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Formulation of Locally Sourced Materials (Wood Ash) As PH Enhancer in Water-Based Drilling Muds

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Abstract
This study investigates the formulation of locally sourced wood ash as a pH enhancer in water-based muds, aiming to identify a cost-effective and sustainable alternative to conventional pH additives. A controlled laboratory investigation was conducted using a base mud formulation comprising water, bentonite, barite, xanthan gum, and potassium chloride, while systematically varying only the pH-enhancing component. Six mud samples were prepared, including a blank mud without a pH additive, a lime-treated reference mud, and four wood ash-treated muds at concentrations of 1.75 g, 3.50 g, 5.25 g, and 7.00 g. The results reveal a clear concentration-dependent increase in mud pH, with wood ash raising alkalinity from an initial value of 8.90 to 12.90, approaching the pH level achieved using lime (13.25). This controlled alkalinity range is critical for clay stabilization, additive activation, and corrosion mitigation. Rheological measurements indicate that plastic viscosity and apparent viscosity remained within operational limits, with Marsh funnel viscosity values maintained between 46 and 48 s, confirming minimal disruption to flow behavior. Filtration analysis reveals a gradual increase in fluid loss, from 4.30 mL to 4.70 mL, and filter cake thickness, from 2.40 mm to 2.62 mm, as the ash concentration increases, remaining within acceptable drilling specifications. A slight reduction in mud density from 9.20 ppg to 8.60 ppg was observed, attributable to the lower specific gravity of wood ash compared to lime. This highlights the potential for utilizing wood ash, a locally available resource, to improve drilling fluid formulations, offering both economic and environmental advantages in drilling operations.

I. INTRODUCTION

Water-based muds are essential fluids in the drilling industry, playing a pivotal role in the successful extraction of hydrocarbons from subsurface reservoirs. These drilling fluids are engineered to provide stability, lubrication, and pressure control during drilling operations. Central to their performance is the maintenance of an optimal pH level (Okon, A. N. et al., 2020). Deviations from the desired pH range can lead to various drilling complications, including clay swelling, corrosion of equipment, and reduced drilling efficiency. Traditionally, the adjustment of pH in drilling muds has been achieved through the use of commercially available chemicals such as caustic soda (sodium hydroxide) and lime (calcium hydroxide). While effective, these chemicals often come at a considerable cost and may require transportation over long distances, increasing the environmental footprint of drilling operations (Wei Z. et al., 2022).

In recent years, there has been a growing emphasis on sustainability and the use of locally sourced materials to address challenges in various industries. Wood ash, a byproduct of combustion in numerous industrial and household settings, has gained attention for its potential as a pH-enhancing agent in water-based muds. Wood ash is rich in alkaline compounds, primarily composed of calcium carbonate ($CaCO_3$) and potassium carbonate (K_2CO_3) (Błońska, E. et al., 2023). Moreover, it is abundantly available in regions with significant forestry or wood-burning activities. The utilization of wood ash as a pH enhancer in drilling fluids has the potential to address several key issues. Firstly, it offers a cost-effective alternative to conventional chemicals, reducing operational expenses. Secondly, the use of locally sourced wood ash may decrease the reliance on chemical imports, contributing to resource conservation and sustainability. Thirdly, it aligns with the broader objectives of reducing the environmental impact of drilling activities, as wood ash is often considered a waste material with limited disposal options (Shafiq M. U. et al., 2024). Despite the promising attributes of wood ash, its practical application in drilling muds requires comprehensive research and testing to determine its effectiveness, compatibility with different mud formulations, and potential environmental implications.

This study seeks to investigate the feasibility and viability of utilizing locally sourced wood ash as a pH enhancer in water-based drilling muds by answering the following questions; In terms of compatibility, how does the introduction of wood ash affect the overall stability, viscosity, and rheological properties of drilling muds? What are the environmental implications of using wood ash as a pH enhancer in drilling muds? Does this approach contribute to reducing the overall environmental footprint of drilling activities? Addressing these questions is essential to determine the feasibility and viability of utilizing locally sourced wood ash as a pH enhancer in water-based drilling muds.

