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Evaluation on the Rheological Properties of Water-Based Drilling Mud: A Case Study of Ire-Ekiti Clay

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Abstract
Rheological properties are tested throughout a drilling operation as it is critical in the control and maintenance of rheological properties. This paper investigates the evaluation on the Marsh funnel viscosity, apparent viscosity, and fluid loss of water-based drilling mud. The native clay originated in Ire-Ekiti, Ekiti State, Nigeria. In order to create water-based mud, the characteristics of the clay were determined and compared with those of bentonite, the preferred clay for drilling operations. The results show that the generated drilling fluid's pH levels and rheological characteristics differ significantly from bentonite. This is due to the fact that it attracts clay and water, and the low concentration of sodium cations (Na^{++}) prevents it from swelling. When the local mud was beneficiated using soda ash (Na^2CO^3) at a concentration of 5.0 g clay at 63 microns screen size to 350 ml of the mud, the pH rose by 15.2% from 8.11 to 11.02 and by 8% from 10.00 to 11.73. When PAC-HV was added to the combination, water loss significantly decreased by 32.8% and 66.8%, while marsh funnel viscosity increased by 4.4% and 7.6%, apparent viscosity fell by 26.6% at 63 microns sieve size, and severely rose by 55.8% at 150 microns filter size. After adding 10 g of barite ($BaSO^4$) to 350 ml of the mixture, the clay density rose by 1.2% at both sieve sizes, from 8.50 lb/gal to 8.70 lb/gal. Therefore, the Ire clay has good rheological properties at substantial concentrations when beneficiated with soda ash (Na^2CO^3), which would compare favorably with those of bentonite; however, PAC-HV must be increased above 1.0 g at 150 microns filter size. Ire clay can therefore be used to make a drilling fluid.

Keywords: *Ire-Ekiti clay, beneficiation, bentonite, rheological properties, water-based mud.*

1.0 Introduction

An essential component of any drilling operation is mud. Drilling mud has several beneficial uses; depending on the use and desired property enhancement, it may contain a variety of additives. It is possible to divide water-based mud into functional classes. Drill bit stick slip, drilling fluid leakage, and borehole collapse are caused by a restricted safe density window, low stratum pressure-bearing capacity, and control of rheology and filtration loss with high solids content. The main function of drilling mud carry drill cutting to surface while drilling. Also, drilling fluid serves to cool the bit, provide power to the mud motor and measuring-while-drilling (MWD) tool, support the walls of the hole and control the well pressure (prevent the well from flowing). Fluid loss and mud cake thickness were reduced by 8.1% and 34%, respectively, at the NPs concentration of 0.5 weight percent. According to the study, SnO_2 NPs can be added to bentonite water-based drilling mud without KCl to enhance its rheology, lubricity, and filtering qualities [1]. When compared to the API specifics, the study's findings demonstrate that the gel strength and its rheological properties were significantly enhanced. Guar gum and ginger work well together as a viscosifier, making them suitable for usage as additives. In the formulation of drilling fluids, ginger primarily functions as a good viscosifier and secondarily as a densifier [2]. The results indicate that at a high shear rate, the rheological and filtration properties improved. Practically speaking, the results of this study can help drillers of low-pressure, depleted, and fractured oil and gas reservoirs by offering stable, affordable, and ecologically safe additives [3].

The town of Ire-Ekiti, which serves as the research area, is situated in the Oye local government area of Ekiti State, Southwestern Nigeria, between latitudes 7^0 47^1 to 7^0 53^1 N and longitudes $5^o18'$ E to $5^o24'$ E (Figure 1.). The hometown of Ogun Onire, who is revered as the "god of iron" by the Yoruba ethnic group in Nigeria. The town's large and naturally occurring clay resources are extracted for a variety of uses. Latitude 7^0 20^1 to 8^0 00^1 N and longitude $4^o50'$E to $5^o50'$E are the coordinates of Ekiti State.

