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Effectiveness of Coconut Fiber as a Drilling Mud Additive

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Abstract

The potential of powdered coconut fiber derived from mature coconut husks, as a natural additive in water-based mud (WBM) formulations is evaluated in this study. Coconut fiber was processed and sieved to obtain different particle sizes using mesh sizes of 10µm, 20µm, and 40 µm. The processed fibers were used as replacement for barite and carboxymethyl cellulose (CMC) in the formulation of drilling mud. Experimentally, the WBM properties evaluated were pH, mud weight (MW), gel strength, plastic viscosity (PV), apparent viscosity (AV), yield point (YP), fluid loss, and filter cake thickness. The results for mesh size 10µm are pH=7, MW=8.7ppg, PV=6cp, 10min Gel Strength=21, AV=25cp, YP=38lb/100ft, n= 0.93, K=0.57, filter cake=1.3mm, for meshed size 20µm; pH=8, MW=8.7ppg, 10min Gel Strength=35, PV=17cp, AV=35cp, YP=36lb/100ft, n= 0.74, K=0.70, Filter Cake= 0.9mm, and for meshed size 40µm; pH=8, MW=8,7ppg, 10min Gel Strength=29, PV=25cp, AV=32.5cp, YP=15lb/100ft, n=0.76, K=0.67, Filter Cake= 2.0mm. These aforementioned data indicate that powdered coconut fiber substantially improves the gel strength, suspension capabilities, and filtration control of the mud. Natural additives such as coconut fiber can be used as replacement for standard WBM by increasing mud performance, reducing fluid loss, and can be useful in promoting sustainability goals.

Keywords: Drilling Mud; Natural drilling fluid additive; Coconut Fiber; Rheological properties; Particle size; Filtration properties

1. Introduction

The oil and gas industry continuously seeks innovative and sustainable solutions to enhance drilling operations, with drilling mud playing a critical role. Drilling mud as known as drilling fluid is a complex mixture that performs several vital functions such as lubricating, cooling, and stabilizing of the drill bit and borehole. It is also instrumental in carrying cuttings to the surface and maintaining wellbore stability (Adesina *et al*. 2012). However, drilling mud's performance often requires enhancement by adding additives that can improve its rheological and filtration properties.

Bentonite, barite, carboxymethyl cellulose (CMC), polyanionic cellulose (PAC), and xanthan gum are widely used as drilling mud additives due to their critical roles in drilling operations. These additives are instrumental in enhancing drilling fluid properties by increasing viscosity, improving suspension for drill cuttings, fluid density, reducing fluid loss to formations, and boosting the carrying capacity of drilling fluids (Caenn *et al*. 2011).

Despite their advantages, these additives have notable limitations such as formation shales, swelling, and instability. This reaction may result in damage to the formation, thus affects the overall well integrity. (Zhang *et al*. 2020). Other limitations include higher cost, slower biodegradability, complex formulation, and reduced stability in low temperature conditions (such as with ester-based fluids) (Davoodi *et al*. 2024).

Previous studies have highlighted the potential of natural and renewable materials as drilling mud additives (Das *et al.* 2016; Elkatatny, 2019, Rafieefar *et al*. 2021, Al-Yasiri, 2023). Coconut fiber derived from the mesocarp of the coconut fruit, has gained attention as a sustainable material with diverse industrial applications due to its biodegradability, low cost, and abundance in tropical regions (Tomar et al. 2021, Abate *et al*. 2022, Kumar & Saha 2024). It is composed mainly of cellulose, lignin, and hemicellulose, which contribute to its structural strength and hydrophilic properties (Kumar and Saha 2024). Otedheke *et al*., (2024) evaluated a composite mix of sawdust and coconut fiber as a fluid loss control additive in water-based drilling mud. The findings indicated that the composite effectively reduced fluid loss, suggesting its potential as an alternative to conventional additives.

The increasing environmental concerns and regulations in the oil and gas industry necessitate research and development of environmentally friendly drilling mud additives. Coconut fiber, a natural and renewable material, offers a sustainable solution to these challenges. However, there is limited information on its performance and efficacy as a drilling mud additive, creating a knowledge gap that this study aims to address.