1.1. Importance of PH Control in Water-based Drilling Mud

pH control plays a crucial role in the performance and stability of water-based drilling muds, especially in challenging geological formations. (Wang et al. 2023), investigated the rheological and filtration control performance of water-based drilling muds under elevated temperature and saline environments. Their research showed the relevance of pH stability in preserving the effectiveness of mud additives and overall fluid behavior. Their investigation demonstrated that in drilling fluids exposed to both high temperature and salt contaminants, disturbances in chemical balance including pH shifts can significantly weaken polymeric and particulate additives responsible for viscosity and filtration control, leading to diminished carrying capacity and higher fluid loss volumes under stress. By maintaining pH within an optimal range, drilling fluids showed improved stability of rheological parameters and reduced degradation of performance-enhancing constituents, which in turn preserved fluid viscosity and shear strength. The study further reported that stable mud chemistry, supported by proper pH control, contributes to enhanced hole cleaning efficiency and sustained suspension of cuttings, thereby reducing operational risks such as pipe sticking and circulation losses at elevated temperatures and salinities. These results highlight that rigorous pH management is essential for consistent drilling fluid performance in harsh downhole conditions.

(Gamal et al., 2019) Research on the effect of pH on rheological and filtration properties of water-based mud -based on Bentonite, also pointed out the importance of pH control in drilling mud. Their research demonstrated that pH directly influences key rheological properties such as plastic viscosity, yield point, and gel strength by altering the electrostatic forces between clay particles. At low pH levels, clay particles tend to flocculate, leading to poor suspension stability and excessive fluid loss. Conversely, maintaining an optimal alkaline pH enhances clay dispersion, improves filter cake quality, and minimizes formation damage. The study clearly demonstrates that proper pH control is crucial for preventing clay swelling and wellbore instability, particularly in formations containing reactive clays.

pH regulation is also closely linked to drilling safety, equipment longevity, and environmental compliance. This was demonstrated by Al-ziyadi et al.(2025) research, which highlighted that acidic drilling fluids increase corrosion rates on drill strings, casing, and surface equipment, while excessively alkaline conditions promote scale formation and chemical instability. The authors also emphasized that many modern drilling fluid additives are pH-sensitive, meaning their functionality depends on precise chemical control. Effective pH management, therefore, ensures additive performance, reduces safety risks such as wellbore failure or blowouts, and helps operators comply with environmental regulations governing drilling fluid disposal.

II. METHODOLOGY

This section provides a description of the methods used to carry out this study, the materials (including specific functions), and experimental steps.

2.1 Materials

a) Water: This is the continuous phase and also represents the base fluid.
b) Bentonite: This is a type of foreign clay used for spud mud formulation. It serves as a primary viscosifier for a water-based mud.
c) Barite: This is a weight additive to the mud formulation.
d) Polyanionic Cellulose (PAC): This is a fluid loss control additive blended into the whole mud.
e) Lime: This is a pH enhancer. It tends to boost the pH of the WBM.
f) Wood ash: This serves as the locally sourced addictive for the pH enhancement.
g) Potassium Chloride (KCL): This is an inhibitor responsible for shale formation stabilization.

2.2 Equipment/Apparatus

c) Weighing scale: For measuring the desired weights of materials during mud formulation.
d) Mud Mixer: This is used for blending bentonite, water, and other additives.
e) Mud Balance: Mud balance was used to measure the density of mud in pounds per gallon (ppg).

f) Filter Press Machine: A low-pressure low-temperature (LPLT) filter press machine was used to ascertain the rate of fluid loss and filter cake thickness from the whole mud.
g) Sand Content Kit: The volume of sand present in all samples of mud was measured with the use of a sand content kit. The ml of sand or % of sand was recorded accordingly.
h) Marsh funnel and cup: This was used as a quick and regular viscosity check during drilling. It measures the time at which a quart of mud flows out through its orifice.
i) Rheometer **(FANN, Models 35A/SR-12)**: To determine the viscosity of the mud samples.
j) pH meter **(PHS 25)**: To determine the hydrogen ion concentration of the mud samples.

2.2 Drilling Fluid Preparation and Testing
To achieve the aim of this work, which is based on the use of wood ash, a drilling additive (pH enhancer), the following procedures were followed:

Spud Mud Preparation
Different compositions of water based muds (WBMs) were prepared and ready for characterization. A variation to the new additives (wood ash) was done so as to compare the performances to the industry based additive for pH enhancement.

