American Journal of Chemical Engineering
2017; 5(3-1): 10-20
http://www.sciencepublishinggroup.com/j/ajche
doi: 10.11648/j.ajche.s.2017050301.12
ISSN: 2330-8605 (Print); ISSN: 2330-8613 (Online)

Application of Starches from Selected Local Cassava (*Manihot Exculenta Crantz)* as Drilling Mud Additives

Tubotamuno F. Harry[1, *], Koyejo Oduola[2], Falitat T. Ademiluyi[3], Ogbonna F. Joel[1]

[1]World Bank African Centre of Excellence for Oil Field Chemicals Research, University of Port Harcourt, Port Harcourt, Nigeria

[2]Department of Chemical Engineering, University of Port Harcourt, Port Harcourt, Nigeria

[3]Department of Chemical/Petrochemical Engineering, Rivers State University of Science and Technology, Port Harcourt, Nigeria

Email address:

tharryford@yahoo.com (T. F. Harry), koyejo.oduola@uniport.edu.ng (K. Oduola), ademuluyi@yahoo.com (F. T. Ademiluyi), ogbonna.joel@ipsng.org (O. F. Joel)

[*]Corresponding author

To cite this article:

Tubotamuno F. Harry, Koyejo Oduola, Falitat T. Ademiluyi, Ogbonna F. Joel. Application of Starches from Selected Local Cassava (*Manihot Exculenta Crantz*) as Drilling Mud Additives. *American Journal of Chemical Engineering*. Special Issue: Oil Field Chemicals and Petrochemicals. Vol. 5, No. 3-1, 2017, pp. 10-20. doi: 10.11648/j.ajche.s.2017050301.12

Received: March 30, 2017; **Accepted**: March 31, 2017; **Published**: April 11, 2017

Abstract: Selected local cassava (*Manihot esculenta Crantz*) starches were investigated as additives for water-based drilling mud. Cassava cultivars, TMS 30572, TMS 98/0505, TMS 98/0581, M98/0068, TMS 92/0057, TMS 96/1632, NR8082, TME 419, TMS 97/4779 and TMS 01/1412 were processed to starches and used for drilling mud treatment at 0.5, 1.0 and 2.0 percent. Polyanionic cellulose (PAC), xanthan gum (XG) and industrial starch-modified drilling muds served as controls. Physicochemical analysis of the starches showed significant differences in their properties. Viscosity and fluid loss profiles revealed that some of the local cassava starches had comparable performance with the commercial polymers. The optimal concentration of the industrial starch in the mud system was 0.5 percent, while that of the local starches were between 0.5 and 1.0 percent. PAC and XG performed best at 1.0 and 2.0 percent respectively. The highest viscosities were shown by muds treated with TMS 98/0581, XG, TMS 96/1632, M98/0068, TMS 92/0057 and PAC, arranged in decreasing order. And the lowest fluid losses were exhibited by muds with PAC, industrial starch, XG, TMS 98/0581 and M98/0068 in increasing order. Viscosity and fluid loss models as functions of cassava starch physicochemical properties were developed. Increase in starch content, amylose content, solubility index would readily increase viscosity, while high starch content, amylopectin content, solubility index and pH would reduce the fluid loss. Local starches from TMS 98/0581, TMS 96/1632 and M98/0068 and TMS 92/0057 could be used as a substitute in drilling mud as viscosity enhancers and fluid loss control agents in Nigeria.

Keywords: Local Cassava Starch, Drilling Fluid, Viscosity, Fluid Loss, Physicochemical Properties

1. Introduction

Rotary drilling takes place, with the application of drilling mud, which performs various functions. Some of the major functions are: controlling subsurface pressure; transportation of drill cuttings from the bottom of hole to the surface; and preventing the wellbore walls from collapsing [1]. Drilling fluid needs additive to enable them to fulfil specific requirements [2]. Polymer additives have been some of the earliest and most common additives for drilling mud. The functions of polymers on drilling fluids are viscosity, deflocculant (thinners), flocculants, surfactant and fluid loss additives.

