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Formulation of Water-Based Mud withWaste Tigernut Fibre as Additive

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***Abstract*— This study was conducted to assess the suitability of wasteTigernutfibre 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, C_1, C_2, and C_3)were preparedwith standard industrial KCl polymer gel. Sample A, which served as the control, was prepared with conventional PAC UL. SamplesC_1, C_2, and C_3were prepared with waste Tigernut fibre of particle sizes 212, 75, and 40 µm respectively. Rheological, API filtration, and selected physicochemical properties of samplesC_1, C_2, and C_3including 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 samplesC_1, C_2, and C_3 were slightly higher (albeit within the recommended values) than those of the control mud sample A. In terms of rheological properties, mud samples C_1, C_2, and C_3had better values compared with control mud sample A. The filtration volume for sample C_3 (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 C_1 and C_2 were totally out of range. These results have conclusively shown that waste Tigernut fibre can be a good substitute for conventional PAC UL additivein 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).

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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 isreadilyavailable 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 manufactures 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 conventionaladditivesin 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 controladditives 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 (Nuria *et al.*, 2014).However, if allowed to decay,it can constitutean environmentalnuisancebecause 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 fibreas an additive in mud formulation. Thus, investigations into the potential of recycling abundant waste Tigernut fibreas a useful additive in mud formulation would be a good waste-to-wealth exercise.The objective of the present studywas to investigatethe possibility of using waste Tigernut fibre as a substitute for conventional PAC UL additivein the formulation of high-quality standard water-based KCl polymer gel mudfor 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 andoven dried at 50^{o}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 KClpolymer 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. Fourmud samples wereformulated using data in Table 1 — one standard WBM KClpolymer gel mud (Sample A) and three others with waste Tigernut fibre of particle sizes 212, 75, and 40µm (Samples C_1, C_2, and C_3, 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 ofthe conventional PAC UL with waste Tigernut fibre of particle sizes 212, 75, and 40 µmat the same concentration to obtain samples C_1, C_2, and C_3as 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. Effectiveviscosity 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 stripsor pH paper). Chloride and alkalinity contents were determined by titration method. Rheological propertiesincluding apparent viscosity, gel strength, k (consistency index), n (flow index), plastic viscosity, and yield pointwere 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 appearancewith little or no significant change in colour. The formulated muds appeared creamyash in colour with light thickness for Sample A, whichflowed normally.But samples C_1, C_2, and C_3 had medium thickness and flowed slowly. Sample A had an indescribable odour but samples Cs 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 2shows the selected physicochemical properties of mud samples C_1, C_2, and C_3 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, C_1, C_2 and C_3 – Standard one Barrel (1bbl) of Water-Based KCl Polymer Gel Drilling Mud

S/N	Additives / Products				Conc. (ppb)	Functions	Mixing Time (mins)
	S_A	S_{C1}	S_{C2}	S_{C3}			
1	Water	✓	✓	✓	329.79	Based Fluid	-
2	Soda Ash	✓	✓	✓	0.10	Calcium ion removal	2
3	Caustic Soda	✓	✓	✓	0.10	Alkalinity control	2
4	Mi Gel / Bentonite	✓	✓	✓	8.0	Viscosifier	15
5	Potassium Chloride	✓	✓	✓	21.05	Inhibition control	10
6	Xamthan Gum	✓	✓	✓	1.2	Viscosifier	5
7	Poly PAC UL	Tigernut fiber (212µm)	Tigernut fiber (75 µm)	Tigernut fiber (40 µm)	1.00	Fluid loss control	3
8	Poly Sal	Poly Sal	Poly Sal	Poly Sal	2.00	Viscosifier and FLC	5
9	Calcium Carbonate Fine (10)	✓	✓	✓	15.46	Weighting material	2
10	Borax	✓	✓	✓	2	Preservative	1

