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# Effect of Raw and Delignified Banana Stem (*Musa Cavendish*) on the Rheological and Filtration Loss Properties of Water Based Mud

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## ABSTRACT

In compliance with environmental laws and safety rules, oil and gas companies have taken necessary steps to eradicate the use of toxic chemicals conventionally used in drilling muds, thereby promoting biodegradable alternatives. This research was carried out to investigate the effect of two banana stem samples; Raw Banana Stem (RBS) and Delignified Banana Stem (DBS) as potential and proficient viscosifiers and fluid loss control agents in water-based mud. The rheological properties evaluated include plastic viscosity (cP), apparent viscosity (cP), yield point (Ib/100ft<sup>2</sup>) and gel strength (Ib/100ft<sup>2</sup>) at 10 seconds and 10 minutes. Filtration loss properties evaluated include filter cake thickness (mm) and fluid loss volume (ml). Each drilling mud sample was prepared using 350 ml, 20 g bentonite and varying contents (g) of carboxyl methyl cellulose (CMC), RBS and DBS. A mixer was used to mix the mud homogeneously; the rheological properties were calculated using a viscometer while the filtration loss properties were calculated using a filter press. The results and analysis were compared to the effects of commercially available carboxymethyl cellulose to validate its properties. RBS and DBS improved the rheological properties of the mud sample contents of 3 g, 5 g, 7 g and 9 g. At contents of 5 g, 10 g, 15 g and 20 g, RBS and DBS samples provide significant fluid loss control and their results are similar to the results of CMC. RBS has a fluid loss volume increase of 6.84 %, 5.69 %, 17.12 % and 8.06 % from CMC's results at slightly similar filter cake thickness while DBS has a fluid loss volume increase of 15.59 %, 15.09 %, 27.55 % and 15.35 % from CMC's result. The data obtained from the experiments showed both banana samples can be used as environmentally friendly viscosifiers and fluid loss control agents.

**KEYWORDS:** Cellulose, Banana stem waste, Water based mud, Rheological properties, Filtration loss properties

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## 1 | INTRODUCTION

Drilling Operations lay the foundations that support and facilitate the milestones and deliverables of oil and gas exploration and exploitation. At the heart of drilling processes is the drilling fluid which is a mixture of water and clay in its basic form. There are three distinct types of drilling muds, all of which share the same fundamental functions.

As drilling techniques got increasingly difficult with each new discovery of hydrocarbon reservoirs, it became evident that the traditional mixture of water and clay lacked the characteristics required to drill complicated lithologies which tend to be associated with conditions of high pressures and temperatures. In order for water-based muds to perform optimally in these complex lithologies and extreme conditions chemical and inorganic additives are added to enhance their properties; these additives are carefully chosen to fulfill the formation requirements, hydraulic considerations and hole cleaning efficiency (Amadi et al., 2018) to suit the lithology unique characteristics.

Oil based drilling fluid systems have a number of drawbacks because they are poisonous, non-biodegradable, and non-renewable. They are therefore excluded from the Health, Safety, and Environmental Agency's list of approved fluids, and the high costs associated with waste treatment procedures resulting from the usage of oil-based muds make them uneconomical. Despite the preference of water-based muds for oil and gas drilling due to its low environmental effect, its overall performance and thermal stability are less favorable for supporting deep drilling than that of oil-based muds. Water based muds have to perform in the same grade and capacity as oil based and synthetic muds and in order to bring their properties up to par chemical additives need to be added into the composition, like the oil/synthetic based drilling fluids some of

these additives pose a risk to the general public's health and hazard to aquatic life. Looking at some unconventional options, a decision was made to focus on biodegradable materials such as food waste products instead of the traditional non-biodegradable chemical additives. The majority of the banana stem is made of cellulose, which makes up more than 50% of the entire stem. Cellulose is a natural, renewable, and biodegradable polymer that may be used in a variety of applications, including paper, insulation, adsorption, and environmental remediation (Li et al., 2015).

This paper studied the effects of food waste material- banana (Cavendish specie) stem on the rheological and filtration loss properties of water-based fluid; two banana stem samples were used. The first banana stem sample is untreated and the second sample is delignified to amplify the cellulose content, then both samples are mixed with the water-based mud and evaluated.