The functions of starch are attributed to the structure of the polymer, which is based on their molecular weight and reactive group [3]. Corn starch, the most widely used additive, was the first polymer used for bentonite drilling mud in 1937 to control filtration characteristics [4]. Starch is mainly used as effective colloids, which decreases the filtration of all kinds of water dispersing drilling fluids and increasing the viscosity. The starch action is caused by its swelling capacity and increasing of its volume due to free water absorption [5]. Swelled starch becomes a component of filtrating deposit to form polymer-clayey mixture. Starch also causes increase of rheological properties of drilling fluids [6]. Starch grains contain amylose and amylopectin polysaccharides [7] as shown in Figures 1 and 2 respectively. The amylose enables starch to exhibit fluid loss control properties. Investigation [8] revealed that the source of starch could also vary its performance in drilling fluid. It was reported [9] that the difference in the performance of the starches was their physicochemical properties. Nigerian Cassava starches were also studied as potential additives for the drilling mud [6, 10-15].

Cassava starch is a polysaccharide polymer. Cassava *(Manihot esculenta Crantz)* is a root crop cultivated and consumed as a staple food in most developing countries; however there are conscious efforts to utilize cassava for non-food industrial raw material [16]. In 2011, cassava root production in the world was estimated at 252 million tonnes [17] and Nigeria is the world's largest producer with production of 45 million metric tonnes in 2008 [18]. There are various varieties of cassava that are grown. Over forty improved cassava mosaic disease-resistant (CMD-resistant) varieties were developed in Nigeria [19]. Several varieties of cassava grown in Nigeria were investigated for physicochemical, functional and pasting properties as well as granule morphology of starches [19-21]. Local cassava starches have potentials for a wide end use; including drilling operation based on the significantly different physicochemical properties they exhibit [22].

Previous studies with less elaborate investigations showed that local cassava starch could be used as additive to drilling fluid, even though some works did not specify the species of local cassava used. This work was carried out to undertake extensive research using selected cultivars of cassava to establish a bench line for use as local substitute as drilling mud additive.

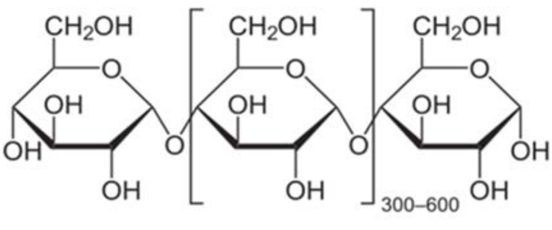

Figure 1. *Structure of amylose.*

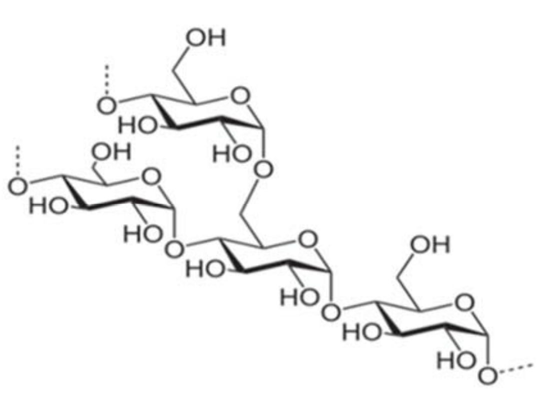

Figure 2. *Structure of amylopectin.*

2. Materials and Methods

Ten cassava cultivars were procured from National Root Crop Research Institute (NRCRI), Umudike, Nigeria. The cassava clones are TMS 30572, TMS 98/0505, TMS 98/0581, M98/0068, TMS 92/0057, TMS 96/1632, NR8082, TME 419, TMS 97/4779 and TMS 01/1412. The cultivars are white root, except TMS 01/1412, which is a yellow root [23]. The cassava tubers were aged 11 to 12 months after planting and freshly harvested. Cassava loses some of its vital physicochemical properties when there is delayed processing [24]. Starch extraction was conducted by methods described by Eke *et al*. [19]. Three commercial drilling polymers, polyanionic cellulose (PAC), xanthan gum (XG) and industrial starch (IS) were provided by POCEMA Limited, Nigeria.

2.1. Physicochemical Properties Determination

Some properties of the local cassava starches and the industrial starch were determined. Starch content, amylose content, amylopectin content, water absorption capacity, swelling power and solubility index were determined by methods described by Onitilo *et al*. [20]. The pH determination was by the method used by Egun and Abah [12].

2.2. Drilling Mud Preparation and Testing

API 13A [25] standard procedures were employed in mud preparation and testing. 22.5g of bentonite and 0.5 percent weight of bentonite of the polymer was weighed with “A and D” electronic weighing balance (model FX-5000i) and added to 350ml of distilled water in a beaker while stirring with Hamilton Beach mixer. The suspension was stirred for 5 minutes. The beaker was removed from the mixer and the sides were scrapped with spatula to dislodge bentonite and polymer clinging to the walls of the beaker. The mixer was further used to stir the suspension for another 15 minutes. The spatula was used to dislodge the solids from the walls of the beaker every 5 minutes. A total of 20 minutes was used for stirring. Polymer concentrations of 1.0 and 2.0 percent weight of bentonite were also prepared in a similar way. The mud types in this work are contained in Table 1.