Source: MI, 2016 Edited

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

Mud Properties	Sample A	Sample C_1	Sample C_2	Sample C_3
Density (g/cm^3)	1.081	1.093	1.098	1.093
(ppg)	9	9.10	9.11	9.10
Marsh (Eff.) Viscosity (cP)	32.93	64.66	47.96	41.89
Sand Content (%)	0.20	0.40	0.35	0.25
Ph	9.5	8.5	9.0	9.0
Chloride Content, ppb	22	25.2	25.2	25
Alkalinity Cc: Pom_1 (ppb)	5	7	7	7
Alkalinity Cc: Pom_2 (ppb)	4.05	5.25	5.25	5.25
API Filtration Volume (cc/ml)	5.2	39	11	5.4
Apparent Viscosity (cP)	18	19.5	20	20
Plastic Viscosity (cP)	10	11	11	11
Yield Point (lbs/100ft^2)	16	17	18	18
Gel Strength (lbs/100ft^2) @10secs	17	19	19	19
Gel Strength (lbs/100ft^2) @10mins	27	30	29	29
K – Con. In(lbs .Sn/100sqft)	717.55	726.04	815.45	715.06
n – Flow Index	0.468	0.478	0.465	0.469

i. Density

As can be seen in Figure 2a, all the muds formulated with local material (samples C_1, C_2, and C_3) are denser (1 – 1.6 g/cm^3) than the standard mud value of 1.081 g/cm^3. Sample C_2 prepared with 75-µmsize Tigernut fibre had the highest mud density of 1.6g/cm^{3}and would be useful for controlling formation pressure and maintaining wellbore stability. Overall, the densities ofthe prepared muds are within thespecified 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 March 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 viscositiesof samples C_1–C_3 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 C_1 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 C_2 and C_3.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 C_2 and C_3 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 2is 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 is advisable to still carryout 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 C_1, C_2 and C_3 indicating a change compared to the pH values reported above. The alkalinity content in samples C_1, C_2 and C_3 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 C_3 and 14.6% % for Samples C_1, and C_2. The increment in chloride content in mud samples C_1, C_2 and C_3 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 pre-sent in all the mud samples are within the specified range for a KCl Polymer Gel WBM.

