# Experimental Investigation of Agricultural Wastes Effect on Drilling Mud Properties

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## Abstract

The future of the oil and gas industry increasingly depends on the development of environmentally sustainable drilling fluids through the utilization of waste materials that have a minimal impact on ecosystems. Conventional drilling muds typically contain chemical additives, water, oil, and drill cuttings, which pose significant environmental risks. To reduce reliance on toxic chemicals in drilling fluids, this study explores the potential of using natural additives such as Palm Oil Fuel Ash (POFA), Wood Ash (WA), and Rice Husk (RH). Water-based drilling muds were formulated with these additives at varying concentrations (0.6, 0.8, and 1 wt%) and particle sizes (75, 150, and 212 µm). The performance of these modified muds was compared against a standard mud without additives. The optimal formulation, identified through experimental analysis, was 0.8 wt% of 212 µm RH. Rice Husk was found to significantly enhance the filtration properties and rheology of the drilling mud, demonstrating its efficacy as an additive. The evaluation of locally sourced agricultural waste as additives not only reduced costs and improved mud performance but also substantially mitigated the environmental impact.

## Introduction

The viscosity of drilling fluids is significantly influenced by temperature. At lower temperatures, both gel strength and apparent viscosity tend to increase, particularly when the fluid remains static. As noted by Zhao et al. (2017), an increase in rheological parameters can be problematic, as it leads to elevated pressures and higher Equivalent Circulating Density (ECD). High-viscosity drilling fluids exhibit greater resistance to flow (Neshat and Shadizadeh 2016). Therefore, to mitigate fluid loss and minimize near-wellbore damage, it is essential to design drilling mud with appropriate properties. As reservoir depth increases, so do temperature and pressure, resulting in changes in mud properties such as Yield Point (YP) and Plastic Viscosity (PV). Maintaining the stability of these parameters is particularly challenging, as they are critical for effective hole cleaning and ECD control. The permeability of the formation may decrease due to damage caused by the invasion of drilling fluid filtrate (Chen and Mohanty 2014), while the formation of a filter cake from solid particles can further reduce the absolute permeability around the wellbore.

In recent years, environmental regulations and safety concerns have become major priorities in the oil and gas industry. To address these issues, the additives applied in this research are designed to be environmentally friendly, ensuring minimal harm to the ecosystem. Additives are introduced to drilling fluids to alter their rheological and surface properties (Olatunde et al. 2012), providing benefits such as minimizing fluid loss and



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reducing reservoir damage during drilling. Currently, the industry is investigating additives that offer a combination of environmental compatibility, thermal stability, and multifunctionality (Galindo et al. 2015). The performance of various additives in the market varies, with common types including weighting agents, viscosifiers, lost circulation materials, lubricating agents, shale stabilizers, and rheological control agents (Ghazali et al. 2015).

The growing expansion of agro-waste has led to an increase in raw residues from agro-industrial processes, crops, and livestock. Agro-waste production is estimated at approximately 998 million tons annually, making effective waste management crucial. The 3Rs principle — reduce, reuse, recycle — has been introduced to promote environmental sustainability. The primary objective of this hierarchy (**Figure 1**) is to minimize waste while maximizing the benefits of waste utilization. Consequently, replacing synthetic polymers with locally available materials such as wood ash, fuel ash, and rice husk is an important step toward sustainable development.

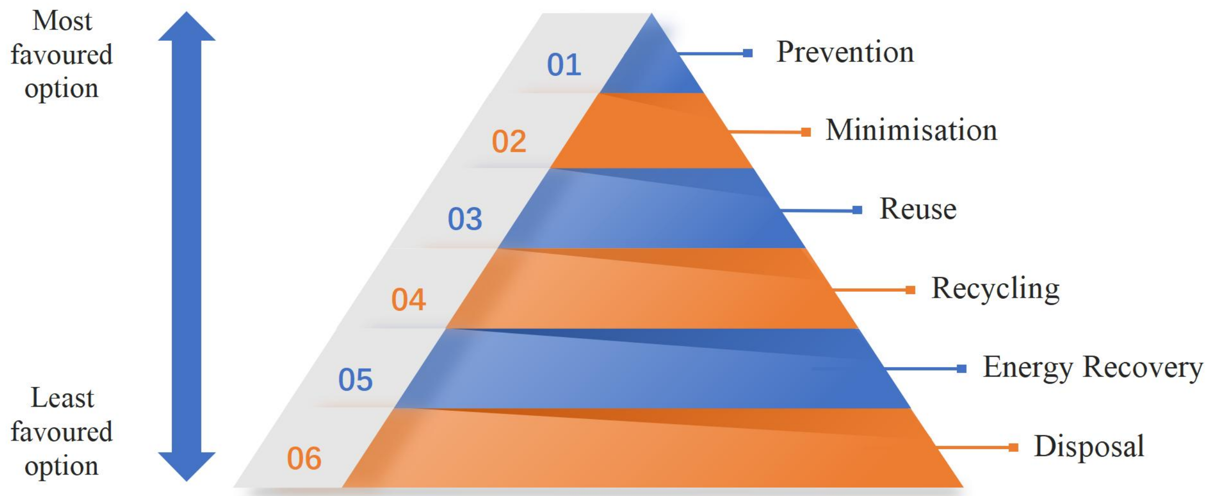



**Figure 1—Hierarchy concept of 3Rs- reducing, reusing, and recycling.**

Due to the increasing demand for hydrocarbon production, it is essential to adopt innovative methods for oil and gas resources extraction. Drilling operations account for approximately 8% of operating expenditures (OPEX). Typically, two types of drilling fluids are employed: water-based mud (WBM) and oil-based mud (OBM). Extensive research has been conducted on WBM, focusing on enhancing its properties by incorporating various additives such as weighting agents, viscosifiers, and stabilizers.

Initially, drilling mud was formulated with clay; however, to manage high-pressure formations, a higher density mud was required, which led to the addition of heavy minerals. In 1922, barite was introduced as a weighting material in drilling mud by the National Pigments and Chemical Company (Apaleke et al. 2012). Since then, various other additives, including surfactants, salts, colloidal solutions, alkalis, organic polymers, and weighting agents, have been utilized. The selection of these additives is typically determined by the characteristics of the formation and the associated project costs.

**Current Formulations of Water-Based Drilling Fluid**. To leverage the advantages of oil-based muds, such as reduced environmental impact and lower fluid disposal costs, high-performance water-based drilling fluids (HPWBFs) were developed. These fluids are designed to enhance borehole cleaning and wellbore stability, typically consisting of a mixture of potassium chloride (KCl) and polymers such as xanthan gum, partially hydrolyzed polyacrylamide (PHPAM), and polyamide derivatives for dehydration. An environmentally friendly aluminum-based high-performance water-based drilling mud (HPWBM) was developed by Ramirez et al. (2007) and successfully applied in an exploratory well in the Argentinian Magellan Strait, replacing oil-based mud with minimal environmental impact. In contrast, Ramy et al. (2016) formulated a new HPWBF using a combination of salt and polymers with varying mud weights, but this formulation proved less environmentally friendly.