Mud Rheology Test: The bentonite-polymer suspensions were transferred into the viscometer cup and subjected to shear in model 800 OFITE 8-speed viscometer. The shear was done at 600, 300, 200, 100, 60, 30, 6, and 3 rpm respectively. At each rotation speed the dial reading was recorded when the speed of rotation was stabilized. The rheology test was conducted for each sample at 80°F, 120°F, 150°F and 190°F. Bentonite-polymer suspensions were aged in a covered container at room temperature for 16 hours. After aging, each of the suspensions was shaken and poured into a mixer container and stirred for 5 minutes and then subjected to rheology tests at 80°F, 120°F, 150°F and 190°F. Measurement of the rheological properties of drilling fluid is used to determine fictional pressure losses; determine the ability of the mud to lift cuttings to the surface; and analyze the contamination of the mud by solids, chemicals and temperature [26].

Statistical software, IBM SPSS 23, was used to analyze the viscosity data from the rheological tests. Tukey HSD (honest significant difference) was used to separate the viscosity means based on viscometer speed, concentration and temperature. SPSS was also used in analyzing data for the physicochemical properties of the starches.

Mud Filtration Test: Filtration test for mud samples before aging was performed at 80°F using OFITE filtration test equipment. The press cell was inspected to ensure it was dry and none of the gasket was worn. The suspension was poured into the filter press cell to about 0.5in to the top of the cell. The press filter was completely assemble and placed in the frame. The relief valve was closed and a container was placed under the drain tube. Pressure of 100±5psi was supplied from a cartridge containing nitrogen. The liquid collected after 7.5 minutes was discarded. A graduated cylinder was placed to collect filtrate between 7.5 to 30 minutes. The filtrate volume was calculated as twice the filtrate collected.

Table 1. *Mud and polymer additive types.*

S/N	Mud type	Polymer type/source	Source name
1	Mud LA	TMS 30572	Local cassava starch
2	Mud LB	TMS 98/0505	Local cassava starch
3	Mud LC	TMS 98/0581	Local cassava starch
4	Mud LD	M98/0068	Local cassava starch
5	Mud LE	TMS 92/0057	Local cassava starch
6	Mud LF	TMS 96/1632	Local cassava starch
7	Mud LG	NR 8082	Local cassava starch
8	Mud LH	TME 419	Local cassava starch
9	Mud LI	TMS 97/4779	Local cassava starch
10	Mud LJ	TMS 01/1412	Local cassava starch
11	Mud FA	PAC	Polyanionic cellulose (control)
12	Mud FB	XG	Xanthan gum (control)
13	Mud FC	IS	Industrial Starch (control)

2.3. Model Development for Viscosity and Fluid Loss

Regression models were developed for viscosities and fluid loss of muds treated with the local cassava starches. Viscosity (at 600 rpm) and fluid loss were expressed as functions of concentration, temperature and some physicochemical properties of the cassava starches. The multivariate regression equations were expressed as [27]:

$$y_i = \beta_{0i} + \sum \beta_i x_i + \sum \beta_{ii} x_i^2 + \cdots + \sum \beta_{ni} x_i^n \quad (1)$$

Where,

y_i represent viscosity (centipoise) or fluid loss (mililitre) for each mud system treated with local cassava starch.

β_{0i} is a constant for viscosity (centipoise) or fluid loss (mililitre) equation.

x_i (in percent) represent the values of starch content, amylose content, amylopectin content, water absorption capacity, swelling power, solubility index and pH respectively for each of the local cassava starch.

$\beta_i, \beta_{ii} \ldots \beta_{ni}$ represent the coefficients (in centipoise or mililitre) of $x_i, x_i^2 \ldots x_i^n$

The regression model equations for viscosities (before and after aging) and fluid loss were developed using statistic software SPSS 23. The correlation was analyzed for the independent variables. To avoid high collinearity in the coefficients, the values of the independent variables were mean centred [28]. That implies to calculate the mean of the predictor values and subtract the mean from each of the values. Linear, quadratic and cubic terms were applied to the independent variables as expressed in equation:

$$Y_i = \beta_{0i} + \sum \beta_i X_i + \sum \beta_{ii} X_i^2 + \sum \beta_{iii} X_i^3 \quad (2)$$

Where,

Y - represents viscosity (centipoise) or fluid loss (mililitre) for mud system treated with local cassava starch.

