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Exploring the Performance of Dry Bamboo Leaves Powder from *Bambusa Heterostachya* as Additive in Water-Based Mud

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***Abstract:** In the evolving landscape of petroleum drilling, the quest for eco-friendly alternatives to traditional mud additives is paramount. This study explored the performance of Dry Bamboo Leaves Powder (DBLP) from Bambusa heterostachya as an additive in water-based mud. Dry Bamboo Leaves were obtained, crushed, and then sieved to 106-micron size. Mud properties, including mud weight, plastic viscosity, yield point, gel strength, mud cake thickness and filtrate volume were examined under fresh conditions by integrating different concentrations of DBLP (3.5 g, 7.0 g, 10.5 g, and 14 g). The laboratory experiments adhered to the standards set by the American Petroleum Institute (API). The introduction of DBLP concentrations resulted in a reduction in the alkalinity and mud weight of the drilling mud. Additionally, the drilling mud's yield point and plastic viscosity were altered at different DBLP concentrations. The inclusion of DBLP enhanced the gel strength and decreased filtrate volume while maintaining the same mud cake thickness.*

***Keywords**: Dry Bamboo Leaves Powder, Filtration, Mud Density, Rheology.*

I. INTRODUCTION

The drilling process involves creating a hole to extract newly discovered hydrocarbons. Drilling activities rely on drilling fluids, which serve various purposes such as cleaning the wellbore, regulating high-pressure zones, lubricating the drill string, and maintaining wellbore pressure, among other functions [1, 2]. Drilling fluids also known as drilling mud are commonly categorized as synthetic, oil-based, or water-based [3, 4]. The selection of the fluid type depends on the estimated conditions of the well or the specific interval being drilled. Drilling fluids possess essential properties that require control to ensure effectiveness and efficiency. These properties include viscosity, loss circulation, rheology, density, flocculation, alkalinity or pH, and filtration control [5]. Traditionally, chemicals and non-biodegradable materials (additives) have been used in drilling fluid formulation to achieve the desired properties. These additives include potassium chloride, sodium hydroxide, fluid loss agents, shale inhibitors, polyamine, potassium sulfate, and others [6-9]. Many of these traditional additives used in water-based mud (WBM) formulations have raised significant environmental and health concerns. For instance, when drilling fluids containing these additives are discharged into the environment through drilling operations or improper disposal, they may contaminate soil, water bodies, and groundwater aquifers.

In recent years, environmental concerns have arisen regarding the use of traditional chemical additives in designing drilling fluids. Consequently, the petroleum industry has shifted its focus toward finding drilling fluid additives that are safe and environmentally friendly. Recent research has emphasized the use of natural and eco-friendly additives as alternatives to traditional drilling additives in drilling fluid formulations [10]. Al-Hameedi et al. [7] investigated the effects of potato peel powder (PPP) in water-based mud (WBM), and their findings indicated that PPP reduced fluid loss, decreased the yield point, and increased plastic viscosity. Once again, Al-Hameedi et al. [11] examined the impact of using mandarin peel powder (MPP), a food waste product, as an environmentally friendly drilling fluid additive. They compared the results of MPP with low-viscosity polyanionic cellulose (PAC-LV), a chemical additive commonly used in drilling fluid formulation. Their research revealed reduced alkalinity and filtration, along with modified plastic viscosity, yield point, and gel strength. Similarly, Medved et al. [3] conducted a study by reducing the particle size of mandarin peel powder to 0.1 mm and within the range of 0.1 mm to 0.16 mm. Their results showed a decrease in API filtration and Permeability Plugging Tester (PPT) filtration while the rheological properties of the fluid improved.

In 2020, Al-Hameedi et al. [12] investigated the use of black sunflower seed shell powder (BSSSF) as an eco-friendly additive. Their findings demonstrated that BSSSF, at various grain sizes, could be utilized to adjust viscosity, control seepage loss, and address partial loss issues. Omotioma et al. [13] investigated the potential use of cashew and mango leaf extracts to enhance the rheological properties of drilling fluid. The findings showed improved rheological properties upon the introduction of cashew and mango leaves. Ismail et al. [14] assessed the impact of henna and hibiscus leaf extracts on the rheological and filtration properties of water-based mud (WBM).