The oil and gas industry is often viewed as environmentally risky due to the use of hazardous chemicals. As a result, significant research has been conducted to develop more environmentally sustainable drilling fluids (Kumar et al. 2013). The emphasis on natural additives and eco-friendly materials has grown, aiming to reduce both overall drilling costs and environmental pollution. **Table 1** highlights the advantages and disadvantages of high-performance water-based muds.

A key focus in current drilling fluid development is environmental sustainability. Udoh and Okon (2011) created a water-based drilling mud that posed fewer environmental risks when combined with eco-friendly additives and demonstrated efficacy in drilling through shale beds. However, the silicates in the fluid posed potential risks to the rock, leading Thaemlitz et al. (1999) to propose the use of micro-sized spherical polymer beads to enhance lubrication. To address challenges in high-pressure high-temperature (HPHT) formations, Thaemlitz et al. (1999) developed a chromium-free, environmentally friendly fluid. HPHT reservoirs, which contain significant quantities of hydrocarbons, are defined by wellbore pressures exceeding 0.8 psi/ft and temperatures around 300 ° F (Yunita et al. 2016). Designing muds capable of withstanding these extreme conditions remains a significant challenge. Organic polymers are commonly added to drilling fluids to minimize filtrate loss during operations (Amani and Al-Jubouri 2012), but their high cost necessitates alternative solutions in many regions (Okon et al. 2014).

**Table 1—Water-based mud pros and cons (Friedheim et al. 2012).**

| Disadvantages | Advantages |
|---|---|
| The salt can be dissolved which increased mud weight | Cost-effective and cheap |
| Hydrocarbon flow can be impeded by WBDF | Environmentally friendly in some sense |
| WBDF supports the dispersal and disintegration of clays | Easy accessibility and availability |
| WBDF is incompetent to penetrate shale or water-sensitive shale | Fast penetration rate |
| The ability of WBDF to corrode iron components | |

To mitigate harmful environmental impacts, Hector et al. (2002) explored the use of potassium silicate in drilling mud, which was later repurposed as a fertilizer. Similarly, Warren et al. (2003) formulated a drilling fluid containing amphoteric cellulose ether (ACE), a water-soluble, eco-friendly polymer that is low-cost and has minimal solid content. In another approach, Davidson et al. (2004) developed a drilling fluid based on a carbohydrate derivative complexed with iron, which effectively removed hydrogen sulfide.

Ramirez et al. (2005) created a biodegradable drilling fluid designed to maintain borehole stability and enable drilling through healing shale. However, the presence of asphalt in the formulation limited its environmental friendliness. Dosunmu et al. (2010) introduced an oil-based drilling fluid (OBDF) utilizing groundnut oil and palm oil, which demonstrated not only environmental benefits but also potential to enhance crop growth.

Meng et al. (2012) investigated the use of carbon ash as an additive in drilling fluids, studying its effects on fluid flow, rheology, and filtration loss. The results indicated that carbon ash enhanced the properties of water-based mud, particularly by improving yield point. Subsequently, Mahto and Jain (2013) employed fly ash, an industrial byproduct, in water-based mud (WBM), observing an increase in yield point without significantly altering physical properties.

Negm et al. (2015) emphasized the importance of replacing harmful substances in drilling mud with naturally less toxic additives. This aligns with the petroleum industry's ongoing efforts to develop low-cost, environmentally safe additives that also improve performance and efficiency.

Field operations such as stimulation, completion, drilling, and production often encounter challenges that can be addressed by modern, environmentally friendly drilling fluids (Ndubi and Ben Mahmud 2019). Nanotechnology has also become a focus in the petroleum industry, particularly for mitigating the environmental concerns associated with oil-based and water-based drilling fluids. Nano-silica, one of the more promising nanoparticle additives, has shown potential, but achieving optimal results requires precise concentration when added to synthetic-based mud.

**Table 2—Existing studies of agro-waste utilization in drilling mud**

| Author | Additives | Fluid | Size of Particle | Concentration | Apparent Viscosity, cp | Plastic Viscosity, lbs | Initial Gel Strength, lb/100ft$^2$ | Yield Point, lbs/100 ft$^2$ | 10-min Gel Strength, lb/100ft$^2$ | Cake Thickness, mm | Filtrate Loss, ml |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (Niemuth 2013) | Fly ash | WBM | 1-100nm | 1-3 wt.% | 28.75 | 17.5 | 5 | 22.5 | 9 | 0.3 | 6 |
| (Okon et al. 2014) | Rice husk | WBM | 125µm | 5,10,15,20g | 18 | 8 | 2.15 | 9.56 | 4.78 | 3.2 | 16.5 |
| (Meng et al. 2014) | Carbon ash | WBM | - | 0.2, 0.4, 0.6, 0.8 wt. % | 13.5 | 5 | - | 8.3 | - | 2 | 21 |
| (Alflah et al. 2015) | Gum Arabic | WBM | 0.15 - 0.425mm | 0.76 9.4, 13.44, 17.15, 21.44wt. % | 12.5 | 10 | - | 2 | - | - | 23 |
| (Ghazali et al. 2015) | Corn starch | WBM | 250µm. | 2,4,6,8,10g | - | 5 | 37 | - | 40 | 2.5 | 31 |
| (Hossain and Wajheuddin 2016) | Grass | WBM | 300, 90, 35µm | 0.25, 0.50, 0.75, or 1.0 g | 11 | 8.5 | 3 | 4 | 15 | - | 12.2 |
| (Onuh 2017) | Corn cobs & coconut shells | WBM | - | 2,4,6,8,10g | - | - | - | - | - | - | 16 |
| (Seteyeobot et al. 2017) | Rice husk | OBM | 125µm | 75g | 119.5 | 93 | 24 | 53 | 63 | 1.21 | 17 |

This study attended to experimentally investigate the performance of different agricultural wastes on the water-based drilling mud. All the recent wastes mentioned in **Table 2** were tested on different parameters of mud. Therefore, the main aim of this project is to widen the application of present agricultural by-products and waste i.e., POFA in drilling mud to determine its performance in improving mud rheology and filtration properties.

## Materials

The rice husk and POFA were collected from the local village located near Miri, Sarawak, and Lambir Palm Oil Mill respectively. While the wood ash (carbon ash) was provided by a plywood company in Miri, Sarawak. All these wastes' material was collected free of cost as they are readily available in Malaysia and are often dumped in landfills. **Table 3** shows the materials used in this research and their purpose.

**Table 3—Materials and purposes.**

| Materials | Purposes |
|---|---|
| Distilled Water | To prepare water-based drilling fluid |
| Bentonite | To be added in water-based mud |
| Rice Husk | Rheological additive |
| De-ionized water | pH meter calibration |
| Wood Ash | Ago-waste additive |
| POFA | Agro-waste additive |

## Experimental Methods

**Rice Husk Preparation.** Rice husk was initially dried to remove all the moisture content by placing it using the crucible inside the oven at 45°C for about 4 hours. The dried husk was grounded into a smaller size using a mortar pestle, sieved to obtain fine particles (75, 150, and 212 µm), and later plastic container was used to seal it with aluminum foil. Schematic diagram of rice husk preparation is shown in **Figure 2** while **Figure 3** shows the prepared rice husk.

