

Experimental Investigation of the Rheology and pH of Drilling Mud Using Sugarcane Bagasse

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ABSTRACT

Drilling is the most important part of petroleum production. In Bangladesh, water-based mud is mostly used instead of oil-based mud in drilling operations, which has both environmental and economic benefits. Different additives are added to drilling mud to improve its properties. The waste generated during drilling operations is considerable and negatively affects the surrounding environment. The utilization of these additives substantially elevates the costs associated with the drilling process. This investigation aims to design a cost-efficient and environmentally friendly drilling mud. Specifically, it seeks to analyze of the rheology and pH of water base mud with two size particle one is less than 125 μm another is higher than 400 μm utilizing it with 1, 2, 3, 4, 5% (w/v) of sugarcane bagasse (SCB) enhances rheology at a 4% w/v concentration by forming hydrogen bonds between cellulose, hemicellulose, and lignin, creating a strong three-dimensional network. This network acts as a glue, while the optimal pH ensures fine particle dispersion in SCB.

Keywords: Cellulose, Drilling Mud, Hemicellulose, Lignin, Rheology, Sugarcane Bagasse



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1. INTRODUCTION

Drilling is a vital part of petroleum production, with the drilling rig, fluids, circulation system, and power source being key components. The cost of drilling is influenced by equipment, fluid, and maintenance expenses. Drilling fluids, commonly called "mud," are crucial for well control, and additives are needed to maintain fluid quality. Drilling fluids for a single well can cost around one million dollars, mainly due to additives. If the drilling fluid does not operate as intended, it may necessary to abandon the well [1]. This study aims to evaluate biodegradable fluid additives like sugarcane bagasse to reduce both costs and environmental impact. Sugarcane bagasse enhances water-based mud's rheology, improving properties such as viscosity, shear strength, and gel strength. Natural fiber, such as sugarcane bagasse, can be used as a rheology modifier in the petroleum industry to modify fluid flow behavior [2]. Drilling fluid is one of the most essential components of a rotary drilling system. Problems often trace back, directly or indirectly, to the drilling fluids. The qualities of the drilling mud determine both the effectiveness and the expense of the operation. While the cost of drilling fluid is not large, improper selection can increase it. Factors like penetration rate and lost circulation play a role in choosing the best fluid. Additives are used to improve efficiency, but their toxicity raises environmental concerns, impacting both surface and underground ecosystems [3].

2. BACKGROUND

Natural materials have increasingly been used as additives in drilling fluid (DF) compositions since the mid-twentieth century to address environmental concerns. Nestle's use of tree bark for filtration control in 1952 was an early example. Various researchers, such as Morris (1962), Lummus and Ryals (1971), Burts (1997), Amanullah and Long (2005),

Sampey (2006), Ekeigwe et al. (2013), Dagde and Nmegbu (2014), Amanullah et al. (2016), and Hossain and Wajheeuddin (2016), have explored natural additives [4]. Materials like tamarind gum and tragacanth gum have shown effectiveness in modifying viscosity with minimal formation damage, while henna extract has been tested as a substitute for potassium chloride in improving clay stability [5]. Palm oil, groundnut oil, and other natural substances like date seeds, powdered grass, and sugarcane have also been studied for adjusting rheological properties and reducing formation damage [6]. Despite progress in developing natural additives, research on eco-friendly drilling fluids that function as both lubricants and pH control agents is limited. Lubrication, essential in horizontal and deep-well drilling, typically relies on harmful substances like graphite and mineral oils. Since 1990, EPA regulations have required biodegradable lubricants for offshore drilling, such as palm oil, soy oil, and linseed oil [5], [7], [8]. However, these alternatives are costly, driving ongoing research for more sustainable solutions [9].

2.1 Types of Drilling Fluid

Drilling fluids are categorized based on their base fluid:

- Water-based mud (WBM)
- Oil-based mud (OBM)
- Pneumatic (gas) fluids (PF) [10]

2.2 Function of Drilling Fluid

- Remove cuttings from the hole's bottom.
- Maintain wellbore stability and control formation pressure.
- Support and lubricate drilling.
- Cool the drill bit.
- Minimize impact on reservoirs.

