Investigation of Oryza Glaberrima Nanoparticle-Assisted Fluid Loss Control in Water-Based Drilling Mud

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Abstract

Drilling mud (DM) serves critical functions in wellbore operations, including drill cuttings removal, borehole stability maintenance, bit cooling, drillstring lubrication, hydraulic energy transmission, and formation of low-permeability filter cakes to mitigate fluid loss. While conventional additives like carboxymethyl cellulose (CMC) and polyanionic cellulose (PAC) are widely used for filtration control, their high cost and environmental drawbacks necessitate sustainable alternatives. This study evaluates the efficacy of Oryza glaberrima (African rice husk, RH)-nanosilica (NS) composites as fluid loss control agents in water-based drilling mud (WBM). Comparative analyses with CMC and PAC were conducted using Fourier Transform Infrared Spectroscopy (FTIR), X-Ray Diffraction (XRD), fluid loss tests, and mud cake characterization. Results demonstrate that the RH-NS blend achieved superior fluid loss reduction (7.5 mL) compared to CMC (9.8 mL) and PAC (8 mL). Additionally, RH-NS exhibited favorable mud cake properties, with a thickness of 0.4 mm and permeability of 0.00068 mD, outperforming standalone RH (12 mL, 0.4 mm, 0.00061 mD) and NS (16 mL, 0.8 mm, 0.00271 mD). The synergistic interaction between RH-derived cellulose and NS nanoparticles highlights the potential of eco-friendly, cost-effective alternatives for optimizing WBM performance.

Introduction

Drilling fluid, commonly referred to as "drilling mud," plays a pivotal role in oil and gas drilling operations (Finger and Blankenship 2010). Its primary functions include removing drill cuttings, preventing the influx of formation fluids into the wellbore, cooling and lubricating the drill bit and drillstring, transmitting hydraulic energy to the bit, maintaining wellbore stability, and forming a thin, low-permeability filter cake to minimize fluid loss (Kerunwa and Gbaranbiri 2018). Drilling mud is broadly categorized into water-based drilling mud (WB-DM), oil-based drilling mud (OB-DM), and pneumatic-based drilling mud (PB-DM). Among these, WB-DM is predominantly favored due to its lower environmental impact (Kerunwa 2020).

The design of effective drilling mud requires careful consideration of its key properties, including density (weight), rheology (viscosity and gel strength), and filtration control. Additional parameters such as pH (alkalinity and acidity), chloride content, calcium content (hard water), and sand content also play critical roles in optimizing mud performance (Igwillo 2000). Among these properties, filtration control has garnered significant global attention due to its critical role in maintaining wellbore integrity during circulation. Filtration loss, defined as the loss of the continuous phase of the drilling mud into the formation, remains a major challenge in drilling operations, particularly in deeper wells. Severe filtration loss can lead to detrimental consequences such as lost circulation, differential pipe sticking, formation damage, mud weight reduction, reduced formation flow rates, and even well control issues like kicks and blowouts (Igbani et al. 2015).

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To mitigate filtration loss, various additives are incorporated into drilling mud formulations (Azar and Samuel 2007). These additives aim to form a low-permeability filter cake, a phenomenon known as filtration loss control (Feng et al. 2009; Agwu and Akpabio 2018). Conventional fluid loss control additives, such as polyanionic cellulose (PAC) and carboxymethyl cellulose (CMC), have been widely used (Caenn and Chillinger 1996). However, their environmental impact and cost inefficiency have driven the search for more sustainable and cost-effective alternatives, particularly locally sourced materials (Kerunwa et al. 2024).

Several studies have explored the use of natural materials as fluid loss control additives. For instance, Olatunde et al. (2012) investigated gum arabic, reporting a fluid loss of 17 mL. Okon et al. (2014) evaluated rice husk (125 µm) and observed fluid losses ranging from 16 to 42.5 mL at concentrations of 5-20 grams. Nmegbu and Bari-Agara (2014) tested corn cob cellulose, achieving fluid losses of 5.8 mL at 2-3 grams. Chinwuba et al. (2016) studied Pleurotus tuber-regium, recording fluid losses of 8-10.8 mL at 5-6 grams. Okon et al. (2020) compared rice husk (RH), Detarium microcarpum (DM), Brachystegia eurycoma (BE), and CMC, with RH demonstrating the best performance at 2.8 mL, compared to 4.5 mL, 7.3 mL, and 4.2 mL for DM, BE, and CMC, respectively. Chinwuba et al. (2021) further evaluated a blend of local bentonite with periwinkle shell and Mucuna solannie, achieving a fluid loss of 12 mL. Ikram et al. (2021) tested okra and starch, with okra yielding fluid losses of 20.8 mL, 17.6 mL, and 17 mL at concentrations of 0.25%, 0.5%, and 1% by weight, respectively, while starch recorded 18.8 mL at 0.25% concentration. Kerunwa et al. (2023) investigated coconut fiber (CF) and corn cobs (CC), with a CF-CC blend achieving the best performance at 8 mL, compared to 8.6 mL, 14 mL, and 10.2 mL for CMC, CF, and CC, respectively.

In recent years, nanoparticles have emerged as promising fluid loss control additives due to their unique properties, such as high surface area and tunable surface chemistry (Uwaezuoke 2022). Ismail (2016) demonstrated the effectiveness of nanosilica, achieving a fluid loss of 7 mL and a gel strength of 7 Pa. Dejtaradon et al. (2019) evaluated zinc oxide (ZnO) nanoparticles, reporting a fluid loss of 14 mL and gel strengths of 15-37 Pa. Cheraghian et al. (2019) studied silica nanoparticles, achieving a fluid loss of 10 mL and gel strengths of 13–32 Pa. Gbadamosi et al. (2019) further confirmed the efficacy of silica nanoparticles, with a fluid loss of 5.1 mL and gel strengths of 7-8 Pa.