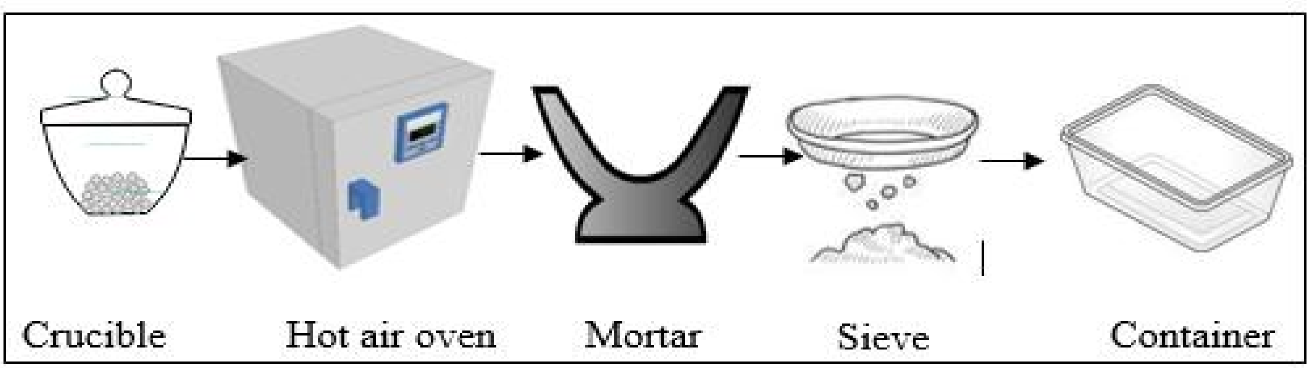



**Figure 2—Rice Husk Preparation Schematic Diagram.**

**Figure 3—Rice husk.**

**Preparation of POFA**. To achieve the required particle size, a combustion process was performed on POFA by putting it in a crucible and placing it into a clean furnace for 4 hours at 500°C. Finally, it was then sieved to obtain the desired particle sizes (75, 150, and 212 μm) and placed in a plastic container, which was sealed with aluminum foil. The whole procedure is presented in **Figure 4**, while **Figure 5** represents prepared POFA.

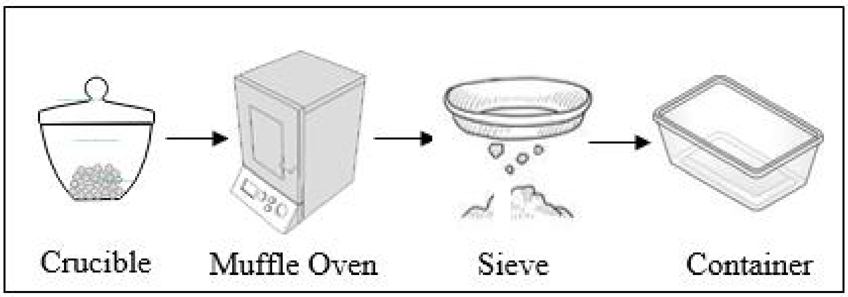



**Figure 4—POFA preparation schematic diagram**

**Figure 5—Palm oil fuel ash (POFA).**

**Wood Ash Preparation**. Wood ash is obtained by burning the wood. Plywood was purchased and combusted in the furnace using a crucible for 4 hours at 800°C. Finally, it was then sieved to obtain the desired particle sizes (75, 150, and 212μm) and placed in a plastic container, which was sealed with aluminum foil. The whole procedure is presented in Figure 4 while **Figure 6** represents prepared wood ash.

**Figure 6—Wood ash.**

**Preparation of Mud Samples**. ***Preparation of base fluid.*** A Fresh WBM of 350 ml of distilled water with 15 grams of bentonite was prepared in a beaker of 500 ml. FANN Multi-Mixer was used to ensure even mixing of the bentonite by continuously stirring it for 15 minutes.

***Preparation of mud samples with additives.*** The total weight of mud played a decisive role in the concentration of additives to be added to the mud. 0.6 wt%, 0.8 wt%, and 1 wt% (3.5g/350ml) concentrations of additives were applied respected to the drilling muds. Once bentonite solution was prepared, additives were added and stirred for almost 10 mins to ensure uniform mixing. **Table 4** shows the formulation of WBM with different additives.

**Table 4—Drilling mud prepared with various additives.**

| Additive Size, (microns) | Concentration, (wt%) | Bentonite, (grams) | Distilled water, (mL) | Rice husk, (grams) | Palm oil fuel ash, (grams) | Wood ash, (grams) |
|---|---|---|---|---|---|---|
| - | - | 15 | 350 | - | - | - |
| 212 | 1 | 15 | 350 | 3.5 | - | - |
| 212 | 1 | 15 | 350 | - | 3.5 | - |
| 212 | 1 | 15 | 350 | - | - | 3.5 |
| 150 | 0.8 | 15 | 350 | 2.8 | - | - |
| 150 | 0.8 | 15 | 350 | - | 2.8 | - |
| 150 | 0.8 | 15 | 350 | - | - | 2.8 |
| 75 | 0.6 | 15 | 350 | 2.1 | - | - |
| 75 | 0.6 | 15 | 350 | - | 2.1 | - |
| 75 | 0.6 | 15 | 350 | - | - | 2.1 |

## Results and Analysis

**Drilling Muds without Additives.** ***Density Measurement***. Density measurement is very important to control the formation pressure, especially high-pressure drilling zones. Different particles and additives are used to form a drilling mud. **Figure 7** showed the results of the density measurement. With the increase in the size of rice husk and the number of husk particles, it was observed that the density of mud increased. However, due to the high density of mud, the penetration rate of drilling mud decreases (Krishnan et al. 2016) due to the hold-down effect. Usually, the mud weight is kept low during the early stages of drilling and increased while drilling deeper into the formation to optimize the penetration rate and mitigate well control (Bamaga et al. 2013). The density of mud increased gradually when rice husk has been added therefore, it can be used as a weighting agent.

The density of standard mud is lowest (8.8 ppg) without the addition of any weighing agent because of the less solid content present in the bentonite. Thus, the high quantity of solid particles in rice husk leads to an increase in mud density.