Therefore, the aim of this study is to investigate the performance of coconut fiber as a drilling mud additive. This includes evaluating the impact of coconut fiber on the rheological properties of water-based drilling mud, assessing the filtration control effectiveness of coconut fiber in drilling mud formulations and comparing the performance of coconut fiber with conventional synthetic additive. The utilization of coconut fiber as a drilling mud additive offers a promising avenue for enhancing the performance of drilling fluids while reducing environmental impacts associated with synthetic additives.

2. Materials and methods

2.1 Samples Preparation

The materials used to carry out this experimental research work were distilled water, Bentonite, Barite, Sodium Hydroxide (NaOH), Carboxymethyl Cellulose (CMC), and powdered coconut fiber.

Mature coconut husks were collected and cleaned to remove dirt and debris. Cleaned husks were air-dried to reduce initial moisture content. A decorticator machine was used to mechanically separate the fibers from the pith and shell of the coconut husks. The extracted fibers were dried in an oven at a controlled temperature of 60°C. Drying continued until the fibers reached a moisture content of 10%, which is essential for preventing microbial growth and ensuring better grinding efficiency. The dried fibers were cut into smaller lengths using a shredding machine. The shredded fibers were grounded into a fine powder using a mechanical grinder. The resultant fine powdered coconut fiber was collected and sieved into mesh sizes of 10µm, 20µm and 40µm.

2.2 Experimental procedure

The American Petroleum Institute (API) standard of formulating WBM was used in this study. The WBM formulation began with preparing a base fluid by mixing 350 mL of water with 25 g bentonite, which served as the primary viscosifier. Then, the bentonite was hydrated to achieve optimal swelling. Additional additives, included 2g of barite for density modification, 1 mL of sodium hydroxide (NaOH), for pH enhancers, and 1g of carboxymethyl cellulose (CMC) for fluid loss control. The water was initially blended in a mud mixing cup with the use of a mud mixer at a moderate speed of 100rpm, followed by the gradual addition of bentonite, which was mixed at a speed of 300rpm to ensure full hydration. Then, barite was added to stabilize the wellbore followed by adding CMC, to improve viscosity and control fluid loss. NaOH was introduced to adjust the pH, and the mixture was blended at a high speed of 600rpm for one minute to achieve uniformity. Following formulation, the WBM properties were evaluated based on standard API (American Petroleum Institute) procedures. The tests conducted include measurements of density, viscosity, gel strength, pH, and fluid loss. Rheological properties were assessed using a rotational viscometer at varying shear rates, while fluid loss was quantified with a standard API filter press.

Similar procedures were followed for formulations containing powdered coconut fiber, but after replacing the standard additives with the powdered coconut fiber of various mesh sizes (10µm, 20µm, and 40µm). In each case, water was blended at low speed, followed by the gradual addition of 25g bentonite, 1mL NaOH, and 5g powdered coconut fiber. Then, the mixture was blended at 600rpm for one minute to ensure homogeneity.

2.3 Drilling Mud Properties Analysis

Viscosity, which indicates a drilling mud's resistance to flow, is typically assessed through two key parameters: apparent and plastic viscosity. Apparent viscosity reflects the fluid's resistance at a defined shear rate and plays a crucial role in preventing drilling complications, thus enhancing wellbore cleaning efficiency (Al-Khdheeawi and Mahdi, 2019). In contrast, plastic viscosity represents the influence of the mud's solid content, serving as an indicator of the concentration of solids present in the fluid (Abdelrahman *et al*. 2019).

The plastic viscosity (PV), apparent viscosity (AV), yield point (YP), power law index (n), and consistency index (K) was determined using Eq. (1-5) (Ali *et al*. 2022).

$$PV = \theta_{600} - \theta_{300} \qquad (1)$$

$$AV = \frac{\theta_{600}}{2} \qquad (2)$$

$$YP = \qquad (3)$$

$$n = \frac{\log\left(\frac{\theta_{600}}{\theta_{300}}\right)}{\log 2} \qquad (4)$$

$$k = \frac{\theta_{600}}{511^{n}} \qquad (5)$$

3. Results and Discussion

The experimental data obtained from the water-based mud (WBM) formulated with and without powered coconut fibre is presented in Table 1. Based on the data in the table, the powered coconut fibre formulated WBM substantially influence the rheological and filtration properties. This finding suggests the potential of natural additives in drilling fluid enhancement. Moreover, the comparative assessment of water-based mud (WBM) formulated with and without powdered coconut fibre (CF) of varying mesh sizes (10 µm, 20 µm, and 40 µm) reveals distinct trends in rheological and filtration properties, offering valuable insights into the performance potential of natural lignocellulosic additives in drilling fluid systems. The effects of the powdered coconut fibre formulated WBM on the specific rheological properties is discussed in the following subsections.

