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Formulation of an Optimal Mix of Indigenous Clay in Water Well Drilling

***Onwuachi-Iheagwara, P.N., Eyenubo, O.J. and Iheagwara, B.I.**

Department of Petroleum Engineering, Faculty of Engineering, Delta State University, Oleh campus, Delta State, Nigeria.
*pniheagwaara@gmail.com; onwuachiiheagwara@delsu.edu.ng

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ABSTRACT

In two neighbouring communities in the Niger delta region, water-well drillers routinely substitute indigenous clays in different proportions into drilling-mud, used during water-wells drilling activities. This article examined the effect of different clay formulations and the resultant mud weights using Scheffe's simplex lattice. Drilling-muds were designed from clay from Koko, Ubeji and the imported bentonite. The clay samples from the two localities were prepared into three types of water-based drilling-mud, namely; E, F and G. Each type had 11 sub-types with different proportions of indigenous clays and bentonite. The results revealed no impediment to the use of local clay in drilling shallow depths. In all combinations of indigenous clays and bentonite, the resultant mud weights ranged from a specific gravity of 8.55 (100% Koko clay) to 8.60 (100% Ubeji clay) and 8.90 (pure bentonite). All formulations were observed to exert sufficient pressure against the formation/ terrain. The practice of substitution of local indigenous mud for imported mud (bentonite) was found to be reliable. The substitution of imported drilling material with local material is expected to be cost -efficient with huge reduction in drilling cost.

1. INTRODUCTION

Clays are hydrous silicates of aluminum characterized by sheet silicate structures of composite layers, produced by extensive chemical weathering and hydrothermal alterations. Clays often contain mineral particles, organic matters; water and air in different ratios and combinations. Their constituents determine the texture, structure, porosity, colour and chemistry of the clay deposit (Onwuachi-Iheagwara, 2012). Characterizations of clay profiles are important for sustainable management of soil nutrient and because of its impact on the ecosystem. Clays can be characterized by structure, color, consistence, and texture (Środoń, 1999; Onwuachi-Iheagwara, 2012).

The Niger Delta lies within the tropical rain forest with approximately 80-120 inches of rain yearly (Reyment, 1966). The area is low lying with a high water table, typically between 3-15 m below ground level (Offodile, 2002). Paradoxically, water is a problem in this area most surface water and run offs in the area are contaminated by hydrocarbon (Onwuachi-Iheagwara and Iheagwara, 2020). The absence of clean portable water has been implicated in most tropical diseases and illnesses (WHO, 2006). In recent times, drilling of water wells has provided much relief. Clays is used in the preparation of drilling-mud. Drilling-mud provides two paramount functions, namely, to cool the drilling bits and to increase the weights on bits, where necessary. The drilling mud therefore, helps to maintain the relationship between the hydrostatic pressure in the formation and mud weight. To control the well, operators generally use a drilling mud formulation with a mud weight that will exert a pressure close to the expected pore pressure.

The study examined the different ratios used by these drillers and the consequences on the resultant mud weights. The Scheffe's simplex lattice approach as recommended by Aggarwal (2002) was used.

2. MATERIALS AND METHODS

2.1. Description of Study Area

This paper examines the common local practice in two (2) communities in the Niger Delta, Ubeji and Koko villages in in Delta State, Nigeria, located at an elevation of 9 and 7 meters above sea level respectively. Geographically, they are situated at (5.544230, 5.760269) and (6.0, 5.4666648) respectively.

2.2. Model Design

The components in the drilling-mud can be specified as:

$$\sum_{i=1}^{q} x_i = 1 \tag{1}$$

Where q = number of components, xi > 0 is the concentration or proportion of component i.

This design is a 4-component quadratic Scheffe polynomial.

$$\begin{aligned} Y = {} & \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{14} X_1 X_4 + \beta_{21} X_2 X_1 + \\ & \beta_{23} X_2 X_3 + \beta_{24} X_2 X_4 + \beta_{31} X_3 X_1 + \beta_{32} X_3 X_2 + \beta_{34} X_3 X_4 + \beta_{41} X_4 X_1 + \beta_{42} X_4 X_2 + \\ & \beta_{43} X_4 X_3 + e. \end{aligned} \tag{2}$$

Because of symmetry, Equation 2 can be reduced to Equation 3:

$$\begin{aligned} Y = {} & \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{14} X_1 X_4 + \\ & \beta_{23} X_2 X_3 + \beta_{24} X_2 X_4 + \beta_{34} X_3 X_4 . + e. \end{aligned} \tag{3}$$

Where e = random error term, β is the coefficient of the model terms.