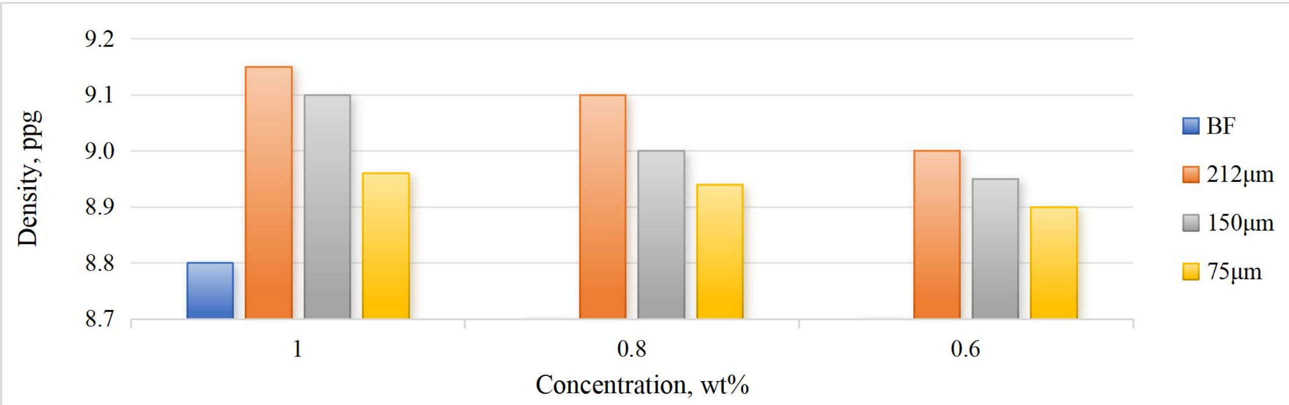


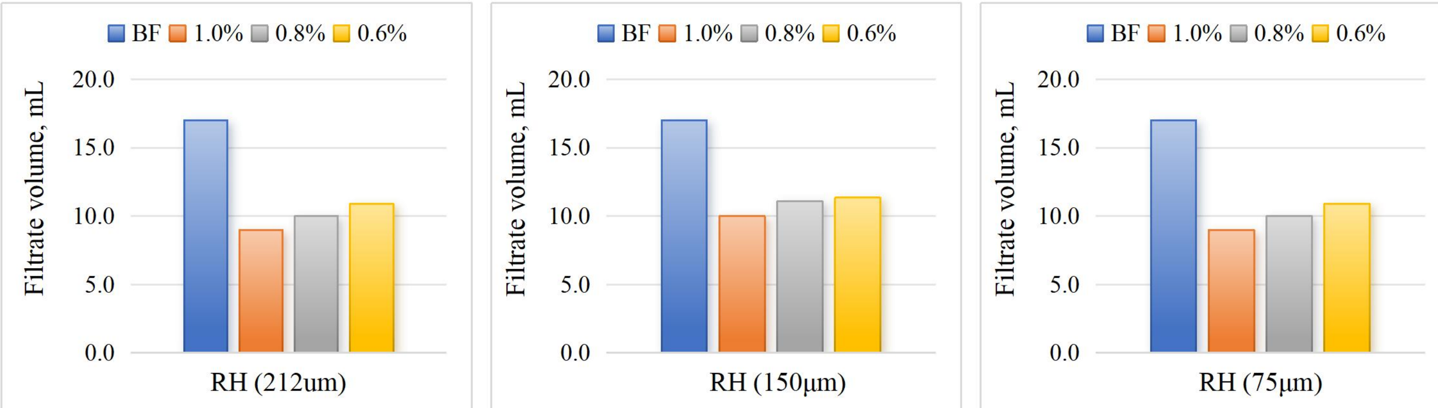

**Figure 7—Drilling fluid density when various concentrations and particle sizes of rice husk added.**

***HPHT Filtration Properties***. Filter properties of drilling mud were determined after incorporating rice husk. 17ml fluid loss was observed and a 3mm thick mud cake was formed when drilling fluid without any additives was tested at HPHT conditions. **Table 5** represent the effects of rice husk with different particle sizes on filtration loss properties of the drilling mud. The loss of filtrate volume was improved when rice husk was added (**Figure 8**). Reduction of 44%, 52%, and 62% in mud filtrate volume was observed when 212μm rice husk was added into drilling fluid at 0.6wt%, 0.8wt%, and 1wt% concentrations respectively, as shown in **Figure 9(a)**. **Figure 9(b)** shows the filtrate loss when 150 μm-sized rice husk was added to the drilling fluid. Further decrease in filtration loss was observed to a maximum of 52% when rice husk (150 μm in size) concentration increased to 1wt%. It was also noticed that the thickness of mud cake was increased by increasing rice husk content, as presented in Table 5. This shows that the presence of more rice husk decreases the pore spaces in the mud cake (Ba et al. 2013). It was also noticed that the thickness of mud cake formed by drilling fluid incorporating rice husk is thinner compared to the base fluid mud cake (Table 5). This is because of the high compressibility of rice husk under high-pressure conditions (Korotkova et al. 2016).

The fluid loss is reduced up to 45% when drilling fluid was added with 75μm rice husk as shown in **Figure 9(c)**. Therefore, rice husk can be used as a filtration loss control agent. Moreover, when the particle size was increased, the fluid loss decreased, which indicates that bigger particles enhance the linkage of solids.

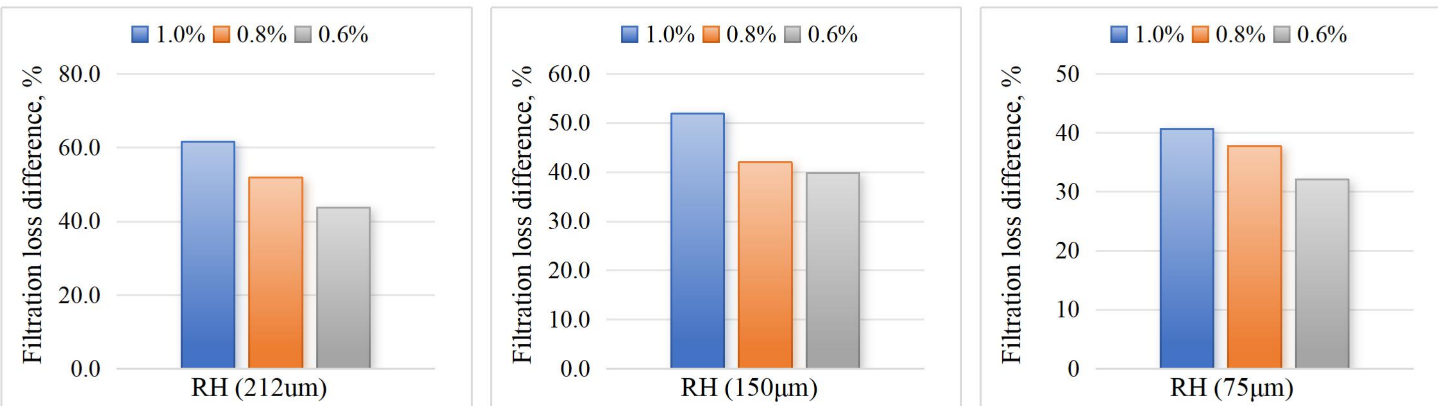
**Table 5—Filtration properties of drilling fluid comprised of various size of rice husk.**

| Filtration test | 212 μm | | 150 μm | | 75 μm | |
|---|---|---|---|---|---|---|
| | Filtrate volume @7.5 min, ml | Mud cake thickness, mm | Filtrate volume @7.5 min, ml | Mud cake thickness, mm | Filtrate volume @7.5 min, ml | Mud cake thickness, mm |
| Base fluid | 9.5 | 3 | 9.5 | 3 | 9.5 | 3 |
| 0.60% | 5 | 2.2 | 6.7 | 2.4 | 8.5 | 2.6 |
| 0.80% | 4.5 | 2.2 | 6.5 | 2.45 | 8.5 | 2.6 |
| 1.00% | 4 | 2.3 | 5 | 2.5 | 8 | 2.7 |