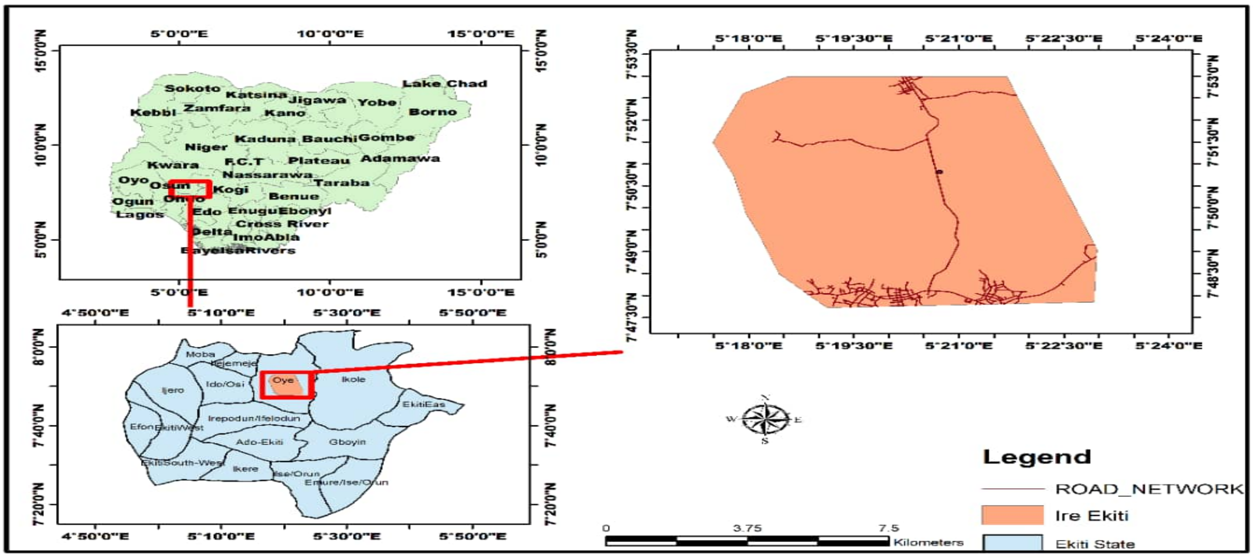

Figure 1: Geologic map of Nigeria, Ekiti State (showing Oye local government area) and Ire-Ekiti (State *et al.*, 2018)

The aim of this study is to characterize the Ire clay, a kaolinite, as a potential replacement for imported bentonite in drilling mud formation.

2.0 Methodology

The methods used in this article included sourcing and mud preparation. The following characteristics of the mud were assessed: density, apparent viscosity, water loss, sand content, pH, and funnel viscosity. When assessing water-based mud, the standard test procedures described in API Rec 13A-2, second edition, were strictly followed.

2.1 Sample Preparation

The Ire-Ekiti deposit was used to gather claystone, which was then dried and ground into a fine consistency in a mortar. The sample of powdered clay was dissolved in water. As residue, organic materials and sand were left behind. The filtrate was decanted to yield clay mud after settling for five hours. The clay mud was sun-dried for four days to produce clay cakes. After that, the cakes were broken up and sieved to create clay powder with sizes ranging from 63 to 150 microns. Next, using a weighing scale, 17.0 g, 19.0 g, 21.0 g, 23.0 g, and 25.0 g of the sieved powdered clay were weighed and appropriately tagged.

Following that, each weighed sample was added to a mixer cup along with 350 milliliters of distilled water. The Hamilton beach stirrer helped the clay dissolve in the water so that it had a consistent consistency. To achieve the best hydration, the resulting homogenous mixture was aged for 24 hours. The mud was stirred again to agitate it for characterization after it had aged for 24 hours.


Figure 2: Ire-Ekiti clay

2.2 Mud Preparation

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The American Petroleum Institute (API) guideline, which specifies that there should be 25 g of untreated bentonite for every 350 ml of water, was followed in the preparation of the bentonite mud sample. A Hamilton Beach Stirrer and 17 g, 19 g, 21 g, 23 g, and 25 g of Ire-Ekiti clay per 350 ml of water were used to prepare the local mud samples. There were 350 milliliters of water-based filth in all. The produced mud samples were assessed for density, rheological properties, pH level, sand content, and water loss during a full day of aging.

2.3 experimental procedure

Claystone was collected from the Ire-Ekiti deposit, the clay was dried and pounded in a mortar to a fine consistency. The powdered clay sample was made dissolved in water. Sand and organic elements were left behind as residue. After five hours of settling, the filtrate was decanted to produce clay mud. Clay cakes were created by sun-drying the clay mud for four days. The cakes were then broken up and sieved to produce clay powder of 63 and 150 microns in size. Next, 17.0 g, 19.0 g, 21.0 g, 23.0 g, and 25.0 g of the sieved powdered clay were weighed and tagged suitably with the use of a weighing scale.

Afterwards, 350 ml of distilled water was measured into mixer cup and add each of the weighed sample. The dissolution of the clay in water was aided by Hamilton beach stirrer to achieve uniform consistency. The homogenous mixture obtained was aged for 24 hours for optimal hydration. After 24 hours of aging, the mud was re-stirred to re-agitate the mud for characterization.

2.4 Bentonite mud preparation

The bentonite mud sample was prepared according to the American Petroleum Institute (API) standard, which calls for 25 g of untreated bentonite per 350 ml of water. The local mud samples were prepared using a Hamilton Beach Stirrer as shown in Figure 3. and 17 g, 19 g, 21 g, 23 g, and 25 g of Ire-Ekiti clay per 350 ml of water. A total of 350 millilitres of water-based mud were recorded. After ageing for a full day, the manufactured mud samples were evaluated for density, rheological characteristics, pH level, sand content, and water loss.

2.5 Clay Mud Beneficiation at 63 Microns Sieve Size

Beneficiation is the process of adding chemicals to low-quality clay to make it perform better. Soda ash (Na_2CO_3), PAC-HV, and barite ($BaSO_4$) were added to mud made from Ire-Ekiti to improve its density, pH values, rheological properties, filtrations, and sand content.