The components that made up each mud sample were presented in the table below and various mud tests were conducted on them. See Table 2.1 for the quantities of the various mud components that made up the compositions. The desired base fluid volume was first measured and poured into a mixer cup and then placed under a mud mixer. The addition of chemicals and other additives to the fresh mud (or spud mud) was done to improve the quality of the mud. The mud additives were added one after the other and blended simultaneously until the last additive was added. The method adopted for this work is the American Petroleum Institute's Recommended Practice for testing water-based mud (**API RP-13B**).

2.3 Mud Composition

Mud sample	Water (ml)	Soda Ash (g)	Bentonite (g)	Barite (g)	Xanthan Gum (g)	KCL (g)	Lime (g)	pH additive (Wood Ash) (g)

Blank	350	4.00	21.00	6.50	2.70	3.00	-----	-----
A	350	4.00	21.00	6.50	2.70	3.00	3.50	-----
B	350	4.00	21.00	6.50	2.70	3.00	-----	1.75
C	350	4.00	21.00	6.50	2.70	3.00	-----	3.50
D	350	4.00	21.00	6.50	2.70	3.00	-----	5.25
E	350	4.00	21.00	6.50	2.70	3.00	-----	7.00

Table 2.1 mud composition

The mud formulations presented in the table above were designed to systematically evaluate the effectiveness of the locally sourced wood ash as a pH enhancer in water-based drilling muds, using a conventional lime-treated system and an untreated base mud as benchmarks. All mud samples were prepared with a constant base composition to ensure that observed variations in properties could be directly attributed to the type and concentration of pH-enhancing additives rather than changes in base mud chemistry. Each formulation contains 350 ml of water, serving as the continuous phase of the drilling fluid and providing the medium for hydration, dispersion, and chemical interactions among the solid and polymeric components.

Bentonite (21.00 g) was included uniformly across all samples as the primary viscosifying and clay-hydration agent. This helps to develop the required gel structure, enhances cutting suspension, and contributes to filter cake formation. Barite (6.50 g) was added as a weighting material to control mud density. Xanthan gum (2.70 g) functions as a high-performance biopolymer viscosifier, providing shear-thinning behavior that improves hole cleaning while maintaining pumpability at higher shear rates. Potassium chloride (3.00 g) was incorporated as a shale inhibition agent to minimize clay swelling and dispersion, particularly in reactive formations. The uniform presence of these components across all samples establishes a controlled baseline mud system suitable for the comparative analysis.

The blank sample represents the reference mud formulation with no pH-enhancing additive, allowing for direct assessment of the natural alkalinity and baseline performance of the base mud system. Sample A contains Lime, a pH enhancer, serving as the conventional industry standard for alkalinity control in water-based muds. This sample provides a benchmark against which the performance of wood ash can be evaluated. Samples B to E replace lime with wood ash at increasing concentrations (1.75 g, 3.50 g, 5.25 g, and 7.00 g, respectively). These samples were designed to assess the dose-dependent effect of wood ash on mud alkalinity and associated drilling fluid properties, as well as to determine the minimum concentration required to achieve performance comparable to lime.

III. RESULT AND DISCUSSION

3.1 Mud Properties Evaluation

Mud Samples	Mud pH	Mud Density (ppg)	Marsh Funnel (Quart/Seconds)	Sand Content (%)
Blank	8.90	9.20	47	Negligible
A	13.25	9.15	48	Negligible
B	11.60	8.80	47	Negligible
C	12.25	8.75	47	Negligible
D	12.60	8.70	46	Negligible
E	12.90	8.60	46	Negligible

Table 3.1 Mud Properties Evaluation

The table above presents data on several key mud properties pH, mud density, Marsh Funnel viscosity, and sand content across the different mud samples from Blank to Sample E.