(a)212 µm (b) 150 µm (c) 75 µm

**Figure 8—Filtrate volume after 30 min of bentonite dispersion when added various sizes of RH to base fluid.**




(a)212 µm (b) 150 µm (c) 75 µm

**Figure 9—Filtrate loss difference when added various sizes of RH to base fluid.**

**Drilling Muds with Wood Ash Particles**. ***Density measurement.*** The effect of wood ash on drilling fluid density is shown in **Figure 10**. It was observed that the density of drilling fluid was decreased with the addition of wood ash. It could be due to the clay particles enhanced dispersity with the addition of wood ash. Moreover, by adding the wood ash, the bentonite particle aggregation decreased. However, density decreases by decreasing the wood ash particle size. It could be because the absorbed wood ash improved the dispersity of the clay particles (Meng et al. 2012).

***HPHT Filtration Properties***. **Table 6** showed the drilling fluid properties after adding wood ash of different sizes. It was observed that increasing the concentration of wood ash increases the filtration loss of bentonite dispersion as shown in **Figure 11**. This is due to the electrostatic adsorption of drilling mud, which is responsible for the reduction in agglomeration between bentonite particles (Meng et al. 2014).

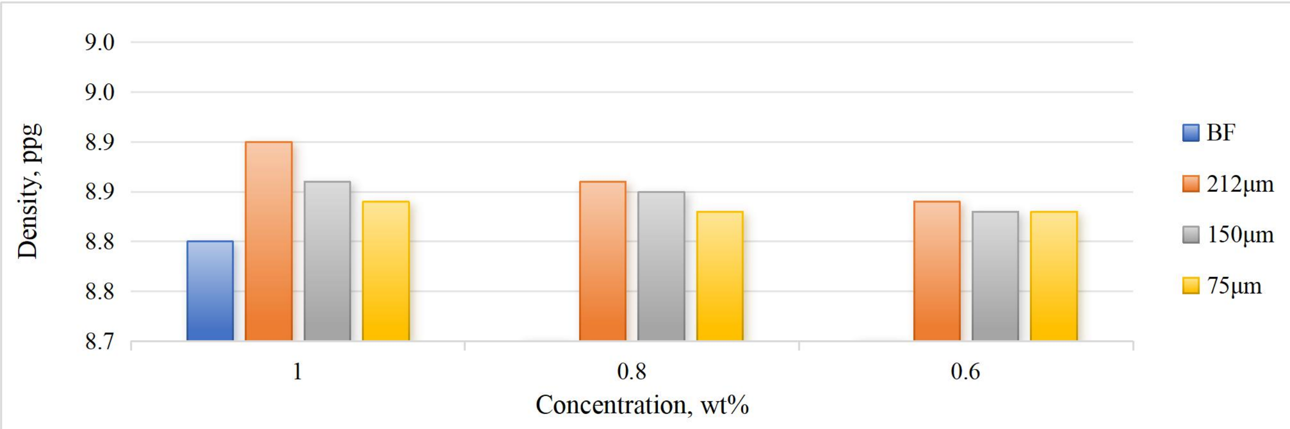
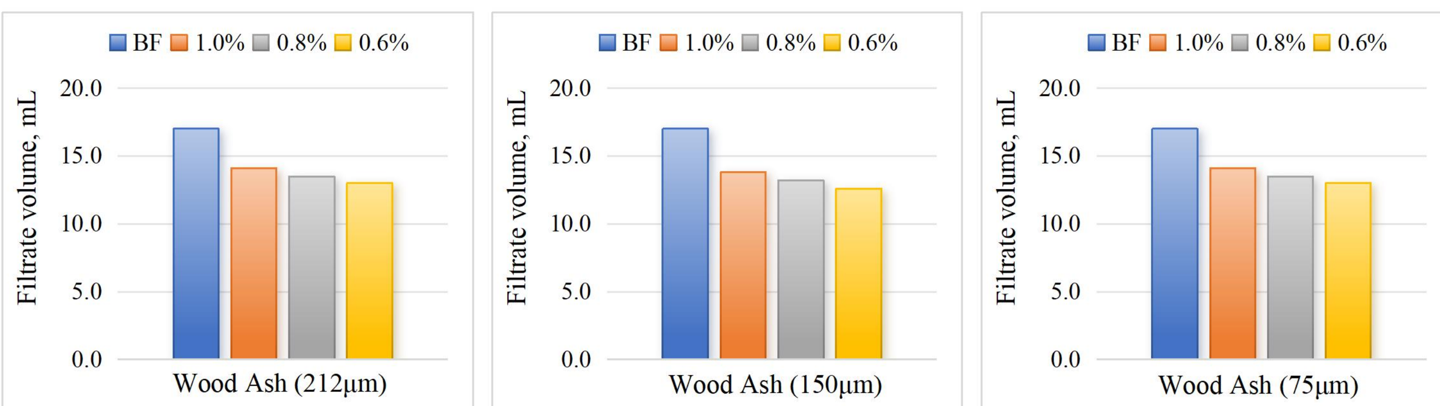



**Figure 10—Drilling fluids density when added various particle sizes and concentrations if wood ash.**

There was also a significant effect of particle size on mud cake thickness and filtration loss. Large additives reduce the fluid loss and increase the mud cake thickness, which resulted in a strong and impermeable mud cake. The results of filtrate loss are presented in **Figure 12**. The least filtrate loss was observed when the drilling fluid consists of 75 µm of wood ash at 0.6 wt%.