In the design of the various drilling mud, conditions were imposed. Each drilling mud was made of 24.5 g of clay (Tables 1, 2, and 3). The amount of water was kept constant in each mix. Each mud type had a total of 11 mix. Therefore, for the mix of the components, for each drilling mud type, the components are:

$$\left.\begin{array}{l} X_1 = \text{proportion of Ubeji clay} \\ X_2 = \text{proportion of Koko clay} \\ X_3 = \text{proportion of Bentonite clay} \\ X_4 = \text{proportion of Water} \end{array}\right\} \begin{pmatrix} 1,0,0,0 \\ 0,1,0,0 \\ 0,0,1,0 \\ 0,0,0,1 \end{pmatrix}_{\text{Pure blends}} \tag{4}$$

$$\begin{bmatrix} X_{12} \\ X_{13} \\ X_{14} \\ X_{23} \\ X_{24} \\ X_{34} \end{bmatrix}_{\text{Interaction blends}} \tag{5}$$

Table 1: Formulation on drilling mud type E

Mix	% Ubeji clay	Amount (g) of Ubeji clay	% Koko clay	Amount (g) of Koko clay
1	100	24.50	0	0.00
2	90	22.05	10	2.45
3	80	19.60	20	4.90
4	70	17.15	30	7.35
5	60	14.70	40	9.80
6	50	12.25	50	12.25
7	40	9.80	60	14.70
8	30	7.35	70	17.15
9	20	4.90	80	19.60
10	10	2.45	90	22.05
11	0	0.00	100	24.50

Table 1: Formulation on drilling mud type F

Mix	% Bentonite clay	Amount (g) of Bentonite clay	% of Koko clay	Amount (g) of Koko clay
1	100	24.50	0	0.00
2	90	22.05	10	2.45
3	80	19.60	20	4.90
4	70	17.15	30	7.35
5	60	14.70	40	9.80
6	50	12.25	50	12.25
7	40	9.80	60	14.70
8	30	7.35	70	17.15
9	20	4.90	80	19.60
10	10	2.45	90	22.05
11	0	0.00	100	24.50

Table 3: Formulation on drilling mud type G

Mix	% Bentonite clay	Amount (g) of Bentonite clay	% of Koko clay	Amount (g) of Koko clay
1	100	24.50	0	0.00
2	90	22.05	10	2.45
3	80	19.60	20	4.90
4	70	17.15	30	7.35
5	60	14.70	40	9.80
6	50	12.25	50	12.25
7	40	9.80	60	14.70
8	30	7.35	70	17.15
9	20	4.90	80	19.60
10	10	2.45	90	22.05
11	0	0.00	100	24.50

2.3. Drilling Mud Formulation

Representative clay samples from the 2 (two) localities were harvested and prepared into water0based drilling-muds. Three (3) drilling-mud types were designed, namely, types E (Table 1), F (Table 2), and G (Table 3). Each type with a total of 11 drilling-muds prepared from its clay components. A total of 33 water-based drilling-muds were prepared with different proportions of clays as shown in Tables 1, 2 and 3. Drilling mud type E was designed from Ubeji and Koko clays, only. It served as "control", and indicates the expected responses at zero bentonite content. Drilling mud types F and G contain bentonite and a local clay. They contained Ubeji and Koko clays, respectively. These were investigated to determine the effect of bentonitic content on mud weight. Mud densities were determined for each drilling-mud in each type Standard procedures according to the American Petroleum Institute (API 2017; ANSI/API, 2017) were adopted for the preparation of drilling-mud, calibration of mud balance and testing.

2.4. Error/Uncertainty Associated with the Method

In this investigation, the mud balance was the primary apparatus used. Errors associated with the mud balance include calibration error, which was avoided by re-calibrated with fresh water at 21 °C. Fresh water gives a reading of 1000 kg/m^3 (8.345 lb/gal or 62.4 lb/ft^3). Another potential source of error is procedural. To avoid this, the mud balance was set on a flat surface. All measurements of drilling-muds were at the same temperature (29 ^{o}C). In addition, care was taken to expel any trapped air and to clean excess drilling fluid before and during measurements with the mud balance.

3. RESULTS AND DISCUSSION

In this experiment an ordered arrangement was maintained by uniformly spaced distribution of by a factor of 10 (Tables 1, 2, and 3). Mud density were determined as show in Tables 4, 5, and 6. An analysis of the data on Table 4 shown that the percentage of Koko or Ubeji clay in the mix did not dully affect the specific gravity of the mixture. It was noted that specific gravities from any combinations of Ubeji and Koko clays (drilling mud type E) were approximately 8.60. The specific gravity only reduced to 8.55 at 100% Koko clay. Thus, the use of Koko or Ubeji clays have the same effect on specific gravity in any drilling mud formulation and either clay could be used interchangeably (at all except 100% substitution of Koko clay). At 100% Koko clay formulation (i.e., the drilling mud that consist of only Koko clay) would have a slightly less specific gravity of 8.55. Thus, any appreciable change in mud weight (in drilling mud types F and G) must be a consequence of the bentonite fraction of the drilling mud types, F and G, as show in Tables 4, 5, and 6. This assertion was supported by correlation analysis, which determined the degrees of association for the Bentonite-Koko and the Bentonite-Ubeji drilling-muds as 0.887 and 0.863, respectively (Table 7).

