Formulation of Water-Based Mud with Waste Tigernut Fibre as Additive

D. E. Jimmy, E. N. Wami, E. O. Ehirim, R. N. Okparanna

Abstract—This study was conducted to assess the suitability of waste Tigernut fibre as an additive in place of polyanionic cellulose ultra-low (PAC UL) in the formulation of standard water-based potassium chloride (KCl) polymer gel mud. Four mud samples (A, C1, C2, and C3) were prepared with standard industrial KCl polymer gel. Sample A, which served as the control, was prepared with conventional PAC UL. Samples C1, C2, and C3 were prepared with waste Tigernut fibre of particle sizes 212, 75, and 40 μm respectively. Rheological, API filtration, and selected physicochemical properties of samples C1, C2, and C3 including density, marsh funnel (effective) viscosity, sand content, alkalinity, chloride content, and pH were tested and compared with those of the control mud sample A. Results showed that all but the pH of mud samples C1, C2, and C3 were slightly higher (albeit within the recommended values) than those of the control mud sample A. In terms of rheological properties, mud samples C1, C2, and C3 had better values compared with control mud sample A. The filtration volume for sample C3 (5.4 cc/ml) at 30 minutes was comparable with that of sample A (5.2 cc/ml) within the same time interval. However, values obtained for samples C1 and C2 were totally out of range. These results have conclusively shown that waste Tigernut fibre can be a good substitute for conventional PAC UL additive in the formulation of high-quality standard water-based KCl polymer gel mud, especially for API filtration and rheology control.

Index Terms—Novel Mud Additive; Proprietary Drilling Mud; Waste Management; Petroleum.

I. INTRODUCTION

Highlight In rotary drilling, drilling fluid plays a central role in facilitating drilling operations to achieve optimization in wellbore performance as well as in maintaining and protecting drilling equipment. Numerous functions of drilling fluid that are critical to successful drilling operation include (among others) the following: supporting drill string and tubular structures, subsurface and formation pressure control, wellbore support and stabilization, cooling and lubricating of the drill bit and string, cutting removal and transporting to the surface, wire-line logging and formation data gathering, prevention of formation damage, improvement of penetration rate, and reduction of stuck pipe (Amoco, 2016; Baroid, 1998).

Performance of a mud type is a function of the type of ingredients used in its formulation and other variables, which include the operational conditions of the fluid (ASME, 2005). Drilling fluids are sometimes mostly formulated using synthetic polymeric materials whose costs are exorbitant thereby making the drilling operation very expensive. It has been estimated that drilling fluids alone account for 10 to 30% of the total drilling cost of a well, with mudadditives being among the most costly items (Daleel, 2015; EKT Interactive, 2019). One of the regular synthetic polymers in use in the formulation of mud is polyanionic cellulose ultra-low (PAC UL), which is readily available at a very high cost. PAC UL is widely used as an additive to regulate the rheological properties and filtration loss requirements in water-based muds. Hence, cost of additives remain a serious concern to drilling fluid manufacturers who are still longing for solution (Daleel, 2015; Ademuliyi et al., 2001). The high cost of additives is currently being addressed through search for local and cheaper additives that could serve as reliable substitutes for expensive conventional additives in mud formulation. Numerous research efforts have been made to explore the use of some local materials as suitable replacement for some of the imported mud ingredients (Krueger, 1963; Slawomir et al., 1996; Okumo and Isehunwa, 2007). Locally produced starch and fibrous substances including corn cob, cassava and plantain peels have been used as filtration loss control additives in mud formulation with promising results (Ademuliyi et al., 2011; Nmegbu and Bekee, 2014; Wami et al., 2016). However, the ability to formulate drilling fluid, especially with readily available and cheap local materials that could meet all the standard mud specifications has been a major challenge. In Nigeria, Tigernut solid waste is generated in high quantities by local Tigernut juice (popularly called ‘kunu’) producing enterprise. According to Tigernut Traders (2018), 100-gmass of Tigernut tuber produces as much as 14.5 % solid waste. When the waste is properly dried, it can be used as fibre (Nurta et al., 2014). However, if allowed to decay, it can constitute environmental nuisance because of the emission of a foul-smelling gas.

