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Rheological and Environmental Performance of Drilling Muds Enhanced with Organic Ash

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Abstract: The paper deals with drilling to evaluate the possible completion of an oil/gas well efficiently. Different activities that drilling fluids perform would ensure that such becomes possible; designing an adequate drilling mud has to consider all good conditions. It is an experiment conducted in a lab. It investigates the behaviour and properties of drilling mud by adding various concentrations by weight of local organic ash to improve the properties of drilling mud and reduce the negative effect of organic ash on the environment and human health. The laboratory experiments included rheological tests to estimate the physical and rheological properties of drilling mud systems that had been developed. The analytical results of laboratory tests showed that adding organic ash to the mud improves its properties. A study on a mud system containing barite and another containing Organic ash was compared, and in all the above parameters as compared to other mud containing barite, the muds containing organic ash were rich in l, gel strength, density, and pH; however, they were worse in filtration loss control.

Keywords: Drilling Mud; Organic Ash; Rheological Properties; Barite Powders; Rheological Test; Mud System; Laboratory Experiments; Analytical Results; Drilled Borehole; Carboxy Methyl Cellulose (CMC).

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1. Introduction

Drilling mud is the main component of oil well drilling because it has to carry the rock pieces from deep below the bit to the surface, exert enough hydrostatic pressure against subsurface formations such that formation fluids cannot leak into the well, maintain newly drilled borehole opening until steel casing can be cemented in the hole, and cool and lube the rotating drill

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string and bit [1]. The drilling mud is bentonite and barite water or oil-based with other additives like cement, lime, starch, graphite, and lig carboxymethyl cellulose, among others [2]. These additives are very expensive and can be sourced from overseas. Fly ash is one of the additives that would make drilling mud more efficient and cheaper than expensive additives [3]. Fly ash is one of the industrial by-products of coal combustion in power plants, and researchers have used it [4]. Careful selection of drilling fluids and alteration in their characteristics once placed under the borehole conditions are major concerns of drilling engineers and operators [5].

This has led to borehole hydration and cuttings dispersion in sensitive formations such as shales, shaly sandstones, and fractured and unconsolidated reservoirs, which will contribute to such scenarios as discussed in the preceding work [6] such as wellbore instability, additional reaming, poor logging, pipe sticking, high torque, and pipe suck-up, among others. The various hole instability types are outcomes of the interaction of drilling fluids with sensitive formations that can be referred to as being due to hydration, swelling, and dispersion [7]. The phenomena included are surface hydration and osmotic swelling. As reported in the previous study, this tends to attract water to adsorb on the clays [8]. In general, the performance of non-aqueous drilling fluids is acceptable as they boast high-performance qualities in terms of properties and behaviour [9]. They are less sensitive to the borehole environment, possess higher lubricity, and produce better drilling efficiency [10]. However, environmental factors concerning the disposal of fluids and expenses limit their applications [11]. Water-based drilling fluids do not have these unwanted issues associated with their application in drilling, as used by various studies [12]. However, they are very sensitive to formation characteristics, and a single fluid cannot be used to drill all wells [13]. Water-based drilling fluids are considered more environmentally acceptable than oil-based or synthetic-based fluids [14]. These drilling fluids hydrate and swell clays, significantly increasing well construction costs, as reported by various studies [15]. During reservoir exploitation, smectite clays are frequently encountered [16].

Due to their structural and chemical characteristics, many clay minerals are important in various industrial and geological processes. Many scientists have expressed a keen interest in noting that exchangeable cations, which accompany clay minerals, have different levels of swelling ability. Such variability can significantly affect the behaviour of such minerals in diverse applications [25]. The cause for this variability is the type of exchangeable cations. Charge density, size, and hydration characteristics are all involved. For example, low valence cations, such as sodium, are more readily swollen by clay minerals than high valence cations, such as calcium or magnesium. This is because the low valence cations are not so effective in neutralizing the negative charge on the surfaces of the clays. It is through the penetration that the water molecules end up swelling the clay layers. The swelling tendency of clay is thus sensitive to the type of cations, the distribution pattern of cations in the clay framework, and other environmental factors such as pH, salinity, and temperature. Therefore, this is a very relevant characteristic in oil exploration and drilling operations, where swelling clay results in unstable wellbores, higher drilling costs, and several operation problems.

To counteract the detrimental effects of clay swelling, inhibitors are generally applied. Inhibitors react with clay particles and, therefore, minimize the tendency of swelling in clay particles. The action mechanism of such inhibitors depends on the composition and functionality of these inhibitors. For example, KCl is one of the most commonly used clay inhibitors, as it can easily replace sodium ions within the framework of clay. This is the way by which clay shows less affinity towards water. In addition, organic polymers such as polyanionic cellulose and polyacrylamide are used as coatings of the clay in a manner in which the protecting layer is such that water cannot come through it; thus, the swelling is minimized. Inhibitor choice may vary according to the type of clay mineralogy, the operating environment, and the degree of inhibition [17].

In some cases, more than one inhibitor is used for high-performance applications. More importantly, inhibitors in water-based mud are sites where interactions between the mud and the sensitive formation result in the swelling and hydration of clay minerals. This leads to sticking pipes, unstable wells, and high torque, which are problems hindering effective safety in drilling operations. The effectiveness of inhibitors in controlling clay swelling is an improvement in the overall performance of drilling fluids, which generally adds up to the stability and success of the drilling process. However, some of these inhibitors have been restricted in their use in environmental applications, especially in areas with a high population or other sensitive regions. This factor has led to the invention of friendly and biodegradable inhibitors with effective clay inhibition, keeping the environmental impact minimal. In a nutshell, the variable swelling ability of clay minerals by their exchangeable cations is quite crucial for industrial and geological applications. Controlling swelling tendencies while ensuring the stability and efficiency of processes involving clay is critical, and an inhibitor plays a great role. As industries place increasing importance on environmental sustainability, the scope for developing innovative, environmentally benign inhibitors is expected to rise, leading towards more sustainable solutions for the challenges thrown up by clay swelling [18].

The use of some inhibitors is limited according to environmental guidelines, particularly for populous regions, because their environment is becoming stricter nowadays [19]. The drilling fluid selection is based on the desired rheological parameters and filtration properties, considering the borehole conditions [20]. A high yield point/plastic viscosity ratio indicates shear-thinning mud, which is desirable for suspending cuttings when circulation stops. Toxic chemicals in some fluids, including heavy metals and radioactive elements, cause environmental concerns. Fly ash is useful as it can either be a raw material for concrete or used as filler in stabilization projects. The fly ash, a lightweight particle generated during coal combustion, has been an opportunity to enhance drilling mud efficiency while offering a solution for disposal.