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Results from the rheology and filtration tests demonstrated enhanced rheological and filtration characteristics of the water-based drilling fluid compared to traditional additives commonly used in the petroleum industry.

Numerous biodegradable materials have been investigated as additives for formulating drilling fluids [15-17]. However, there is still a need to assess additional non-toxic and biodegradable waste materials for their potential as drilling fluid additives. Dry Bamboo Leaves (DBL) represent one such non-toxic and biodegradable waste material. In this research, DBL were processed into powder and its impact on the density, pH, rheological, and filtration properties of water-based mud (WBM) was examined under fresh conditions. This initial investigation will offer valuable insights for future studies exploring Dry Bamboo Leaves Powder (DBLP) as a biodegradable additive in designing water-based mud.

II. LITERATURE REVIEW

Bamboo is a tall, tree-like grass belonging to the genus Bambusa that grows quickly in tropical or semitropical climates. It has hollow, woody stems with ringed joints and edible young shoots. Bamboo is a perennial plant that has wide ecological and economic value. The bamboo plant is made up of the node, internode, leaves, culm, sheath, rhizomes, and roots (Fig. 1). Bamboo is often called the 'poor man's timber,' and it is the cheapest and oldest building material used by humans [18].

Fig. 1 Parts of Bamboo Plant [18]

Bamboo plants (species) can be grouped into sympodial (clumping) and monopodial (running) based on the development of their rhizome system and culm habit. However, there are cases in which species show a blend of the two kinds. Examples of sympodial bamboo are Bambusa vulgaris, Bambusa heterostachya and Bambusa vulgaris vitata. Bambusa vulgaris is a common green bamboo plant in Ghana. The monopodial bamboo types are the Guadua chacoensis, Phyllostachys and Pleioblastus species. Bamboo stands are mainly found in the southern part of Ghana with few species distributed in the northern part of Ghana. Bamboo is a versatile plant that has notable economic and cultural significance in the world. Throughout history, bamboo leaves have been utilized as a wrapping material to preserve food from spoilage. Additionally, bamboo leaves are abundant in protein and soluble fibre, which contribute to digestive health and gut functions. In traditional medicine, these leaves have been used to address various conditions such as hypertension, cardiovascular disease, and other illnesses [18-22] [38, 39, 40].

III. MATERIALS AND METHODS

The primary materials used for the experiment include dry bamboo leaves powder (DBLP), bentonite, and distilled water. The DBLP, sourced from bamboo leaves, served as the main eco-friendly additive. Various equipment was utilized for these assessments, including a ball mill (Fig. 2), electronic balance (Fig. 3), mud mixer (Fig. 4), viscometer (Fig. 5), API filter press (Fig. 6), pH meter (Fig. 7) and mud balance (Fig. 8).

Fig. 2 Ball Mill

Fig. 3 Electronic Balance

Fig. 4 Mud Mixer

Fig. 5 Viscometer

Fig. 6 Filter Press

Fig. 7 pH Meter

Fig. 8 Mud Balance

A. Preparation of the Dry Bamboo Leaves Powder

Dry bamboo leaves (DBLs) from *Bambusa heterostachya* were gathered from a swampy area at the University of Mines and Technology, Tarkwa, Ghana. These collected leaves underwent cleaning to eliminate any dirt or impurities.

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The DBL (Fig. 9a) were placed in an oven at 176 °F – 185 °F (80 °C - 85 °C) for 30 minutes to ensure complete drying. Once dried, the DBL were crushed using a ball mill (Fig. 2) for 2 hours 30 minutes. To achieve a finer texture, the crushed bamboo leaves were sieved through a fine screen, resulting in a particle size of 106 microns, as depicted in Fig. 9b.