## 2 | MATERIALS AND METHODS

### 2.1 First Stage: Extraction of Cellulose from banana stem through the process of Delignification

Mire et al (2005) method of cellulose extraction was used in this experiment. The Chemicals used include Formic Acid ( $\text{CH}_2\text{O}_2$ ), Acetic acid ( $\text{CH}_3\text{COOH}$ ) and Water. The equipment used are Beaker, thermometer, Oven, hot plate.



**Figure 1.** Delignification Process (Mire et al. 2005)

There are two stages in the delignification process as shown in the figure 1 above; the First

Stage of the extraction is the Impregnation Stage. 800 ml of solution containing a volume concentration of 35 % v/v water and 65 % v/v formic acid was prepared. That's 520 ml of formic acid and 280 ml of water. The solution placed on a hot plate and allowed to heat to 60 degrees Celsius. At 60 degrees Celsius, 20 grams of dried banana stem is cut into 3cm lengths and put into the solution. A spatula was used to make sure the banana stem cuttings were all inside the solution; the solution was stirred for about 30 seconds and allowed to rest for the next 1 hour at a constant temperature of 60 degree Celsius. At the hour mark the banana stem chips were removed from the solution and were rinsed with room temperature water repeatedly.

The second stage is the cooking stage. 800 ml of solution containing a volume concentration of 50 % v/v of formic acid ( $\text{CH}_2\text{O}_2$ ), 30 % v/v of acetic acid ( $\text{CH}_3\text{COOH}$ ) and 20 % v/v of water was prepared. That's 400 ml of formic acid, 240 ml of acetic acid and 160 ml of water. It was heated to a temperature of 105 degree Celsius in an oven. When it reached this temperature the banana chips derived from the impregnation stage were put in it and cooked for 3 hours at a constant temperature of 105 degree Celsius in an oven. At the 3-hr. mark, the banana stem chips were removed from the solution. The Delignification process was complete after the chips were rinsed with room temperature water repeatedly and placed in the sun to dry.

## 2.2 Second Stage: Rheological Test

Three variations of drilling fluid having 12 distinct contents (g) of additives were prepared for the experimental procedure;

1. Set A - Bentonite (20 g) + CMC (0.3 g, 0.5 g, 0.7 g and 0.9 g) + water (350 ml)
2. Set B - Bentonite (20 g) + Raw Banana stem (granulated) (3 g, 5 g, 7 g and 9 g) + Water (350 ml)

3. Set C - Bentonite (20 g) + Delignified Banana stem (granulated) (3 g, 5 g, 7 g and 9 g) + Water (350 ml)

The first variation which included the bentonite, carboxyl methyl cellulose and Water, a piece of paper was placed on a digital weighing; it weighed 0.3 g. The weight was zeroed then 20 g of bentonite was poured on the paper and measured simultaneously. Next, 0.3 g of CMC was measured on the weighing device. After accurate measurements of bentonite and CMC have been attained, 350 ml of water was measured using a measuring cylinder. Then the water was poured into the mud mixer cup; the cup set on the mud mixer cup holder and the mud mixer was switched on; this activated the rotor; spinning it at incredible speed. While the water was gyrating in the mud mixer cup, 20 g bentonite of scooped gently and poured into the cup. After all the bentonite had been applied, 0.3 g of CMC was applied next, the mixture was allowed to mix at high speed for 5 minutes. After the mixture had been mixed for 5 minutes, the mud cup was removed from cup hold; the mixture of water, bentonite and CMC was poured into the viscometer cup to the datum level. The viscometer was set and results are obtained. This process was repeated 3 more times with varying mass of CMC; these 4 runs accounted for the first group of results regarding CMC recorded as Mud A. For Mud B and Mud C the same process was repeated. The only exception was that CMC was substituted for Raw Banana Stem (granulated) for Mud B and for Mud C, CMC was substituted for delignified Banana Stem (granulated). The mud density and pH value were also determined at each content (g) of additives.

## 2.3 Third Stage: Filtration Test

The filtration test is one of the most relevant drilling fluid tests. It was carried out at ambient (room) temperature and at a pressure of 700 kPa (100 psi) for thirty minutes, and this is the LT-LP API standard. Filtration test measured the

property of filtrate volume of drilling fluid which included filtrate volume (ml) and mud thickness (mm). 3 sets of drilling mud were prepared for evaluation. Each set has 4 distinct muds of 4 additive mass content.