Fly ash is essentially greyish, nearly alkaline, and refractory. Chemical composition: silica, alumina, and Fe_2O_3. Fly ash enhances the filtration property of drilling fluids, poses no environmental concerns, and adds fertility to the soil. Its properties make it a cheaper and lighter additive than conventional ones, such as calcium carbonate. Fly ash, a low-density fine particle has long been used as an additive in cement and drilling fluids. The research is focused on improving drilling fluid properties by adding additives with different compositions and sizes. Fly ash stabilizes the drilling fluids, improves the stability of the well, and reduces the costs associated with filtrate losses. Ultra-fine fly ash mixed with drilling fluids is analyzed for changes in rheological and filtration properties, showing promising results.

With pozzolanic properties, fly ash has broad applications in the cement industry and drilling operations. With more and more coal-fired power plants coming into operation, there is an increasing availability of fly ash for these applications. The science of deformation and flow of matter is crucial in developing drilling fluids with desired properties. Advances in rheology have significantly contributed to the understanding and applying materials such as fly ash in drilling operations. The main objective of this study the main aim of this project is to determine the influence of organic ash on the rheological properties of drilling mud to enhance its efficiency.

- To formulate inverted emulsion drilling fluid samples and investigate their rheological behaviour.
- To optimize drilling fluid rheology performance and determine the optimum Vis Plus concentration.
- To study the rheology and rheological models of drilling fluid and select the most accurate model to represent its behavior.

2. Literature Review & Theoretical Background

Relevant topics and previous findings in the research were assessed to improve knowledge on water-based drilling mud and its applications, additive use, fly ash properties, and API standard practices. This paper delineates drilling mud rheology that serves to identify the mud and marks as important factors defining the characteristics. Fly ash is considered the product of coal burning in a power plant, which creates environmental pollution. It is greyish, abrasive, mostly alkaline, refractory, and made of particles between 1 and 200 micrometers. Fly ash contains all the important macronutrients for plant growth (P, K, Ca, Mg) and micronutrients for plant growth, such as Zn, Fe, Cu, Mn, B, and Mo. Pulverized coal fly ash is used in Portland-pozzolan cement, which is prepared from siliceous or siliceous-aluminous materials that form cementitious products with water and calcium hydroxide, as discussed in earlier studies [12]. Fly ash has geotechnical properties such as specific gravity, permeability, angular friction, and consolidation, as the studies carried out earlier depict [13]. The main constituents of the bituminous coal fly ash consist of silica, alumina, iron oxide, and calcium, with variable carbon content from LOI. Lignite and sub-bituminous coal fly ash contain a higher calcium and magnesium oxide content but have less silica, iron oxide, and carbon content, as observed in the study results of reference [14]. As in earlier research, fewer quantities of anthracite coal fly ash are due to the lower consumption of utility boilers [15].

The mineral composition of fly ash consists of the crystalline and glassy components in the amorphous phase, containing some unburned carbon. Fly ash is sorted into three phases-primary, secondary, and tertiary, based on the formation. Coal combustion produces secondary ones, while the tertiary types- portlandite and gypsum- emerge during transport analyses, as shown in previous work [16]. Silica, oxygen, calcium, aluminum, carbon, iron, and magnesium, among many others, are a composition for fly ash. Cooling rates determine particle size, and high cooling rates result in small glassy particles, while low cooling rates produce large crystalline ones, according to studies on the topic [17]. Fly ash is categorized by oxide composition, mainly CaO, SiO_2, Al_2O_3, and Fe_2O_3. An increase in CaO content depicts a reduction in SiO_2, Al_2O_3, and Fe_2O_3, as well as an increase in alkalis and SO_3, according to experimental studies reported [18]. The iron and carbon content impacts fly ash density; the higher carbon enhances the reduction in density. This has been well-established [19]. The LOI also assesses the effects of carbon content on water demand and workability. Class F fly ash contains a higher LOI than Class C, which has been determined and reported by previous researchers [20].

The mass of crystalline phases is 5–50%, which includes anhydrite, mullite, quartz, hematite, magnetite, and lime. These phases indicate reactive and stable constituents, as found in the study through XRD, for sulfate and hydration reactions, as suggested by previous studies [21]. Fly ash characterization in composition, mineralogy, surface chemistry, and reactivity is important in many applications. The physical characteristics include fine, spherical, mainly glassy particles, while carbonaceous materials are angular, as reported by earlier workers [22]. Particle size in Fly Ash is the same as silt, less than 75 µm; specific gravity ranges from 2.1 to 3.0, and surface area is within the range of 170-1000 m^2 /kg. It ranges from tan to black colour influenced by unburned carbon, as per prior literature [23]. As found in prior work, coal properties and handling practices greatly impact fly ash [24].

Additives play a very important role in enhancing the characteristics of drilling mud, which is critical to viscosity, density, fluid loss control, and efficient drilling operations. The forms that drilling mud additives take serve diverse purposes in addressing the wide range of drilling challenges. As earlier studies reported, the most commonly used additives are fly ash, dolomite, rice husk ash, lime, and starch, which have different benefits because of their properties and applications [1]. For instance, fly ash is a coal combustion by-product, and it has been widely used due to its pozzolanic properties, which can improve the stability and density of drilling mud, as earlier studies have found [15]. Similarly, dolomite, which contains magnesium and calcium, improves the density and rheological properties of the mud, as established by studies on the effectiveness of this chemical [6]. Rice husk ash, an agricultural waste product, is rich in silica content, making it an excellent additive for formulating drilling mud strength, as previous studies have examined [5]. Lime is used to adjust pH to increase the alkalinity of the mud, and starch is applied as a natural polymer to control fluid loss and increase viscosity. So, it is a good additive in earlier studies [8]. Advances in research recently focus more on using environmentally friendly additives like modified starches, which show enhanced fluid loss control at increased temperatures. These additives provide an eco-friendly alternative to conventional synthetic materials, as the industry is trying to reduce its environmental impact, as discussed in earlier studies by other researchers [21]. Modified starches exhibit excellent performance in thermal stress and compatibility with other drilling mud components that ensure their optimum performance under severe drilling conditions, as proved by experimental results [4].