2.6 Clay Mud Beneficiation at 150 Microns Sieve Size

Beneficiation is the process of improving low-quality clay's performance by adding chemicals to it. Soda ash (Na_2CO_3), PAC-HV and barite were added, and the evaluation of the properties were carried out. Five mud samples weighing 17 g, 19 g, 21 g, 23 g, and 25 g of clay each were made using 350 milliliters of distilled water. To each of the five samples, about 2.0 g, 3.0 g, 4.0 g, 4.5 g, and 5.0 g of soda ash were applied. The following characteristics of the samples were measured and recorded: density, mud pH, marsh funnel viscosity, sand content, apparent viscosity, and filter loss. Additionally, PAC-HV in the amounts of 0.2 g, 0.4 g, 0.6 g, 0.8 g, and 1.0 g was added to the mixture of mud samples. The tests listed above were also identified and documented. Ultimately, the mixture of the corresponding mud samples was mixed with barite at concentrations of 2 g, 4 g, 6 g, 8 g, and 10 g, and the aforementioned qualities were ascertained and noted.

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Figure 3: Hamilton beach stirrer used in formulating mud

Rheological properties

The experiment involved filling a funnel and measuring fluid drainage rate as shown in Figure 4. Marsh funnel time was simulated numerically, providing a correlation for effective viscosity of non-Newtonian fluids. The final equation for M.J. Pitt is:

$$\mu eff. = \varrho\ (t - 25) \quad (1)$$

An experimental correlation between apparent viscosity and Marsh time was estimated, using experimental data instead of numerical simulation.

Figure 4: Marsh funnel used in measuring the rate at which the test fluid drains

Filtration properties test

The test aimed to determine the filtration properties of formulated and industrial mud, including the size of the mud cake and fluid loss. The filtration unit was set up with a filter paper and a graduated cylinder, and the mud was poured into the cell as shown in Figure 5. The regulator was adjusted to 100 psi, and the test was stopped after 30 minutes. The filtrate volume was measured and air flow was stopped by turning the regulator valve.

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Figure 5: Dead weight filter press used to determine the filtration properties of the mud

3.0 Results and Discussion

According to Table 1, bentonite exhibited higher density, pH, and viscosity than Ire-Ekiti mud samples at 63 microns after 24 hours of ageing without beneficiation. Ire-Ekiti mud samples, on the other hand, showed reduced filter loss and Marsh funnel viscosity, suggesting a more thick and viscous substance.

Table 1: Properties of bentonite and Ire-Ekiti mud at 63 microns without beneficiation after 24 hours of ageing

Bentonite /Clay conc. In 350 ml of water	Density (lb/gal)	Mud pH	Marsh funnel viscosity (qt/sec)	Sand content (% vol.)	Apparent viscosity (cp)	Filter loss (ml)
Bentonite	8.65	10.95	40	0.4	12.46	17.0
Sample 17 g	8.50	8.11	30	0.01	2.04	38.0
Sample 19 g	8.55	7.91	29	0.01	1.03	37.2
Sample 21 g	8.60	7.77	29	0.01	1.03	39.0
Sample 23 g	8.52	7.73	30	0.01	2.04	33.4
Sample 25 g	8.60	7.73	30	0.02	2.06	33.8

The findings indicate that compared to the Ire-Ekiti mud samples, the bentonite has a higher density, mud pH, sand concentration, and apparent viscosity. The Marsh funnel viscosity of the Ire-Ekiti mud samples is lower than that of the bentonite. Table 2 illustrates that with a size of 150 microns, the Ire-Ekiti mud samples had a lower viscosity and a faster filtration rate than the bentonite.

Table 2: Properties of bentonite and Ire-Ekiti mud at 150 microns without beneficiation after 24 hours of ageing

Bentonite /Clay conc. In 350 ml of water	Density (lb/gal)	Mud pH	Marsh funnel viscosity (qt/sec)	Sand content (% vol.)	Apparent viscosity (cp)	Filter loss (ml)
Bentonite	8.65	10.95	40	0.40	12.45	17.0
Sample 17 g	8.50	8.28	30	0.40	2.04	79.2
Sample 19 g	8.52	9.46	29	0.50	1.02	41.0
Sample 21 g	8.52	8.24	30	0.60	2.04	45.6
Sample 23 g	8.58	8.22	30	0.65	2.06	46.8
Sample 25 g	8.60	7.97	31	0.75	3.10	53.2

Clay Mud Beneficiation at 63 Microns Sieve Size

By adding soda ash, PAC-HV, and barite, the study sought to enhance the density, pH, rheological characteristics, filtrations, and sand content of Ire-Ekiti mud. Tables 3 through 17 display the measurements and records of the density, pH, sand content, apparent viscosity, filter loss, and PAC-HV characteristics.

Five samples of mud at different measurement of pH in five places were prepared.