Set 1 – 350 ml of water + 20 g Bentonite + (1 g, 2 g, 3 g, 4 g) of CMC

Set 2 - 350 ml of water + 20 g Bentonite + (5 g, 10 g, 15 g, 20 g) of raw banana stem

Set 3 - 350 ml of water + 20 g Bentonite + (5 g, 10 g, 15 g, 20 g) of delignified banana stem

Experimental procedure for filtration test:

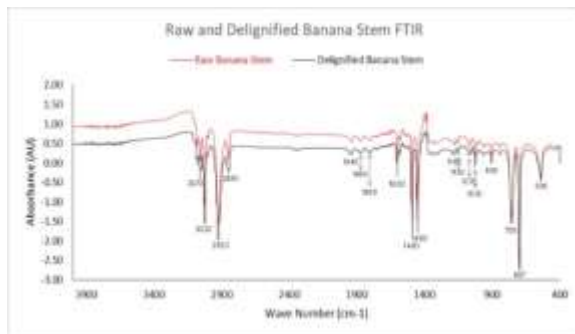
1. Freshly mixed drilling mud was prepared using 350 ml of water, 20 g of Bentonite and 1 g of CMC
2. Filtration press was assembled, mud was poured into the cell up to the approved datum level to prevent contamination of the filtrate by CO<sub>2</sub>, and the cell was sealed appropriately and inserted in the frame of the filter press equipment.
3. Graduated cylinder was placed on the support under the mud cup and the thumb screw was adjusted to lift the cylinder to the approved height in order to collect the discharged filtrate from the mud chamber. Filtrate measurements were in milliliters (ml)
4. This was a low-pressure low temperature filtration test; therefore, it was carried out at room temperature and at a pressure of 100 psi for 30 minutes. The pressure regulator was adjusted to the 100-psi mark and 30 mins countdown began immediately the cell was pressurized. The pressure gauge was monitored frequently to make sure the reading stays consistent through the course of 30 minutes.
5. After 30 mins, volume of fluid loss in the graduated cylinder was recorded in ml.

6. Pressure from the pressure regulator was relieved before the mud cup was removed from the filter press frame
7. The mud cup is opened and the filter paper with the filter cake thickness was removed; both of these should be done with extreme care so as to avoid distorting the filter cake which can affect final results.
8. Thickness of the filter cake (mm) was recorded.
9. The filter paper was washed, cleaned and dried for further experiments.

### 3 | RESULTS AND DISCUSSION

The model of FTIR equipment used was a thermo scientific, NICOLET iS5 with OMNIC software, sample holder iD1. Fig. 2 shows the infrared spectroscopy of two banana stem samples; raw banana stem and delignified banana stem gotten from the FTIR device. The x-axis represents the wavelength (cm<sup>-1</sup>) and the y-axis represents the absorbance of light by the sample. There's a hydroxyl (OH) functional group starting at peak at 3070 cm<sup>-1</sup>, the peak's width is more narrow than broad in size, it continues on a declining pattern on the chart and ends at peak 3020 cm<sup>-1</sup> (Morán et al., 2007; *Infrared Spectroscopy Table*, 2020 & Mathias, 2022). At 2920 cm<sup>-1</sup> peak, a weak intensity of -C-H stretch functional group is established, gradually it invades the Alkyl, Aliphatic and Aldehydic (*Infrared Spectroscopy Table*, 2020 & Wade & Simek, 2017) groups at variable intensities (H-C-H) at peak 2850 cm<sup>-1</sup>. The peak at 1940 cm<sup>-1</sup> can be assigned to a CO stretching mode, based on extensive studies on metal carbonyl complexes (Nakamoto, 2008). A very similar weak peak at 1860 cm<sup>-1</sup> and 1800 cm<sup>-1</sup> was calculated as C=O anhydride (*Infrared Spectroscopy Table*, 2020 & Wade & Simek, 2017), At 1600 cm<sup>-1</sup>, a peak is assigned to C=C aromatic functional group, the intensity is weak at this peak. There are two distinct peaks that are very close to one another; 1490 cm<sup>-1</sup> and 1450