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- Mitigate corrosion.
- Assist in completion and cementing.
- Transmit hydraulic energy to the drill bit. [11]

2.3 Drilling Mud Properties

Density: Maintains hydrostatic pressure, calculated as $P_h = \gamma_m D$ (1)
It ensures stable drilling conditions.

Viscosity: Indicates resistance to flow, measured by Marsh funnel or rotating viscometer. It is influenced by solid particle characteristics.

Gel Strength: Reflects the mud's ability to suspend particles post-circulation. It indicates thixotropic behavior in the drilling fluid.

Yield Point: Represents the initial resistance to flow, found using $\tau_p = \theta_{300} - \mu_p$ (2)
A unit of yield point is $lb/100ft^2$. It measures the binding force of particles.

Filtration: Assesses fluid loss to formation via filter cake formation. It impacts the mud's efficiency and stability.

Alkalinity: Determined by the volume of standard acid to the endpoint of the pH indicator. It indicates the presence of various ions.

Sand Content: Analyzed for particles larger than 200 μm . Excess sand can affect drilling performance and fluid properties.

Solid Content: Refers to the amount of soluble or insoluble particles in the mud. High solid levels can hinder performance and stability

3. DESIGN OF EXPERIMENT



Fig. 1 Work Flowsheet

Nine experiments were conducted using an orthogonal array with two distinct parameters: five levels for sugarcane bagasse concentration (0.01 to 0.05 g/mL of water) and two levels for particulate size. The fine particles had sizes less than 125 μm , while coarse particles were greater than 400 μm .

3.1 Preparation of Fiber from Sugarcane Bagasse

Bagasse is the fibrous residue left after sugarcane is crushed for juice extraction, with about 40-45% discarded after sugar extraction. It consists mainly of parenchyma and sclerenchyma fibers. Sugarcane bagasse was collected from a juice shop, cleaned, cut, sun-dried for 5 days, ground, and sieved for particles less than 125 μm (fine) or more than 400 μm (coarse) [12].

3.2 Mud Preparation

Mud formulation was carried out, achieving the standard mud weight. The base mud consisted of fresh water, Bentonite, Barite, xanthan gum, NaOH, CaCO₃, and Starch in fixed proportions [2].

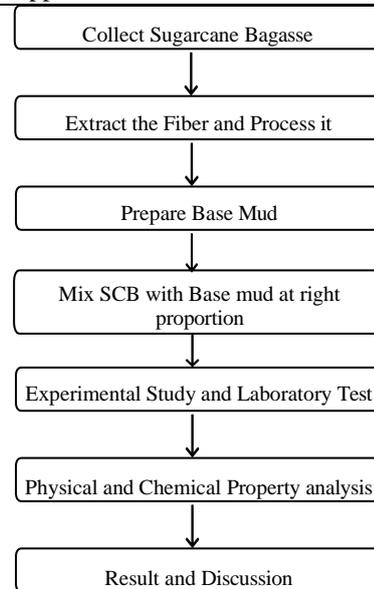


Fig. 2 Sugarcane Fiber Extraction process

Table 1 Base mud Composition [13]

Ingredients	Quantity (g)
Fresh Water	350 ml
Bentonite	23
Starch	6
NaOH	1
Barite	27
Xanthan Gum	0.7
CaCO ₃	5

3.2.1 Mixing Process

Table 2 Mixing Procedure of Base Mud [13]

Ingredients	Time (Min)	Mixing Speed
Water	-	-
NaOH	1	Low
Starch	2	Low
Bentonite	3	Medium
Xanthan Gum	8	Medium
CaCO ₃	9	Medium
Barite	12	High

3.2.2 Drilling Mud Composition with Addition of SCB

Table 3 Base Mud with SCB<125 μm

Ingredients	Base Mud (Sample-1) (g)	Base Mud+0.01 g/mL SCB (Sample-2) (g)	Base Mud+0.02g/mL SCB (Sample-3) (g)	Base Mud+0.03g/mL SCB (Sample-4) (g)
Fresh Water	350 ml	350 ml	350 ml	350 ml
Bentonite	23	23	23	23
Starch	6	6	6	6
NaOH	1	1	1	1
Barite	27	27	27	27
Xanthan Gum	0.7	0.7	0.7	0.7
CaCO ₃	5	5	5	5
Sugarcane Bagasse	-	3.5	7	10.5