X_i represents centred parameters such as concentration, temperature, starch content, solubility index, amylose content, water absorption capacity, swelling power, pH, and amylopectin.

3. Results and Discussion

3.1. Physicochemical Properties of Starches

Some physicochemical properties of the ten selected local cassava starches and the industrial starch are presented in Table 2. The starch contents of the selected local cassava starches ranged between 74.82 ± 0.02 and 87.72 ± 0.01 percent. TMS 01/1412, β-carotene cassava species, had the lowest starch content. This is similar to previous work [29] that revealed that β-carotene cassava species had lower starch content than TMS 30572, a white cassava root. Cassava starch content ranging from 60.34 to 91.78 percent was previously reported [19]. The starch content of the industrial starch was 94.40 ± 0.02 percent, and differs significantly with that of the local cassava starches. The amylose contents of the starches were significantly different. The lowest was that of TMS 98/0581 at 22.45 ± 0.02 percent, while the highest was that of industrial starch (26.40 + 0.10 percent). Amylose contents of cassava starches between 15 to 30 percent were previously reported [16, 20, 24]. TMS 01/1412 had the highest amylose content of the cassava starches at 25.41 ± 0.01 percent. β-carotene cassava varieties had higher amylose content than the check clones in a set of report [16]. The amylopectin is a complement of the amylose content and it values among the starches differs significantly. Filtration property of drilling mud is enhanced by effective swelling [9] and from previous report [3], swelling is a property of amylopectin molecule. The water absorption capacities of TMS 01/1412, TME 419, M98/0068 and the industrial starch were significantly different from one another and with the remaining of the starches. The industrial starch had the lowest water absorption capacity at 1.60 ± 0.10 g/g. the highest was that of M98/0068 at 1.98 + 0.01g/g. TMS 30572, TMS 98/0505, TMS 98/0581, TMS 92/0057, TMS 96/1632 and NR8082 water absorption capacities were not significantly different at p>0.05. The water absorption capacities of TMS 92/0057, TMS 96/1632 and NR 8082 were not significantly different. The lowest value of swelling power was that of the industrial starch at 6.30 ± 0.10 percent and it was significantly different from the cassava starches. TMS 01/1412 had the highest swelling power (12.41 ± 0.02 percent), which was not significantly different from that of NR 8082, TMS 97/4779 and TMS 98/0505. The swelling powers of TMS 30572, TMS 98/0581, TMS 96/1632 and M98/0068 were not significantly different. Swelling powers of cassava starches between 4 and 18 percent were reported [19, 24]. Solubility indices of all the starches were significantly different. The solubility index of the industrial starch was the highest at 7.17 ± 0.15 percent. The lowest value of solubility index was that of TMS 01/1412 at 0.80 ± 0.01 percent. Eke *et al.* [19] reported solubility index ranging from 2.07 to 26.36 percent, while Onitilo *et al*. [20] report ranged from 1.03 to 2.10 percent. The pH of the starches ranged from 5.51 ± 0.01 to 6.37 ± 0.06 percent, and they were significantly different from one another at p<0.05. Previous reports [30, 31] had pH range between 5.07 and 8.39. There are significant properties differences among the local cassava starches and with the industrial starch.

Table 2. *Physicochemical properties of local cassava starches and an industrial starch.*