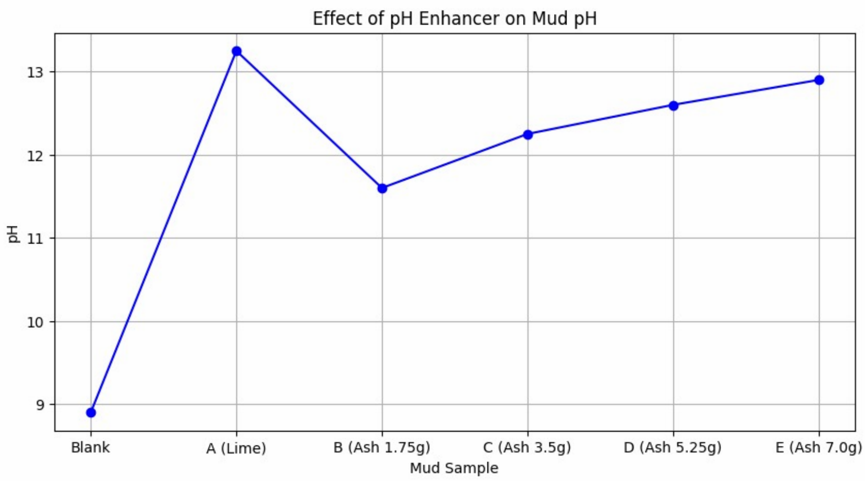

Figure 3.1 effect of pH enhancer on mud Ph

The graph above (see figure 3.1) presents the variation of mud pH as a function of pH enhancer type and concentration, providing a clear comparison between the conventional additive (lime) and the locally sourced wood ash. The blank mud sample exhibits a pH of 8.90, which reflects the inherent alkalinity of the base water-based mud system prior to chemical modification. Upon the addition of lime in Sample A, a sharp increase in pH to 13.25 is observed in the first graph, confirming the strong alkalizing effect of lime and its high solubility in the aqueous phase. This abrupt rise in alkalinity highlights lime's efficiency as a pH enhancer but also suggests the potential for over-alkalization, which can adversely affect clay stability and additive compatibility if not carefully controlled. In contrast, the wood ash–treated samples (B–E) display a gradual and systematic increase in pH from 11.60 to 12.90 with increasing ash concentration, as evidenced by the steadily ascending trend in the first graph. This behavior indicates a concentration-dependent release of alkaline constituents from the wood ash, likely associated with the dissolution of potassium, calcium, and magnesium oxides and carbonates present in the ash matrix. The smoother pH progression observed for the wood ash samples suggests improved controllability compared to lime, allowing the mud system to attain and maintain

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alkalinity within the operationally desirable range for water-based drilling fluids.

Importantly, the pH values achieved by the wood ash formulations, as shown in Figure 3.1, fall within the optimal range required for effective clay inhibition, enhanced additive performance, and corrosion mitigation in drilling operations. This comparative analysis therefore demonstrates that although lime produces a higher peak pH, wood ash offers a more moderate and tunable alkalinity response. This reinforces the technical viability of wood ash as a locally sourced pH enhancer capable of delivering stable and controlled pH adjustment in water-based mud systems.