Table 4 Base Mud with SCB>400 μm

Ingredients	Base Mud (Sample- 1) (g)	Base Mud+0.0 1 g/mL SCB (Sample- 5) (g)	Base Mud+0.0 2g/mL SCB (Sample- 6) (g)	Base Mud+0.0 3g/mL SCB (Sample- 7) (g)	Base Mud+0.0 4g/mL SCB (Sample- 8) (g)	Base Mud+0.05 g/mL SCB (Sample- 9) (g)
Fresh Water	350 ml	350 ml	350 ml	350 ml	350 ml	350 ml
Bentonite	23	23	23	23	23	23
Starch	6	6	6	6	6	6
NaOH	1	1	1	1	1	1
Barite	27	27	27	27	27	27
Xanthan Gum	0.7	0.7	0.7	0.7	0.7	0.7
CaCO ₃	5	5	5	5	5	5
Sugarcane Bagasse > 400 Micron	-	3.5	7	10.5	14	17.5

3.3 Rheological Property Tests

The apparent viscosity, plastic viscosity, and yield point are key rheological parameters in drilling fluids for oil or gas wells. Rheology is the study of the flow of matter, particularly fluids through conduits. The Bingham plastic and Power-law models describe drilling fluid rheology [6]. Plastic viscosity is determined using a rotational viscometer at 600 and 300 rpm:

$$\text{Plastic Viscosity, } \mu_P = \theta_{600} - \theta_{300} \tag{3}$$

Yield point (YP) is calculated as:

$$\text{Yield point, } \tau_P = \theta_{300} - \mu_P \tag{4}$$

Gel strength measures shear stress needed to initiate flow, crucial for maintaining circulation during drilling [6].

3.4 Testing Procedure

OFITE 800 viscometers test oils and drilling fluids by measuring shear rate and stress at atmospheric pressure across time and temperature. The test procedure includes filling the sample cup to the line, placing it onto the viscometer, stirring the fluid for 10 seconds, and adjusting speeds to 600 and 300 rpm. Gel strength is recorded after stopping the sleeve, and further measurements are taken after resting for 10 seconds and 10 minutes [14].

4. RESULTS AND DISCUSSION

The results of laboratory experiments, including rheology studies and pH testing of base mud, can be obtained by varying sugarcane bagasse (SCB) concentrations and fiber diameters. These experiments should be repeated as necessary, with results collected and recorded in tabular form for each variation.

4.1 Experimental Data Collection

Table 5 Experimental Data Tabulation

Sample	pH	Plastic Viscosity	Yield Point	Gel Strength (10 sec)	Gel Strength (10 min)
1	11.2	8	39	34	38
2	11.6	10.5	42.5	35	39
3	12	14	47	37	43
4	12.3	17	53	41	47
5	12	12	108	54	58
6	12.2	22	111	65	68
7	12.3	43	117	67	73
8	12.6	54	155	72	82
9	12.6	22	286	99	113

4.2 pH Result Analysis

The pH test results showed that the base mud had a pH of 11.2. By adding fine-sized SCB, the pH slightly increased, and for 3% SCB, the final pH reached 12.1. The standard pH range for drilling mud is 9-12. Adding 1%, 2%, and 3% of finer SCB fiber kept the pH within this standard range, giving the best results.