Starch	Starch content (%)	Amylose content (%)	Amylopectin content (%)	Water absorption capacity (g/g)	Swelling power (%)	Solubility index (%)	pH
TMS 30572	86.12 ± 0.02	23.81 ± 0.01^{g}	76.19 ± 0.01^{d}	$1.78 \pm 0.01^{d,e}$	$9.01 \pm 0.01^{c,d,e}$	2.21 ± 0.02^{f}	6.21 ± 0.01^{b}
TMS 98/0505	77.10 ± 0.02	24.28 ± 0.01^{f}	75.72 ± 0.01^{e}	$1.81 \pm 0.01^{c,d,e}$	$11.51 \pm 0.01^{a,b}$	1.12 ± 0.01^{i}	5.73 ± 0.02^{e}
TMS 98/0581*	80.46 ± 0.01	22.45 ± 0.02^{j}	77.55 ± 0.02^{a}	$1.80 \pm 0.01^{c,d,e}$	$9.21 \pm 0.01^{c,d,e}$	3.12 ± 0.03^{d}	6.10 ± 0.02^{c}
M98/0068*	81.25 ± 0.01	23.73 ± 0.02^{h}	76.27 ± 0.02^{c}	1.98 ± 0.01^{b}	$10.51 \pm 0.01^{b,c}$	1.31 ± 0.01^{h}	6.24 ± 0.01^{b}
TMS 92/0057	87.72 ± 0.01	25.06 ± 0.02^{d}	74.94 ± 0.02^{g}	$1.84 \pm 0.01^{c,d}$	$8.12 \pm 0.01^{e,f}$	3.31 ± 0.01^{b}	6.13 ± 0.01^{c}
TMS 96/1632	78.44 ± 0.01	24.92 ± 0.01^{e}	75.08 ± 0.02^{f}	$1.86 \pm 0.01^{c,d}$	$9.81 \pm 0.02^{c,d}$	1.46 ± 0.01^{g}	5.81 ± 0.01^{d}
NR 8082	81.74 ± 0.02	25.21 ± 0.01^{c}	74.79 ± 0.01^{h}	$1.82 \pm 0.01^{c,d}$	12.01 ± 0.01^{a}	1.08 ± 0.01^{j}	6.11 ± 0.01^{c}
TME 419	76.11 ± 0.01	23.61 ± 0.01^{i}	76.39 ± 0.01^{b}	2.02 ± 0.01^{a}	$8.14 \pm 0.01^{e,f}$	3.21 ± 0.01^{c}	5.59 ± 0.02^{f}
TMS 97/4779	86.42 ± 0.02	23.85 ± 0.02^{g}	76.15 ± 0.02^{d}	1.88 ± 0.01^{c}	$8.61 \pm 0.02^{d,e}$	2.80 ± 0.01^{e}	6.14 ± 0.01^{c}
TMS 01/1412	74.82 ± 0.02	25.41 ± 0.01^{b}	74.59 ± 0.01^{i}	1.74 ± 0.02^{e}	12.41 ± 0.02^{a}	0.80 ± 0.01^{k}	5.51 ± 0.01^{g}
Industrial starch*	94.40 ± 0.02	26.40 ± 0.10^{a}	73.70 ± 0.02^{j}	1.60 ± 0.10^{f}	6.30 ± 0.10^{g}	7.17 ± 0.15^{a}	6.37 ± 0.06^{a}

Means in the same column with similar superscript are not significantly different at p>0.05

3.2. Viscosities Profiles of Bentonite-Polymer Muds at 600 rpm

It was specified that the minimum viscosity required for bentonite suspension at 600 rpm is 30 cP [25]. The viscosities at 600 rpm before and after aging for bentonite mud samples with different concentrations of polymers and at various temperatures are presented in Figures 3 to 8. At 0.5 percent polymer concentrations in bentonite mud before aging as shown in Figure 3, the statistical mean viscosities for all temperatures for the three commercial polymer based muds (FA, FB and FC) and five local cassava starch based muds (LC, LD, LE, LF, LG), ranging between 31 and 43 cP, were above the API minimum requirement. Mud samples LA, LB, LH, LI and LJ viscosities (ranging between 19 and 27) were below the API minimum requirement. For 0.5 percent polymer concentration in bentonite mud after aging (see Figure 4), the mean viscosities for mud samples above the API minimum requirement ranges from 33 to 45cP for mud samples LA, LB, LC, LD, LE, LF, LG, FA, FB and FC. Mud samples LH, LI and LJ have mean viscosities, ranging between 22 and 26cP, below the API minimum requirement. For 1.0 percent polymer, as shown in Figures 5 and 6, the mean viscosities for muds LB, LH, LI, LJ and FC were lower than the API minimum, for both before aging (ranging from 20 to 25cP) and after aging (ranging from 23 to 29cP), while the rest of the samples have mean viscosities above API minimum. At 2.0 percent polymer concentration, the mean viscosities above API minimum requirement for mud samples before aging ranged from 31 to 57cP (see Figure 7). The mud samples were LC, LD, LE, LF, LG, LH, FA and FB. The rest had mean viscosities below the API minimum requirement. In Figure 8, after mud aging, with the exception of LH, LI and LJ, all other muds were above API minimum.