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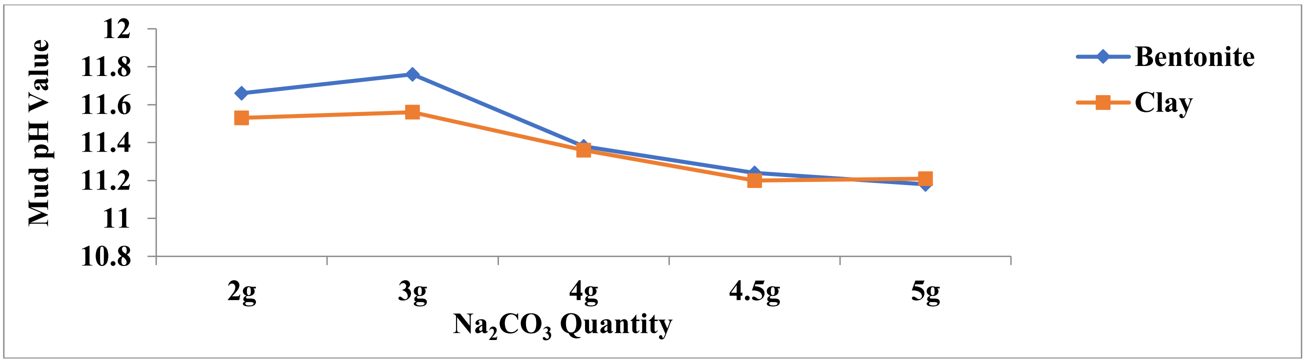

Figure 6.: Effect of Na_2CO_3 on Ire-Ekiti mud pH

Five samples of mud at different measurement of PAC-HV in five places were prepared.