Table 1: Formulation of Water-Based Mud, using powdered coconut fiber

Parameter	Coconut fiber mesh size				Broad Bean Peel Powder (Awl *et al.* 2023)	Watermelon rind powder (Madu *et al.* 2024)
	Control mud	10µm	20µm	40µm	1 wt% (7g)	3 wt% (21g)
Ph	12	7	8	8	6.9	10.5
Mud Weight (ppg)	8.6	8.7	8.7	8.7	7.8	8.7
Plastic Viscosity (PV, cp)	28	6	17	25	4	5
Apparent Viscosity (AV, cp)	21.5	25	35	32.5	11	8.5
Yield Point (YP, lb/100ft^2)	13	38	36	15	14	7
Power Law Index (n)	0.63	0.93	0.74	0.76	-	-
Consistency Index (K)	0.28	0.57	0.70	0.67	-	-
Fluid Loss (ml)	10	5	65	5	14	15
Filter Cake Thickness (mm)	2.75	1.3	0.9	2.0	1.25	1.56
Sand Content (%)	0.5	0.4	0.6	0.5	-	-
Gel Strength 10s (lb/100ft^2)	6	17	23	21	10	10

3.1 Effect of WBM formulated with coconut fiber on pH

The resultant pH from the formulated powdered coconut fibre WBM is presented in Figure 1. As shown in the figure, the control mud exhibited a highly alkaline pH of 12, typical of WBMs treated with caustic soda to inhibit microbial activity and stabilize the fluid. The addition of coconut fiber resulted in a consistent pH reduction across all tested mesh sizes—decreasing to pH 7 with 10 µm fibers and stabilizing at pH 8 with both 20 µm and 40 µm fibers. These pH adjustments are comparable to those achieved using broad bean peel powder, which lowered the pH from 8.6 to 7.8, and watermelon rind powder, which exhibited a marginal shift from 8.6 to 8.7, indicating that coconut fiber demonstrates a similar buffering capacity and acid-base interaction profile to the other local materials. This shift could be mostly be due to the slightly acidic or neutral buffering capacity of lignocellulosic materials such as lignin and hemicellulose found in coconut fibre (Otedheke *et al*. 2024; Otitigbe, 2021).

The pH level of drilling mud indicates its acidity or alkalinity, with values below 7 considered being acidic and above 7 as alkaline. Acidic drilling fluids can pose environmental risks and contribute to corrosion of drilling equipment and piping (Amanullah and Yu, 2005). Therefore, maintaining an appropriate pH is essential to minimize corrosion and support the fluid’s rheological performance. Water-based drilling fluids typically function most effectively within a pH range of 8.0 to 10.5 (Peretomode, 2018).