The overall statistical analysis of viscosities of bentonite-polymer muds before aging at 600 rpm for 80°F, 120°F 150°F and 190°F; and polymer concentrations at 0.5, 1.0 and 2.0 percent indicated that Muds LB, LC, LE, LF, LG, FA, FB and FC have mean viscosities above the API required minimum at 30 cP. Muds LA, LH, LI and LJ have their mean viscosities below the API minimum. Mud FA (46.42 ± 8.72cP), FB (38.67 ± 6.90cP), LC (37.00 ± 2.94cP) and LD (35.67 ± 3.20cP) had the highest average viscosities. However, after aging the viscosities of all the mud types were above the API minimum except for Muds LH, LI and LJ. The highest mean viscosities were Mud FB (45.67 ± 7.36cP), LC (43.17 ± 1.72cP), LF (41.50 ± 1.78cP) and LD (41.00 ± 2.54cP). The viscosities of the some of the muds treated with local cassava starches were higher than that treated with the industrial starch and comparable with PAC and XG.

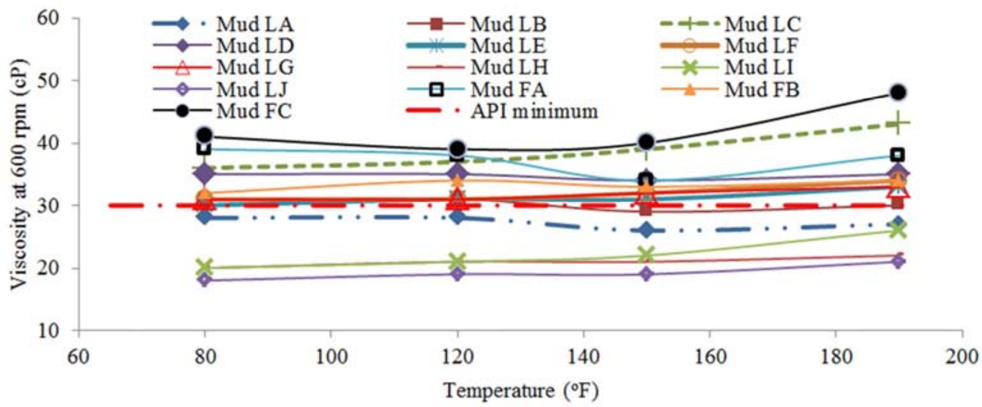

Figure 3. *Viscosity profiles at 600 rpm of bentonite muds with 0.5% polymer before aging.*

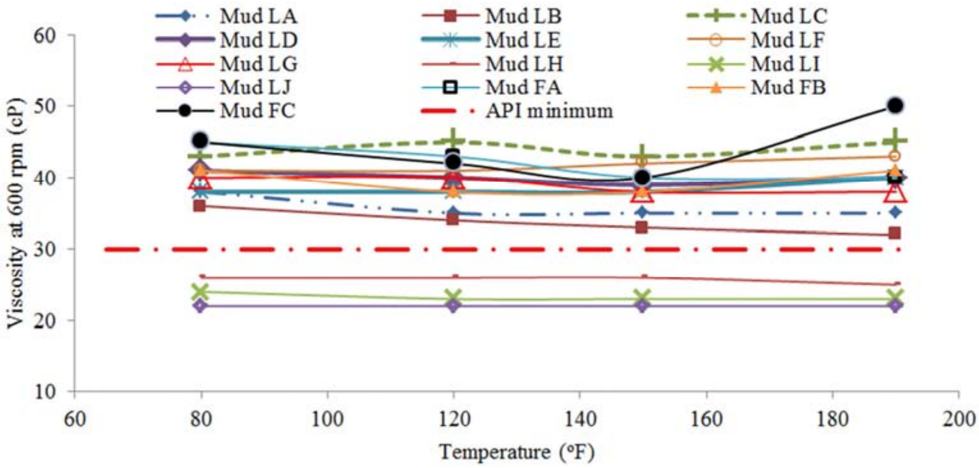

Figure 4. *Viscosity profiles at 600 rpm of bentonite muds with 0.5% polymer after aging.*