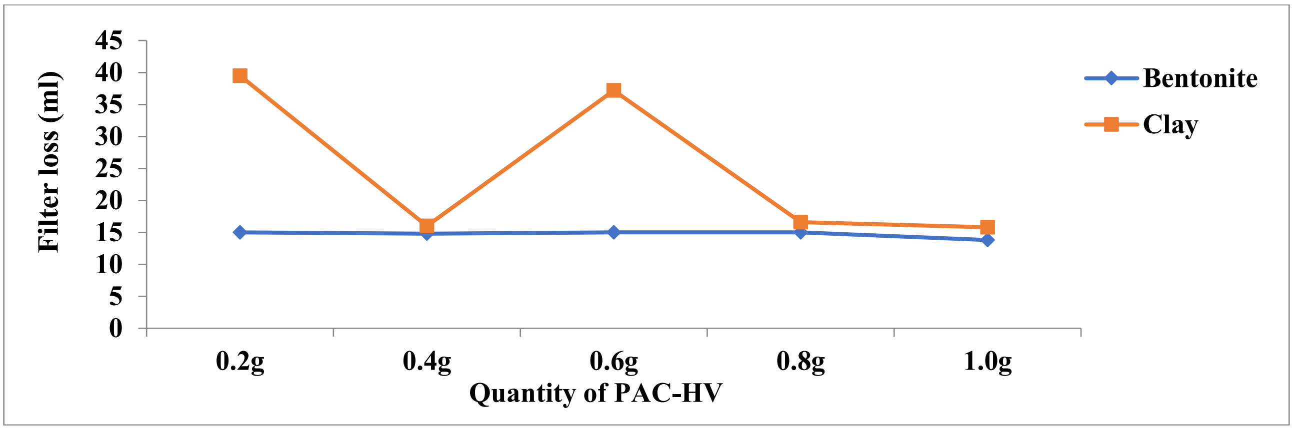

Figure 7: Effect of PAC-HV on Ire-Ekiti mud filter loss

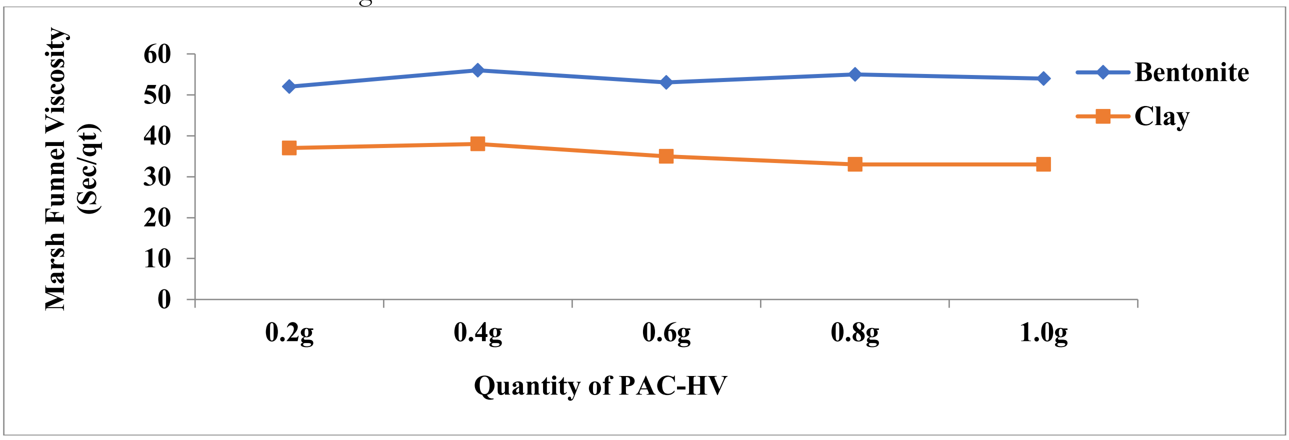

Figure 8: Effect of PAC-HV on Ire-Ekiti mud marsh funnel viscosity

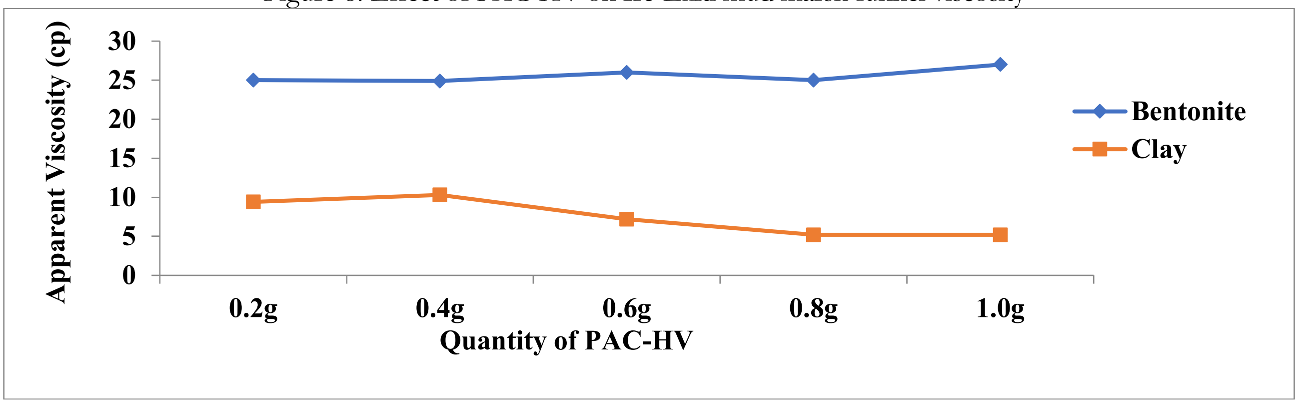

Figure 9: Effect of PAC-HV on Ire-Ekiti mud apparent viscosity

Five samples of mud at different measurement of barite ($BaSO_4$) in five places were prepared.

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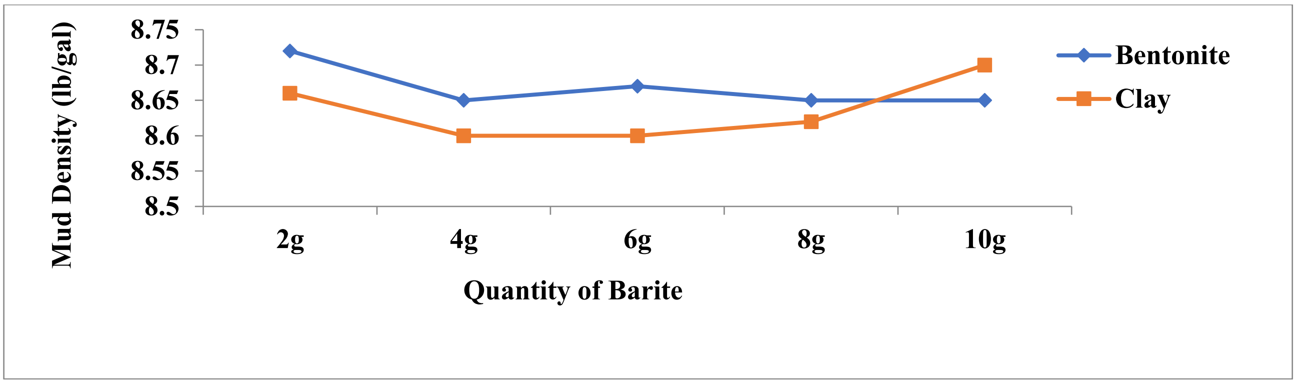