(a) (b)

Fig. 9 Dry Bamboo Leaves and Powder

B. Formulation of the Mud Samples

Five distinct mud samples were formulated, with all materials for the drilling fluid measured using an electronic balance (Fig. 3). Each drilling fluid sample consisted of 350 ml of fresh water and 22.5 grams of bentonite, with varying concentrations of DBLP at 3.5 g, 7.0 g, 10.5 g, and 14.0 g (Table 1). The reference fluid (RF) was prepared without DBLP. A uniform mixture of each mud sample was achieved using a mud mixer (Fig. 4). The mud samples were unaged so the pH, density, rheological and filtration properties were determined immediately after preparation at room temperature.

Table 1 Composition of the Mud Samples

Mud Sample	Composition
RF	350ml of water + 22.5g of bentonite
A	350ml of water + 22.5g of bentonite + 3.5g of DBLP
B	350ml of water + 22.5g of bentonite + 7.0g of DBLP
C	350ml of water + 22.5g of bentonite + 10.5g of DBLP
D	350ml of water + 22.5g of bentonite + 14.0g of DBLP

C. Mud Properties Determination

A rheology test was performed to analyze the flow characteristics of the formulated mud sample using a viscometer (Fig. 5). Gel strength was also measured directly with the viscometer. The dial readings from the viscometer were used to calculate the plastic viscosity (PV) and yield point (YP) of the drilling fluid using Equations 1 and 2 [23-26].

$$PV, cP = \theta_{600} - \theta_{300} \quad \text{--------} \quad (1)$$

$$YP, lb/100\ ft^2 = \theta_{300} - PV \quad \text{--------} \quad (2)$$

where, θ_{300} and θ_{600} are the dial readings at 300 and 600 rpm, respectively.

The filtration test was conducted at room temperature using an API filter press under a pressure of 100 psi (Fig. 6). The volume of filtrate and the thickness of the mud cake formed within 30 minutes were measured using a graduated cylinder and vernier caliper, respectively. Additionally, the pH of each sample was determined using a pH meter (Fig. 7). The density of the mud samples was determined using the mud balance shown in Fig. 8.

IV. RESULTS

The results obtained from the pH, mud density, rheology and filtration tests are presented in this section for subsequent discussion.

A. pH and Mud Density Results

The results for the pH and mud density of each of the mud samples are presented in Table 3.

Table 3: Results for pH and Density of Mud Samples

Mud Sample	RF	A	B	C	D
pH	10.21	9.51	9.43	9.32	8.81
Density (Ib/gal)	8.5	8.4	8.3	8.3	7.6

B. Rheology Results

The results obtained from the rheological tests performed on the various samples are indicated in Table 4.

Table 4: Rheological Characteristics of Water-Based Mud with Varying Concentrations of DBLP

Mud Sample	Dial Readings						Gel Strength ($Ib/100ft^2$)	
	θ_{600}	θ_{300}	θ_{200}	θ_{100}	θ_6	θ_3	*Initial 10 sec.*	*Final 10 min.*
(RF)	19	15	12	10	6	6	9	25
A	20	15	13	10	8	7	10	21
B	20	14	13	10	8	9	10	19
C	19	12	10	7	5	5	9	15
D	22	12	11	9	7	7	10	15

C. Filtration Results

Tables 5 and 6 present the results of the filtrate volume and mud cake thickness, respectively, from the filtration tests conducted on all five samples.

Table 5 Results of Filtrate Volume

Time (mins)	Filtrate Volume (ml)				
	RF	A	B	C	D
1	1.0	1.2	1.0	2.0	1.4
2	2.7	2.6	2.6	3.8	2.8
3	4.1	3.8	3.8	5.2	4.0
5	6.3	6.0	5.6	7.4	6.2
7	7.7	7.6	7.2	9.2	7.8
9	9.1	9.0	8.6	10.6	9.2
10	9.7	9.6	9.2	11.0	9.8
11	10.5	10.2	9.8	11.2	10.2
13	11.6	11.2	11.0	11.8	11.6
15	12.7	12.0	12.0	12.2	12.4
17	13.8	13.4	13.0	13.0	13.4
19	13.4	14.2	13.8	14.0	14.4
20	14.9	14.8	14.2	14.4	14.8
21	15.6	15.2	14.8	14.8	15.0
23	16.4	16.0	15.6	15.6	15.8
25	17.2	16.8	16.2	16.4	16.4
27	18.0	17.6	17.0	17.2	17.0
29	18.7	18.4	17.6	17.8	17.4
30	19.1	18.8	18.0	17.8	17.6