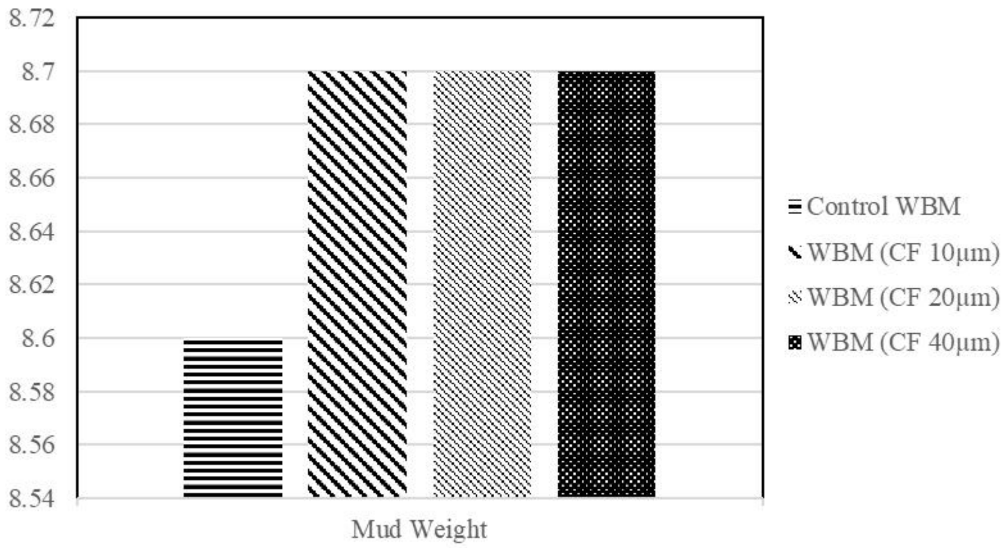

Figure 1: Variation of Drilling Mud pH with Coconut Fiber Particle Size

3.2 Effect of WBM formulated with coconut fiber on mud density

The mud weight across all formations is shown in Figure 2. As shown in the figure, the mud weight increased marginally from the control value of 8.6 ppg to 8.7 ppg following the addition of coconut fibre which is the same for Watermelon rind powder and from 8.6 to 7.8 for broad bean peel powder. This marginal increase suggests that the lightweight nature of the fibre has negligible impact on overall fluid density. These minimal effects are advantageous, as they require lower pump pressure to circulate the drilling mud throughout the system (Awl *et al*. 2023). Mud density, is a critical parameter in drilling fluid design, essential for achieving efficient and safe drilling operations (Bridges and Robinson, 2020). According to Madu *et al*. (2024) the mud weight should be slightly higher than the formation's pore pressure but remain below the fracture pressure to avoid damaging the formation. This ensures wellbore stability and promotes effective cuttings transport. An increase in mud weight raises the hydrostatic pressure, helping to equalize formation pressures and maintain well integrity. Additionally, it plays a key role in preventing kicks and blowouts, minimizes the intrusion of formation fluids such as gas, oil, or water, and reduces the likelihood of mud losses.

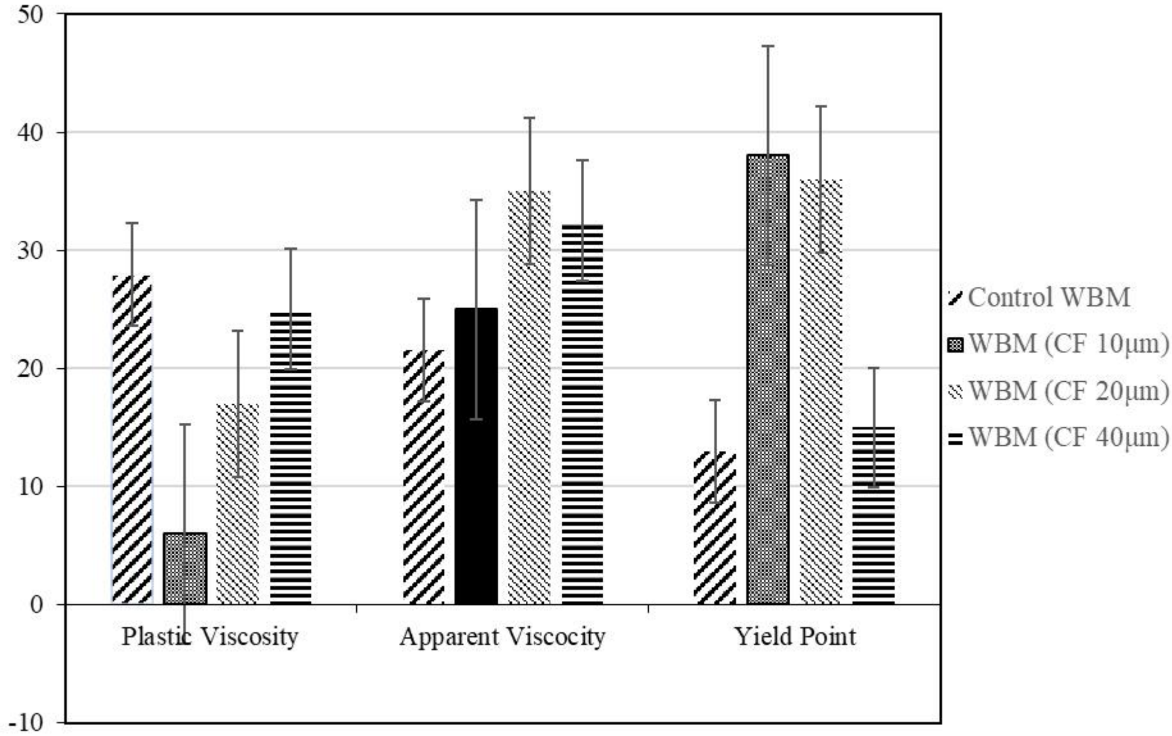

Figure 2 Effect of Drilling Mud Density with Coconut Fiber Particle Size

3.3 Effect of WBM formulated with coconut fiber on Rheological properties

Rheological properties are key indicators of a drilling fluid's behaviour under various flow conditions, directly influencing its ability to carry cuttings to the surface, maintain wellbore stability, and reduce drilling complications. These properties include plastic viscosity (PV), apparent viscosity (AV), yield point (YP), power law index (n), consistency index (K), and gel strength at different time intervals. The effect of coconut powder on the rheological properties of the reference water-based drilling mud is presented in Figure 3.