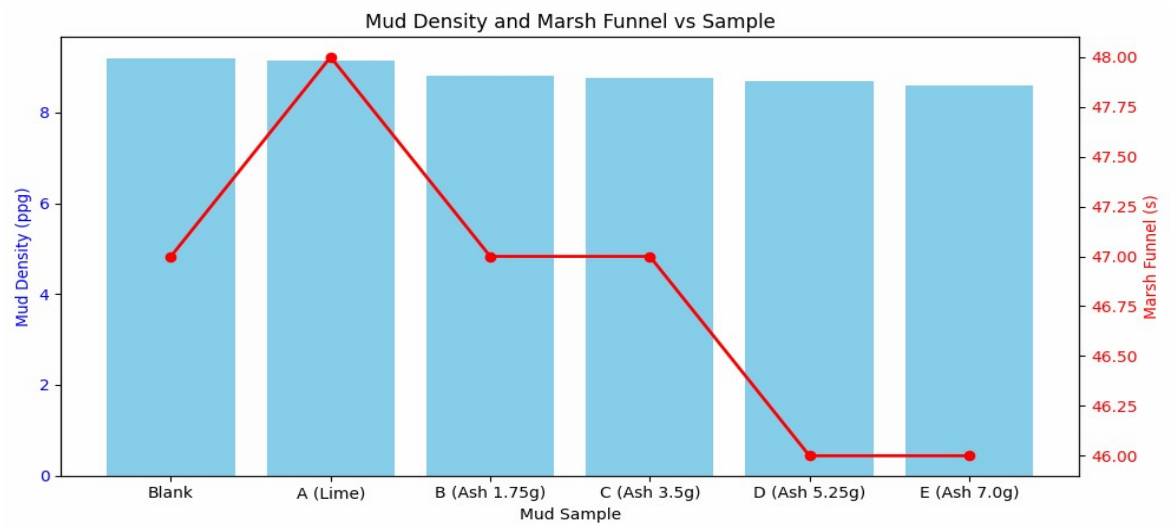

Figure 3.2 effect of mud density and marsh funnel vs sample

Figure 3.2 above shows a graph that illustrates the combined effects of the pH enhancers on mud density and Marsh funnel viscosity, providing insight into the influence of wood ash on the overall flow behavior and solids loading of the drilling mud. The blank sample shows a mud density of 9.20 ppg with a Marsh funnel time of 47 s, representing the baseline rheological condition of the formulated water-based mud. With the addition of lime in Sample A, the mud density remains nearly unchanged at 9.15 ppg, while the Marsh funnel time slightly increases to 48 s, as indicated, suggesting a marginal increase in flow resistance due to lime addition. For the wood ash–based samples (B–E), there is a gradual decrease in mud density from 8.80 to 8.60 ppg with increasing ash concentration, accompanied by a slight reduction in Marsh funnel time from 47 to 46 s. This trend indicates that wood ash does not significantly increase the effective solids concentration of the mud and may even promote a lighter mud system with improved flow characteristics. The relatively stable Marsh funnel times across all samples demonstrate that the addition of wood ash does not adversely affect mud pumpability or induce excessive viscosity.

3.2 Mud Filtration Properties Evaluation

Mud Samples	Filtration properties	
	Fluid loss (ml)	Filter cake thickness (mm)
Blank	4.30	2.40
A	4.30	2.45
B	4.40	2.50
C	4.50	2.53
D	4.50	2.55
E	4.70	2.62

Table 3.2 Mud filtration properties evaluation

Table 3.2 above outlines the filtration properties of various mud samples. Each mud sample was assessed for its fluid loss (measured in milliliters) and filter cake thickness (measured in millimeters), both of which are important indicators of how well the mud can control the invasion of drilling fluids into the formation.

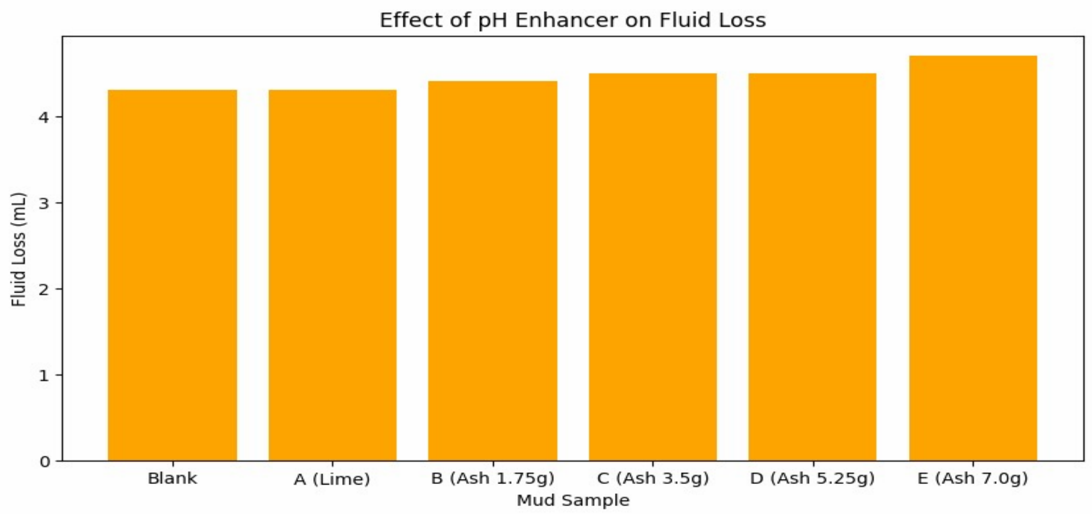

Figure 3.3 effect of pH enhancer on fluid loss

Figure 3.2 illustrates the effect of pH enhancers on the filtration behavior of the formulated water-based muds, as represented by the measured fluid loss. The blank sample records a fluid loss of 4.30 mL, serving as the baseline performance of the base mud system. The introduction of lime in Sample A does not significantly alter this value, indicating that lime addition maintains filtration control comparable to the untreated mud, as reflected by the near-identical bars in the second graph. In contrast, the wood ash–treated samples (B–E) exhibit a gradual increase in fluid loss from 4.40 to 4.70 mL with increasing ash concentration, as shown by the progressive rise in figure 3.2. This trend suggests that while wood ash effectively enhances pH, its

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particulate nature may slightly disrupt the formation of a tight, low-permeability filter cake, resulting in marginally higher filtrate volumes. Nevertheless, the observed increases remain relatively small and within acceptable operational limits for water-based drilling fluids.