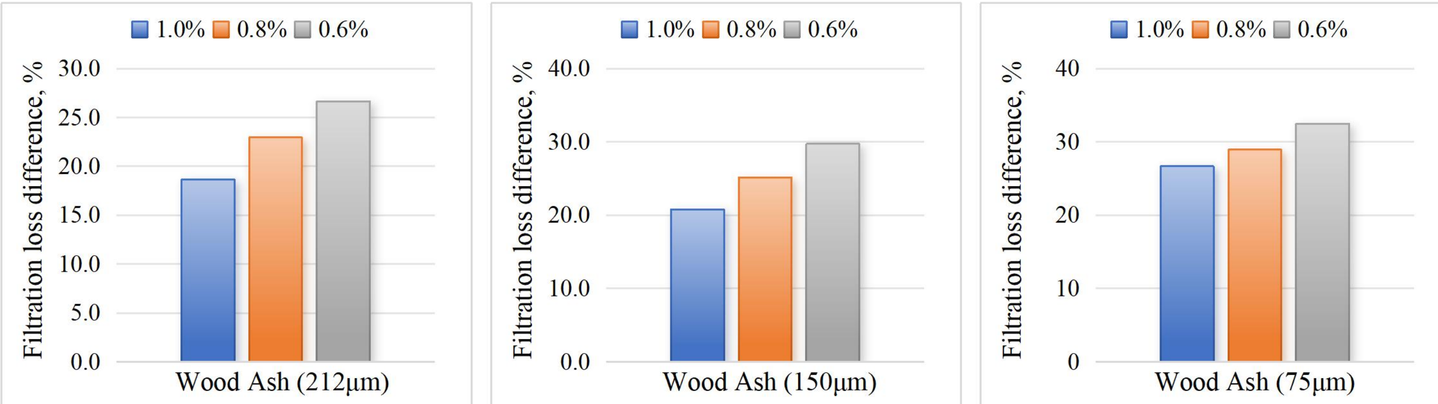
**Table 6—Filtration properties of drilling fluid comprised of various size of wood ash.**

| Filtration test | 212 µm | | 150 µm | | 75 µm | |
|---|---|---|---|---|---|---|
| | Filtrate volume @7.5 min, ml | Mud cake thickness, mm | Filtrate volume @7.5 min, ml | Mud cake thickness, mm | Filtrate volume @7.5 min, ml | Mud cake thickness, mm |
| Base fluid | 9.5 | 3 | 9.5 | 3 | 9.5 | 3 |
| 0.60% | 5 | 3.33 | 5.5 | 3.17 | 5.5 | 3.1 |
| 0.80% | 5.5 | 3.35 | 6.55 | 3.24 | 6.5 | 3.15 |
| 1.00% | 6.5 | 3.38 | 8.5 | 3.29 | 8 | 3.2 |




(a)212 µm (b) 150 µm (c) 75 µm

**Figure 11—Filtrate volume after 30 min of bentonite dispersion when added various sizes of wood to base fluid.**




(a)212 µm (b) 150 µm (c) 75 µm

**Figure 12—Filtrate loss difference when added various sizes of wood to base fluid.**

**Drilling Muds with POFA Particles**. ***Density measurement.*** The density of mud after adding POFA is shown in **Figure 13**. The value of density range between 9.46 ppg and 9.55 ppg after adding POFA. The density value increased by adding the POFA because solid content increased in the bentonite solution. The highest value of density was obtained using 1 wt% of 212 µm POFA.

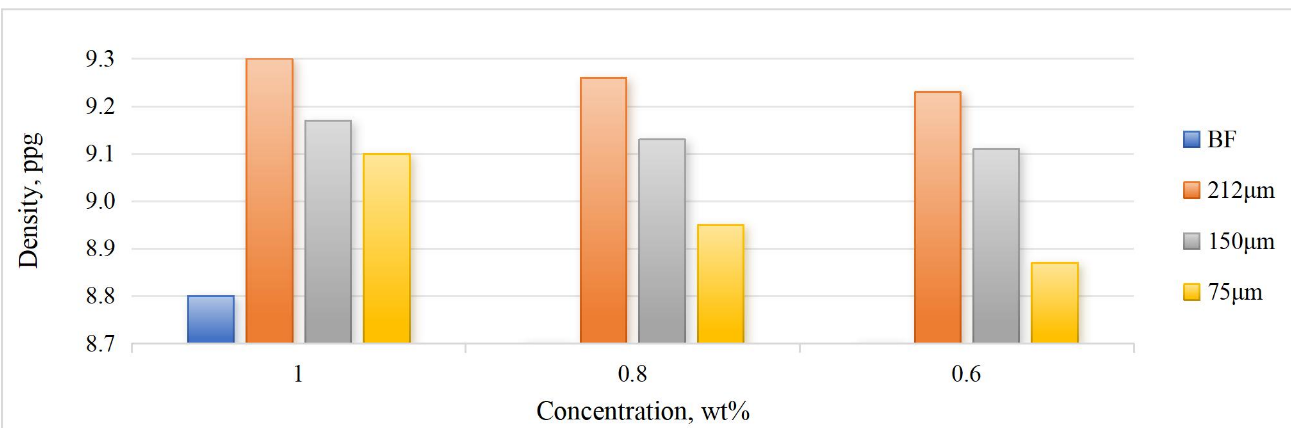


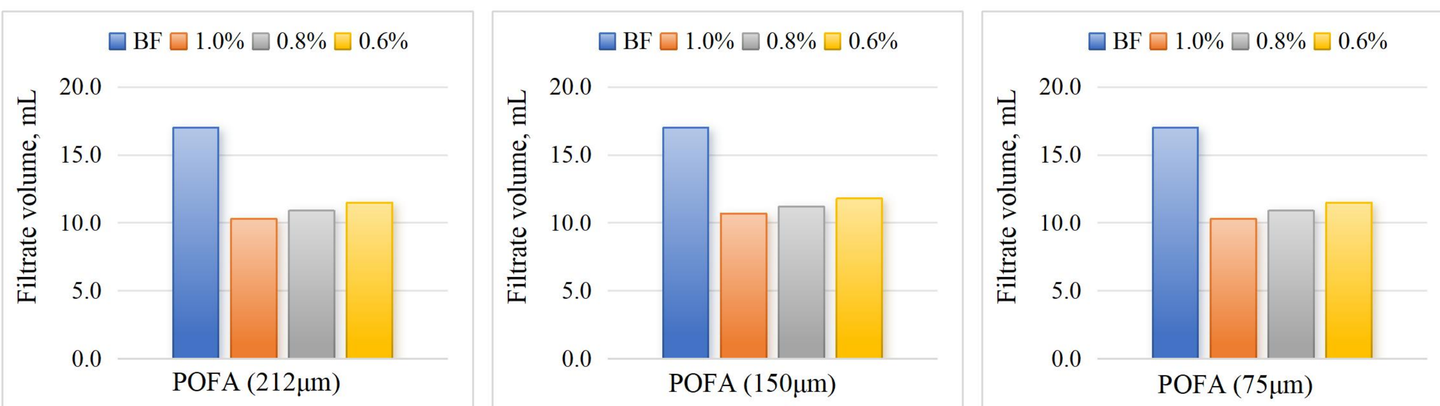

**Figure 13—Drilling fluids density when added different particle sizes and concentrations of POFA.**

***HPHT Filtration Properties***. **Figure 14** shows that the filtrate loss was decreased when the amount of POFA increased compared to the base mud. By adding POFA, the filtrate loss of drilling fluid was decreased as well. The potential of POFA to be used as a filtrate control agent is shown in **Figure 15**, where a maximum 52% reduction in filtrate loss was observed. The highest filtrate loss of 11.8 ml was obtained when using 0.6 wt% of 212 µm (Figure 15 a). But all the drilling muds that incorporated with POFA showed less filtrate loss compared to standard mud loss (17 ml). With the reduction in the size of POFA particles, filtration loss also decreases, because the smaller particles of POFA offered a high surface area, which enables effective plugging and sealing of the pores. However, it was observed that the thickness of mud cake increases with increasing the particle size and concentration of POFA, as seen in **Table 7**. However, thicker mud cakes posed problems during drilling and cementing. Therefore, the size and concentration of additives should be optimized to avoid drilling problems with less fluid loss.