Figure 10: Effect of barite ($BaSO_4$) on Ire-Ekiti mud weight

Before beneficiation, the mud pH of the mud samples containing 17 g to 25 g of clay was 7.73 to 8.11, according to Table 1's analysis. This demonstrated that the mud samples did not meet the API's 9.5 minimum numerical value requirement. The foreign bentonite mud sample's pH was determined to be 10.95. As seen in Figure 1, the mud samples' pH rose from 11.02 to 11.56 following beneficiation with 2.0 g to 5.0 g soda ash, meeting API numerical value standards (9.5–12.5). Figure 8 shows that the Marsh funnel viscosity of mud samples with varying clay contents (17–25 g) was 29–30 sec/qt, which is significantly lower than the recommended minimum numerical value of 52 sec/qt for drilling mud. The Marsh funnel viscosity values of the mud samples during beneficiation from Figure 8 varied from 30 to 38 seconds per minute with 0.2 g to 1.0 g PAC-HV. This demonstrated the extremely low viscosity of the mud in our local sample. Prior to beneficiation, the Marsh funnel viscosity of the foreign mud sample was 40 sec/qt. The Marsh funnel viscosity values of the mud samples dropped from 150 sec/qt to 63 cp after beneficiation with 0.2 g to 1.0 g PAC-HV. This demonstrated that the fall of the mud samples was below the usual API maximum numerical value of 52–56 sec/qt. However, the mud sample's viscosity reading at 1.0 g PAC-HV was 63 sec/qt, which was still nearer the API maximum numerical value limit of 56 sec/qt. Before beneficiation, the mud weights of the 21 g and 25 g clay concentration mud samples were both 8.60 lb/gal, as indicated in Table 1. This is slightly below than the 8.65 lb/gal minimum API numerical requirement. The imported bentonite sample weighed 8.65 pounds per gallon of mud. According to Figure 10, the mud sample concentrations during beneficiation using 2 g of barite of 25 g clay and 10 g of barite of 25 g clay were 8.66 lb/gal and 8.70 lb/gal, respectively, and they were within the API numerical value standard. The sand content of the mud samples for the sand content analysis ranged from 0.01% to 0.25%, all falling within the API numerical value standard (1-2) % maximum, with clay concentrations ranging from 17 g to 25 g. The imported bentonite mud sample's sand content ranged from 0.40% to 0.58%. Figure 8 through 12 listed the present mud samples' filtering characteristics. PAC-HV's capacity to lower the filtrate volume was enhanced. When used as a filtrate control agent in a bentonite-based mud system, the PAC-HV showed encouraging results in table 8 when compared to table 1, satisfying the API maximum numerical value standard of 15 ml. The lowest volume, 15 ml, fell below the API maximum numerical value threshold, while the biggest fluid loss, 27 ml, was observed from tables 8 to 12. API 2009's suggested range. The standard control mud satisfied API criteria at a pressure of 12 mPa. The minimum apparent viscosity required for drilling-grade bentonite mud is between 12 and 15 mPa.

Clay Mud Beneficiation at 150 Microns Sieve Size

In a similar manner, samples of mud were made and beneficiated for 150 microns. Five mud samples were prepared, each with a distinct measurement of soda ash (Na_2CO_3).

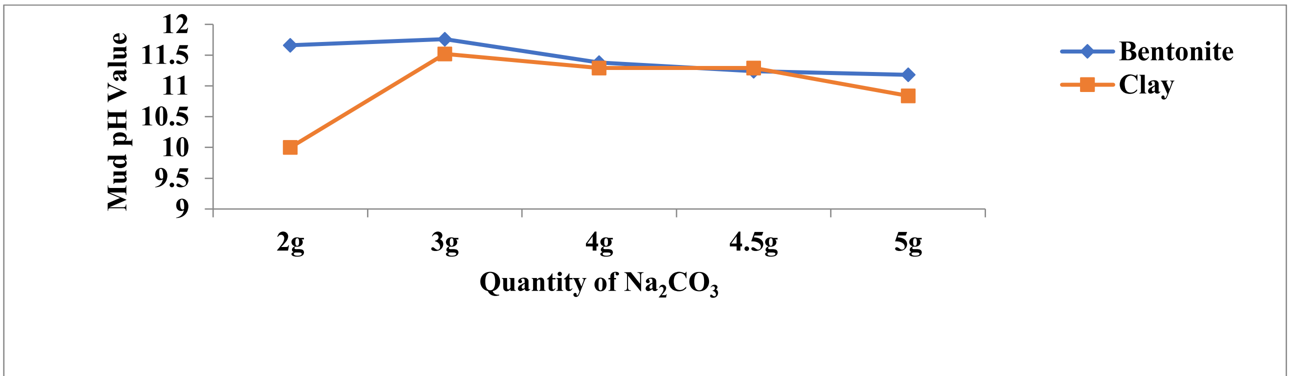

Figure 11: Effect of Na_2CO_3 on Ire-Ekiti mud pH

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Five mud samples with varying PAC-HV measurements were generated in five separate locations. The lowest amount was 15.6 ml, which was closer to the typical API maximum numerical value of 15 ml, while the biggest fluid loss was 39.5 ml, as shown in Tables 23 to 27. range recommended by API 2009.