cm<sup>-1</sup>, both of these peaks are attributed to medium intense bending CH<sub>2</sub> and CH<sub>3</sub> functional groups and C=C aromatic skeletal mode (Morán et al., 2007). At 1180 cm<sup>-1</sup>, 1150 cm<sup>-1</sup>, 1070 cm<sup>-1</sup>, 1030 cm<sup>-1</sup>, small peaks were assigned in the ranges of strong stretching C-O-C, C-OH, and C-F functional groups. Weak peaks at 906 cm<sup>-1</sup> and Strong and intense peaks at 756 cm<sup>-1</sup>, 697 cm<sup>-1</sup> and 538 cm<sup>-1</sup> constituted one or more of the following; CH, C-Cl and C-Br functional groups (*Infrared Spectroscopy Table*, 2020; Morán et al., 2007 & Wade & Simek, 2017). At multiple peaks on the chart, it is observed the absorbance is negative, this happens because the intensity of light passing through the sample is greater than the intensity of light passing through the reference. Both samples of FTIR spectrums are identical but the absorption bands are different, this implies the molecular content of the raw banana stem was not the same as that of the delignified banana stem, therefore the results indicate that the banana molecular content changed following the delignification process.



**Figure 2.** FTIR analysis of Raw and Delignified banana stem

**Table 1-** The effect of various contents (g) of CMC on rheological properties of *water-based* mud

| Rheological Properties | 0.3 g | 0.5 g | 0.7 g | 0.9 g |
|------------------------|-------|-------|-------|-------|
| 600rpm                 | 32    | 41    | 47    | 55    |
| 300rpm                 | 20    | 32    | 38    | 44    |

|                                      |     |      |      |      |
|--------------------------------------|-----|------|------|------|
| Apparent Viscosity (cP)              | 16  | 20.5 | 23.5 | 27.5 |
| Plastic Viscosity (cP)               | 12  | 9    | 9    | 11   |
| Yield point (Ib/100ft <sup>2</sup> ) | 8   | 23   | 29   | 33   |
| 10 sec Gel (Ib/100ft <sup>2</sup> )  | 2.5 | 4    | 4.5  | 6    |
| 10 min Gel (Ib/100ft <sup>2</sup> )  | 5.6 | 7    | 9    | 11   |
| pH                                   | 9   | 9    | 9    | 9    |
| Density (ppg)                        | 8.6 | 8.6  | 8.65 | 8.65 |

**Table 2 -** The effect of various contents (0.3, 0.5, 0.7 and 0.9 g) of raw banana stem on the rheological properties of *water-based* mud

| Rheological Properties               | 0.3 g | 0.5 g | 0.7 g | 0.9 g |
|--------------------------------------|-------|-------|-------|-------|
| 600rpm                               | 2     | 3     | 4     | 5     |
| 300rpm                               | 1     | 2     | 3     | 3     |
| Apparent Viscosity (cP)              | 1     | 1.5   | 2     | 2.5   |
| Plastic Viscosity (cP)               | 1     | 1     | 1     | 2     |
| Yield point (Ib/100ft <sup>2</sup> ) | 0     | 1     | 1     | 1     |
| 10 sec Gel (Ib/100ft <sup>2</sup> )  | 1     | 1     | 1     | 1     |
| 10 min Gel (Ib/100ft <sup>2</sup> )  | 1     | 1     | 2     | 2     |
| pH                                   | 8.5   | 8.6   | 8.6   | 8.6   |
| Density (ppg)                        | 8.5   | 8.5   | 8.5   | 8.5   |

**Table 3 -** The effect of various contents (g) of delignified banana stem on the rheological properties of *water-based* mud

| Rheological Properties | 0.3 g | 0.5 g | 0.7 g | 0.9 g |
|------------------------|-------|-------|-------|-------|
|                        |       |       |       |       |

|                                      |     |     |     |     |
|--------------------------------------|-----|-----|-----|-----|
| 600rpm                               | 3   | 3   | 5   | 7   |
| 300rpm                               | 2   | 2   | 3   | 4   |
| Apparent Viscosity (cP)              | 1.5 | 1.5 | 2.5 | 3.5 |
| Plastic Viscosity (cP)               | 1   | 1   | 2   | 3   |
| Yield point (Ib/100ft <sup>2</sup> ) | 1   | 1   | 1   | 1   |
| 10 sec Gel (Ib/100ft <sup>2</sup> )  | 1   | 1   | 2   | 2   |
| 10 min Gel (Ib/100ft <sup>2</sup> )  | 2   | 2   | 2   | 3   |
| pH                                   | 8.5 | 8.5 | 8.5 | 8.5 |
| Density (ppg)                        | 8.5 | 8.5 | 8.5 | 8.5 |