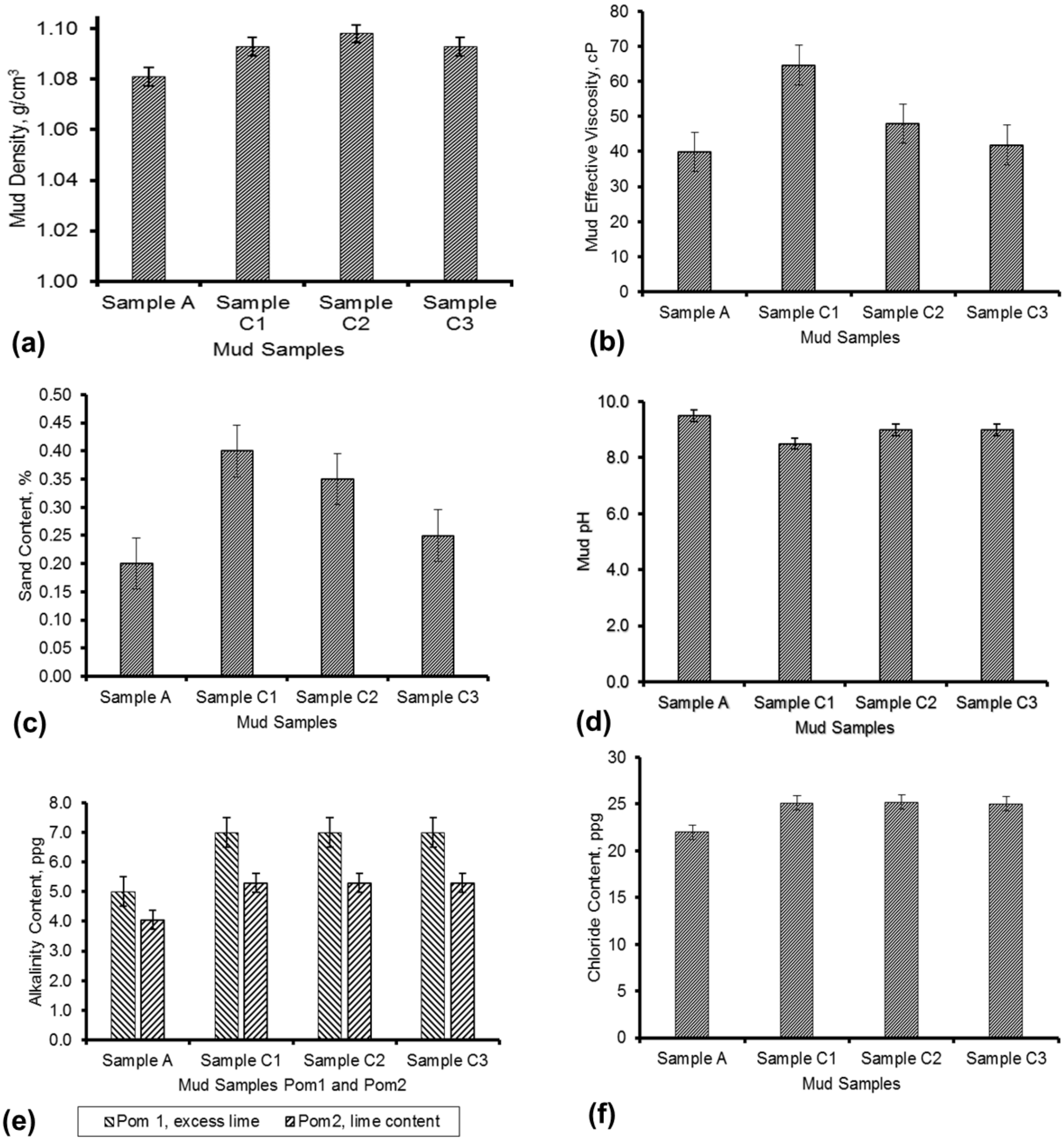

Figure 2: Comparison of the Physicochemical Properties of the Mud Samples: (a) Density, (b) Marsh Funnel (Effective) Viscosity, (c) Sand Content, (d) pH, (e) Alkalinity, and (f) Chloride Content (Charts show error bars with Standard Error)

vii. Mud Flow (Rheology)Properties

The flow (Rheology) properties of the various mud samples obtained in figure 3 is by plotting theviscosity (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.

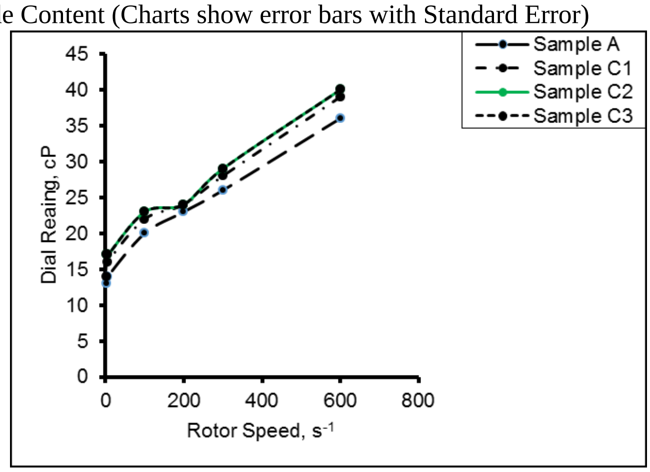

Figure 3: Plot of Dial Reading (θ) Vs Rotor Speed (S-1) Values for Mud Samples (A, C_1, C_2 and C_3)

Rheological Properties: **Yield Point, Plastic and Apparent Viscosity, Flow Index, Consistency Factor, and Gel strength**

From the plot of Yield Point, lbs/100ft^2, Plastic viscosity, cP, Apparent viscosity, cP, Flow Index (n), Gel strength, lbs/100ft^2 (illustrated in the Figures 4) andConsistency 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 C_1, C_2 and C_3 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 canbe a good viscosifying agent in the formulation of KCl Polymer Gel mud.