Another promising additive is rice husks, which have been put in the limelight because of their high porosity and reactive surface functionalities for petroleum adsorbents. The detailed studies show that agricultural by-products, otherwise considered waste, can be thermally treated to enhance their sorption capacity [21]. Thermal treatment changes rice husks' physical and chemical structure with an increase in surface area and the development of more active sites for adsorption. This modifies rice husks to have the ability to absorb petroleum as well as other hydrocarbons efficiently, making it useful in cleaning environmental contamination and enhancing the performance of drilling fluids, as recently reported in studies [12]. Rice husk addition to drilling mud enhances the properties of the drilling mud while furthering waste-to-resource concepts by using agricultural residues to form functional materials, as previously discussed [3]. The dual benefits of thermally treated rice husk ash for drilling mud formulations are that it enhances the mud characteristics and makes the formulation sustainable. High silica content in rice husk ash contributes to higher density and viscosity.

On the contrary, the porous structure of rice husk ash has proven helpful in reducing fluid loss, as shown by experiments carried out on agricultural by-products [24]. Further, the advantages of the environmental use of agricultural waste as a drilling additive raise no issues as it alleviates waste disposal problems and helps reduce the carbon footprint associated with drilling operations, as seen in the extensive research done on the subject [5]. The integration of several additives, such as fly ash, dolomite, rice husk ash, lime, and starch, has made remarkable progress in the performance and sustainability of drilling mud. Environmentally friendly solutions, such as modified starches and thermally treated rice husks, point towards promising new solutions that can achieve improved drilling fluid properties with minimal environmental effects. These technological advancements are sure to improve efficiency in drilling activities while aligning with global policies toward sustainable resource usage, as shown by recent studies.

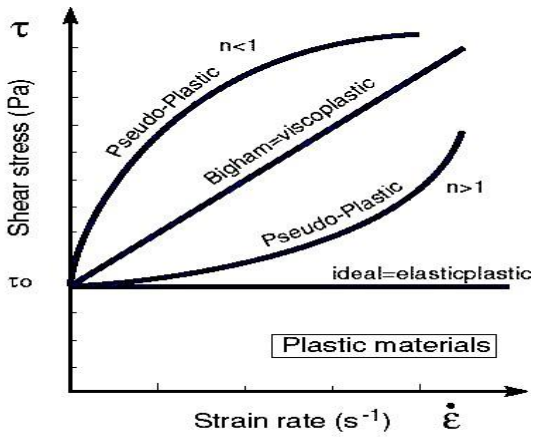

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Figure 1: Shear stress-shear rate relationship in the bingham plastic model [26]

The differences in muds are distinguished as water- or oil-based; the latter usually contains hydrocarbons as the main liquid. Three important properties of drilling mud are viscosity, gel strength, and filtration characteristics. Marsh funnels and viscometers determine viscosity. Filtration characteristics are obtained using filter presses. Alkalinity is determined by titration. According to detailed studies, bent onite and carbon ash additives increase rheological properties, suspension stability, and filtration [12]. Experimental investigations that utilize mixtures of lignite and bentonite exhibit improved control over gelation and filtration behaviour at elevated temperatures in the extended study [13]. Other lignites and bentonites from other countries, including Greece, performed well. Fluid loss to content humic and fulvic acid showed poor correlation. The interaction between fly ash, additives, and properties of coal while using the formulated cost-effective drilling muds advanced toward efficient utilization within industrial standards during research work. Several examples are clay suspensions, drilling mud, etc. Once the yield stress has been exceeded, changes in shear stress are proportional to changes in shear rate, and the constant of proportionality is called the plastic viscosity. The graphical representation of this model is shown in Figure (1). The plastic viscosity decreased with increased shear rate due to a phenomenon called "shear thinning."

This power law model, sometimes termed the yield pseudoplastic model, shows fluid behavior with various shear rates. For n=1n=1, a fluid will represent a Newtonian fluid because its identical power law equation is the same for Newtonian fluids. In a case of n>1n>1, the fluid would be termed dilatant, which depends on shear rates; the apparent viscosity increases as the shear rate increases. However, when n<1n<1, the fluid is termed pseudoplastic, dependent on the shear rate but with an apparent viscosity lowering with an increase in the shear rate. This model is useful for characterizing the flow of pseudoplastic drilling muds, which require an initial stress to initiate flow. In such cases, a rheogram plotting shear stress minus yield stress versus shear rate gives a straight line on log-log coordinates. It can be widely applied to drilling operations; it can very well describe the flow behavior of drilling fluids; it has included a yield stress value critical for hydraulic considerations; and both the Bingham plastic and Power law models are included as special cases. The significant parameters of other rheological models are calculated using plastic viscosity and yield point obtained from the Bingham plastic model and reported in API Drilling Fluid reports to extend the utility and applicability of this technique on site (Figure 2).

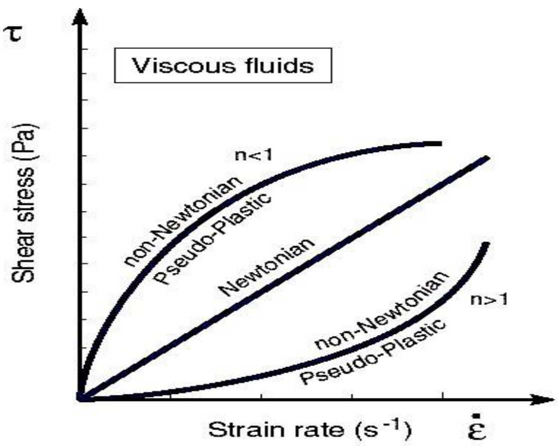

Figure 2: Rheological behavior and flow characteristics of the power-law model [26]

3. Methodology and Experimental Work

This method considers the systematic investigation into the impacts of organic ash on drilling fluids' rheology and filtration characteristics to develop less expensive, eco-friendly mud formulations. The process starts by drilling mud using 350 cc of water and 15 grams of bentonite for uniform mixing. Two mud samples were prepared to investigate the impacts of organic ash. The first setup involved adding varying proportions of organic ash into water and bentonite 0.5, 1, 1.5, and 2 g. Barite and water with bentonite were applied during the procedure, followed by the setup before applying organic ash concentrations, which were applied again. The rheological properties of the samples prepared were accessed using a viscometer model 900 to obtain the plastic viscosity (PV), yield point (YP), and gel strength at 10 seconds and 10 minutes. Other determinations included pH and density to study the alkalinity of the mud and its stability.