This study investigates the fluid loss control performance of Oryza glaberrima-derived nanoparticles blended with silica oxide, comparing their efficacy with conventional additives such as carboxymethyl cellulose (CMC) and polyanionic cellulose (PAC). The evaluation is based on Fourier Transform Infrared Spectroscopy (FTIR), X-Ray Diffraction (XRD), and Low Pressure-Low Temperature (LPLT) fluid loss tests. The findings aim to provide insights into the potential of Oryza glaberrima nanoparticles as a sustainable and efficient alternative for fluid loss control in water-based drilling muds.

Materials and Methods

The materials used in this study include:

1. Fluid Loss Control Additives: Rice Husk (RH) (local fluid loss control additive), Nanosilica, conventional fluid loss control additives, such as Polyanionic Cellulose (PAC-R) and Carboxymethyl Cellulose (CMC).
2. Drilling Fluid Components: Barite (density control), Bentonite (viscosifier), Calcium Carbonate, Sodium Hydroxide (pH control agent), Water (continuous phase).
3. Laboratory Equipment and Tools: Buck 530 IR-spectrophotometer, Mud balance, Rotary viscometer, Agitator, Spatula, Small teaspoon, sand content tube, sieve and sieve shaker, weighing balance, washing bucket, gas oven, tray pan, measuring cylinder, stopwatch, mixer, grinding machine, pH paper, metre rule, Low Temperature Low Pressure (LTLP) API filter press.

Sourcing and Preparation of Fluid Loss Control Additives. ***Sourcing of Materials***. CMC, PAC-R, and Nanosilica were produced from an industrial chemical store. Rice Husk (RH) sourced from a milling factory in Abakaliki, Ebonyi State, Nigeria, and transported to the laboratory for processing.

Preparation of Rice Husk (RH): In the laboratory, unwanted particles and debris were manually removed from the RH to ensure purity. The cleaned RH was dried in a laboratory oven at 50°C for 72 hours to reduce its moisture content. The dried RH was ground into fine particles using an industrial blender. The pulverized RH was sieved using a US 250-mesh sieve to obtain uniformly sized particles. Finally, the uniform RH particles were collected in airtight bottles and stored at room temperature for further use. **Figure 1** illustrates the RH before and after the treatment process, highlighting the transformation from raw material to a refined fluid loss control additive.

(a)Natural RH (before) (b)Pulverized RH (After)

Figure 1--RH before and after treatment.

Fourier Transform Infrared Spectroscopy. Fourier Transform Infrared (FTIR) analysis was conducted using an IR-Spectrophotometer to characterize the molecular structure and chemical bonds of the selected materials, including Rice Husk (RH), Nanosilica (NS), Rice Husk-Nanosilica blend (RH-NS), Polyanionic Cellulose (PAC-R), and Carboxymethyl Cellulose (CMC). The FTIR analysis generated absorbance spectra plots, which reveal the unique molecular arrangements and chemical bonds present in each material. The spectra exhibit distinct peaks corresponding to specific functional groups, such as alkanes, ketones, chlorides, and carboxylic acids. These functional groups absorb infrared radiation at characteristic wavelengths, allowing for their identification. The obtained spectra were cross-referenced with a standard reference library to determine the functional groups present in each material.

X-Ray Diffraction. X-Ray Diffraction (XRD) was employed to analyze the chemical composition and physical properties of the test samples. The XRD analysis was performed as follows:

Instrument Setup. The XRD device was powered on, and the operating parameters were set to a voltage of 45 kV, a current of 40 mA, and a temperature of 21 ± 2°C.

Software Initialization. The computer system was switched on, and the XRD software was launched to initiate the analysis.

Sample Preparation. The RH sample was ground into a fine powder and placed into the sample holder, which was then positioned in the sample chamber column.

Measurement Settings. The scan axis was set to Gonio, and the start and end positions, scan angle, and scan time were configured.

Analysis Execution. The scan was initiated and allowed to run for the specified duration. Upon completion, the results were saved for further analysis.

Mud Formulation. For the fluid loss experimental evaluation, five distinct water-based mud (WBM) samples were formulated:

(1) RH-WBM: Containing Rice Husk as the fluid loss control additive.
(2) NS-WBM: Containing Nanosilica as the fluid loss control additive.
(3) CMC-WBM: Containing Carboxymethyl Cellulose as the fluid loss control additive.
(4) PAC-R-WBM: Containing Polyanionic Cellulose as the fluid loss control additive.

(5) RH-NS-WBM: Containing a blend of Rice Husk and Nanosilica as the fluid loss control additive.

The detailed formulation of each mud sample, including the concentrations of additives and base components, is provided in **Table 1**.

Table 1—Fluid loss control additive formulation utilized for the study.

S/N	Mud-Type	PAC-R	CMC	RH	NS
1	PAC-R	0.5g, 1g, 1.5g, 2g	Nil	Nil	Nil
2	CMC	Nil	0.5g, 1g, 1.5g, 2g	Nil	Nil
3	RH	Nil	Nil	2g, 4g, 6g, 8g	Nil
4	NS	Nil	Nil	Nil	2g, 4g, 6g, 8g
5	RH-NS	Nil	Nil	7.5g	0.5g
6	RH-NS	Nil	Nil	7.0g	1.0g
7	RH-NS	Nil	Nil	6.5g	1.5g
8	RH-NS	Nil	Nil	6.0g	2.0g

Mixing Procedure of Mud Sample Formulation. The mud samples were prepared following a standardized mixing procedure to ensure consistency and reproducibility. First, the required quantities of additives, as specified in Table 1, were accurately weighed using a precision weighing balance. Next, 300 mL of distilled water, as detailed in **Table 2**, was measured using a scientific measuring cylinder. The measured distilled water was then poured into a mud cup and placed on a Hamilton Beach mixer, which was activated to agitate the water at a consistent speed.

To begin the formulation, 25 grams of bentonite were gradually added to the agitated water, and the mixture was allowed to mix thoroughly for 5 minutes to ensure complete hydration of the bentonite. Following this, 0.5 grams of sodium hydroxide (NaOH) and 10 grams of calcium carbonate ($CaCO_3$) were added to the slurry, and the mixture was agitated for an additional 2 minutes to achieve homogeneity.