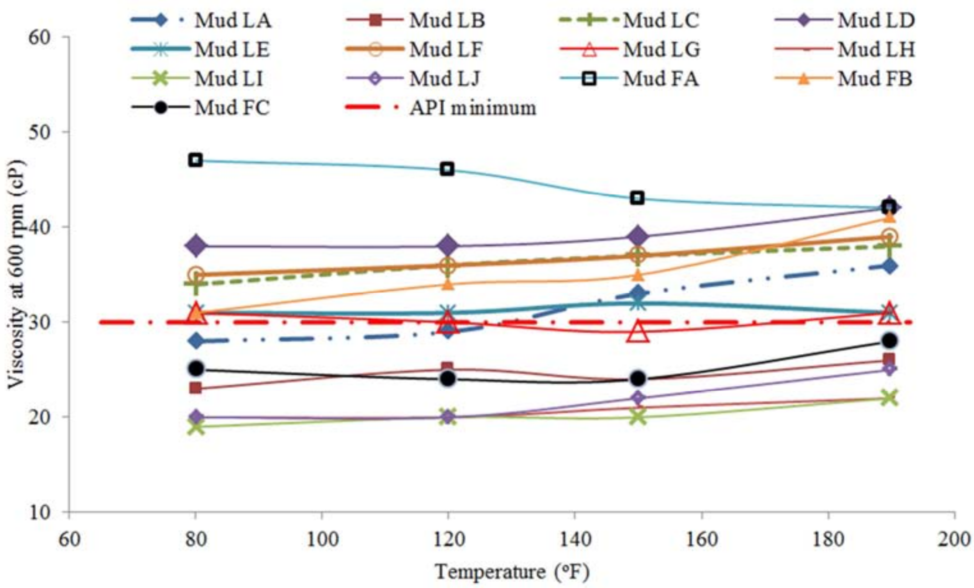

Figure 5. *Viscosity profiles at 600 rpm of bentonite muds with 1.0% polymer before aging.*

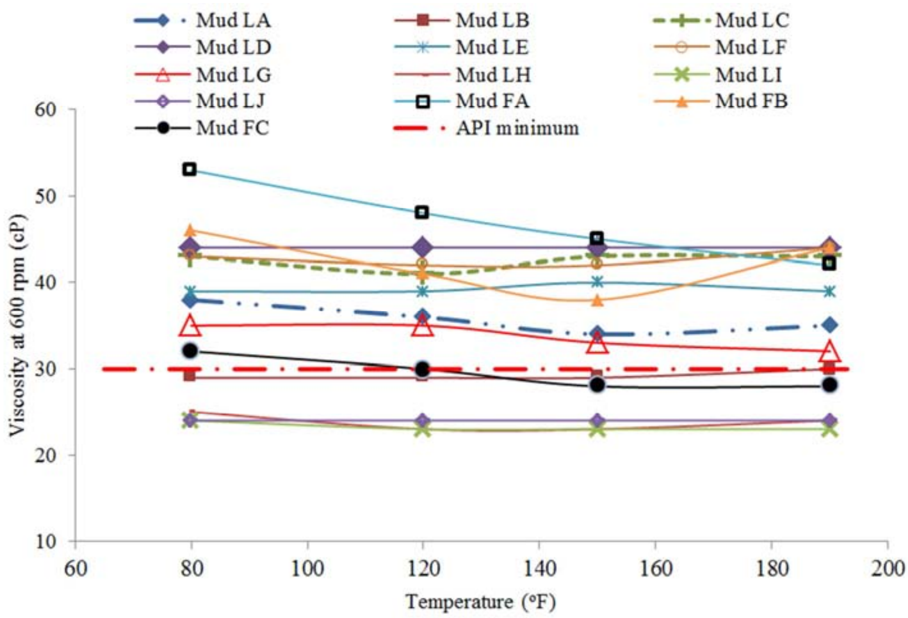

Figure 6. Viscosity profiles at 600 rpm of bentonite muds with 1.0% polymer after aging.

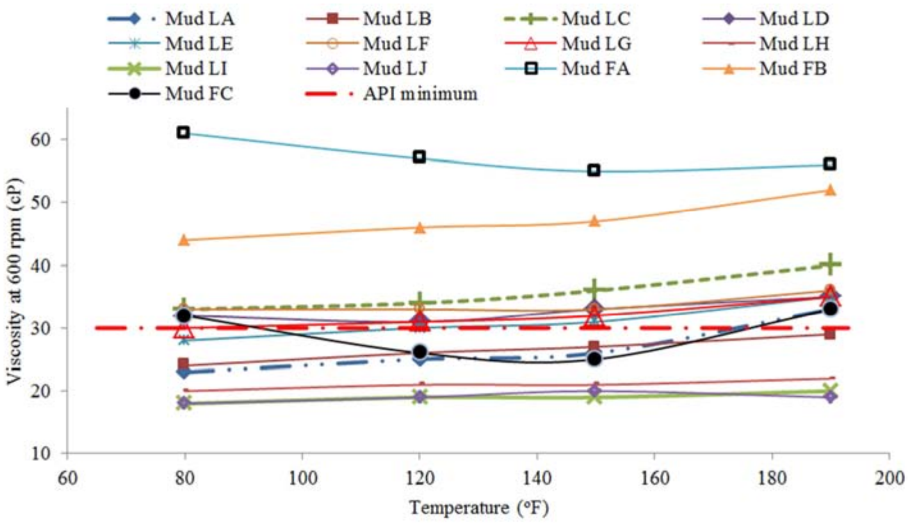

Figure 7. Viscosity profiles at 600 rpm of bentonite muds with 2.0% polymer before aging.

