118	0.191	0.181	0.000	0.066
20.88	20.64	0.2367	0.793	1.218	1.252	0.569	2.452
23.02	22.79	0.2337	0.793	1.202	1.233	0.554	2.415
28.13	28.05	0.0765	0.118	0.191	0.181	0.000	0.066

25.97	26.18	-0.2058	0.491	-0.675	-0.655	0.044	-0.644
19.37	19.77	-0.3983	0.793	-2.049	-2.552	1.610	-4.998
25.69	25.28	0.4142	0.491	1.358	1.427	0.178	1.401
25.03	24.61	0.4202	0.491	1.378	1.452	0.183	1.426
24.47	24.01	0.4557	0.793	2.344	3.314	2.108	6.490
28.13	28.05	0.0765	0.118	0.191	0.181	0.000	0.066
25.31	25.96	-0.6498	0.491	-2.131	-2.736	0.438	-2.687
28.13	28.05	0.0765	0.118	0.191	0.181	0.000	0.066
20.79	20.87	-0.0763	0.793	-0.393	-0.375	0.059	-0.735
27.69	27.71	-0.0238	0.491	-0.078	-0.074	0.001	-0.073
25.99	26.63	-0.6438	0.491	-2.111	-2.690	0.430	-2.642
22.17	22.04	0.1337	0.793	0.688	0.669	0.181	1.309
28.13	28.05	0.0765	0.118	0.191	0.181	0.000	0.066

3.2.3 Three-dimensional plots of the RSM Results

Three-dimensional plots of the RSM Results are presented in Figures 1 – 6. The 3-D plots demonstrated the interactive effects of process variables on the viscosity (V) and yield point (YP) of the muds; each of the plots displayed a parabolic curve, which is the ideal representation of a quadratic equation; the optimum V and YP of the mud were also revealed along with optimum process variables. In Figure 1, as the temperature increases, the viscosity increases until the optimum temperature of 313k before viscosity starts decreasing. On the other hand, as the clay dosage increases, viscosity increases until the optimum dosage of 7 wt%, before viscosity starts decreasing. This implies that high temperatures and high clay dosage negatively affect the viscosity of the drilling mud formulation. Figure 2 shows the interaction of time and clay dosage on viscosity. Viscosity increases with an increase in time. Figure 3 is the interaction of temperature and time on viscosity of the formulated mud which confirms that high temperature decreases the viscosity, and an increase in time favours the viscosity of the formulated mud. Figures 4 to 6 followed the same pattern seen in figures 1 to 3 for the yield point of the formulated mud.