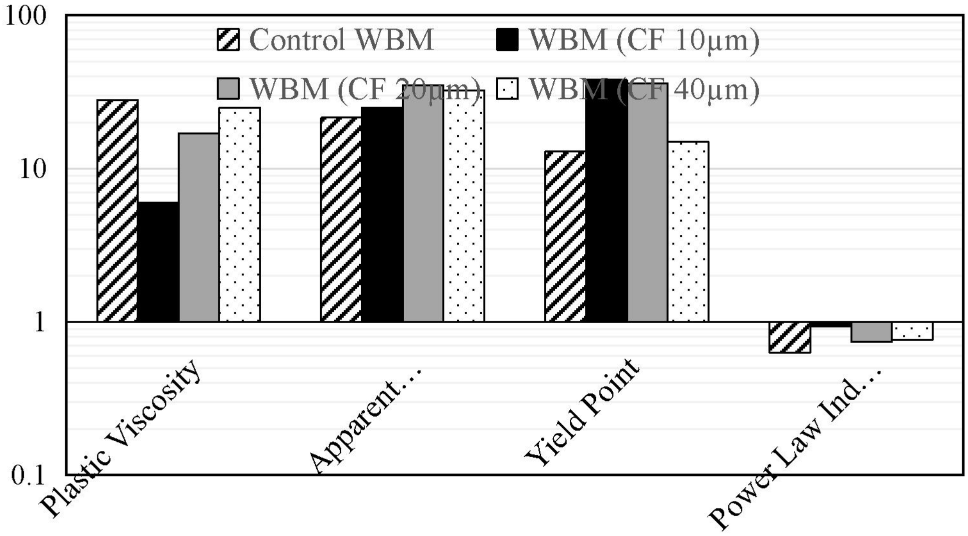

Figure 3: Comparison of Rheological properties of drilling mud with coconut fiber particle size

3.3.1 Effect of WBM formulated with coconut fiber on Plastic and Apparent Viscosity

High apparent viscosity can increase friction, hinder mud flow, enhances fluid circulation efficiency and reduce pump efficiency (Li, 2000). Therefore, it is essential to keep apparent viscosity within an optimal range. The introduction of coconut fibre led to a general reduction in plastic viscosity, most notably with the 10 µm fibre, where PV dropped reduced from 28 cp to 6 cp. For the 20 µm and 40 µm fibres also showed reductions to 17 cp and 25 cp, respectively as seen in Figure 3. These trends suggest improved laminar flow conditions due to reduced interparticle friction and flocculation. The finest fibre size (10 µm) demonstrated the most substantial improvement, likely due to better dispersion and the formation of a more stable suspension system. In contrast, broad bean peel powder exhibited no change in PV, remaining constant at 4 cp, while watermelon rind powder slightly increased PV from 4 cp to 5 cp. This suggests that, while these agricultural additives introduce some degree of structural interaction, their impact on internal resistance to flow is minimal compared to the finer grades of coconut fiber. (Awl *et al.* 2023).

Conversely, apparent viscosity (AV) increased with the addition of coconut fibre, rising from 21.5 cp (control) to 25 cp (10 µm), 35 cp (20 µm), and 32.5 cp (40 µm). This trend reflects an enhancement in low-shear viscosity and structural development within the fluid. These increases are characteristic of fluids with improved shear-thinning behavior and greater microstructural complexity, aiding in the suspension of cuttings and weighting materials under static or low-flow conditions (Madu et al., 2024). In contrast, broad bean peel powder increased AV slightly from 10 cp to 11 cp, indicating a mild enhancement in structural viscosity. Watermelon rind powder showed a decrease in AV from 10 cp to 8.5 cp, suggesting reduced structural formation or breakdown of existing fluid networks.