The filtration characteristics of each formulation were assessed with the aid of an API filter press, determining fluid loss and filter cake thickness, which would give an insight into the ability of the mud to prevent damage to the formation during drilling. Organic ash was chosen because it has a small particle size and a mineral composition that can be a good bridging agent. Substantial work has been done involving the interaction of organic ash with the mud system. Samples of two sets were run for comparison to study the comparison effects that barite and organic ash may have on the mud performance. The mixing sequences of polymers and ash were controlled for consistency and uniformity in the samples. This allowed a complete evaluation of the organic ash effect on some important properties, including plastic viscosity, yield point, apparent viscosity, and gel strength, all erratic as a function of ash concentration. It is established that organic ash filtration performs better at higher concentrations owing to the finer particle size of organic ash, enhancing the bridging effect but reducing fluid loss and cake thickness.

The organic ash effect observed includes lubricity and stability, and it could also improve the thermal and colloidal stability of drilling fluids. Particle size distribution and mineral composition of organic ash were also used to examine its chemical and physical properties. The experiments were arranged in such a way as to evaluate whether organic ash can be utilized as the primary or supplemental additive for drilling mud while being compared with the use of more conventional additives like barite. This methodology demonstrates the environmental and economic advantages of using organic ash as an industrial by-product to produce sustainable drilling fluids. Results would reveal deep insight into how organic ash helps enhance rheological properties and the drilling mud's filtration quality and keeps it synchronized with other additive ingredients. Results will allow for the optimal formulation optimization of the drilling mud system for improved operational efficiency and will give the well-drilling activity a smaller environmental footprint. The above systematic test and evaluation process means that the organic ash additive in the system of a drilling fluid shall have a high sustainability assessment.

Supplies for the bentonite and barite were provided through the Turkish Petroleum Corporation, TPAO. The fly ash was purchased from a 1200 MW coal-fired plant at İskenderun, Turkey, that includes a fabric filter for ash capturing. The preparation steps were weighed to measure the bentonite and barite powders mixed in water. Fly ash was then added to the mixture in concentrations of 1%, 2%, 3%, 4%, 5%, 6%, and 7%. 0.1 M NaOH neutralized the pH of the mixture. CMC was added to control filtration losses and viscosities according to API standards. Hamilton Beach stirrer was used in the order of addition of the additives. Potassium chloride was the first additive added into the drilling fluid for viscosity increase, and afterward, xanthan gum was used for extra viscosity improvement. Low-viscosity grade CMC and polyanionic cellulose were used for fluid loss control. In order to minimize foam, 2-3 drops of octanol were used. A Fann V-G meter 35SA was used to take dial readings that were then converted to determine plastic viscosity, apparent viscosity, yield point, and gel strength at various intervals. API Filter Press assessed properties of filtration. To determine the influence of fly ash concentration on solution density, the Fann Mud Balance Model 140 was applied. Further determination of particle size distribution was achieved through Zetasizer Nano S90. Great improvement was recorded in performance in mud systems by incorporating fly ash as a bridging agent. Finally, fly ash concentrations that could meet the requirements of a non-damaging drilling fluid system were identified.

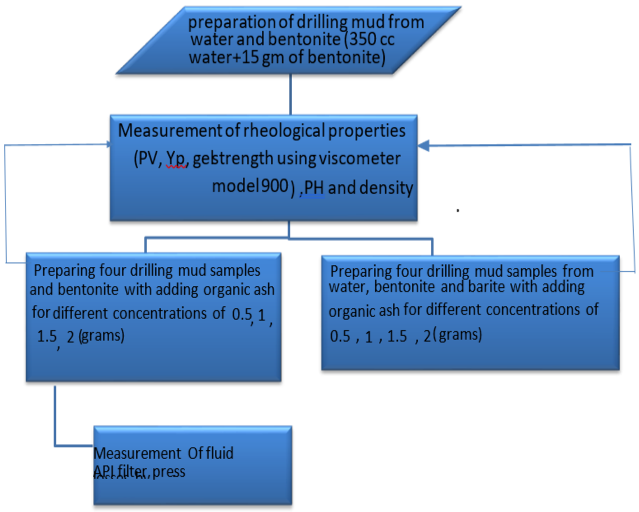

Figure 3: Rheological properties test procedures

Figure 3 shows the experimental procedure for determining the rheological properties of drilling mud. Prepare the drilling mud by mixing 350 cc of water with 15 grams of bentonite. Then, the rheological properties of the drilling mud were tested using the viscometer model 900. The properties tested are plastic viscosity, yield point, gel strength, pH, and density. Two sets of drilling mud samples should be prepared. The first set has water with a percentage of bentonite and organic ash in a small amount at 0.5, 1, 1.5, and 2 grams. The second set is made with water, bentonite, and barite, while organic ash is used again and added to that percentage. These sets will be tested further to determine fluid loss on an API filter press. It methodically addresses the influence of organic ash on the characteristics of the drilling mud so that insight into its rheological properties and filtration ability is afforded for its future use in drilling.

4. Result and Discussion

Sufficiently minute levels of organic ash addition have significantly impacted rheological drilling-fluid performance under all operational conditions in a major way. High concentrations significantly influence the viscosity, yield stress, and gel strength of such drilling fluids, especially agricultural or biomass waste residues derived from organic ashes. Organic ash addition indicated the improvement in plastic viscosity and the yield point of the drilling fluid, which enhanced good suspension of the drill cutting and improved efficiency in the hole cleaning process. The reason behind it was said to be its finer particle size and better interaction with the base fluid toward forming stable and homogenous dispersion. Organic ash addition also improved the gel strength characteristic, which prevents sedimentation under static conditions and points towards the good structural integrity of the drilling fluid.

In this regard, the present work also emphasized the temperature stability of drilling fluids containing organic ash additives, as they have helped maintain rheological properties even at elevated temperatures. Thus, they are applicable in high-temperature drilling operations. This composition contains a good natural viscosity strengthener, organic ash, very rich in silica, alumina, and other minerals that replaced chemical polymers typically used in chemical additives, which further provided stability at an alkaline pH during the addition of organic ash, further compatible with other drilling fluid additives and minimized any corrosion problems. Filtration tests showed less fluid loss since the ash particles were left at the wall of the wellbore. This thin, impermeable filter cake prevented the invasion of the drilling fluid into the formation, reducing the danger of damage. This paper demonstrated the outcome of a study in organic ash to enhance the thermal stability of the fluid to a point where its rheological properties persisted for a reasonable duration thereafter, and degradation did not occur at high temperatures.