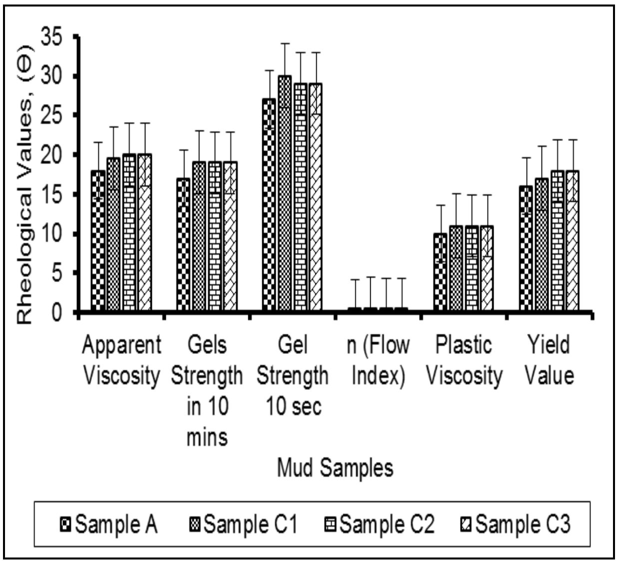

Figure 4: Summary Comparison of the Rheological Properties of the Mud Samples (Charts show error bars with Standard Error)

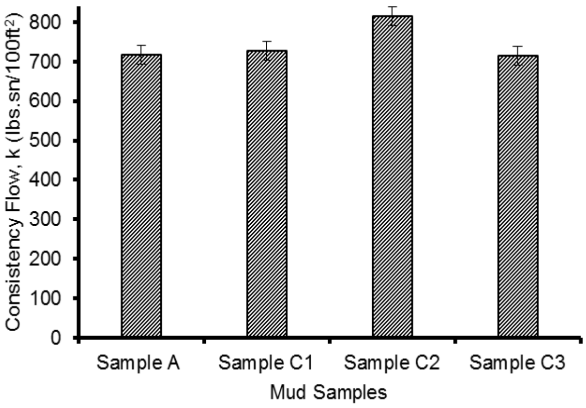

Figure 5: Comparison of Consistency Factor, k, of the Mud samples (Charts show error bars with Standard Error).

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 C_3, 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 C_3 has good filtration loss quality comparable to literature values of between 5.2 – 5.8 cc/ml (Nmegbu & Bekee, 2014; QDrill, 2014, etc). Sample C_1 and C_2 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 C_3 compared to standard ones, is due to the similarity of the materials (both the conventional and local materials are grainy) and the particle sizesat 40μm.Sample C_3 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.

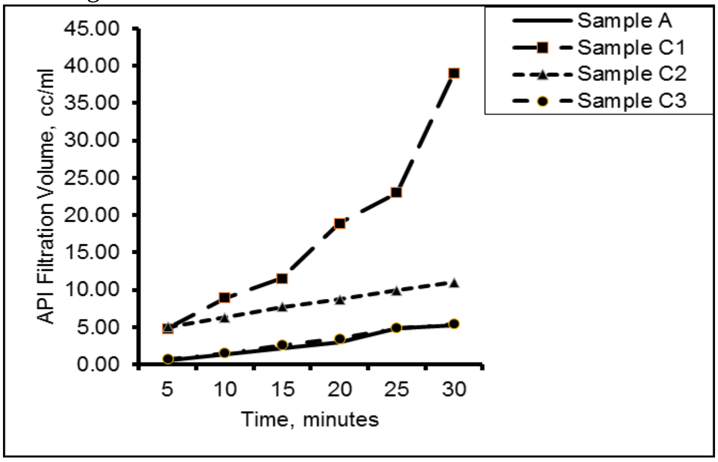

Figure 6: Plot Comparing the API Filtration Loss for the Mud Samples

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 C_1, C_2, and C_3 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 C_1, C_2, and C_3 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 C_1, prepared with coarser fiber particle size (212µm) is double (100%) that if the control mud (sample A), while the mud (sample C_3) 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 lees 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 Ul-tra-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.

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