For the incorporation of fluid loss control additives, 0.5 grams of Polyanionic Cellulose (PAC-R) were introduced to the slurry, and the mixture was agitated for 3 minutes to ensure uniform dispersion of the additive. This procedure was repeated for the preparation of mud samples containing other fluid loss control additives, including Carboxymethyl Cellulose (CMC), Rice Husk (RH), Nanosilica (NS), and the Rice Husk-Nanosilica blend (RH-NS), as outlined in Table 1.

Table 2—Composition of other additives utilized for WBM formulation.

S/N	Additives	Function	Concentration
1	Water (ml)	Base Fluid	300ml
2	Bentonite	Viscosifier	25g
3	$CaCO_3$	Bridging Agent	10g
4	NaOH	pH Enhancer	0.5g

Mud Filtration Test. The mud filtration analysis was conducted under LPLT conditions using API Filter Press depicted in **Figure 1**. The filter press is utilized for the experiment and consists of 6 independent filter cells, placed on a system. The cells were cleaned and dried to remove unwanted particles, while the rubber gasket was inspected to ensure compliance. The dried cells were coupled-up using the following sequence base-cup, followed by rubber-gasket, followed by screen, followed by filter paper, followed by rubber gasket and finally the cell body. 130ml of the formulated DM with additives from Table 1 and 2 was introduced to the cell before being placed into the base and tightened to ensure closure. 50ml measuring cylinder was placed at the bottom of the cell to recover filtration. The cell was pressurized to 100psi before the filtrate volume was derived after 30 minutes.

Figure 2—API filter press.

Filter Cake Analysis. The formulated mud on the filter paper on the mud after the filtration loss experiment was qualitatively and quantitatively evaluated using API concepts. The qualitative approach for the filter cake was conducted by viewing and touching the mud cake to determine its nature, while the quantitative approach was conducted by deriving the thickness of the mud cake in mm.

Mud Cake Permeability Test. The mud cake was derived using Lomba (2010) formulation for WBM.

$$K = 8.95 * 10^{-5} q_w \mu \varepsilon, \quad (1)$$

whrer k, q_w, μ and ε represents mud cake permeability (mD), mud filtrate volume (cm^3), mud filtrate viscosity (cp) and mud cake thickness (mm).

Results and Discussion

FTIR Characterization Analysis. The Fourier Transform Infrared (FTIR) spectra for Carboxymethyl Cellulose (CMC), Polyanionic Cellulose (PAC-R), Rice Husk (RH), Nanosilica (NS), and the Rice Husk-Nanosilica blend (RH-NS) in Water-Based Mud (WBM) are presented in **Figures 3** to **7**. The FTIR analysis revealed the presence of distinct functional groups in each material, which are critical for understanding their chemical interactions and fluid loss control mechanisms.

The FTIR spectrum of CMC (Figure 3) exhibited characteristic peaks corresponding to functional groups such as carboxyl (–COOH), hydroxyl (–OH), SP hybridizing carbon (C≡C or C≡N), aromatic rings (C=C), and carbonyl (C=O) bonds. These groups are indicative of CMC's polymeric structure and its ability to form hydrogen bonds, which contribute to its effectiveness as a fluid loss control additive. Similarly, the spectrum of PAC-R (Figure 4) showed the presence of carboxyl (–COOH), SP hybridizing carbon (C≡C or C≡N), aromatic rings (C=C), and hydroxyl (–OH) groups. These functional groups are consistent with the chemical structure of PAC-R, enabling it to interact effectively with clay particles and form a stable filter cake.

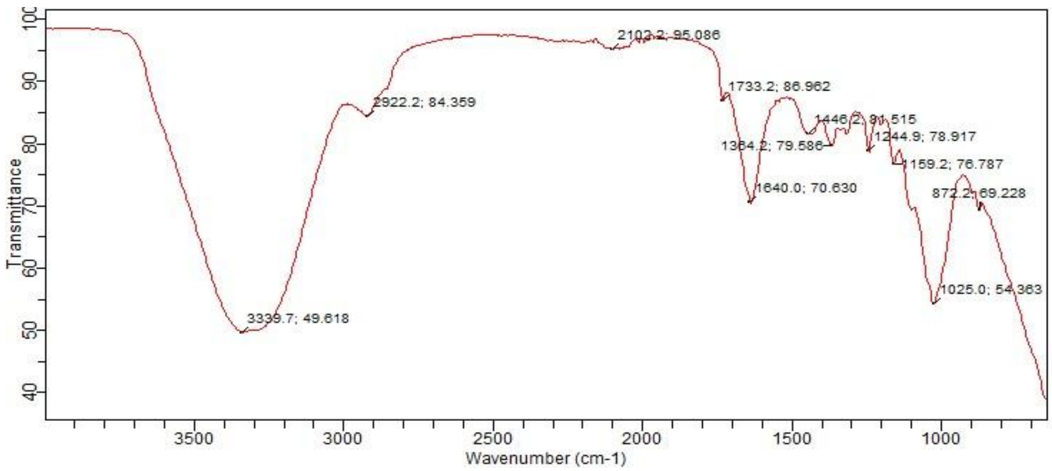

Figure 3—FTIR spectra for CMC WBM sample.