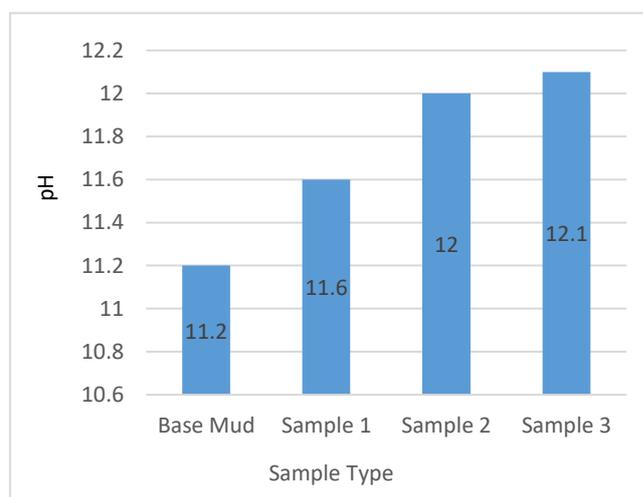


Fig. 3 pH Variation for less than 125 micron SCB

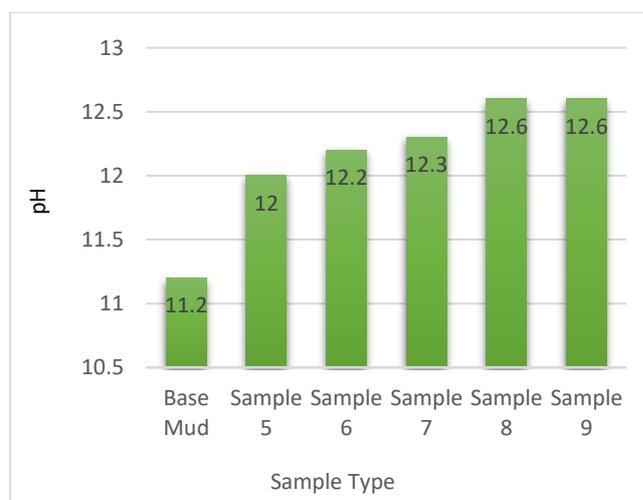


Fig. 4 pH Variation for Higher than 400 micron SCB

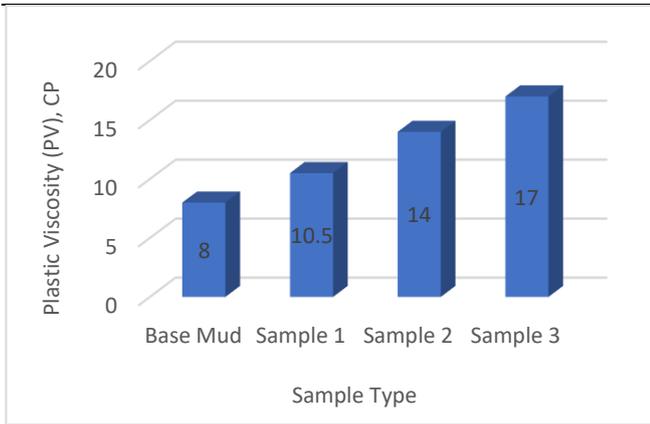


Fig. 5 Plastic Viscosity variation for fine fiber

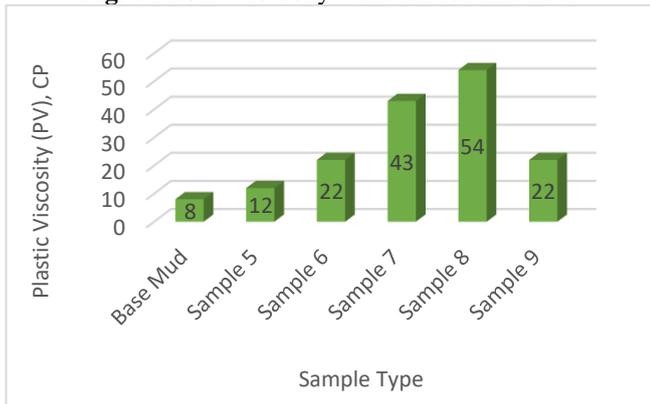


Fig. 6 Plastic Viscosity variation for coarser fiber

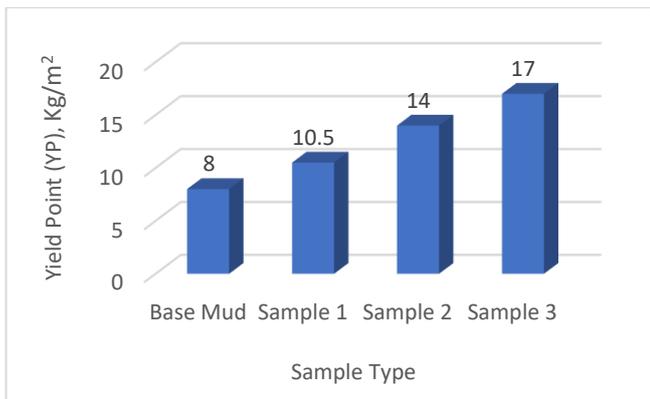


Fig. 7 Yield Point variation for fine fiber

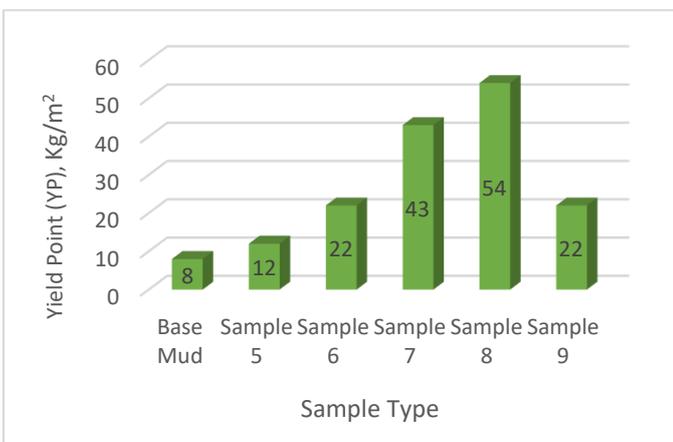


Fig. 8 Yield Point variation for coarser fiber

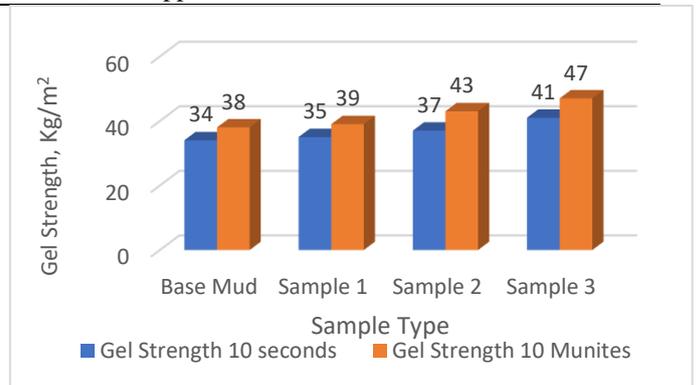


Fig. 9 Gel Strength variation in addition fine fiber

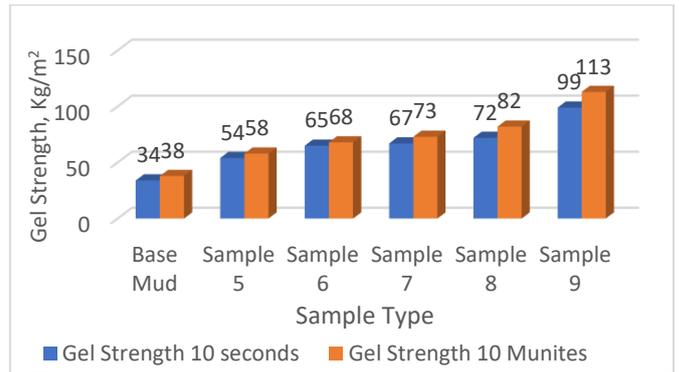