Table 6: Mud Cake Thickness

DBLP Concentration	Filter Cake Thickness (mm)
RF	3
3.5 g	3
7.0 g	3
10.5 g	3
14.0 g	3

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V. DISCUSSION

A. Effect of Dry Bambo Leaves (DBLP) on Mud Density

Mud density is crucial for pressure control during oil well drilling operations. It must be accurately selected to maintain formation pressure and prevent blowouts. Low mud density can lead to wellbore breakout, while excessive density can fracture the formation, causing partial circulation loss and reduced rate of penetration (RoP) [27, 28]. Fig. 10 illustrates the effect of DBLP on the density of water-based mud. As shown, mud density decreased with higher DBLP concentrations compared to the reference fluid (RF) without DBLP. This reduction in density was due to foam formation in the fluid, a phenomenon also observed by Al-Hameedi et al. [12]. Foams in the drilling fluid lower the density because of entrapped bubbles. This issue can be mitigated by adding defoamers (anti-foaming agents) during the formulation of the drilling fluid.

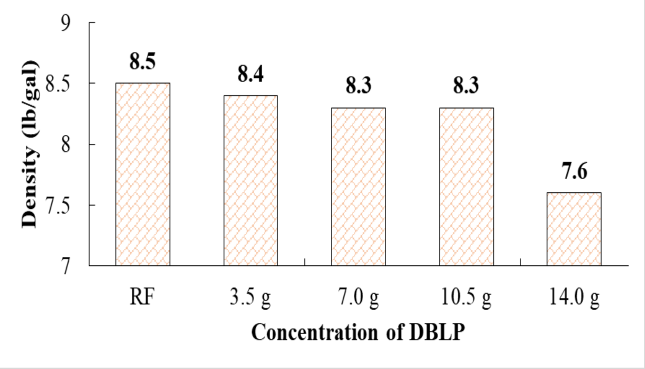

Fig. 10 Effect of DBLP on Mud Density

B. Effect of DBLP on pH

Fig. 11 demonstrates the influence of DBLP on the pH of water-based mud. The experiment revealed that the pH of the drilling mud decreased with increasing concentrations of DBLP. Specifically, the DBLP additive reduced the pH by 6.9%, 7.6%, 8.7%, and 13.7% at 3.5 g, 7.0 g, 10.5 g, and 14.0 g, respectively, compared to the RF. This decrease in pH indicates that DBLP can reduce the alkalinity of the drilling fluid, making it an effective pH-reducing agent in water-based mud, particularly at higher concentrations. DBLP can be particularly useful as a pH-reducing agent when penetrating cement [29]. This trend aligns with studies by Al-Hameedi et al. [29, 30] who used biodegradable waste materials such as palm tree leaves and grass.

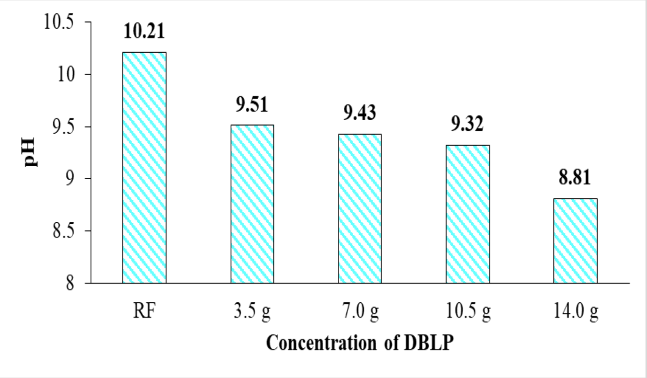

Fig. 11 Effect of DBLP Concentrations on pH

C. Effects of DBLP on Yield Point and Plastic Viscosity

Fig. 12 illustrates the effects of DBLP on the yield point and plastic viscosity of water-based mud. The yield point indicates the electrochemical or attractive forces within the mud under flow dynamics conditions [26]. It measures the mud's ability to carry drill cuttings in suspension while circulating in and out of the wellbore annulus, which helps prevent differential pressure sticking [31]. As shown in Fig. 12, the yield point decreased with increasing concentrations of DBLP compared to the RF.