Effect of WBM formulated with coconut fiber on Yield Point (YP)

A higher yield point of drilling mud is needed for carrying the cuttings from the wellbore to the surface (Mohammadsalehi and Malekzadeh, 2011). The yield point, a measure of the mud's capacity to initiate flow and suspend solids, was significantly influenced by coconut fibre incorporation. The 10 µm and 20 µm fibres led to increases—from 13 lb/100ft² in the control to 38 lb/100ft² and 36 lb/100ft². In contrast, the 40 µm fibre produced only a marginal increase to 15 lb/100ft² respectively, this is indicative of the additive structure building capacity and this is seen in Broad bean peel powder which increased YP from 12 to 14 lb/100ft². Also, watermelon rind powder showed a decline in YP from 12 to 7 lb/100ft², indicating a weakening of interparticle interactions and reduced suspension efficiency. This could result in diminished hole-cleaning capabilities under low flow conditions. As fibre size increases, the capacity to enhance yield stress diminishes, which is could due to reduced surface area and weaker particle interaction.

3.3.2 Effect of WBM formulated with coconut fiber on Power Law Index (n) and Consistency Index (K)

All fibre-enhanced muds exhibited higher Power Law Index values compared to the control (n = 0.63), reflecting a shift toward more Newtonian behaviour. The increase was most pronounced with the 10 µm fibre (n = 0.93), followed by the 40 µm (n = 0.76), and 20 µm (n = 0.74). This trend suggests that finer fibres disperse more uniformly, minimizing shear-thinning characteristics. In parallel, the consistency index (K), representing low-shear viscosity, increased across all samples, most notably with the 20 µm fibre (K = 0.70), followed by 40 µm (0.67) and 10 µm (0.57). These results indicate that fibre incorporation enhances the structural integrity of the mud at low shear rates, albeit with varying degrees based on particle size.

3.3.3 Effect of WBM formulated with coconut fiber on Gel Strength (10-Second and 10-Minute)

Gel strength reflects the mud's capacity to suspend solids within the fluid (Novrianti *et al*. 2021). A decrease in gel strength indicates that less energy is required to restart fluid circulation after a stoppage. However, this also means the mud becomes less effective at holding cuttings in suspension when pumping ceases. Gel strength was observed to have substantial enhancements across all fibre sizes. The 10-second gel strength increase from 6 lb/100ft² in the control to 17 lb/100ft² (10 µm), 23 lb/100ft² (20 µm), and 21 lb/100ft² (40 µm) as compared to a slight increase from 9.3 to 10 lb/100ft² with Broad bean peel powder and Watermelon rind powder increase, implying limited structural development. Similarly, 10-minute gel strength increased from 1 lb/100ft² to 21 lb/100ft², 35 lb/100ft², and 29 lb/100ft², respectively. These improvements indicate stronger thixotropic recovery and structural development after static periods—key for preventing settling and maintaining wellbore stability during circulation pauses. The fibre network, especially when fine enough to interlace effectively, provides internal scaffolding that supports suspended materials.

3.4 Effect of WBM formulated with coconut fiber on Filtration Properties (Fluid Loss and Filter Cake Thickness)

Filtration properties of drilling mud are generally evaluated and controlled by API filter loss test (API SPEC 13A, 1993). This property helps in controlling fluid loss, well bore stability, prevention of formation damage, enhancing drilling operation efficiency and well control. According to Awl et al. (2023), filtration loss decreased from 20.4 ml to 14 ml after incorporating 1 wt% broad bean peel powder. This represents a 31% reduction, indicating moderate effectiveness. However, this performance is considerably less impressive than that of coconut fiber at 10 µm and 40 µm, which achieved a 50% reduction (from 10 ml to 5 ml) and also data from Madu et al. (2024) showed a reduction in filtration loss from 20.4 ml to 15 ml with the addition of 3 wt% watermelon rind powder.