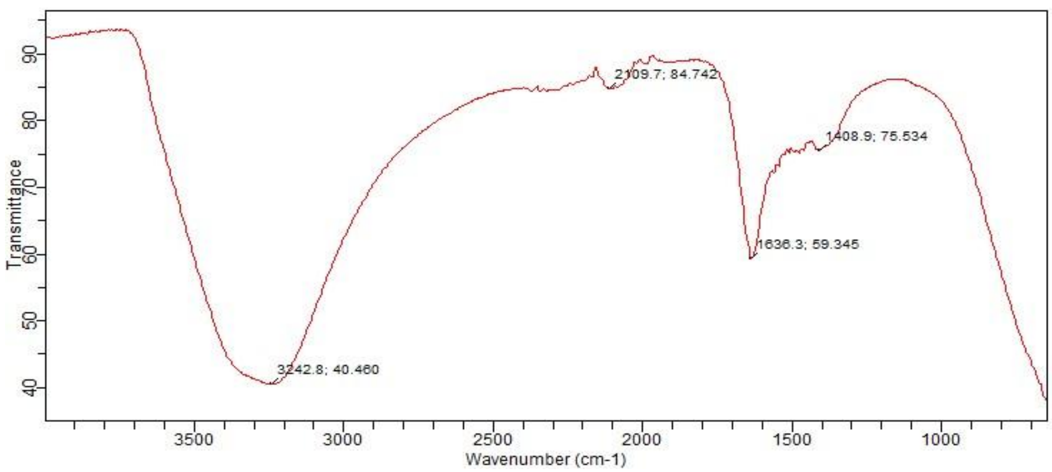

Figure 4—FTIR spectra for PAC-R WBM sample.

The FTIR analysis of RH (Figure 5) revealed the presence of carboxyl (–COOH), SP hybridizing carbon (C≡C or C≡N), and hydroxyl (–OH) groups. These functional groups are attributed to the organic components of rice husk, such as cellulose, hemicellulose, and lignin, which contribute to its fluid loss control properties. In the case of NS (Figure 6), the spectrum displayed peaks corresponding to hydroxyl (–OH), SP hybridizing carbon (C≡C or C≡N), and carboxyl (–COOH) groups. These groups are associated with the surface chemistry of nanosilica, which enhances its ability to adsorb clay particles and reduce fluid loss.

The FTIR spectrum of the RH-NS blend (Figure 7) showed the presence of carboxyl (–COOH), hydroxyl (–OH), SP hybridizing carbon (C≡C or C≡N), and aromatic rings (C=C). The presence of these functional groups, which are also found in CMC and PAC-R, suggests that the RH-NS blend exhibits similar chemical interactions and bonding mechanisms. This similarity likely contributes to its competitive performance as a fluid loss control additive.

Key observations from the FTIR analysis include the identification of functional groups such as carboxyl, hydroxyl, and SP hybridizing carbon in RH, NS, and RH-NS, which are also present in CMC and PAC-R. This indicates that these materials share similar chemical properties, essential for effective fluid loss control. The presence of hydroxyl and carboxyl groups in all materials suggests their ability to form hydrogen bonds with water molecules and clay particles, enhancing their ability to stabilize the drilling fluid and reduce fluid loss. Additionally, the aromatic and SP hybridizing carbon groups observed in CMC, PAC-R, and RH-NS further highlight their potential for forming strong intermolecular interactions, which are critical for maintaining wellbore stability and minimizing fluid invasion into the formation.

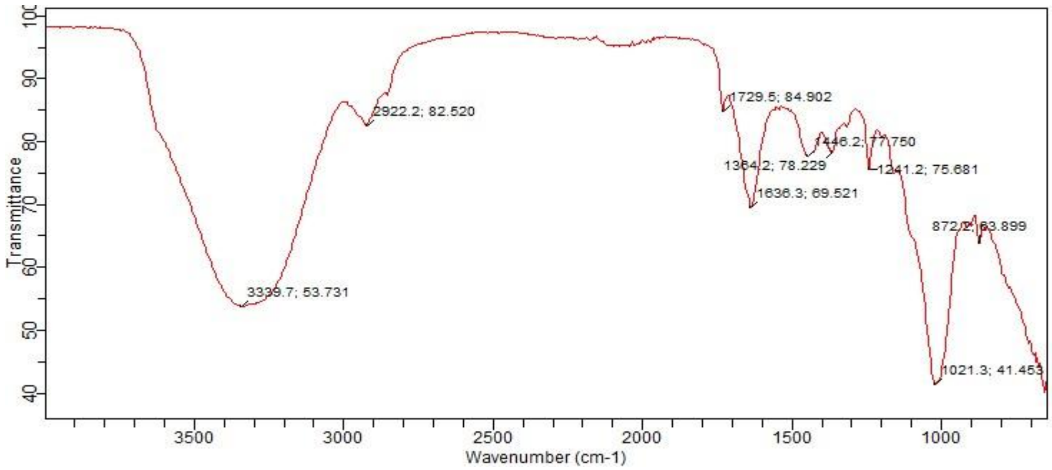

Figure 5—FTIR spectra for RH WBM sample.

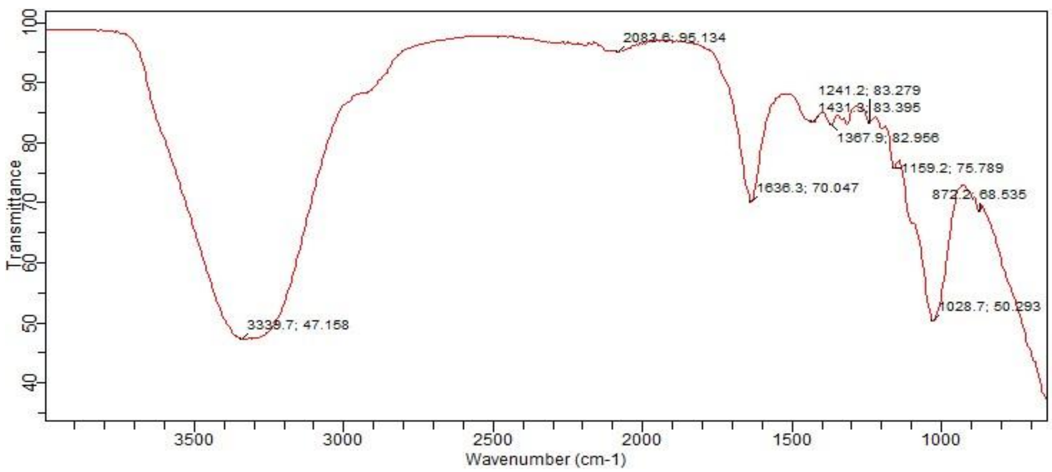

Figure 6—FTIR spectra for NS WBM sample.