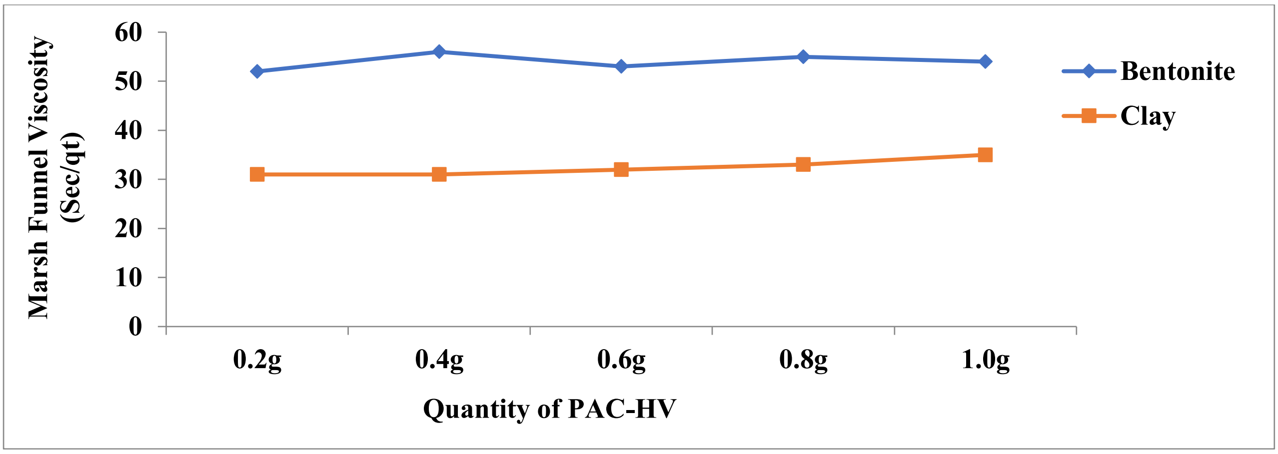

Figure 12: Effect of PAC-HV on Ire-Ekiti mud marsh funnel viscosity

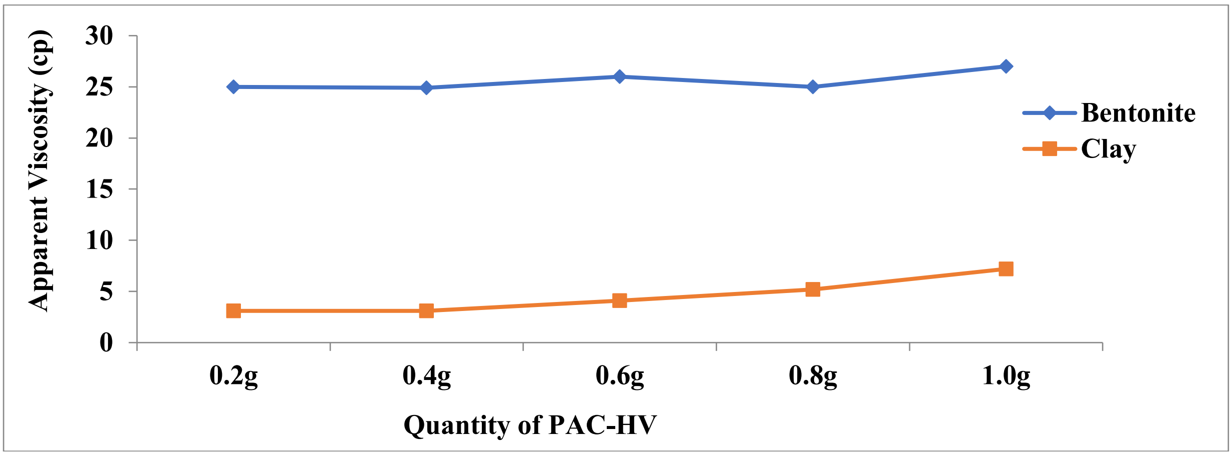

Figure 13: Effect of PAC-HV on Ire-Ekiti mud apparent viscosity

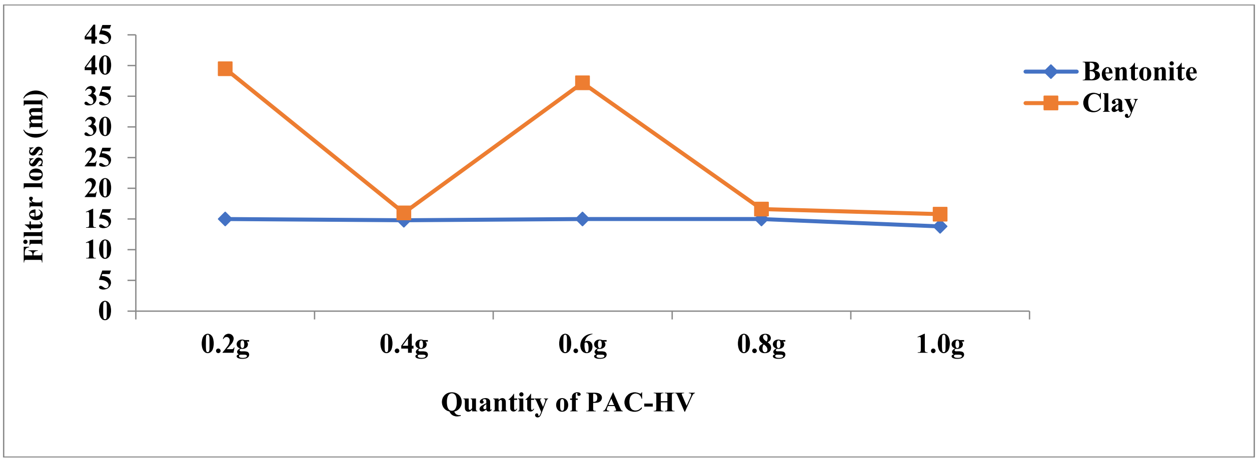

Figure 14: Effect of PAC-HV on Ire-Ekiti mud filter loss

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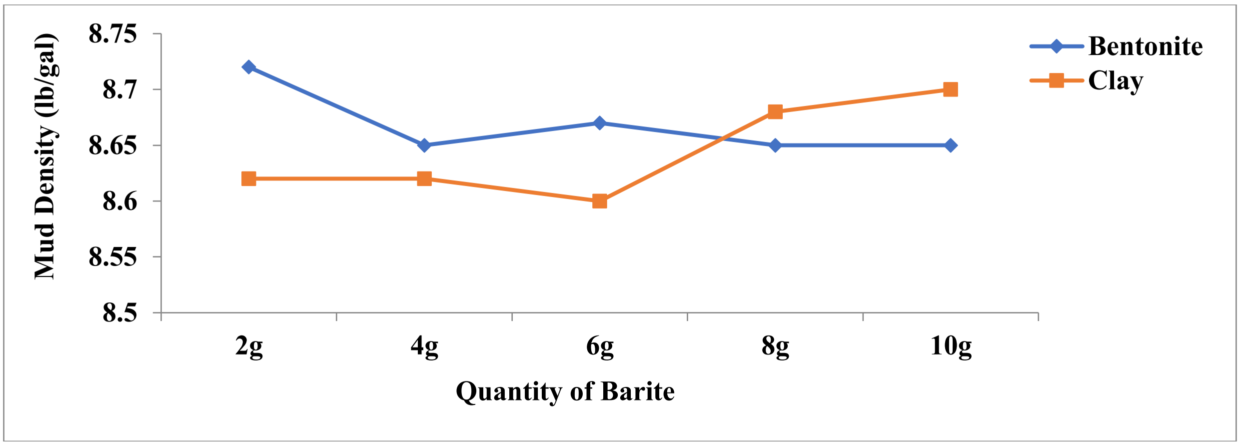

Figure 15: Effect of barite ($BaSO_4$) on Ire-Ekiti mud density

Table 2 shows that the mud pH of the 17 g to 25 g clay concentration ranged from 7.97 to 8.46 before beneficiation. The findings showed that the mud samples did not meet API's minimum numerical value requirement of 9.5. The pH of the foreign bentonite mud sample was found to be 10.95. Following beneficiation with 2.0 g to 5.0 g soda ash, the pH of the mud samples rose from 10.00 to 11.73, from Figure 11, and subsequently matched API numerical value standards (i.e., 9.5-12.5). The marsh funnel viscosity of mud samples containing 17–25 g of clay ranged from 29 to 31 seconds/qt, as shown in Figure 12. This is far less than the drilling mud minimum numerical value of 52 seconds per qt. The Marsh funnel viscosity values of the mud samples varied from 30 to 35 seconds per minute during beneficiation with 0.2 g to 1.0 g PAC-HV (Figure 12). This illustrated how the mud in our local sample had a very low Marsh funnel viscosity. The Marsh funnel viscosity of the foreign mud sample was 40 sec/qt before beneficiation. The mud sample viscosity values reduced from 150 sec/qt to 63 cp during beneficiation with 0.2 g to 1.0 g PAC-HV. This indicated that the mud samples had felt values greater than the standard API maximum numerical value of 52–56 sec/qt. Nonetheless, the mud samples' viscosity reading at 1.0 g PAC-HV was 63 sec/qt, which was still nearer the