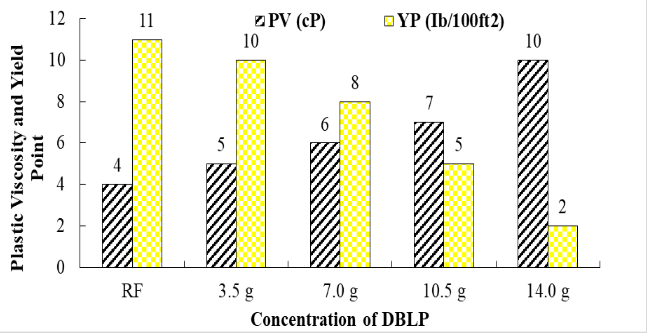

Fig. 12 Effect of DBLP Concentrations on Yield Point and Plastic Viscosity

Plastic Viscosity (PV) represents the resistance of drilling fluid to flow due to mechanical friction [26]. It is influenced by the viscosity of the liquid phase and the solids content in the mud [32]. As shown in Fig. 12, the plastic viscosity of the mud increased with higher concentrations of DBLP. Specifically, the DBLP additive raised the PV of the drilling fluid by 25%, 50%, 75%, and 150% at 3.5 g, 7.0 g, 10.5 g, and 14.0 g, respectively, compared to the RF. Many soluble polymers used for fluid-loss control significantly increase plastic viscosity [32]. Hence, the higher values of PV are a result of the DBLP additive exhibiting fluid loss control characteristics (see Fig. 14).

D. Effect of DBLP on Gel Strengths

Gel strength serves as an indicator of a mud's thixotropic characteristics and its attractive forces when stationary. This property arises from the bonding of electrically charged particles, forming a rigid structure within the fluid [32].

The initial 10-second and 10-minute gel strengths provide insight into the extent of gelation upon cessation of circulation and the mud's static state. Higher gelation during shutdown periods necessitates increased pump pressure to recommence circulation [33]. As shown in Fig. 13, adding various concentrations of DBLP increased the initial (10-second) gel strengths by 11.1% compared to the RF, except at 10.5 g, which recorded the same value as the RF. For the final (10-minute) gel strength results, values decreased with increased DBLP concentration compared to the RF. However, at concentrations of 10.5 g and 14.0 g, the final gel strength values remained the same. The addition of DBLP improved gel strength performance since the difference between the initial and final gel strengths at all concentrations, except 3.50 g, was below 10 lb/100ft².

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This indicates that drilling fluid with DBLP concentrations of 7.0 g, 10.5 g, and 14.0 g will not require extra pressure to break the gel strength from pump-off to pump-on conditions. Consequently, induced fractures in weak formations would be avoided, and pump efficiency would be maintained [11].

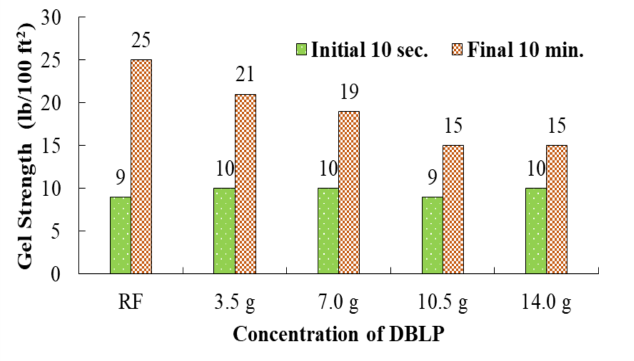

Fig. 13 Effect of DBLP on Gel Strength

E. Effect of DBLP on Filtration Characteristics

Filtration involves the segregation of fluid, typically water and soluble chemicals, from a drilling mud into a permeable formation under the effect of varying pressure. As fluid is depleted, mud solids accumulate on the wellbore's surface, forming what is known as the filter cake. The rate of filtration and the volume of filtrate are closely linked. Excessive filtration and a thick filter cake accumulation can lead to heightened resistance in a narrow wellbore, increasing the risk of differential sticking caused by greater pipe contact with the filter cake. Additionally, this buildup may result in excessive formation damage and pose challenges in evaluating wireline logs [34-37]. Fig. 14 shows the filtrate volume and mud cake results obtained from a static filtration test.