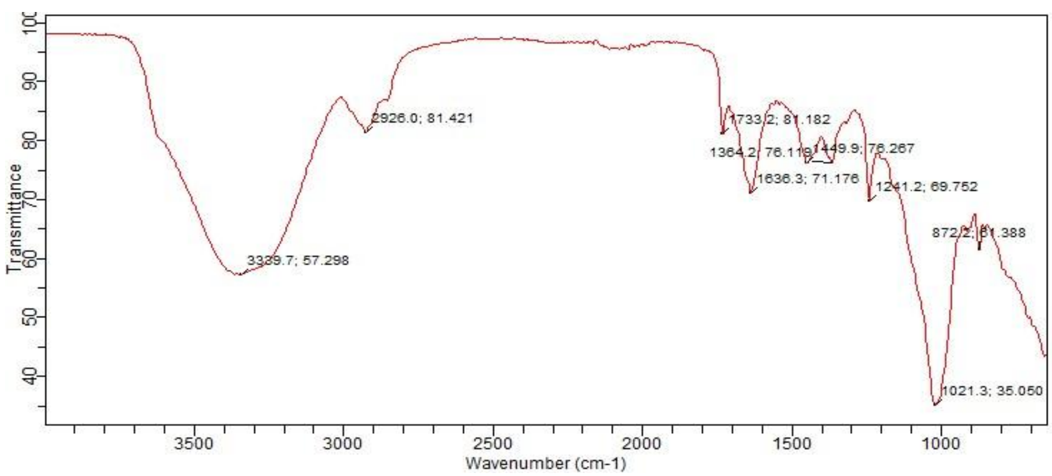

Figure 7—FTIR spectra for RH assisted NS WBM sample.

As observed, the FTIR analysis provides valuable insights into the chemical composition and functional groups of the tested materials, demonstrating that RH-NS exhibits chemical properties comparable to conventional additives like CMC and PAC-R. This supports its potential as a sustainable and effective alternative for fluid loss control in water-based drilling fluids.

X-Ray Diffraction (XRD) Analysis. **Table 3** presents the X-Ray Diffraction (XRD) results for Carboxymethyl Cellulose (CMC), Polyanionic Cellulose (PAC), and the Nanosilica-Rice Husk blend (NS-RH) in Water-Based Mud (WBM). The XRD analysis provides insights into the mineralogical composition and crystalline structure of these materials, which are critical for understanding their performance as fluid loss control additives.

CMC exhibited a diverse mineral composition, including Quartz (42%), Muscovite (11.1%), Anorthite (5.8%), Anthophyllite (3.14%), Calcite (10.4%), Orthoclase (11.3%), Vermiculite (9.5%), and Garnet (3.9%). The high percentage of Quartz and the presence of minerals such as Muscovite and Orthoclase indicate a well-defined crystalline structure, which contributes to CMC's stability and effectiveness in fluid loss control. Similarly, PAC showed a mineral composition dominating by Quartz (48%), with significant amounts of Orthoclase (23%) and Calcite (8%). Other minerals, such as Muscovite (3%), Anorthite (5%), Anthophyllite (5%), Vermiculite (6%), and Garnet (0.1%), were also present. The high Quartz content and the presence of Orthoclase suggest a robust crystalline framework, which enhances PAC's ability to form a stable filter cake.

Table 3—XRD analysis of the materials utilized for the study.

CMC-WBM		PAC(r)-WBM		RH+NS-WBM	
Mineral	Composition (%)	Mineral	Composition (%)	Mineral	Composition (%)
Quartz	42(3)	Quartz	48(106)	Quartz	42(3)
Muscovite	11.1(7)	Muscovite	3(6)	Muscovite	4.7(7)
Anorthite	5.8(6)	Anorthite	5(10)	Anorthite	8(2)
Anthophyllite	3.14(19)	Anthophyllite	5(19)	Anthophyllite	3.0(4)
Calcite	10.4(12)	Calcite	8(17)	Calcite	19(2)
Orthoclase	11.3(7)	Orthoclase	23(80)	Orthoclase	7.3(10)
Vermiculite	9.5(7)	Vermiculite	6(11)	Clinochlore	3. 8(11)
Osumilite	3.12(16)	Osumilite	3(6)	Osumilite	1.5(5)
Garnet	3.9(10)	Garnet	0.1(2)	Garnet	10.3(12)

The NS-RH blend recorded a mineral composition of Quartz (42%), Muscovite (4.7%), Anorthite (8%), Anthophyllite (3%), Calcite (19%), Orthoclase (7.3%), Vermiculite (3.8%), and Garnet (10.3%). Notably, NS-RH exhibited a similar percentage of Quartz (42%) and Anthophyllite (3%) as CMC, along with comparable amounts of other minerals such as Calcite and Orthoclase. This indicates that NS-RH shares a similar crystalline structure with CMC and PAC, which is essential for effective fluid loss control. The presence of well-defined crystalline minerals such as Quartz, Orthoclase, and Calcite in all three materials (CMC, PAC, and NS-RH) indicates a strong and stable crystal composition. This is critical for maintaining the integrity of the filter cake and minimizing fluid loss during drilling operations.

The similarity in mineral composition between NS-RH and conventional additives like CMC and PAC highlights its potential as a sustainable and effective alternative for fluid loss control. The presence of Calcite (19%) in NS-RH, which is higher than in CMC (10.4%) and PAC (8%), may further enhance its ability to interact with carbonate formations, improving its performance in specific drilling environments. The XRD analysis confirms that CMC, PAC, and NS-RH exhibit good crystalline compositions, with NS-RH showing a mineralogical profile like that of conventional additives. This similarity, combined with the unique mineral composition of NS-RH, supports its potential as a viable and sustainable alternative for fluid loss control in water-based drilling fluids. The findings underscore the importance of mineralogical composition in designing effective drilling fluid additives and highlight the promising role of NS-RH in advancing environmentally friendly drilling practices.