**Table 7—Filtration properties of drilling fluid comprised of various size of POFA**

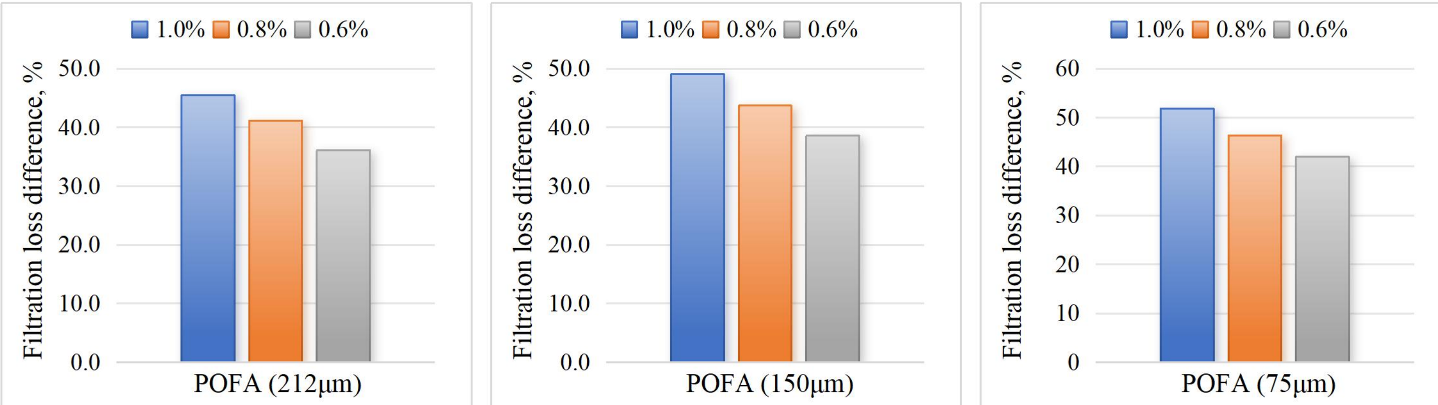
| Filtration test | 212 µm | | 150 µm | | 75 µm | |
|---|---|---|---|---|---|---|
| | Filtrate volume @7.5 min, ml | Mud cake thickness, mm | Filtrate volume @7.5 min, ml | Mud cake thickness, mm | Filtrate volume @7.5 min, ml | Mud cake thickness, mm |
| Base fluid | 9.5 | 3 | 9.5 | 3 | 9.5 | 3 |
| 0.60% | 6.8 | 3.16 | 5.5 | 3.1 | 5.1 | 3.08 |
| 0.80% | 6.5 | 3.18 | 5.3 | 3.16 | 4.8 | 3.13 |
| 1.00% | 6 | 3.22 | 5 | 3.2 | 4.5 | 3.15 |

The permeable formation can be damaged significantly due to filtrate invasion, which causes water blocking, clay swelling, or particle plugging (Fleureau 1992). The thickness and permeability of filter cake depend on the particle size distribution as large particles tend to form less permeable filter cake (Wu et al. 2015). Figure 16 shows the same results that drilling fluid with rice husk demonstrated better fluid loss control. The low permeability results were obtained because of the development of bridging and cross-linking between bentonite and additive particles. Rice husk particles contain lignin, which helps in the flocculation and binding strength of particles, creating a low permeable seal of filter cake when high pressure is applied (Seteyeobot et al. 2017). That is why the rice husk is responsible for the compressibility at high-pressure conditions without decreasing the borehole diameter.



(a)212 µm (b) 150 µm (c) 75 µm

**Figure 14—Filtrate volume after 30 min of bentonite dispersion when added various sizes of POFA to base fluid.**

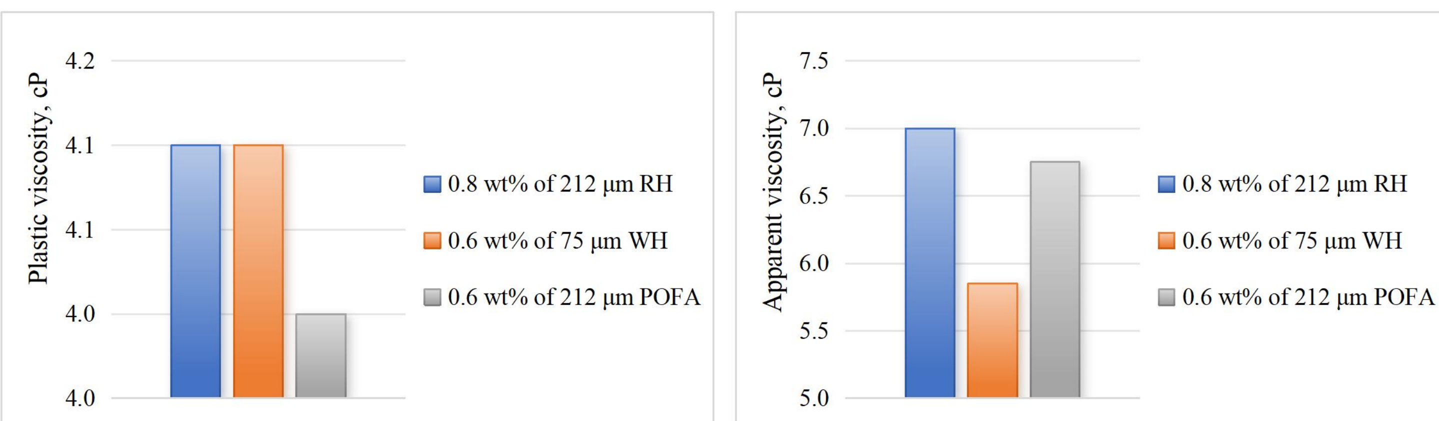



(a)212 µm (b) 150 µm (c) 75 µm

**Figure 15—Filtrate loss difference of bentonite dispersion when added various sizes of POFA to base fluid.**

**Viscosity Analysis**. **Figure 16** shows the viscosities of drilling fluids with different additives. The low plastic viscosity is desired to avoid internal resistance while the high apparent viscosity is desired as it shows the flowability of the fluid. The highest value of apparent viscosity was achieved by 212 µm rice husk at 0.8 wt%. Therefore, it is favorable as an alternative option for viscosifiers. The value of mud YP should be low but when it is high enough, it could hold solid particles and allows effective hole cleaning (Power and Zamora 2003). Drilling fluid having 0.8 wt% of 212 µm rice husk was selected because it showed the highest YP as shown in **Figure 17**. The relationship between the bridging particles and filtration loss was discussed by Song et al. (2016). The decline in filtrate loss was observed with the increase in the concentration of bridging particles shown in **Figure 18**.