Fig. 10 Gel Strength variation in addition coarser fiber

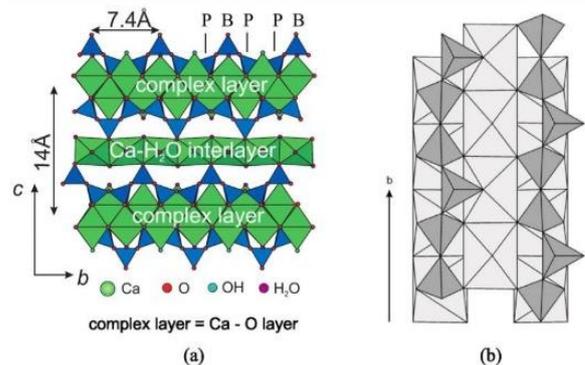


Fig. 11 Tobermorite Structure with two complex layers [16]

5. ANALYSIS

Water is a key component of drilling fluid, and natural water is often used in wells. As drilling solids mix with water, natural mud forms. Some clays hydrate quickly, raising mud viscosity and improving cutting-carrying capacity. Clays with low swelling tendencies are contaminants. Inert materials can be removed, and Bentonite, which absorbs water and increases viscosity, is added when necessary. To control pH and rheology, sugarcane bagasse (SCB) is added, ensuring smooth drilling operations [15].