Filtration Loss Analysis. Figure 8 illustrates the fluid loss control performance of Rice Husk (RH), Nanosilica (NS), Polyanionic Cellulose (PAC-R), and Carboxymethyl Cellulose (CMC) in Water-Based Mud (WBM). The initial fluid loss volume of the drilling mud was 40 mL, which was significantly reduced upon the addition of the tested additives.

For CMC-WBM, the fluid loss volume decreased to 12 mL, 10.5 mL, 10 mL, and 9.8 mL when 0.5 g, 1.0 g, 1.5 g, and 2 g of CMC were introduced, respectively. Similarly, PAC-R-WBM demonstrated a reduction in fluid loss volume to 18 mL, 11 mL, 9 mL, and 8 mL at the same concentrations. In the case of NS-WBM, the fluid loss volume was reduced to 20 mL, 18.9 mL, 17 mL, and 16 mL at 2 g, 4 g, 6 g, and 8 g, respectively. RH-WBM also showed a notable reduction in fluid loss volume, achieving 19.5 mL, 17 mL, 15.8 mL, and 12 mL at 2 g, 4 g, 6 g, and 8 g, respectively.

As observed in Figure 8, PAC-R-WBM recorded the best fluid loss control performance, achieving the lowest fluid loss volume of 8 mL at 2 g. In comparison, CMC-WBM, NS-WBM, and RH-WBM recorded fluid loss volumes of 9.8 mL, 16 mL, and 12 mL, respectively, at their optimal concentrations. The superior performance of PAC-R-WBM can be attributed to the ability of PAC to form a higher cellulose content when used as an additive, which enhances its ability to create a low-permeability filter cake and effectively reduce fluid loss (Agwu et al. 2019).

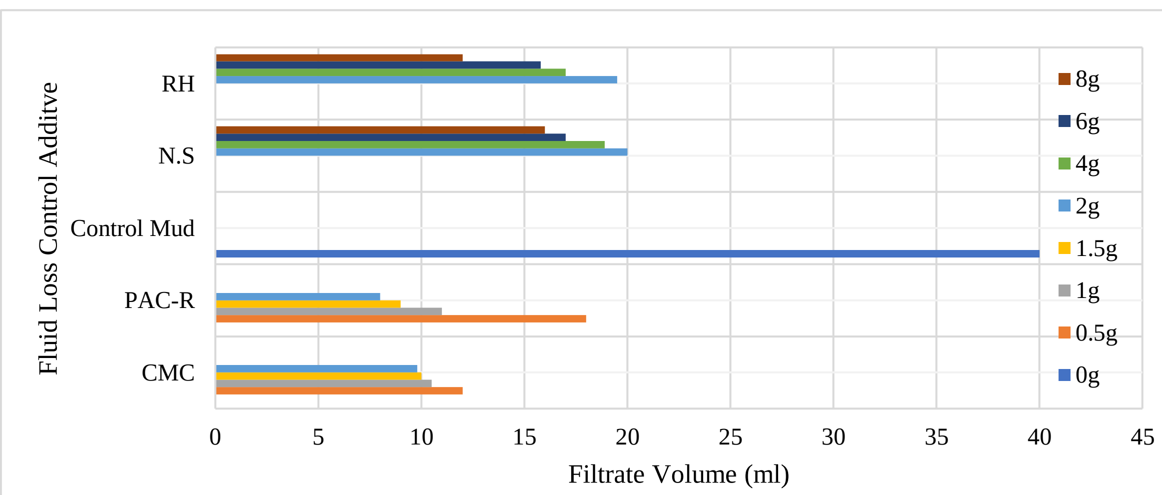

Figure 8—Fluid loss control performance of RH, NS, PAC-R and CMC.

Figure 9 demonstrates the fluid loss control performance of Rice Husk (RH) Water-Based Mud (WBM) when partially replaced by Nanosilica (NS) at varying concentrations. The replacement of 0.5 g of RH with 0.5 g of NS resulted in a reduction of fluid loss volume from 12 mL to 11.2 mL. Further replacement studies using 1 g, 1.5 g, and 2 g of NS showed a progressive decrease in fluid loss volume to 10 mL, 9.8 mL, and 7.5 mL, respectively.

When compared to the fluid loss volumes of RH, PAC, and CMC, the RH-NS blends consistently recorded lower fluid loss volumes. This enhanced performance can be attributed to the synergistic combination of the cellulose effect of RH and the sealing effect of NS. The cellulose content in RH contributes to the formation of a stable filter cake, while the nanosilica particles effectively seal micro-fractures and pores in the formation, reducing the volume of the continuous phase lost to the formation. The optimal proportion of RH and NS in the blend ensures a balanced interaction between these mechanisms, resulting in superior fluid loss control performance.

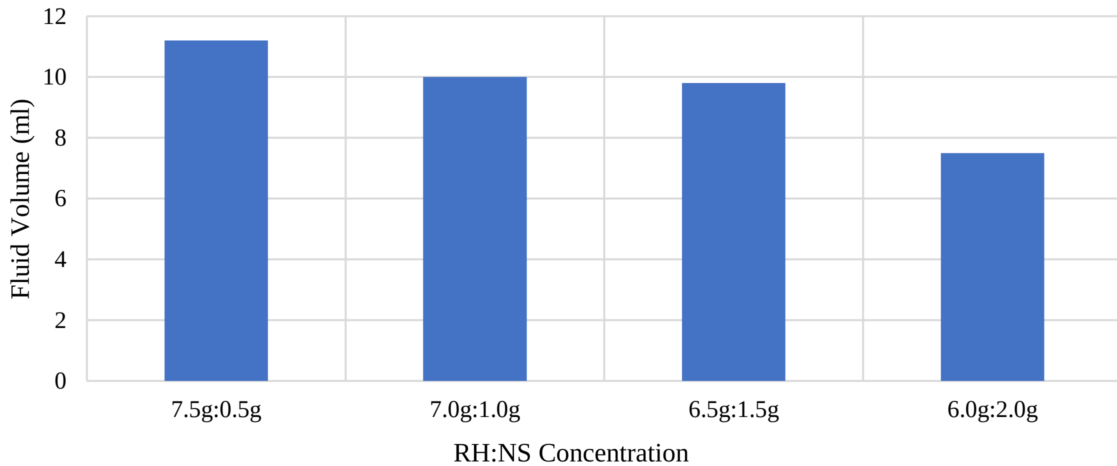

Figure 9—Fluid loss control performance of various RH assisted NS at various concentration.