From experimental results, it is found that organic ash significantly affects the electrokinetic properties of the drilling fluid as zeta potential values improve. This will enhance the colloidal stability, thereby allowing the suspension of solid particles in the fluid. Its porosity and surface reactivity will make the ash absorb contaminants and improve fluid clarity. Organic ash was as good as or even better than commercial drilling fluid additives in rheological stability, environmental friendliness, and cost. This method utilized organic ash as an additive. Thus, the whole practice depicted environmental advantages such as reducing dependency on non-renewable additives and using agricultural wastes, which directly supports the achievement of sustainable development goals. Considering its economic viability, organic ash was introduced as a substitutive practical element because it reduced the consumption of expensive chemical-based additives with the same performance and even better results.

The present research highlighted the versatility of organic ash in various applications. In some concentrations, optimum results are obtained at balanced performance and cost. Moreover, the synergistic effects of organic ash with bentonite and polymers contribute to the enhanced overall functionality of drilling fluids. Overall, from the rheological and sustainability aspects for both the environment and lower costs, organic ash potentially proves to be a multi-purpose and nontoxic additive with improved quality. Such performance in terms of reducing environmental footprint and operating cost makes possible the inclusion of organic ash into a regular practice of drilling step to greener drilling operations with more efficient operation. PIastic Viscosity (PV) is:

$$PV = \frac{\tau_2 - \tau_1}{\dot{\gamma} - \dot{\gamma}} \qquad (1)$$

where τ_1, τ_2 are shear stresses and $\dot{\gamma}, \dot{\gamma}$ are shear rates. Yield Point (YP) is given below:

$$YP = \tau_0 - PV \cdot \dot{\gamma} \qquad (2)$$

where τ_0 is the shear stress at zero shear rate. Apparent Viscosity (AV) is:

$$AV = \frac{\tau}{\dot{\gamma}} \qquad (3)$$

where τ is the shear stress and $\dot{\gamma}$ is the shear rate. Fluid Loss(FL) is framed as:

$$FL = \frac{V}{A \cdot t} \qquad (4)$$

Where V is the filtrate volume, A is the filter area, and t is time. pH calculation is given below:

$$pH = -\log_{10}[H^+] \qquad (5)$$

where $[H^+]$ is the concentration of hydrogen ions. Filter Cake Thickness (T) is:

$$T = \frac{W}{\rho \cdot A} \qquad (6)$$

Where W is the weight of the cake, ρ is the density, and A is the area. Mud Density (ρ_m) is:

$$\rho_m = \frac{\text{Weight of Mud}}{\text{Vo1ume of Mud}} \quad (7)$$

Details are provided in this regard as far as drilling mud with additives is concerned. The basic formulation consists of 350 cc of water, 10 grams of barite, and 15 grams of bentonite; the sole additive is organic ash material. Drilling mud, which happens to be based on water, has four certain organic ash quantities appropriate for the values. Then, percentages of organic ash are added to result in some novel drilling mud formulations combined with other drilling mud. Six viscometer readings of water-based drilling mud, as expressed through shear stress and shear rate values, are given in Table 1. Average values of the mean viscometer readings are then used in calculations for shear stresses and shear rates in the following way.

Shear rate (γ), sec $^{-1}$ =1.7023 × ω
Shear Stress (τ), Ib/100ft^2 = 1.065 × ϕ

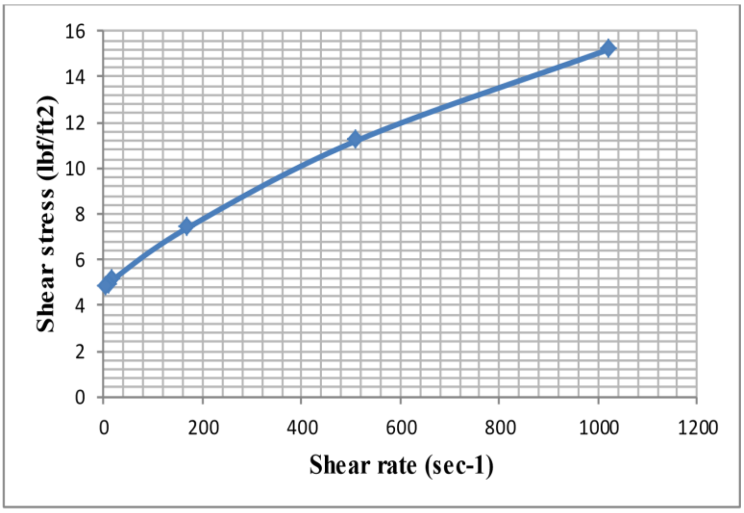

Figure 4: Shear stress–shear rate plot of water-based drilling mud (Linear Fit)

The calculated values are plotted as shown, with an outcome to attain a good fit for the Bingham Plastic curve, whereby linearity is manifested as follows: Figure 4 wherein the fluidity follows Bingham plasticity as can be visualized from the fact that the next Figure ensures the consistency plot for organic ash of the water-based drilling mud obtained is indeed of good correlation required; thereby rendering it to be a fitting rheological model applicable to the rest of samples also. The water-based mud drilling samples fall into two completely different categories whose consistencies are recorded in their curves in Figures 5 and 6.