At the moment, there is a dearth of information in the open access literatures on the use of waste Tigernut fibres as an additive in mud formulation. Thus, investigations into the potential of recycling abundant waste Tigernut fibres as a useful additive in mud formulation would be a good waste-to-wealth exercise. The objective of the present study was to investigate the possibility of using waste Tigernut fibre as a substitute for conventional PAC UL additive in the

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The formulation of high-quality standard water-based KCl polymer gel mud for API filtration and rheology control.

II. MATERIALS AND METHODS

A. Sample Collection and Preparation

A 4-litre plastic container of freshly harvested Tigernut from Northern Nigeria, properly stored in storage bags was locally purchased, washed with de-ionized water, and then spread on a clean towel to air dry. After air-drying, the Tigernut was blended to coarse texture and the juice (milk) extracted by squeezing. The chaff (fibre) was poured into a tray and oven dried at 50°C for 24 hours as shown in Figure 1. Afterwards, it was sieved down to 212, 75, and 40μm and put in three separate bags according to their particle sizes.

Figure 1: Ground oven-dried Tigernut fibre

B. Mud Formulation

The American Petroleum Institute (API) standard of 8.0g of conventional bentonite per 1 lab barrel of water for water-based KCl polymer gel mud (WBM) formulation was used in the preparation of the mud. The mud samples formulated were replications of a standard mud prepared and used by a multinational oil company operating in Rivers State, Nigeria, as shown in Table 3. Four mud samples were formulated using data in Table 1 — one standard WBM KCl polymer gel mud (Sample A) and three others with waste Tigernut fibre of particle sizes 212, 75, and 40μm (Samples C1, C2, and C3, respectively). The four mud samples were in liquid states.

To formulate the muds; first, water was measured into a mixing cup and the rest of the products, in the order listed, were then added. The mixture was mixed continuously using the electric mixer while adding each additive according to the mixing time interval given in Table 1 to give the control sample A. Secondly, step 1 was repeated three more times but with the substitution of the conventional PAC UL with waste Tigernut fibre of particle sizes 212, 75, and 40μm at the same concentration to obtain samples C1, C2, and C3 as shown in Table 1. Aliquots of the four mud samples were then collected for analysis.

C. Determination of Physicochemical Properties of the Formulated Muds

Conventional API standard methods for testing mud properties were used for testing the physicochemical properties of the formulated muds. Density was tested with Baroid mud balance. Effective viscosity was tested with a Marsh funnel. Sand content was tested with sand screen set and glass measuring tube. pH was measured with an indicator paper (paper test strips or pH paper). Chloride and alkalinity contents were determined by titration method. Rheological properties including apparent viscosity, gel strength, k (consistency index), n (flow index), plastic viscosity, and yield point were determined with a Fann Viscometer. API filtration was tested with API filtration set-up.

III. RESULTS AND DISCUSSION

A. Visual Inspection of the Formulated Mud Samples

Visual inspection showed that the formulated muds looked alike in terms of physical appearance with little or no significant change in colour. The formulated muds appeared creamy in colour with light thickness for Sample A, which flowed normally. But samples C1, C2, and C3 had medium thickness and flowed slowly. Sample A had an indescribable odour but samples C has had a sweet non-chocking odour because of the two drops of octyl-alcohol deformer that was added to remove air bubbles for proper analysis of mud properties.