Mud Cake Thickness Analysis. Figure 10 illustrates the mud cake thickness for CMC, PAC, RH, NS, and RH-NS at varying concentrations. The results highlight the influence of additive type and concentration on the formation and thickness of the mud cake, which is critical for effective fluid loss control.

For CMC, the mud cake thickness decreased from 0.6 mm at 0.5 g to 0.4 mm, 0.4 mm, and 0.3 mm at 1 g, 1.5 g, and 2 g, respectively. Similarly, PAC exhibited a reduction in mud cake thickness from 0.8 mm at 0.5 g to 0.6 mm, 0.4 mm, and 0.3 mm at 1 g, 1.5 g, and 2 g, respectively. These results indicate that both CMC and PAC are effective in forming thin and stable mud cakes at higher concentrations, which is essential for minimizing fluid loss. In the case of RH, the mud cake thickness decreased from 0.8 mm at 2 g to 0.7 mm, 0.6 mm, and 0.4 mm at 4 g, 6 g, and 8 g, respectively. This demonstrates that increasing the concentration of RH leads to the formation of thinner mud cakes, enhancing its fluid loss control performance.

Conversely, NS showed a different trend, with the mud cake thickness remaining constant at 0.8 mm from 2 g to 4 g, before increasing to 1 mm and 1.1 mm at 6 g and 8 g, respectively. This increase in thickness at higher concentrations may be attributed to the agglomeration of nanosilica particles, which can hinder the formation of a compact filter cake. The RH-NS blend exhibited a mud cake thickness of 1.1 mm at a concentration ratio of 7.5 g RH to 0.5 g NS, which remained constant at 7.0 g RH to 1.0 g NS. However, the thickness decreased to 0.6 mm and 0.4 mm at concentration ratios of 6.5 g RH to 1.5 g NS and 6.0 g RH to 2.0 g NS, respectively. This suggests that the optimal proportion of RH and NS in the blend is crucial for achieving a thin and effective mud cake.

The consistent formation of thinner mud cakes by CMC and PAC at higher concentrations was observed, demonstrating their effectiveness as fluid loss control additives. RH also showed a reduction in mud cake thickness with increasing concentration, highlighting its potential as a sustainable alternative. However, NS exhibited an increase in mud cake thickness at higher concentrations, likely due to particle agglomeration, which may limit its effectiveness. The RH-NS blend achieved the thinnest mud cake (0.4 mm) at a concentration ratio of 6.0 g RH to 2.0 g NS, indicating that the synergistic combination of RH and NS can enhance fluid loss control performance.

The mud cake thickness analysis underscores the importance of additive type and concentration in optimizing fluid loss control. The RH-NS blend demonstrates promising potential as a sustainable and effective alternative to conventional additives like CMC and PAC.

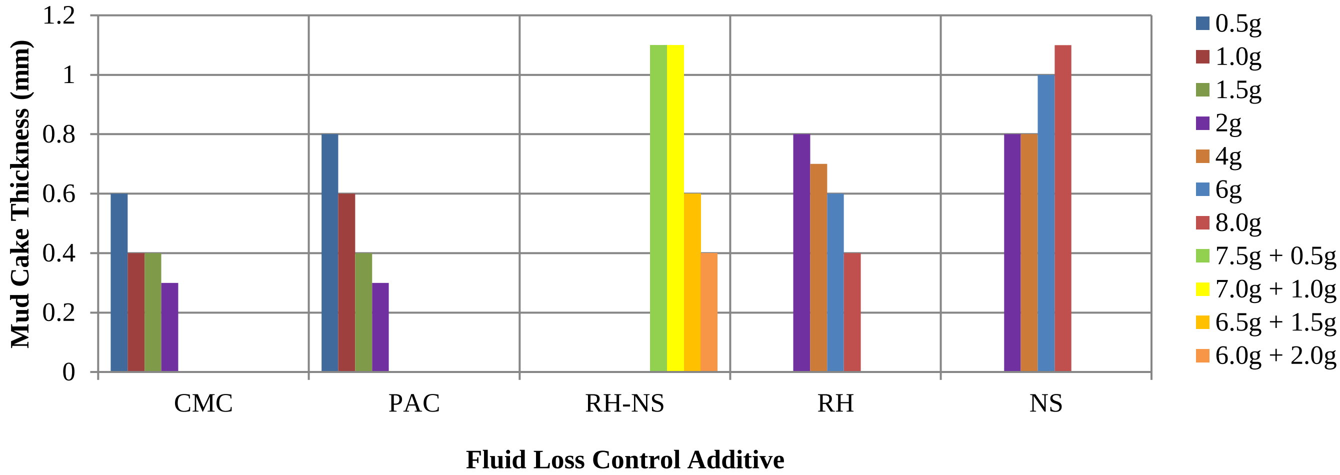

Figure 10—Mud cake thickness of CMC, PAC, RH-NS, RH and NS.

Combining Figures 8 to 10, CMC, PAC, RH-NS and RH recorded continuous reduction in mud cake thickness and fluid volume with increase in concentration. The reduction in mud cake thickness can be attributed to the ability of the mud to form thin filter cake to prevent loss of the continuous phase of the formation and is in-line with Kerunwa et al. (2024) study. NS however recorded an increase in mud cake thickness and reduction in fluid loss volume with increase in concentration. This can be attributed to depositional effects of the nanoparticles which reduce fluid volume but stacks up to form thicker filter cake.