Table 4: Mud contents and specific gravities of drilling mud type E

Mix	% Ubeji clay	Amount (g) of Ubeji clay	% Koko clay	Amount (g) of Koko clay	Specific gravity of Ubeji-Koko drilling mud
1	100	24.50	0	0.00	8.60
2	90	22.05	10	2.45	8.60
3	80	19.60	20	4.90	8.60
4	70	17.15	30	7.35	8.60
5	60	14.70	40	9.80	8.60
6	50	12.25	50	12.25	8.60
7	40	9.80	60	14.70	8.60
8	30	7.35	70	17.15	8.60
9	20	4.90	80	19.60	8.60
10	10	2.45	90	22.05	8.60
11	0	0.00	100	24.50	8.55

Table 5: Mud contents and specific gravities of drilling mud type F

Mix	% Bentonite clay	Amount (g) of Bentonite clay	% of Koko clay	Amount (g) of Koko clay	Specific gravity of Bentonite-Koko drilling mud
1	100	24.50	0	0.00	8.90
2	90	22.05	10	2.45	8.78
3	80	19.60	20	4.90	8.69
4	70	17.15	30	7.35	8.67
5	60	14.70	40	9.80	8.65
6	50	12.25	50	12.25	8.65
7	40	9.80	60	14.70	8.63
8	30	7.35	70	17.15	8.62
9	20	4.90	80	19.60	8.60
10	10	2.45	90	22.05	8.60
11	0	0.00	100	24.50	8.55

Table 6: Mud contents and specific gravities of drilling mud type G

Mix	% Bentonite clay	Amount (g) of Bentonite clay	% of Ubeji clay	Amount (g) of Ubeji clay	specific gravity of Bentonite-Ubeji drilling mud
1	100	24.50	0	0.00	8.90
2	90	22.05	10	2.45	8.74
3	80	19.60	20	4.90	8.71
4	70	17.15	30	7.35	8.68
5	60	14.70	40	9.80	8.67
6	50	12.25	50	12.25	8.67
7	40	9.80	60	14.70	8.65
8	30	7.35	70	17.15	8.64
9	20	4.90	80	19.60	8.62
10	10	2.45	90	22.05	8.60
11	0	0.00	100	24.50	8.60

Figures 1 and 2, show the effect of increasing substitution of bentonite in the mixtures. From the trend, it is seen that with increasing amount of bentonite, the specific gravity increases. The specific gravities are seen to be directly proportional to bentonite concentrations.

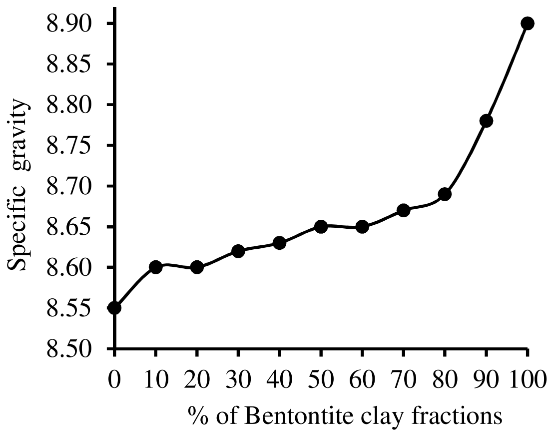

Figure 1: Variation of specific gravity with clay fraction for Bentonite-Koko clays

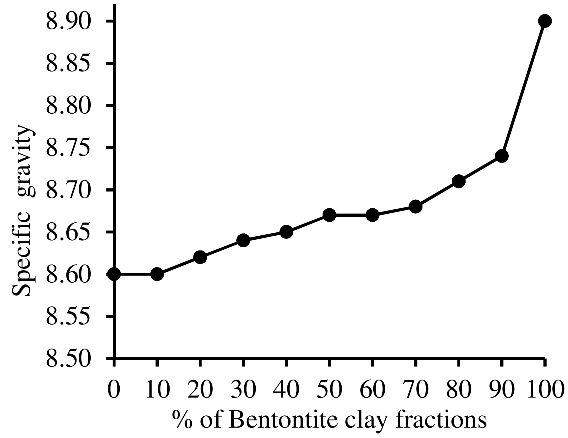

Figure 2: Variation of specific gravity with clay fraction for Bentonite-Ubeji clays

3.2. Error/Uncertainty Associated with the Method

To determine the error or uncertainty associated with the result, regression analysis was used.