**Table 4** - The effect of various contents (3, 5, 7, 9 g) of raw banana stem on the rheological properties of *water-based* mud

| Rheological Properties               | 3 g   | 5 g   | 7 g  | 9 g  |
|--------------------------------------|-------|-------|------|------|
| 600rpm                               | 22.5  | 24.5  | 37   | 48   |
| 300rpm                               | 14.5  | 15.5  | 24.5 | 31.5 |
| Apparent Viscosity (cP)              | 11.25 | 12.25 | 18.5 | 24   |
| Plastic Viscosity (cP)               | 8     | 9     | 12.5 | 16.5 |
| Yield point (Ib/100ft <sup>2</sup> ) | 6.5   | 6.5   | 12   | 15   |
| 10 sec Gel (Ib/100ft <sup>2</sup> )  | 1     | 2     | 2    | 3    |
| 10 min Gel (Ib/100ft <sup>2</sup> )  | 3     | 4     | 4    | 5    |
| pH                                   | 9     | 9     | 9.1  | 9.2  |
| Density (ppg)                        | 8.6   | 8.7   | 8.7  | 8.7  |

**Table 5** - The effect of various contents (3, 5, 7, 9 g) of delignified banana stem on the rheological properties of *water-based* mud

| Rheological Properties               | 3 g  | 5 g  | 7 g   | 9 g   |
|--------------------------------------|------|------|-------|-------|
| 600rpm                               | 29   | 36   | 44.5  | 52.8  |
| 300rpm                               | 17.6 | 22.1 | 28.6  | 31.7  |
| Apparent Viscosity (cP)              | 14.5 | 18   | 22.25 | 26.4  |
| Plastic Viscosity (cP)               | 11.4 | 13.9 | 15.9  | 21.11 |
| Yield point (Ib/100ft <sup>2</sup> ) | 6.5  | 8.2  | 12.7  | 10.6  |
| 10 sec Gel (Ib/100ft <sup>2</sup> )  | 2    | 3    | 4     | 4     |
| 10 min Gel (Ib/100ft <sup>2</sup> )  | 3    | 5    | 6     | 7     |
| pH                                   | 8.8  | 8.8  | 8.7   | 8.7   |
| Density (ppg)                        | 8.6  | 8.6  | 8.65  | 8.7   |

### 3.1 Plastic viscosity (PV)

Both banana stem muds in Tables 4 and 5 have gradual increase in plastic viscosities as the contents (g) are increased. In Table 1, the plastic viscosity starts at 12 cP, declines to 9 cP for 0.5 g and 0.7 g and increases to 11 cP. The average PV rating of DBS, RBS and CMC is 15.58, 11.5 and 10.25 cP respectively. This shows DBS has the highest plastic rating. Generally, the plastic viscosity is supposed to increase with increase in additive content; the uneven gradation is no cause of concern as the plastic viscosity range is in accord with the API standard range of 8-35 cP. If it is below the standard range then the rate of penetration from the drill bit will increase significantly signifying low viscosity, and if the plastic viscosity is above the API standard range,

it means the viscosity is too high as a result of excess solids in the mud which is bad for well stability and thus, can lead to wellbore problems. High viscosity can be addressed by dilution, shake screens and desanders. DBS has the highest plastic viscosity rating with 21.11 cP at 9 g and raw banana stem has the lowest plastic viscosity with 8 cP at 3 g. The Plastic viscosities of CMC, RBS and DBS were within the API range of 8-35 cP which is very good.

### 3.2 Yield point (YP)

Yield point indicates the carrying potential of drill cuttings; the higher the yield points the more effective the mud's ability to carry drill cuttings. The effect of contents (g) on the yield has a direct relationship; an increase in additive content (g) is equivalent with increase in yield point. The CMC additive has the highest yield point of the three samples with 33 Ib/100 ft<sup>2</sup> at 0.9 g. Raw and Delignified are tied for lowest yield point with 6.5 Ib/100 ft<sup>2</sup> at 3 g. Raw banana stem have 18.75 %, 71.74 %, 58.62 % and 54.54 % lower yield point than CMC across the table; therefore, its drill cut carrying potential is significantly less. Delignified banana stems have 18.75 %, 64.35 %, 56.21 % and 67.87 % lower yield point than CMC. Between raw and delignified banana stem, raw banana stem has the better yield point with average percentage of 50.91 % while delignified stem has 51.80 % with a minute difference of 0.89 %. The yield points of raw and delignified banana did not compete with the yield point of CMC but their carrying potential was still good.