5.1 Chemical Property Analysis

Sugarcane bagasse (SCB) contains SiO₂, CaO, K₂O, SO₃, Al₂O₃, Fe₂O₃, MgO, and MnO₂, while drilling mud includes minerals such as Barite, Kaolinite, and Quartz. When mixed with SCB, drilling mud's composition includes SiO₂, SO₃, Al₂O₃, Fe₂O₃, CaO, and SrO, affecting calcium silicate hydrate mineral formation and increasing density, viscosity, and gel strength. Gypsum, Pyrolusite, and hematite regulate

pH between 9 and 12, ensuring stable and efficient drilling operations by influencing rheology and viscosity [21].

5.2 Water Absorption Mechanism

Tobermorite forms when cementitious materials like SCB interact with water in drilling fluid, resulting in tobermorite-like compounds. It is a calcium silicate hydrate mineral with the formula $\text{Ca}_5\text{Si}_6\text{O}_{16}(\text{OH})_2 \cdot 4\text{H}_2\text{O}$ [15]. Calcium provides structural stability, while silicon forms a framework of interconnected SiO_4 tetrahedra. The hydroxyl groups (OH) contribute to the mineral's stability, and water molecules are incorporated as crystallization water, giving tobermorite its hydrated state. When SCB interacts with sodium montmorillonite, it enhances swelling and increases the viscosity, yield stress, and gel strength of mud [22].

5.2.1 Three-dimensional network Formation

Sugarcane stalks consist of the outer rind and inner pith, with bagasse composed of both fiber types. It contains 40-50% cellulose, 25-35% hemicellulose, and other components, with cellulose's crystallinity varying from 50-90% [14]. Cellulose has a linear polymer structure linked by β -1,4-glycosidic bonds, featuring hydroxyl groups that form strong hydrogen bonds, crucial for stability in the bagasse network [17]. These bonds enhance the gel-like structure and thixotropic behavior in drilling mud, especially with coarser particles, which improve interactions and yield strength [18].

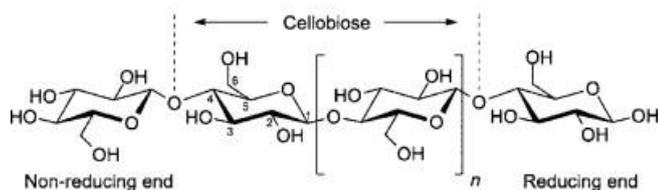


Fig. 12 Cellulose polymer chain structure [14]

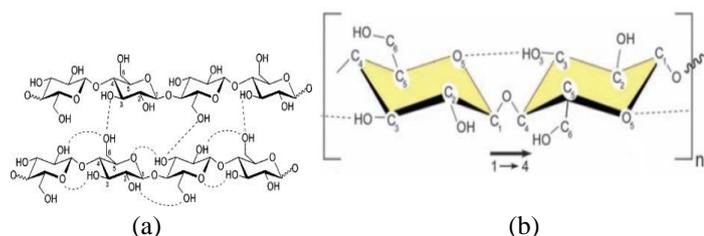


Fig. 13 (a) Intra- and intermolecular hydrogen bonds in cellulose (b) β 1,4-glycosidic Bond [14]

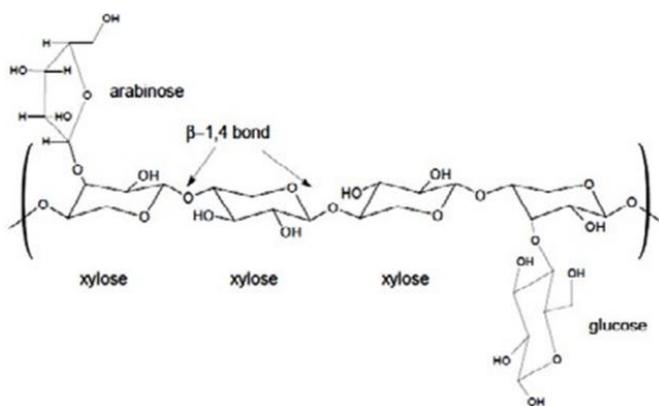


Fig.14 Simplified structure of bagasse main hemicellulose [19]