B. Physicochemical Properties of the Formulated Muds Samples

Figure 2 shows the selected physicochemical properties of mud samples C1, C2, and C3 as compared with those of control sample A, plotted using the data in Table 2. The differences in the selected physicochemical properties of the four mud samples are clear.
Table 1: Sample A, C₁, C₂ and C₃ – Standard one Barrel (1bbl) of Water-Based KCl Polymer Gel Drilling Mud

<table>
<thead>
<tr>
<th>S/ N</th>
<th>Additives / Products</th>
<th>Conc. (ppb)</th>
<th>Functions</th>
<th>Mixing (mins)</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Water</td>
<td>329.79</td>
<td>Based Fluid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Soda Ash</td>
<td>0.10</td>
<td>Calcium ion removal</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Caustic Soda</td>
<td>0.10</td>
<td>Alkalinity control</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Mi Gel / Bentonite</td>
<td>8.0</td>
<td>Viscosifier</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Potassium Chloride</td>
<td>21.05</td>
<td>Inhibition control</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Xanthan Gum</td>
<td>1.2</td>
<td>Viscosifier</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Poly PAC UL Tigernut fiber (212μm)</td>
<td>1.00</td>
<td>Fluid loss control</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Poly Sal Poly Sal Poly Sal Poly Sal</td>
<td>2.00</td>
<td>Viscosifier and FLC</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Calcium Carbonate Fine (10)</td>
<td>15.46</td>
<td>Weighting material</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Borax</td>
<td>2</td>
<td>Preservative</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Source: MI, 2016 Edited

Table 2: Summary Values of the Mud Properties Obtained for all the Mud Samples

<table>
<thead>
<tr>
<th>Mud Properties</th>
<th>Sample A</th>
<th>Sample C₁</th>
<th>Sample C₂</th>
<th>Sample C₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm³)</td>
<td>1.081</td>
<td>1.093</td>
<td>1.098</td>
<td>1.093</td>
</tr>
<tr>
<td>Marsh (Eff.) Viscosity (cP)</td>
<td>32.93</td>
<td>64.66</td>
<td>47.96</td>
<td>41.89</td>
</tr>
<tr>
<td>Sand Content (%)</td>
<td>0.20</td>
<td>0.40</td>
<td>0.35</td>
<td>0.25</td>
</tr>
<tr>
<td>pH</td>
<td>9.5</td>
<td>8.5</td>
<td>9.0</td>
<td>9.0</td>
</tr>
<tr>
<td>Chloride Content, ppb</td>
<td>22</td>
<td>25.2</td>
<td>25.2</td>
<td>25</td>
</tr>
<tr>
<td>Alkalinity Cc: Pom₁ (ppb)</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Alkalinity Cc: Pom₂ (ppb)</td>
<td>4.05</td>
<td>5.25</td>
<td>5.25</td>
<td>5.25</td>
</tr>
<tr>
<td>API Filtration Volume (cc/ml)</td>
<td>5.2</td>
<td>39</td>
<td>11</td>
<td>5.4</td>
</tr>
<tr>
<td>Apparent Viscosity (cP)</td>
<td>18</td>
<td>19.5</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Plastic Viscosity (cP)</td>
<td>10</td>
<td>11</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Yield Point (lbs/100ft²)</td>
<td>16</td>
<td>17</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Gel Strength (lbs/100ft²) @10secs</td>
<td>17</td>
<td>19</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>Gel Strength (lbs/100ft²) @10mins</td>
<td>27</td>
<td>30</td>
<td>29</td>
<td>29</td>
</tr>
<tr>
<td>K – Con. In(lbs .Sn/100sqft)</td>
<td>717.55</td>
<td>726.04</td>
<td>815.45</td>
<td>715.06</td>
</tr>
<tr>
<td>n – Flow Index</td>
<td>0.468</td>
<td>0.478</td>
<td>0.465</td>
<td>0.469</td>
</tr>
</tbody>
</table>

i. Density
As can be seen in Figure 2a, all the muds formulated with local material (samples C₁, C₂, and C₃) are denser (1 – 1.6 g/cm³) than the standard mud value of 1.081 g/cm³. Sample C₂ prepared with 75-μm size Tigernut fibre had the highest mud density of 1.6g/cm³ and would be useful for controlling formation pressure and maintaining wellbore stability. Overall, the densities of the prepared muds are within the specified range as shown in Table 3. Therefore, waste Tigernut fibre can be used as a weighting agent in mud formulation.