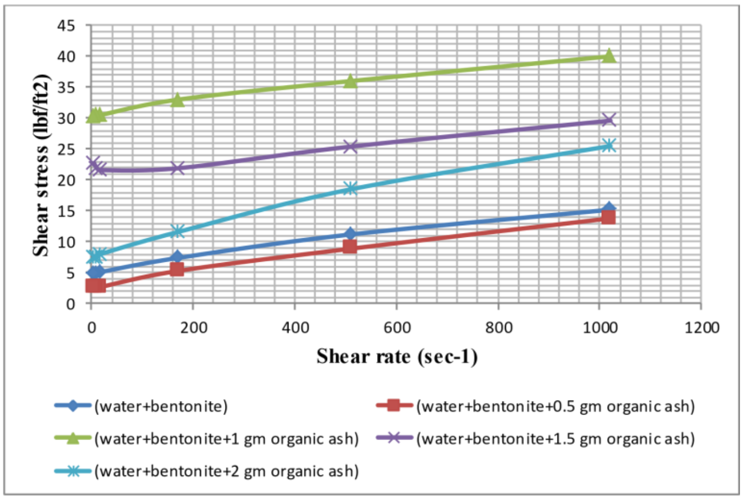

Figure 5: Shear behavior of organic ash-enhanced water-based drilling mud

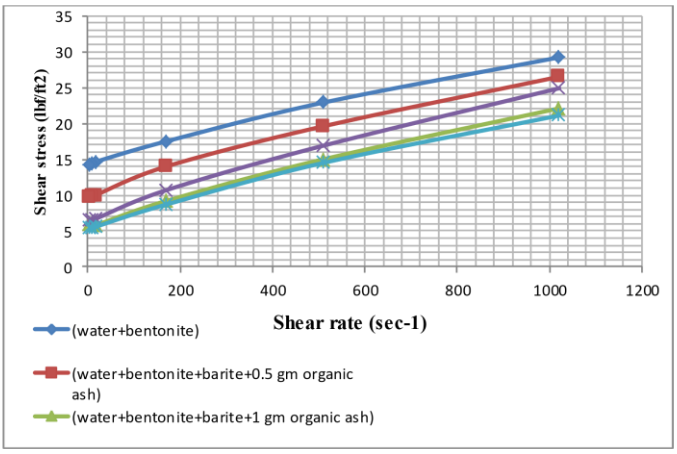

Figure 6: Shear profile of water-based drilling mud with organic ash additive

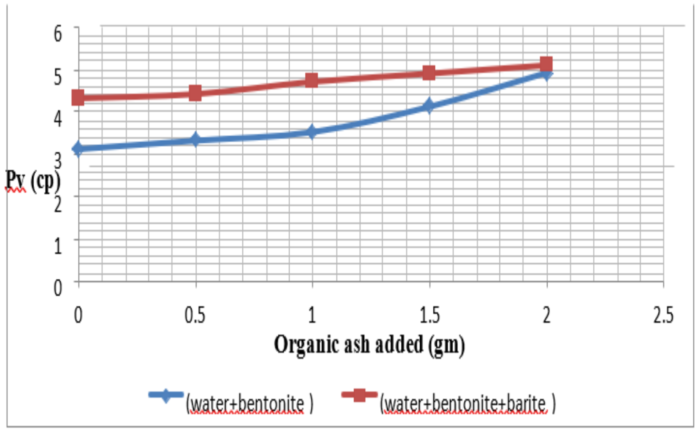

Figure 7: Plastic viscosity with organic ash additive

From Figure 7, it is obvious that as the amount of ash is added, the plastic viscosity increases, indicating that bentonite's internal friction increases gradually (plastic viscosity is proportional directly to solid concentration). The yield point of the drilling mud samples shows a pronounced trend with the addition of fly ash. As shown in Table 1, the yield point decreases with percentages of fly ash up to 6% and then increases. These properties, among others, plastic viscosity, apparent viscosity, gel strength, mud weight, alkalinity, and filtrate volume, are summarised in the figures and table.

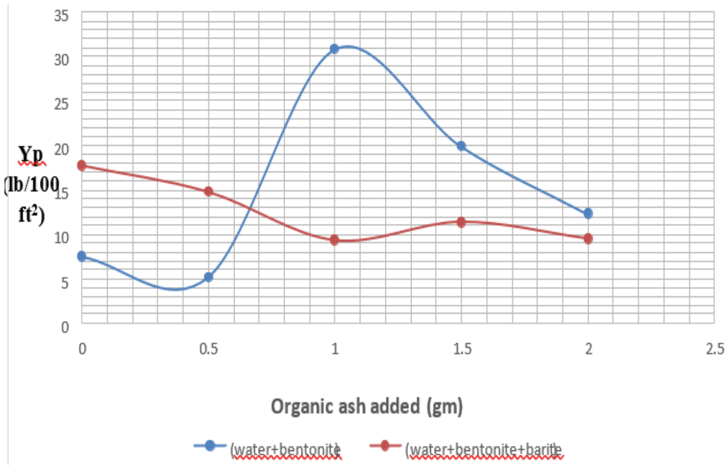

Figure 8: Yield point with organic ash additive

Figure 8 plots the rheological parameters of blended water-based drilling mud and fly ash. The information deduced is that the plastic viscosity increases with an increase in the ratio of fly ash, which may indicate a proportional increase in higher solid concentrations due to the internal friction of bentonite. Rheological properties of drilling fluids were checked after the incorporation of fly ash at different weight/volume concentrations of 1%, 2%, 3%, 4%, 5%, 6%, and 7%. From the above discussion, it has been observed that the apparent viscosity (AV) and plastic viscosity (PV) increase with an increase in fly ash concentration up to 6% and then decrease after that point. At 6% fly ash, apparent viscosity increased by 13% cP, plastic viscosity increased by 39% cP, and the result was the improved flowability of the fluid, avoiding surge, swab pressure, differential sticking, and slow penetration rate problems commonly faced during drilling operations. The yield point also varies with the percentage concentration of fly ash, first decreasing up to 6% followed by an increase, as depicted in Figure 8. This is because ash adsorbs on the surface of bentonite particles, reducing aggregation.

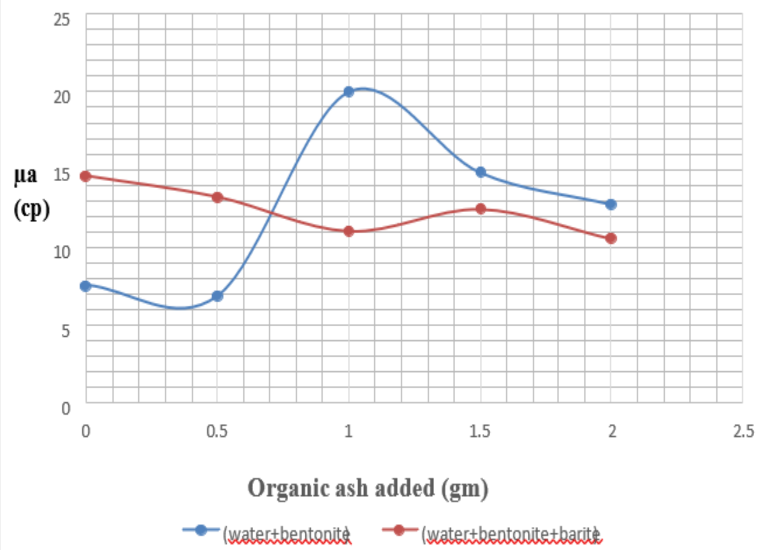

Figure 9: Apparent viscosity with organic ash additive

As shown in Figure 9, apparent viscosity with the addition of fly ash increases owing to the electrostatic attraction between bentonite and ash. Adsorption of ash affects the structure of the gel formed because it disrupts the gel structure and thus affects viscosity. Gel strength, which measures particle-to-particle attractions, increases with additive ash up to saturation, from which it subsequently drops, as illustrated in Figure 10. In the same aspect, gravity mud trends build with more material constituent weights of types that contain barite, as presented in Figure 11. Increasing the amount of fly ash increases the mud alkalinity or pH value, which is also found to increase in Figure 12. All the above data indicate that fly ash will affect water-based drilling mud rheological properties and filtration characteristics.