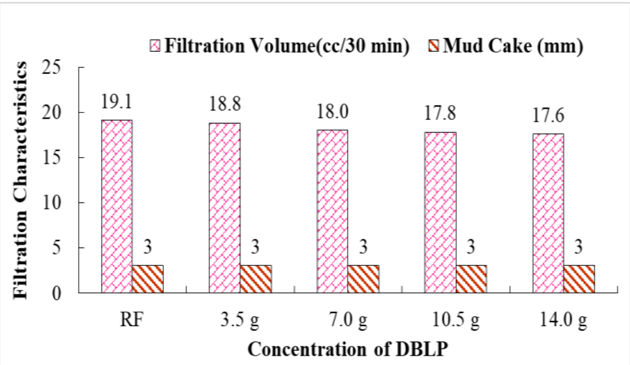

Fig. 14 Effect of DBLP on Filtration Characteristics

From Fig. 14, it is evident that filtrate volume decreased with the addition of DBLP compared to the RF. This indicates that higher DBLP concentrations led to lower fluid loss. Specifically, at concentrations of 3.5 g, 7.0 g, 10.5 g, and 14.0 g, the filtrate volume reduced by 1.6%, 5.8%, 6.8%, and 7.9%, respectively. Regarding mud cake characteristics, Annis and Smith [32] stated that a thin mud cake is always desirable because low fluid loss and thin cake thickness result in low cake permeability. From Fig. 14, the addition of various concentrations of DBLP did not affect the thickness of the cake compared to the RF. A mud cake thickness of 3 mm was recorded for all the samples. The observations regarding filtration characteristics suggest that DBLP can serve as a fluid loss control additive.

VI. CONCLUSION

This study aimed to explore the impact of Dry Bamboo Leaves Powder (DBLP) on the density, pH, rheological, and filtration properties of water-based mud. A reference fluid (RF) was formulated and compared to four fluid samples containing different DBLP concentrations: 3.5 g, 7.0 g, 10.5 g, and 14 g. All experiments adhered to the American Petroleum Institute's specifications. The mud density decreased slightly with increasing concentrations of DBLP compared to the RF, except at a DBLP concentration of 14.0 g, which resulted in a 10.6% reduction in RF density. This decrease in the drilling fluid's density was due to foam formation in the fluid. The pH of the drilling fluid decreased as the concentration of DBLP increased, indicating a reduction of the mud's alkalinity. Therefore, DBLP can be used as an effective pH reducer.

The addition of DBLP concentrations increased the plastic viscosity and decreased the yield point of the drilling fluid compared to the RF without DBLP. Adding various concentrations of DBLP increased the initial (10-second) gel strengths except at 10.5 g and decreased the final (10-minute) gel strengths. This enhanced the gel strength performance, as the difference between the initial and final gel strengths at all concentrations was below 10 lb/100ft², except for the 3.50 g concentration. Incorporating DBLP led to a decrease in the filtrate volume of the drilling fluid when compared to the reference fluid (RF). Nevertheless, the thickness of the filter cake remained consistent across all concentrations compared to the RF. These results indicate that DBLP exhibits favorable filtration properties, suggesting its potential use as an additive for controlling fluid loss.

DECLARATION STATEMENT

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Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material	Not relevant.
Authors Contributions	The individual contributions of each author are presented below for clarity and transparency. E.B.B., original concept and initial draft of the paper, D.O. supervised and coordinated the work, R.T.O., conducted the experiment, E.B.B. O.D. and R.T.O., processing and data analysis. All the authors have read and agreed to the final version of the manuscript for publication.

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