### 3.3 Gel strength (GS)

This property defines the propensity for drill cuttings to stay suspended in the drilling mud after circulation is stopped as stated earlier in the chapter 2. The content of colloidal particles in drilling mud determines gel strength rating. A high gel strength value will allude to high content (g) of colloids (glue like organic and inorganic matter) in the additive and thus a strong ability to

suspend drill cuttings. Increase in additive contents (g) is directly proportional to increase in gel strength. CMC had the highest gel strength of 11 Ib/100ft<sup>2</sup> at 0.9 g and overall had better gel strength capabilities than raw and delignified banana stem. Raw banana stem was 60 %, 50 %, 55.56 % and 50 % lower than CMC at 10 sec gel strength and 46.42 %, 42.86 %, 55.56 % and 54.55 % lower than CMC at 10 min gel strength. Delignified banana stem was 20 %, 25 %, 11.11 % and 33.33 % lower than CMC at 10 sec gel strength and 46.43 %, 28.57 %, 33.33 % and 36.36 % lower than CMC at 10 min gel strength evaluation. Delignified banana stem results were closer to CMC gel strength, thus better than its counterpart. Though raw stem had higher density, its gel strength was less than that of delignified gel strength and CMC, this is logical due to the light nature of colloids which are the key elements in gel strength characteristics.

### 3.4 Filtration Properties

**Table 6** - The effect of various contents (g) of CMC on the fluid loss volume and filter cake thickness property of *water-based* mud

| Additive content (g) | Experimental Run 1 (ml) | Experimental Run 2 (ml) | Experimental Run 3 (ml) | Avg. Fluid loss volume (ml) |
|----------------------|-------------------------|-------------------------|-------------------------|-----------------------------|
| 1                    | 38.3                    | 37.6                    | 38.4                    | 38.1                        |
| 2                    | 31.4                    | 31.9                    | 31.2                    | 31.5                        |
| 3                    | 21.6                    | 20.2                    | 22.1                    | 21.3                        |
| 4                    | 17.6                    | 17.2                    | 16.5                    | 17.1                        |

| Additive content (g) | Experimental Run 1 (mm) | Experimental Run 2 (mm) | Experimental Run 3 (mm) | Avg. Filter cake thickness (mm) |
|----------------------|-------------------------|-------------------------|-------------------------|---------------------------------|
| 1                    | 1.0                     | 0.8                     | 1.2                     | 1                               |
| 2                    | 1.2                     | 1.7                     | 1.6                     | 1.5                             |
| 3                    | 2.4                     | 2.7                     | 2.4                     | 2.5                             |
| 4                    | 2.7                     | 3.7                     | 2.6                     | 3                               |

**Table 7.** The effect of various contents (g) of raw banana stem on the fluid loss volume and

filter cake thickness property of *water-based mud*

| Additive content (g) | Experimental Run 1 (ml) | Experimental Run 2 (ml) | Experimental Run 3 (ml) | Avg. Fluid loss volume (ml) |
|----------------------|-------------------------|-------------------------|-------------------------|-----------------------------|
| 5                    | 40.4                    | 41.5                    | 40.8                    | 40.9                        |
| 10                   | 33.3                    | 32.2                    | 34.7                    | 33.4                        |
| 15                   | 27.2                    | 26.0                    | 23.9                    | 25.7                        |
| 20                   | 17.4                    | 21.1                    | 17.3                    | 18.6                        |

| Additive content (g) | Experimental Run 1 (mm) | Experimental Run 2 (mm) | Experimental Run 3 (mm) | Avg. Filter cake thickness (mm) |
|----------------------|-------------------------|-------------------------|-------------------------|---------------------------------|
| 5                    | 0.9                     | 1.1                     | 1.0                     | 1                               |
| 10                   | 2.1                     | 1.4                     | 1.3                     | 1.6                             |
| 15                   | 1.9                     | 2                       | 3                       | 2.3                             |
| 20                   | 2.7                     | 3.7                     | 2.9                     | 3.1                             |