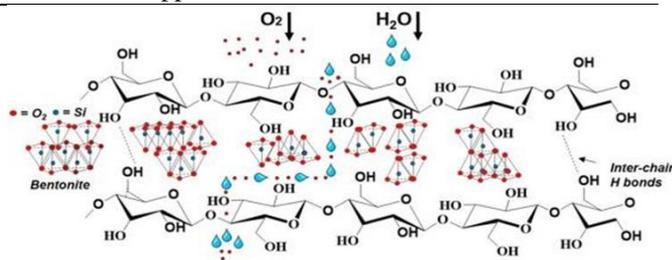


Fig.15 Insertion of bentonite particles within cellulose network [20]

The entangled fiber arrangement provides stability and enhances thixotropic behavior.

5.3 Biodegradability of SCB

Sugarcane bagasse (SCB) is highly biodegradable, making it an environmentally sustainable drilling mud additive. Biodegradability is the ability of materials to break down naturally through microorganisms. SCB contains complex organic compounds like cellulose, hemicellulose, and lignin, which enzymes (e.g., cellulase, hemicellulase, and ligninase) can degrade. This process converts SCB into smaller molecules, such as carbon dioxide and water, reducing waste accumulation and minimizing environmental impact. Using SCB promotes sustainability in drilling operations, as it is renewable and biodegradable [23].

6. CONCLUSION

In summary, this study investigated sugarcane bagasse as a rheology modifier in drilling mud for oil and gas operations. It aimed to understand the impact of sugarcane bagasse on viscosity, shear rate, and yield stress in drilling mud. The findings could provide insights into its effectiveness as a sustainable option, contributing to environmental sustainability, cost efficiency, and waste management in the industry. By incorporating sugarcane bagasse, the research supports the development of eco-friendly drilling practices, advancing sustainable methods in the drilling industry [24].

6.1 Key Findings

- Incorporating sugarcane bagasse as a rheology modifier in drilling mud significantly affects flow behavior and properties [20].
- Its addition alters rheological parameters and pH, including viscosity, shear rate, and yield stress.
- Sugarcane bagasse serves as a sustainable alternative, enhancing drilling performance while reducing reliance on synthetic additives.
- The study underscores sugarcane bagasse's role in promoting environmental sustainability, cost efficiency, and waste management in the oil and gas industry.

6.2 Limitation of the Study

Limited scope: The study focused on the rheological properties of drilling mud with sugarcane bagasse, neglecting aspects like filtration control, lubricity, and cuttings transport capacity.

Lack of comparative analysis: It did not extensively compare sugarcane bagasse with other rheology modifiers, missing a comprehensive assessment of its effectiveness.

Mechanical errors: Potential mechanical errors were acknowledged, indicating that experimental instruments might not have been perfectly calibrated, introducing uncertainties.

Temperature effects: The study recognized temperature's influence on results, but the extent was not thoroughly examined, affecting accuracy [2].

6.3 Recommendation for Further Study

- The experimental study shows that SCB improves rheology at 4% weight per volume, yielding better results for coarser particles, but it increases pH beyond the standard range, necessitating a pH reducer to mitigate corrosive effects.
- Investigating drilling mud performance with sugarcane bagasse under varying temperature, pressure, and salinity conditions would enhance understanding of its stability and effectiveness as a modifier.
- Comparative studies with traditional rheology and pH modifiers would assess bagasse's advantages and limitations for informed drilling mud formulation.
- Assessing mud stability over extended periods with sugarcane bagasse would provide insights into its long-term performance effects [6].

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8. NOMENCLATURE

WBM	Water Based Mud
OBM	Oil Based Mud
PF	Pneumatic Fluid
API	American Petroleum Institute
SCB	Sugarcane Bagasse
YP	Yield Point