API maximum numerical value standard of 56 sec/qt. Table 2 shows that the mud density of the 25 g clay concentration of the mud sample was 8.60 lb/gal before beneficiation. This is just below the API minimum numerical value standard of 8.65 lb/gal. For every gallon of mud, the imported bentonite sample weighed 8.65 pounds. After beneficiation using 8 g barite of 17 and 19 g clay and 10 g barite of 25 g clay, the concentration of mud samples was 8.84 lb/gal, 8.65 lb/gal, and 8.70 lb/gal, respectively. The API numerical value criterion was met by these values. For the sand content examination, the 17 g to 25 g clay concentration of mud samples varied between 0.40% and 1.10%, falling within the API numerical value standard (1-2) % maximum. Sand concentration ranged from 0.40% to 0.75% in the imported bentonite mud samples. The present mud samples' filtering characteristics are shown in Figure 14. In terms of reducing the filtrate volume, PAC-HV's performance was improved. When applied as a filtrate control agent, the PAC-HV showed promising results in the bentonite-based mud system from Figure 14. Compared to Table Figure 7, the mud sample's 21 g clay concentration (i.e., 15.6 ml) seemed closer to the API maximum numerical value standard (i.e., 15 ml).

4.0 Conclusion

Drilling mud properties were greatly enhanced by the Ire-Ekiti clay when it was beneficiated with soda ash, PAC-HV, and barite. The Marsh funnel viscosity and apparent viscosity increased significantly at 150 microns sieve size, the pH value of the formulated drilling fluid increased by 15.2% and 8% at both sieve sizes, and the density of the mud increased by 1.2% when mixed with barite. These results imply that the Ire-Ekiti clay has strong rheological qualities that are comparable to bentonite.

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