The pH tests were conducted to find the concentration of hydrogen ions in the drilling mud (Vryzas and Kelessidis 2017). The pH value of the drilling fluid changed with the addition of rice husk as presented in **Table 8**. The increase in pH value was observed when rice husk was added to the drilling fluid, which means that the mud becomes more alkaline. Grass particles were used by Hossain and Wajheeuddin (2016) as an additive to control corrosion. It was noticed that the pH value was increased, which ultimately can mitigate the corrosion process. Therefore, Rice Husk can be considered as an alternative pH control environmentally friendly agent.




(a) Plastic viscosity (b) Apparent viscosity

**Figure 16—Drilling fluids viscosity when added with designated additives.**

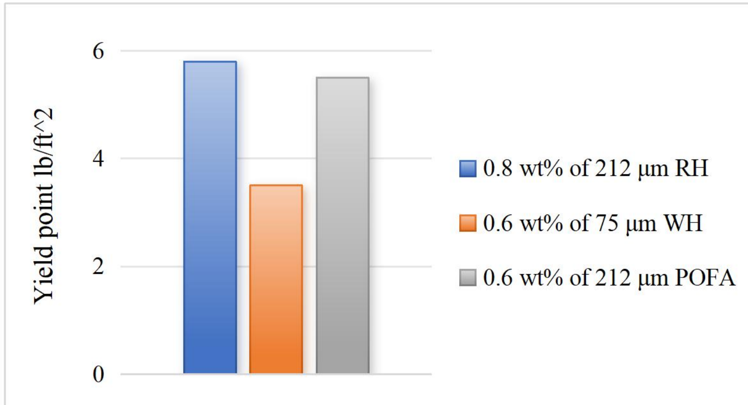
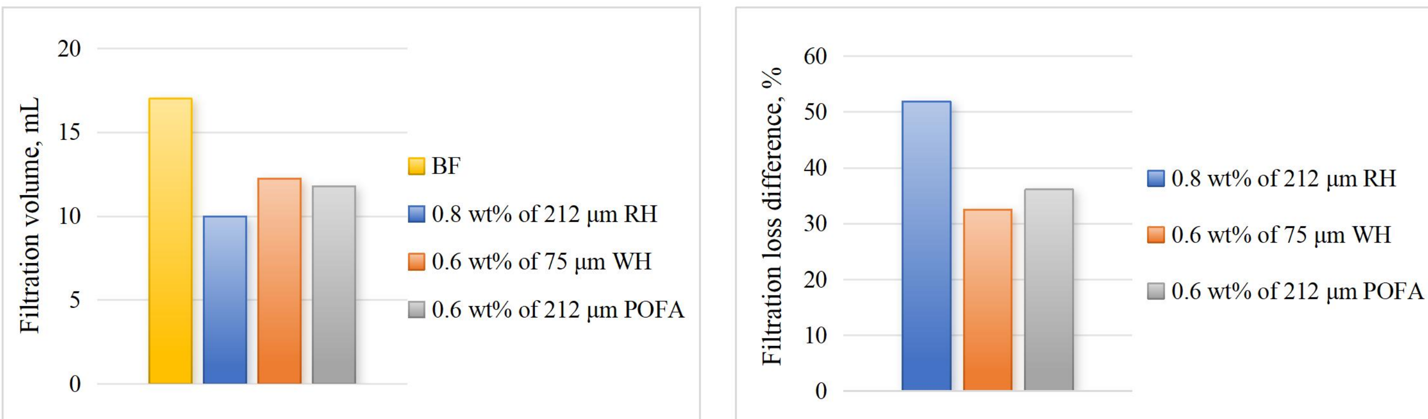



**Figure 17—Drilling fluids yield points when added with designated additives.**




(a) Filtration volume (b) Filtration loss

**Figure 18—Filtrate volume of drilling fluids comprised of designated additives.**

**Table 8—pH values of drilling fluids consisting of agricultural additives.**

| Test material | pH | Unit | Base Fluid | 0.8 wt% of 212 µm Rice Husk | 0.6 wt% of 75 µm Wood Ash | 0.6 wt% of 212 µm POFA |
|---|---|---|---|---|---|---|
| Drilling Fluid | Alkaline | ppg | 9.42 | 9.54 | 9.51 | 10.14 |
| Filtrate fluid | | | 9.52 | 9.93 | 9.90 | 9.93 |

**Effect on Drilling Properties**. The experimental evaluation of Palm Oil Fuel Ash (POFA), rice husk (RH), and wood ash in water-based mud formulations highlights their effectiveness in enhancing key properties of drilling fluids. The optimal formulation, consisting of 0.8% rice husk with a particle size of 212 µm, led to a notable 29% improvement in viscosity compared to standard mud. This increase in viscosity results in higher equivalent circulating density (ECD), which, while beneficial for well control, may decrease the rate of penetration (ROP) and increase the risk of differential sticking.

Rice husk emerged as the most effective agent for controlling fluid loss, reducing it by 52%, compared to reductions of 30% with wood ash and 35% with POFA. These results demonstrate the potential of agro-wastes in controlling mud rheology and reducing fluid loss during drilling operations. In addition, viscosity enhancements of approximately 15% were observed for wood ash and POFA under optimal conditions.

The overall benefits of incorporating agro-waste materials into water-based drilling mud include improved control over filtrate loss, reduced mud cake thickness, and increased mud density. The increased density can help in managing formation pressures, making these additives particularly valuable for deep-well drilling operations where pressure control is critical. This suggests that agro-wastes may offer a sustainable, cost-effective alternative to conventional drilling fluid additives while also contributing to environmental protection.

## Conclusions

The effects of Palm Oil Fuel Ash (POFA), rice husk, and wood ash on the properties of water-based mud have been experimentally evaluated and compared with standard mud formulations. The optimal composition was found to be 0.8% rice husk (RH) with a particle size of 212 µm, resulting in a 29% improvement in viscosity compared to the standard mud. This substantial increase in viscosity leads to a rise in equivalent circulating density (ECD) and a decrease in penetration rate, with the added risk of differential sticking.

Rice husk proved to be the most effective filtration control agent in the water-based drilling fluid, reducing fluid loss by 52%. Comparatively, fluid loss was reduced by 30% with wood ash and 35% with POFA. These findings indicate that agro-wastes exhibit significant potential in managing mud rheology and controlling fluid loss volume. Additionally, the viscosity improvements achieved with wood ash and POFA under optimal conditions were approximately 15%.

Overall, the use of agro-wastes as additives in drilling mud effectively controls filtrate loss and reduces mud cake thickness. Furthermore, the increase in mud density achieved through the addition of these materials suggests that these additives could aid in managing formation pressure at greater depths.

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## Conflicting Interest

The author(s) declare that they have no conflicting interests.

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