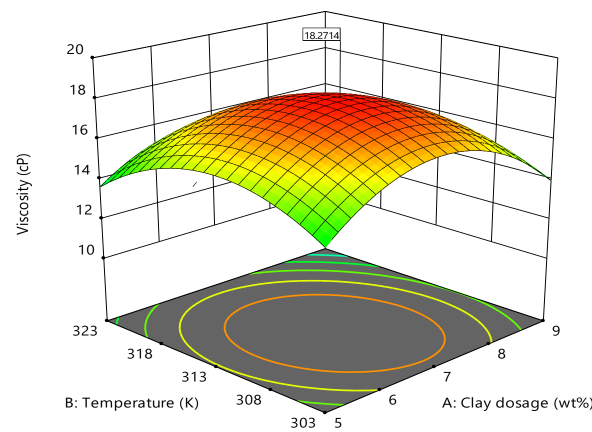

Figure 1: Clay dosage and temperature influence on the mud's Viscosity

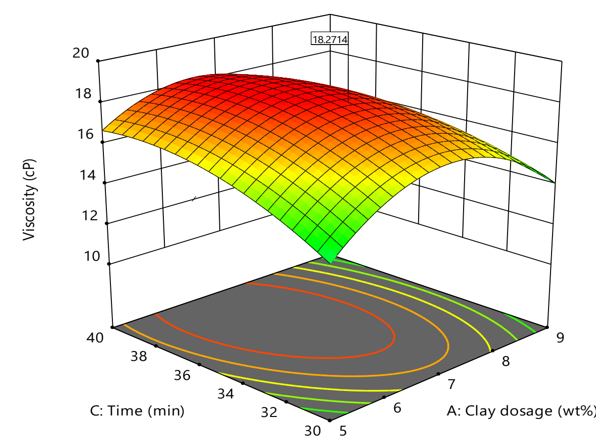

Figure 2: Clay dosage and time influence on the mud's Viscosity

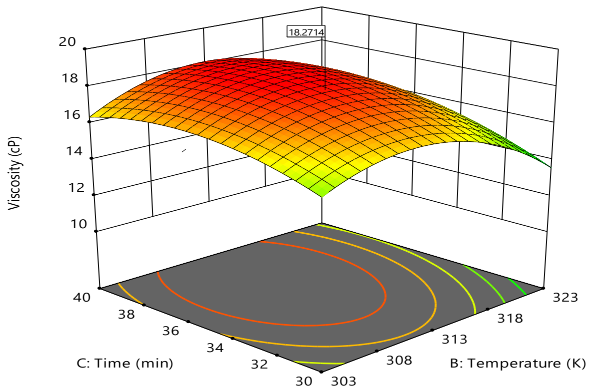

Figure 3: Temperature and time influence on the mud's Viscosity

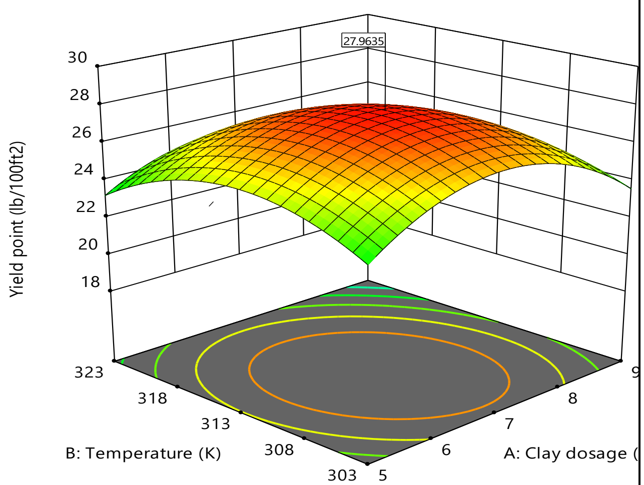

Figure 4: Clay dosage and temperature influence on the mud's yield point

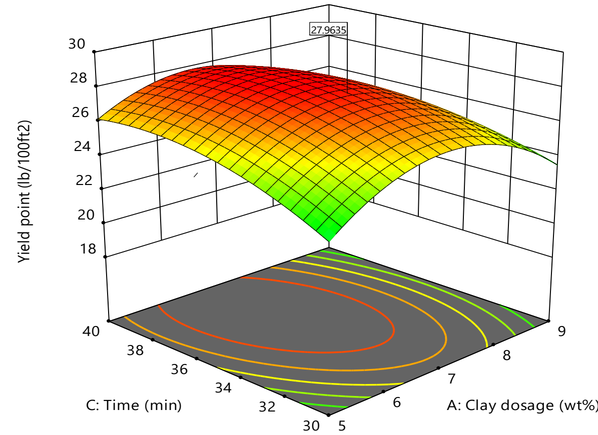

Figure 5: Clay dosage and time influence on the mud's yield point

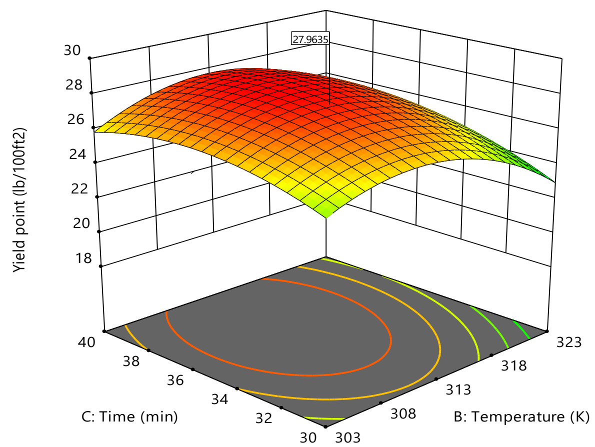

Figure 6: Temperature and time influence on the mud's yield point

3.3.4 Optimum Results

The optimum viscosity of mud with Ohubo clay additive was revealed as 18.27 cp. Its corresponding optimum yield pointwas recorded as 27.96 lb/100 ft2. These values are within the API standard. The findings show that the oil-based mud (OBM) formulated using Ohubo clay additive is suitable for drilling operations.

Table 4:Optimization of RSM results of the mud's viscosity and the yield point

CD	Temp. (K)	T (min)	Opt.V (cP)
6.97	311.61	34.16	18.27
CD	Temp. (K)	T (min)	Opt. yp (lb/100 ft2)
6.97	311.61	34.16	27.96

CD = Clay dosage, Temp. = temperature, t = Time.

3.3.5 Validation of the RSM results of the mud's viscosity and the yield point

To validate the RSM results, values of the predicted and experimental viscosity and yield point were compared with those of the experimental; Table 5. Percentage deviation as a statistical tool was applied. All the values of the percentage deviation are less than 5%, which confirms the RSM as a suitable optimization tool for the mud rheological analysis.

Table 5:Validation of RSM results of the viscosity and the yield point

CD	Temp. (K)	T (min)	Opt.V (cP)	Exp. V (cP)	PD (%)
6.97	311.61	34.16	18.27	18.37	0.54
CD	Temp. (K)	T (min)	Opt. yp (lb/100 ft2)	Exp. yp (lb/100ft^2))	PD (%)
6.97	311.61	34.16	27.96	28.13	0.60

CD = Clay dosage,T = temperature, t = Time, V = viscosity, yp = yield point, PD = percentage division

Conclusion

Analysis of the elemental composition of Ohubo clay revealed the presence of S, Cl, K, Ca, O, Al, Si, Ti, V, Cr, Mn, Fe, Co, Zr, Nb, Ag, Cu, Zn, Rb, Sr, Ta, and Ba at various percentages. Treatment of the clay enhanced its characteristics. It shows high value of oxygen (O), aluminiun, silicon, calcium, and a minor value for other trace elements. The high values of silicon and oxygen show the presence of silicate compound typical of kaolinitic clay. The viscosity and yield point of the mud are functions of temperature, time and dosage of Ohubo clay.Quadratic equation generated effectively explained the relationship between the responses and the considered factors.The optimum viscosity of mud with Ohubo clay additive was revealed as 18.27 cp. Its corresponding optimum yield pointwas recorded as 27.96 lb/100ft^2. These values are within the API standard. As such, the oil based mud (OBM) formulated using Ohubo clay additive is suitable for drilling operation.

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