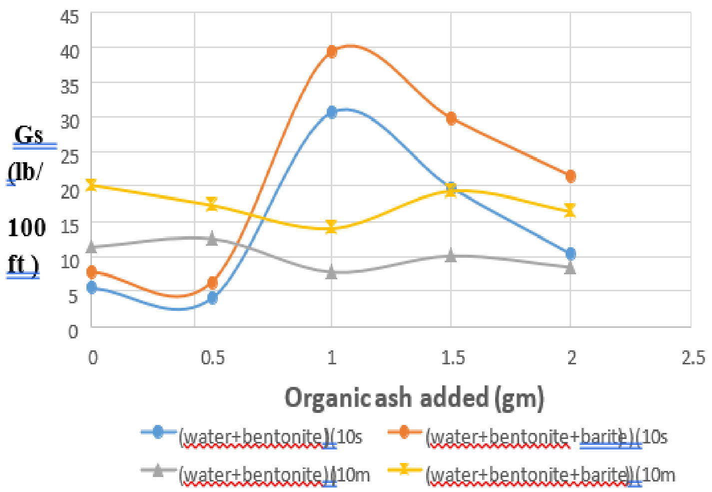

Figure 10: Gel strength plot of water-based mud (water+bentonite) and (water+bentonite+barite) with organic ash

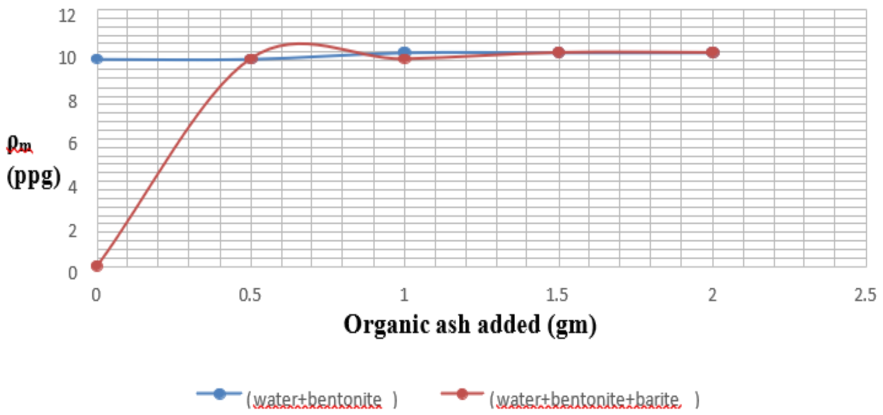

Figure 11: Mud density with organic ash additive

Table 1 gives the pH values for ten different drilling fluid samples, which gives a general idea of the differences in alkalinity among the samples. Samples 1-5 exhibit a progressive increase in pH values from 9.5 for Sample 1 to stabilizing at pH 10 by Sample 4 and Sample 5. This indicates a systematic alteration of drilling fluid composition, probably through the addition of organic ash or another pH-altering additive. Samples 6 to 10 were within a relatively stable pH range, with Sample 6 and Sample 7 starting at 9.7 and then increasing to 10 for Samples 8, 9, and 10. The pH values of Sample 8 onwards became consistent, indicating that the alkalinity of the drilling fluid had reached an equilibrium point, possibly because the additive effect was saturated or the interaction among the fluid components was balanced.

Table 1: Mud alkalinity (pH) for all samples of mud

Sample No.	pH	Sample No.	pH
Sample1	9.5	Sample 6	9.7
Sample2	9.8	Sample 7	9.7
Sample3	9.8	Sample 8	10
Sample4	10	Sample 9	10
Sample5	10	Sample10	10

The increase in pH seen in the earlier samples, from Sample 1 to Sample 4, indicates the additive or modification that enhances the alkalinity of the fluid, critical for stabilizing the drilling mud and preventing corrosion in the wellbore. The constancy in the later samples, from Sample 6 to Sample 10, signifies the ability of the fluid to maintain pH stability under steady conditions. This condition is required to ensure the drilling operation has the right predictability and reliability. The data show that additive concentration is proportional to pH stabilization; thus, formulation control will be of the essence in arriving at the desired properties for the drilling fluids.

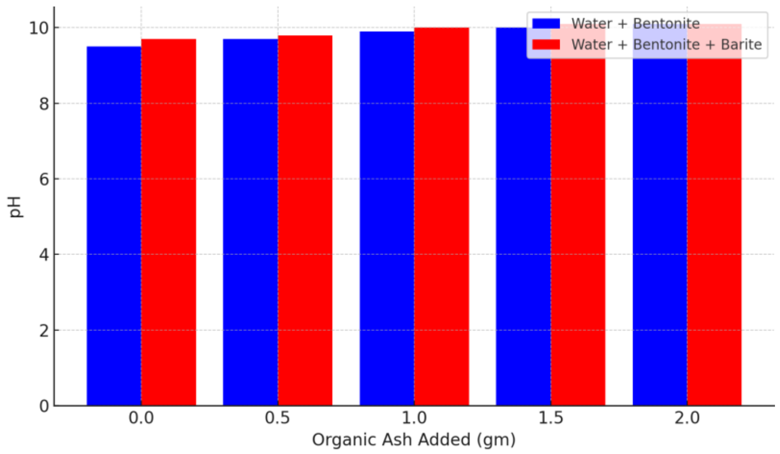

Figure 12: Mud alkalinity (pH) with organic ash additive

The concentration of milligrams of organic ash in association with pH is depicted in Figure 12. Here, two formulation types have been mentioned: "Water + Bentonite" and "Water + Bentonite + Barite." The bar has different heights, thus suggesting how pH increases when concentration increases. The same formulation colors, blue and red, have been applied. The side-by-side bars of different concentrations for each organic ash help avoid confusion from the reader while comparing the two mixtures. As can be seen in this graph, both the preparations are on the rising scale of pH, yet the mixture "Water + Bentonite + Barite" has always remained a bit high in terms of the pH level compared to the "Water + Bentonite" mixture. This trend demonstrates the role of barite in maintaining the buffering and stabilization of the alkalinity of the drilling fluid. The bar graph format gives a clear comparison that makes it easy to observe progressive changes and differences between the two systems at each level of ash addition.