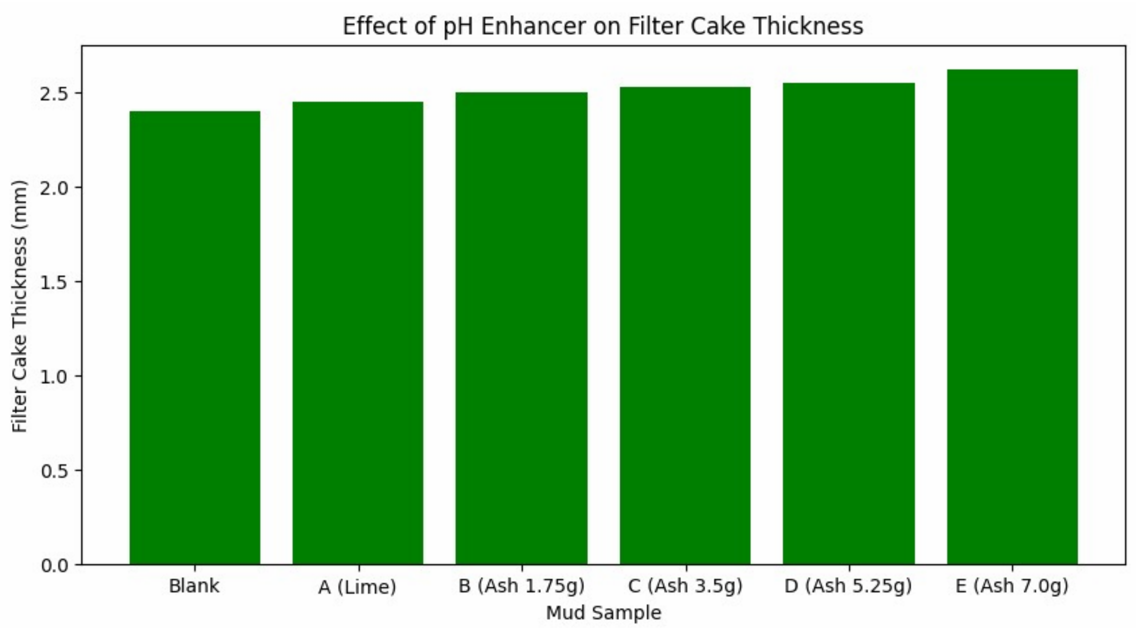

Figure 3.4 effect of pH enhancer on filter cake thickness

Figure 3.3 above presents the variation in filter cake thickness for the different mud samples, highlighting the influence of pH enhancers on filter cake development. The blank mud sample exhibits the thinnest filter cake at 2.40 mm, representing the baseline filtration behavior of the untreated mud system. The addition of lime in Sample A results in a slight increase in filter cake thickness to 2.45 mm, as shown in Figure 3.3, indicating minimal alteration to the mud's ability to form a compact and low-permeability cake. For the wood ash–treated samples (B–E), they show a gradual increase in filter cake thickness from 2.50 to 2.62 mm with increasing ash concentration. This progressive trend suggests that the solid constituents of wood ash contribute to the formation of a slightly thicker filter cake, likely due to the presence of fine, non-uniform particles that affect particle packing and cake structure. Despite this increase, the filter cakes formed remain relatively thin and uniform, which is desirable for minimizing differential sticking and maintaining wellbore integrity.

IV. CONCLUSION

This research set out to evaluate the suitability of locally sourced wood ash as a pH enhancer in water-based drilling muds by directly comparing its performance with a conventional lime-treated system and an untreated base mud. All formulations were prepared with identical base components 350 ml water, 21.00 g bentonite, 6.50 g barite, 2.70 g xanthan gum, and 3.00 g KCl ensuring that observed differences in mud behavior could be attributed solely to the type and concentration of the pH-enhancing additive. The blank mud exhibited a baseline pH of 8.90, providing a reference point for assessing the alkalinity contribution of lime and wood ash. Upon the addition of lime at 3.50 g, the mud pH increased sharply to 13.25, confirming lime's strong alkalizing capacity. In comparison, wood ash increased mud pH progressively from 11.60 at 1.75 g to 12.90 at 7.00 g, demonstrating a clear dose-dependent response. This controlled rise in alkalinity is significant, as it places the mud pH within the optimal operational range for clay stabilization and additive performance without the risk of excessive alkalinity associated with lime. The gradual pH trend observed with wood ash highlights its potential for more manageable and tunable pH control in drilling fluid systems.