3.2.1. Regression statistics

With the analysis, it was observed from Tables 4 and 5, that 75-79 % of the variations in specific gravity of the drilling muds can be explained by the bentonite content. In Table 7, the degrees of association for the drilling-muds were calculated using the CORREL function in Microsoft Excel. It showed a positive association between the fraction of bentonite in the drilling muds and the specific gravity. The very low P-values (1.42E-19 for Bentonite -Koko and 9.14E-20 for Bentonite-Ubeji) in Tables 8 and 9 respectively indicate the significance of the results. Statistical analysis shows the slope of the entonite +Ubeji and the Bentonite +Koko clays mixtures to be 0.0022 and 0.0026 respectively (Equations 6 and 7). This indicates a slight edge for the Bentonite +Koko clays mixtures. This however is not significant and each clay can be substituted for the other.

3.2.2. Regression output

The residual indicates how far the actual data points are from predicted. From an analysis of Table 10, the predicted specific gravity and low average residual values for each of the drilling mud types indicates a good fit.

Table 7: The degrees of association for the drilling-muds types

Bentonite +Ubeji clays	degrees of association		Bentonite +Koko clays	degrees of association	
% of bentonite clay in drilling mud	1		% of bentonite clay in drilling mud	1	
Specific gravity of bentonite +Ubeji clays	0.863	1	Specific gravity of bentonite +Koko clays	0.887	1

Table 8: ANOVA results for Bentonite-Koko drilling mud

Regression Statistics	
Multiple R	0.8874
R Squared	0.7876
Adjusted R Squared	0.7640
Standard Error	0.0472
Observations	11

ANOVA

	df	SS	MS	F	Significance F	
Regression	1	0.0744	0.0744	33.3649	0.0003	
Residual	9	0.0201	0.0022			
Total	10	0.0944				
	Coefficients	SE	t stat	P-value	Lower 95%	Upper 95%
Intercept	8.5373	0.0266	320.5952	1.42E-19	8.4770	8.5975
% bentonite	0.0026	0.0005	5.7762	0.0003	0.0016	0.0036

Table 9: ANOVA results for Bentonite-Ubeji drilling mud

Regression Statistics	
Multiple R	0.8635
R Squared	0.7456
Adjusted R Squared	0.7173
Standard error	0.0451
Observations	11

ANOVA

	df	SS	MS	F	Significance F
Regression	1	0.0537	0.0537	26.3729	0.0006
Residual	9	0.0183	0.0020		
Total	10	0.072			

	Coefficients	SE	t stat	P-value	Lower 95%	Upper 95.0%
Intercept	8.5695	0.0254	336.7359	9.14E-20	8.5120	8.6271
% bentonite	0.0022	0.0004	5.1355	0.0006	0.0012	0.0032

Thus, the regression equations for the Bentonite Ubeji and the Bentonite- Koko drilling muds are:

Specific gravity =8.5695 + 0.0022* % bentonite in drilling mud (6)

Specific gravity =8.5373 + 0.0026 * % bentonite in drilling mud (7)

Table 10: Residual outputs for the drilling muds

Mix	Actual Bentonite +Ubeji clays mixture	Predicted Bentonite +Ubeji clays mixture	Residuals	Actual Bentonite +Koko clays mixture	Predicted Bentonite +Koko clays mixture	Residuals
1	8.90	8.79	0.1095	8.90	8.78	0.1027
2	8.74	8.77	-0.0284	8.78	8.77	0.0087
3	8.71	8.75	-0.0363	8.69	8.75	-0.0553
4	8.68	8.72	-0.0442	8.67	8.72	-0.0493
5	8.67	8.70	-0.0321	8.65	8.70	-0.0433
6	8.67	8.68	-0.0100	8.65	8.67	-0.0173
7	8.65	8.66	-0.0079	8.63	8.64	-0.0113
8	8.64	8.64	0.0042	8.62	8.62	0.0047
9	8.62	8.61	0.0063	8.60	8.59	0.0107
10	8.60	8.59	0.0084	8.60	8.56	0.0367
11	8.60	8.57	0.0305	8.55	8.54	0.0127

4. CONCLUSION

The results of this work have revealed no significant differences in mud weight of drilling mud designed from indigenous clays from the two villages studied. In different ratios and combinations specific gravities of 8.55-8.90 were observed. The Ubeji and Koko clays were found to exhibit similar property on the mud formulations and could be interchange in the scarcity of the other. The utilization of local materials would be positive step in the Nigerian industrialization bid. Therefore, Ubeji and Koko clays can be exploited for drilling of water wells in the Niger Delta.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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