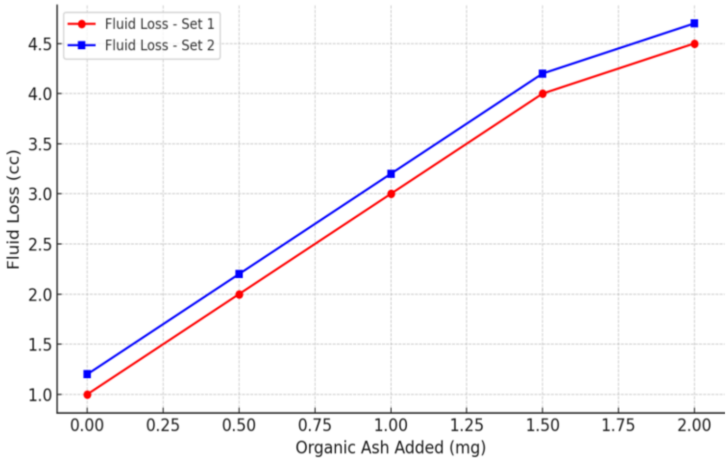

Figure 13: Mud cake thickness with organic ash additive

The organic ash was introduced, and based on this, the effect on the fluid loss in cubic centimeters for two data sets is represented using Figure 13. Two lines use red circles, and the other uses blue squares to establish the two data sets, representing the fluid loss when adding organic ash incrementally. The red line is the baseline trend, and the blue line is the elevated fluid loss pattern. It is a comparative dataset; two lines move in the same direction, so fluid loss is high when the ash concentration is high. This correlation signifies that ash particles affect the permeability and morphology of the filter cake developed from the drilling fluid application. The multi-line plot shows an identical trend in the data sets. It affords a good view of the comparative fluid loss effect based on ash concentration that might support the optimization of the ash-based drilling fluid formulation.

The study indicated that ash concentration strongly correlates with drilling mud rheological properties, reflecting consistent trends and fluctuations. As the ash concentration increases, shear stress and shear rate increase proportionally, implying increased flow resistance under applied stress. It is a trend that reflects the influence of ash particles on the strength of the structural integrity of mud, which in turn helps to have stronger particle inter-contacts. Similar to plastic viscosity, with increased ash concentration, plastic viscosity increased. This indicated an improved ability of the fluid to suspend solid particles and resist deformation under steady flow. However, the yield point and apparent viscosity had fluctuating behaviors. The yield point and apparent viscosity alternately increased and decreased with ash concentration. These variations indicate a complex interaction between ash particles and the base fluid, probably decided by the ash particle distribution and the saturation point of the fluid.

The strength of the gel initially increased with the ash concentration and enhanced the drilling mud's capacity against sedimentation during the static condition. However, at higher saturation levels, gel strength began to decrease. It indicates that an ash concentration that is too high can rupture the fluid's structural balance. The mud density is always on the rise due to the increase in ash concentration that results from solid particles being put into the system, which promotes wellbore stability. There is also a minimal increase in mud alkalinity due to the ash's chemical constitution that influences the fluid's pH levels. Summary: These findings underlined the critical role optimization of ash concentration plays in drilling mud formulations that can reach desirable rheological properties while ensuring stability and efficiency during drilling operations.

5. Conclusions and Future Work

The drilling fluid is similar to Bingham plastic fluids, in which organic ash greatly impacts the change in fluid properties. Plastic viscosity and fluid density increase with the addition of organic ash; hence, there is an increase in resistance to deformation and stability in the wellbore. Fluid loss, however, increases with significant organic ash addition, which requires optimized concentrations. The yield point, apparent viscosity, and gel strength measured at 10 seconds and 10 minutes are erratic when adding organic ash and show complex interactions between the ash particles and fluid matrix. The filtration properties of the developed drilling fluid system improve with a decrease in particle size resulting from the addition of fly ash. Smaller particle size leads to an improved bridging effect, decreasing filter cake thickness and fluid loss and enhancing working efficiency. Also, when nanoparticles are present in a system, the fluid is characterized by better suspension properties, stability, and fluid control. However, the step sequence and method are to be seriously taken with the addition of polymer and ash because lousy mixing may lead to unevenness and poor function. Although the overall effectiveness of fly ash as a bridging agent is not nullified, it has no apparent effect on some rheological characteristics like yield point. Fly ash even surpasses the traditional bridging agents used in drilling fluids because of better performance, smaller particle sizes, cost-effectiveness with high availability, and environmental advantages through its application. As it is an industrial by-product, its use in a renewable way would lead to the optimum waste reduction and the effective improvement of fluid performance.

In further research, organic ash might be used in drilling muds like OBM to broaden the potential application and explore how it performs under operational conditions. For superior thermal stability and lubricity, OBM is predominantly used in difficult drilling operations. The introduction of organic ash into an OBM system could yield quite exciting results in terms of rheological and filtration properties. Organic ash could also be considered an active ingredient in preparing drilling mud or additives to improve performance and achieve the environmental sustainability of mud formulates. Organic ash can also be considered and explored for its effect on the performance of the lubricity of drilling mud. Lubricity provides improved performance that reduces the friction between the drill string and the wellbore to improve operational performance and extend the lifetime of drilling equipment. A detailed mineralogical analysis of organic ash should also be carried out to determine its chemical composition. Such an analysis would also help identify the active components responsible for the performance, thus guiding the optimization of drilling fluid formulations. These leads will further solidify the variety and effectiveness of organic ash in contributing to sustainable, efficient drilling practices.

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Ethics and Consent Statement: This study was conducted by ethical standards, with informed consent obtained from all participants. Measures were taken to ensure the confidentiality and privacy of all individuals involved.

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