Physical and rheological properties showed minimal sensitivity to wood ash addition. Mud density decreased gradually from 9.20 ppg in the blank to 8.60 ppg at 7.00 g of wood ash, reflecting the lower specific gravity of ash compared to conventional weighting agents. Marsh funnel viscosity remained largely stable, varying only between 46 and 48 seconds across all samples, indicating that mud flow behavior and pumpability were preserved. The consistently negligible sand content across all formulations confirms that wood ash did not introduce undesirable solid contaminants into the system. The filtration behavior further supports the technical viability of wood ash. Fluid loss increased modestly from 4.30 mL in the blank sample to 4.70 mL at the highest ash concentration, while filter cake thickness increased from 2.40 mm to 2.62 mm. Although these values are slightly higher than those observed for the lime-treated mud, they remain within acceptable operational limits and indicate that wood ash does not significantly impair filtration control. The relatively uniform and thin filter cakes suggest that the ash-treated muds would still provide adequate wellbore protection with minimal risk of formation damage or differential sticking.

The experimental results demonstrate that wood ash can effectively raise and control the pH of water-based drilling muds while maintaining acceptable filtration, density, and rheological properties. At a concentration of 7.00 g, wood ash achieved a pH of 12.90, closely approaching the performance of lime but with a more controlled alkalinity profile. These findings confirm that locally sourced wood ash is a technically feasible and sustainable alternative to conventional pH enhancers, particularly for cost-sensitive and locally driven drilling operations, and provide a strong basis for further optimization and field-scale validation.

V. RECOMMENDATION

Based on the experimental results, further research should first address the slight increase in fluid loss and filter cake thickness observed with increasing wood ash concentration, which rose from 4.30 mL to 4.70 mL and from 2.40 mm to 2.62 mm, respectively. Although these values remain within acceptable operational limits, they indicate that the particulate nature and heterogeneous particle size distribution of wood ash may reduce filter cake compactness. Future studies should therefore focus on particle size classification and beneficiation of wood ash, including sieving, grinding, and chemical pretreatment, to improve particle packing and reduce permeability of the filter cake. Investigating the synergistic use of wood ash with low-cost filtration control agents, such as starches or modified celluloses, would also provide insight into optimizing filtration performance without compromising sustainability.

Closely linked to filtration behavior is the chemical variability of wood ash, which likely contributed to the non-linear pH response observed across the tested concentrations. Since wood ash composition depends strongly on biomass source and combustion conditions, future work should include detailed mineralogical and chemical characterization using techniques such as XRF and XRD to quantify alkaline oxides and carbonates responsible for pH elevation. Establishing a compositional–performance relationship would enable more precise dosage control and reduce uncertainty in field applications, particularly when targeting specific pH windows for different formation conditions. The observed slight reduction in mud density, from 9.20 ppg to 8.60 ppg, suggests that wood ash may partially dilute the effective solids content of the mud system. While this may be advantageous in low-pressure formations, further investigation is required to evaluate the interaction between wood ash and conventional weighting materials such as barite. Future studies should examine density compensation strategies, including optimized barite–ash ratios, to ensure that hydrostatic pressure requirements can be met without sacrificing pH control or rheological stability. Although Marsh funnel viscosity remained relatively stable, more comprehensive rheological testing is recommended to fully capture the influence of wood ash on low-shear-rate viscosity, gel strength development, and thixotropic behavior. These parameters are critical for hole cleaning and cuttings suspension, particularly under static and low-flow conditions. Advanced rheological measurements using rotational viscometers would provide deeper insight into long-term mud stability and the potential impact of ash-induced solids on flow behavior.

Finally, to bridge the gap between laboratory findings and practical deployment, long-term aging and contamination studies should be conducted to assess the stability of wood ash–treated muds under downhole conditions. Evaluating thermal stability, resistance to salt and calcium contamination, and performance under extended circulation would provide critical data for field-scale application. Such studies would strengthen confidence in wood ash as a reliable pH enhancer and support its integration into environmentally sustainable drilling fluid systems.

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