ii. Marsh Funnel (Effective) Viscosity
The values of effective viscosity of the various mud samples are shown in Figure 2b using Marsh Funnel viscosity data in Table 2. Figure 2b shows that all the muds formulated...
with waste Tigernut fibre are more viscous than the standard KCl mud with sample C1 prepared with 212 μm fibre having the highest mud viscosity of 64.66 cP. It was further observed that reduction in fibre particle size reduced the effective viscosity of the mud samples (Figure 2b). Even then, the effective viscosities of samples C1–C3 were still higher than that of the control sample A. This finding suggests that waste Tigernut fibre would be useful for providing buoyancy to drilling operations and has the ability to cope with some extraneous geological conditions (McCray and Cole, 1979).

iii. Sand Content

The sand content % of the mud samples are shown in Figure 2c using data in Table 2. From Figure 2c, all the muds formulated with Tigernut fiber have higher percentage sand content than the standard mud. Sample C1 being the fluid containing the highest fiber particle size - 212μm has the highest sand content of 0.40% (twice the amount of Sample A). This is understandable since the lower the mesh size of the sieve, the more difficult for the sand particle to pass through, thereby reducing the sand content in the sieved Tigernut fiber as observed in Sample C2 and C3. Sand is an impurity and therefore a very serious problem to E&P operations of oil and gas, a recommended or acceptable value of less than 1% sand content in the drilling mud is advised (API RP 13D, 2003) and all the prepared mud samples in this study met specifications (Table 3).

iv. pH

The pH values of the various mud samples are illustrated in Figure 2d using data in Table 2. Figure 2d illustrates the pH values of the mud samples. Sample A has a pH value of 9.5 – which is weak basic and so are the Samples C2 and C3 with a pH of 8.5 to 9 which are 5 to 10 % less alkaline than the control sample A but still within the mud specification range (Table 3).

v. Alkalinity Content

The alkalinity content of the various mud samples using data stated in Table 2 is shown in Figure 2e. Although pH gives an indication of alkalinity, it has been observed that in spite of a constant pH, the characteristics of a mud with a high pH value can vary considerably, therefore it is advisable to still carry out further analysis to be able to accurately assess the mud alkalinity. From Figure 2e, it is observed that Standard mud has less alkalinity content of excess lime and lime content values of 5 and 4.05 ppg respectively and the alkalinity content increases by 40% for Samples C1, C2 and C3 indicating a change compared to the pH values reported above. The alkalinity content in samples C1, C2 and C3 containing Tigernut fiber might have increased as a result of the presence of the local material. According to API Standards and literature report (QDrill, 2014), an alkalinity content of 5 – 9ppg is allowed, therefore the alkaline content all the mud samples are within the specified range for a KCl Polymer Gel WBM.

vi. Chloride Content

Figure 2f shows the chloride content of the various mud samples using data in Table 2. The chloride content of the muds as illustrated in Figure 2f, shows that Standard mud, sample A has less Chloride content value of 22ppg and the Chloride content increased by 13.6% for sample C3 and 14.6% % for Samples C1, and C2. The increment in chloride content in mud samples C1, C2 and C3 must be as a result of the fibrous nature of the local material present. According to API Standards, chloride content of 20 – 30ppg is allowed, therefore the chloride content present in all the mud samples are within the specified range for a KCl Polymer Gel WBM.
vii. Mud Flow (Rheology) Properties

The flow (Rheology) properties of the various mud samples obtained in figure 3 is by plotting the viscosity (cP) values (a conversion of rotor speed values to shear rate and shear stresses, then to viscosity) against Dial reading values of the V-G meter using data in Table 2. Figure 3 is a summary plot, comparing the flow properties obtained of all the mud samples. The Rheograms of all the mud samples did not pass through the origin but intercepted on the viscosity axis of the plot and present a near-linear relationship. Their intercepts on the viscosity (cP) axis indicate the yield points, which is the force required to initiate flow of mud. As this force increases, flow will increase indicating plug to viscous flow transition. The slopes of the line give the plastic viscosity values of each mud sample.
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Rheological Properties: Yield Point, Plastic and Apparent Viscosity, Flow Index, Consistency Factor, and Gel strength

From the plot of Yield Point, lbs/100ft², Plastic viscosity, cP, Apparent viscosity, cP, Flow Index (n), Gel strength, lbs/100ft² (illustrated in the Figures 4) and Consistency factor (k) (illustrated in figure 5) of the mud samples, mud composed with Tigernut fiber of different particle sizes (212, 75, and 40 µm), sample C₁, C₂ and C₃ are slightly higher than the standard mud values but are within the specification value ranges (Table 3) for rheological parameters; this shows that Tigernut fibre can be a good viscosifying agent in the formulation of KCl Polymer Gel mud.