Mud Cake Permeability. Figure 11 illustrates the mud cake permeability of Rice Husk (RH), Nanosilica (NS), and the Rice Husk-Nanosilica blend (RH-NS) in Water-Based Mud (WBM). As shown in the figure, RH exhibited a permeability of 0.002 md at 2 g. Increasing the concentration to 4 g, 6 g, and 8 g resulted in a progressive reduction in permeability to 0.0015 md, 0.0012 md, and 0.00061 md, respectively. Similarly, NS recorded a permeability of 0.00286 md at 2 g. When the concentration was increased to 4 g, the permeability decreased slightly to 0.00271 md. However, further increases to 6 g and 8 g led to an inconsistent trend, with permeability rising to 0.00304 md at 6 g before decreasing to 0.00295 md at 8 g.

In contrast, the RH-NS blend demonstrated a more consistent reduction in permeability with increasing concentration. At a concentration ratio of 7.5 g RH to 0.5 g NS, the permeability was 0.00278 md. This value decreased to 0.0025 md, 0.00133 md, and 0.00068 md at concentration ratios of 7.0 g RH to 1.0 g NS, 6.5 g RH to 1.5 g NS, and 6.0 g RH to 2.0 g NS, respectively.

The continuous reduction in mud cake permeability for RH and RH-NS can be attributed to the formation of a compact and low-permeability filter cake, which effectively inhibits the flow of the continuous phase into the formation. This is critical for minimizing fluid loss and preventing issues such as reduced oil productivity and formation damage (Kosynkin et al. 2012). On the other hand, the inconsistent permeability values observed for NS are likely due to the nature and stacking behavior of the nanoparticles, which can lead to uneven particle distribution and agglomeration at higher concentrations.

Comparing the results from Figures 8 through 11, the reduction in fluid loss volume for RH and RH-NS is closely linked to the formation of thin, low-permeability filter cakes. These filter cakes act as effective barriers, preventing the continuous phase from invading the formation and thereby mitigating potential drilling challenges. The superior performance of RH-NS, in particular, highlights its potential as a sustainable and efficient alternative for fluid loss control in water-based drilling fluids.

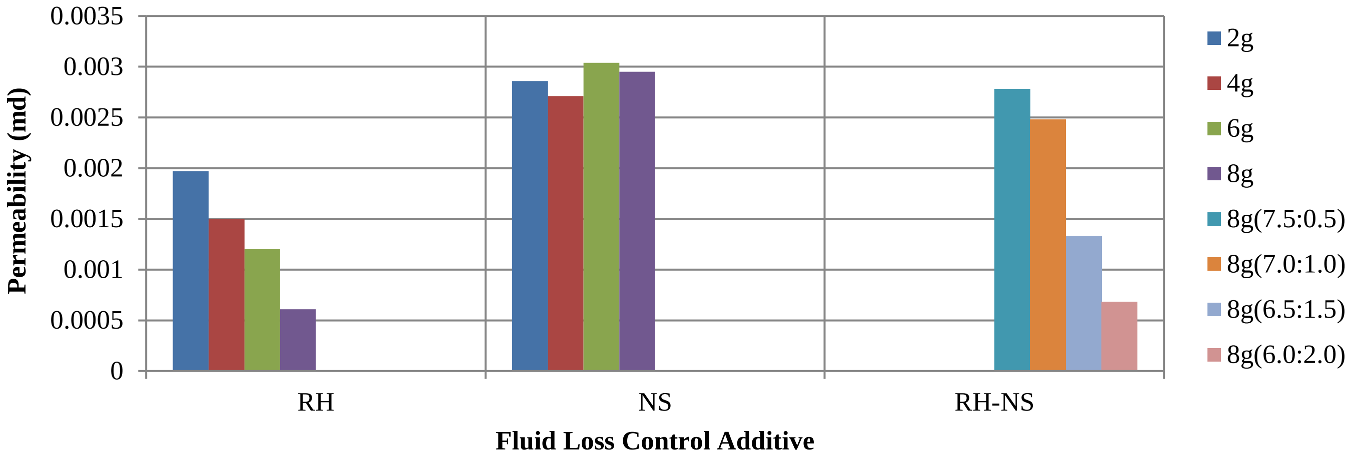

Figure 11—Mud cake permeability of RH, NS and RH-assisted-NS.

Conclusion

Based on the experimental study conducted with the selected materials, the following conclusions can be drawn:

1. The incorporation of nanosilica (NS) into rice husk (RH) significantly improved its fluid loss control capabilities, enabling it to compete effectively with conventional additives such as polyanionic cellulose (PAC) and carboxymethyl cellulose (CMC).
2. The Fourier Transform Infrared Spectroscopy (FTIR) study revealed that the RH-NS blend exhibited functional groups such as carboxyl, hydroxyl, and SP hybridizing carbon, which are also present in CMC and PAC-R. This indicates similar chemical bonding and molecular interactions, contributing to its effectiveness as a fluid loss control additive.
3. The X-Ray Diffraction (XRD) study demonstrated that CMC, PAC, and RH-NS possess well-defined crystalline structures, confirming their stable and effective chemical compositions.
4. The fluid loss study showed that the RH-NS blend outperformed other additives, reducing fluid loss to 7.5 mL. In comparison, RH, NS, PAC, and CMC recorded fluid losses of 12 mL, 16 mL, 8 mL, and 9.8 mL, respectively.
5. The study of mud cake thickness indicated that CMC and PAC formed thinner mud cakes (0.3 mm), while RH-NS, RH, and NS produced slightly thicker mud cakes of 0.4 mm, 0.4 mm, and 0.8 mm, respectively.
6. The permeability study of the mud cakes revealed that RH, NS, and RH-NS exhibited low permeability values of 0.00061 md, 0.00271 md, and 0.00068 md, respectively. These results suggest that the RH-NS blend effectively forms a low-permeability filter cake, further enhancing its fluid loss control performance.

In summary, the RH-NS blend demonstrated superior fluid loss control performance, comparable chemical properties to conventional additives, and the ability to form a low-permeability filter cake. These findings highlight its potential as a sustainable and efficient alternative to traditional fluid loss control additives in water-based drilling fluids.

Conflicting Interests

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

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