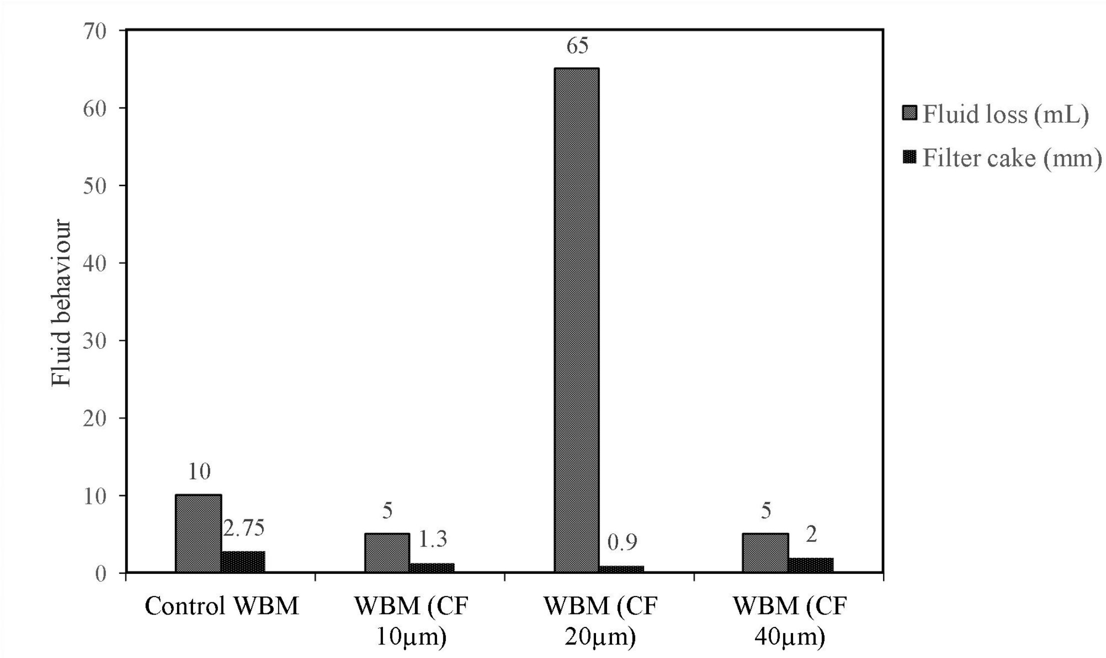

Figure 4: Filtration Behaviour of Water-Based Drilling Fluid with Varying Coconut Fiber Sizes

This reflects a 26.5% reduction, which is similar in trend to broad bean peel but still less effective than coconut fiber coconut fiber, which favors better filtration control through enhanced bridging, sealing, and matting behaviour.

In terms of filter cake thickness, all fibre sizes led to reductions when compared to the control (2.75 mm). The most notable decrease was observed in the 20 µm sample (0.9 mm), followed by 10 µm (1.3 mm), and 40 µm (2.0 mm). The powdered coconut fiber demonstrates the most effective reduction in filter cake thickness, particularly at 20 µm, where the thickness drops to just 0.9 mm, while broad bean peel powder moderately improves filter cake quality by reducing from 1.75 to 1.25 mm and watermelon rind powder minimal enhancement from 1.75 to 1.56 mm. This suggests that even though fluid loss may increase with certain fibre sizes, the resulting filter cakes may still be thin and operationally favourable if not entirely impermeable. In water-based drilling fluids, the thickness of the filter cake is a crucial factor in effectively sealing the wellbore. However, if the filter cake becomes too thick, it can lead to wellbore instability, which is considered unfavorable (Yousefirad *et al*. 2020).

4. Conclusion

This study demonstrates the potential of powdered coconut fibre derived from mature coconut husks as a natural additive in water-based mud (WBM) formulations. This study showed that use of coconut fibre, processed at various mesh sizes (10, 20, and 40µm), can be used as replacement to traditional synthetic additives such as barite, sodium hydroxide (NaOH), and carboxymethyl cellulose (CMC), offering significant improvements in mud performance. The results showed that coconut fibre enhances gel strength, suspension capabilities, and filtration control, with the best performance observed in the formulations with mesh sizes 10 and 20µm. These formulations exhibited notable increases in yield point, apparent viscosity, and fluid loss control while maintaining a low filter cake thickness. Compared to conventional WBM, coconut fibre-based muds contributed to enhanced drilling efficiency, reduced formation damage, and improved wellbore stability. The findings highlight the sustainability and effectiveness of coconut fibre as a natural alternative in drilling mud, offering a promising solution for more eco-friendly and efficient drilling practices. Thus, powdered coconut fibre is highly recommended for incorporation into WBM formulations to improve overall mud performance and support sustainability goals in the drilling industry. Future studies should further investigate its long-term performance and cost-effectiveness in various drilling environments.

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