**Table 8.** The effect of various contents (g) of delignified banana stem on the fluid loss volume and filter cake thickness property of *water-based mud*

| Additive content (g) | Experimental Run 1 (ml) | Experimental Run 2 (ml) | Experimental Run 3 (ml) | Avg. Fluid loss volume (ml) |
|----------------------|-------------------------|-------------------------|-------------------------|-----------------------------|
| 5                    | 45.6                    | 46.5                    | 43.8                    | 45.3                        |
| 10                   | 35.7                    | 39.6                    | 36.0                    | 37.1                        |
| 15                   | 30.7                    | 28.5                    | 29.0                    | 29.4                        |
| 20                   | 20.9                    | 20.0                    | 19.7                    | 20.2                        |

| Additive content (g) | Experimental Run 1 (mm) | Experimental Run 2 (mm) | Experimental Run 3 (mm) | Avg. Filter cake thickness (mm) |
|----------------------|-------------------------|-------------------------|-------------------------|---------------------------------|
| 5                    | 0.9                     | 0.9                     | 1.2                     | 1                               |
| 10                   | 2.1                     | 1.4                     | 1.6                     | 1.7                             |
| 15                   | 2.8                     | 2.1                     | 2.6                     | 2.5                             |
| 20                   | 3.1                     | 3.1                     | 3.7                     | 3.3                             |

Table 6 displays fluid loss properties of water-based mud using CMC as a fluid loss agent/additive. At 1 g, a mud thickness of 1 mm

yielded 38.1 ml of filtrate. This liquid filtrate signifies the amount of fluid loss that will be experienced in the hole over a 30-minute drilling operation. This fluid leaks into the formation, interacting with it to create invaded zones; the filtration rate at 1 g was very high. As the content (g) of CMC is increased, the thickness of the filter cake (mm) increases with a corresponding decrease in fluid loss volume (ml). A fluid loss of 17.1 ml was recorded at filter cake thickness of 3 mm. As stated earlier the filtration rate is very high at 1 g of CMC, over the course of the experiment the filtration rate reduces significantly due to the increase of filter cake's thickness and compactness, this is expected because increase in CMC content fills up or clogs the filter paper pores thus inhibiting the permeable medium of the filter paper. The 55.12 % decrease of fluid loss volume at 4 g of CMC from 38.1 ml over the course of experiments after 2 mm increase in filter cake thickness proves CMC is a very good fluid loss additive. The filter cake was thin, flexible and compact, these are all recommended features of a good fluid loss agent. Table 7 depicts the raw banana stem filtration properties, at 5 g of RBS the fluid loss is 40.9 ml with a filter cake thickness of 1 mm, that's a 6.84 % increase from 1 g of CMC from table 6, in descending order the percentage increases are 5.69 %, 17.12 % and 8.06 %, the fluid loss volume and filter cake thickness are slightly similar as seen from the percentage increases stated above when compared to the values of CMC. Delignified banana stem filtration properties in table 8, has a much higher deviation from filtration properties of CMC in Table 6, compared with RBS in table 7. The fluid loss volume of DBS has percentage increases of 15.89 %, 15.09 %, 27.55 % and 15.35 % in comparison to the fluid loss volume CMC, the filter cake thickness is also higher. The filter cake was compact but not as fine as CMC's filter cake. DBS was a good fluid loss control agent.

#### 4 | CONCLUSIONS AND RECOMMENDATIONS

The effects of local and cost-effective additives RBS and DBS on the rheological and filtration loss properties on water-based mud were investigated. In order to fully understand the level of performance they have, their results were compared to industry standard CMC viscosifier and filtration loss agent, the following conclusions were made; RBS and DBS can be used as viscosifiers. For RBS and DBS to have competing performance values as CMC, their respective contents must be increased. Banana stem are easy to find in large quantities and are considered waste from where they were sourced; therefore, this is not an availability or cost effective setback.

Delignification of Banana stem was not cost effective, though DBS has a better rating on the apparent viscosity, gel strength 10 secs and 10 min scales. Overall RBS is a better viscosifier and fluid loss agent because it is cheaper to process, similar apparent viscosity, gel strength (10secs and 10mins) and a better YP, PV and fluid loss rating.

Based on the results from the experiment, it is recommended that banana stem (*Musa Cavendish*) be used as an alternative to industry imported viscosifiers and fluid loss control agent. Also other local additives should be investigated as potential viscosifiers and fluid loss agents. This research was carried out under Low Temperature Low Pressure (LTLTP) conditions. Future research can explore effects of raw and delignified banana stem on the rheological and filtration loss properties of water-based mud under High Temperature High Pressure (HTHP) conditions.

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