![Figure 4: Summary Comparison of the Rheological Properties of the Mud Samples (Charts show error bars with Standard Error)](image)

![Figure 5: Comparison of Consistency Factor, k, of the Mud Samples (Charts show error bars with Standard Error).](image)

viii. API Filtration

Figure 6 illustrates the API Filtration Volume (cc/ml) - results obtained for the various mud samples using API data in Table 2. Figure 6 shows that sample C₃, mud with 40µm Tigernut fiber had a closer filtrate end-value of 5.4cc/ml (at 30mins) against the filtrate end-value of 5.2cc/ml for sample A (Standard mud). This indicates that Sample C₃ has good filtration loss quality comparable to literature values of 5.2 – 5.8 cc/ml (Nmegbu & Bekee, 2014; QDrill, 2014, etc). Sample C₁ and C₂ had higher fluid loss values apparently due to the larger fiber particle sizes of 212 and 70 respectively, that was used for their formulation, and are therefore unsuitable as hole plugging agents. This close range value sample C₃ compared to standard ones, is due to the similarity of the materials (both the conventional and local materials are grainy) and the particle sizes at 40 µm. Sample C₃ concentration of filtrate value is also still within the value range given in the mud specification (Table 3), API Standards and literature reports (QDrill, 2014; Nmegbu & Bekee, 2014 and API RP 13D, 2003).

Therefore Tigernut fiber at 40µm, as a local waste material for mud filtration additives can be used to re-place PAC UL at the same concentration (ppb), in water based KCL Polymer Gel drilling mud.

![Figure 6: Plot Comparing the API Filtration Loss for the Mud Samples](image)

IV. CONCLUSIONS

Important mud properties of water-Based drilling fluid formulated using Tigernut fiber (waste) of different particle sizes, including Density, Rheological parameters, Sand and Chloride contents, pH, Alkalinity and API filtration volume had been tested for and the following conclusions made:

The Density of the mud samples C₁, C₂, and C₃ prepared with Tigernut fiber of particle sizes 212, 75 and 40 µm are quite close with values of 1.0925, 1.0978 and 1.0926 g/cm³ respectively compared to the value of 1.081 g/cm³ for the control Sample A. The values of the Effective viscosity (Marsh funnel) for samples C₁, C₂, and C₃ are 64.66, 47.96 and 41.89 cP respectively and are higher compared to the Sample A of 32.93 cP. The sand content in sample C₁, prepared with coarser fiber particle size (212µm) is double (100%) that if the control mud (sample A), while the mud (sample C₃) prepared with the least fiber particle size (40µm) is only higher by 25%. The Alkalinity is same for all the Tigernut fiber mud samples at 5.3ppg against 4.1ppg for the control mud. Similarly the Chloride content in the fiber mud samples are relatively the same and higher than the control sample value of 22ppg by 14.5%. The pH of the fiber mud samples are 5 – 10 % less alkaline than sample A with pH of 9.5.

Mud samples prepared with the least Tigernut fiber particle size (40µm) has the least fluid loss value within the API
specification range. These findings show that Tigernut fiber waste, especially with fine particle size less than or equal to 40µm, could serve as a potential good fluid loss control additive and also as rheological improver for the replacement of Polyanionic cellulose Ultra-Low (PAC UL) – a conventional additive – as a fluid loss control additive for the formulation of a Standard Water-Based Potassium Chloride (KCl) polymer Gel mud, that is environmentally friendly.

REFERENCES