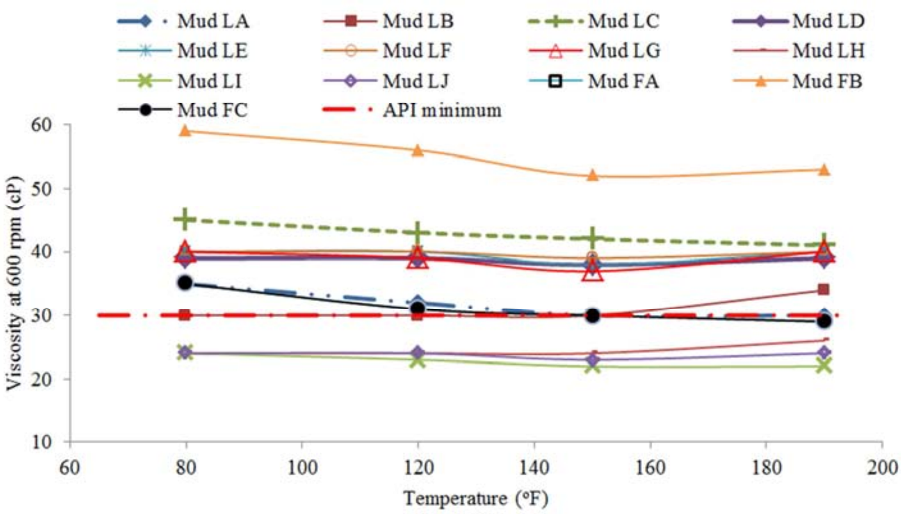

Figure 8. Viscosity profiles at 600 rpm of bentonite muds with 2.0% polymer after aging.

3.3. Effect of Speed on Viscosity of Bentonite Mud

For all the mud samples before aging, viscosity increased with increase in speed, which is in agreement with previous report [6]. Increased shearing increase swelling, thus increases the viscosity [3]. The viscosities for each speed were significantly different ($p<0.05$), except for speeds at 3 and 6 rpm. Mud FA had the highest viscosity (46.42 ± 8.72cp) at 600 rpm and the lowest viscosity (10.33 ± 4.03cP) at 3 rpm. The viscosities of muds after 16 hours of aging were higher at different rotational speed than the viscosities before aging, except for muds LH and FA. Muds LC had the highest viscosities at 3 rpm before (17.67 ± 3.94cP) and after (20.83 ± 2.08cP) aging.

3.4. Effect of Polymer Concentration on Viscosity of Bentonite Mud

The mean viscosities for bentonite muds treated with local cassava starches and commercial polymers before and after aging are shown in Figures 9 and 10. The highest viscosity before aging was Mud FA with 2.0 percent polymer. This was followed by Mud FC with 0.5 percent polymer, Mud FB with 2.0 percent polymer and Mud LC with 0.5 percent polymer. Mud FA and FB viscosities increased with increase in polymer concentration. Mud FC (with industrial starch) viscosity at 0.5 percent polymer concentration was good, but poor at 1.0 and 2.0 percent polymer. This was similar to the maximum performance of potato starch modified drilling mud at 0.6 percent reported [32]. Like Mud FC, Mud LC (with TMS 98/0581 polymer) performed best at 0.5 percent polymer concentration, though at 1.0 and 2.0 concentrations the performances were not poor compared to that of Mud FC. Muds LI and LJ had relatively low viscosities at the three polymer concentrations. For Muds LA, LD, LE, LF and LJ, the best concentrations were 1.0 percent, while 0.5 percent was the best concentrations for Muds LB, LC, LI and FC. 2.0 percent polymer concentration was best concentration for Muds FC, FB, LH and LG. While some cassava starch treated mud systems increased in viscosity with increase in starch concentration, which is in line with previous work [10], some cassava starch species have optimum concentration, hence decreased in performance with increase in concentration.

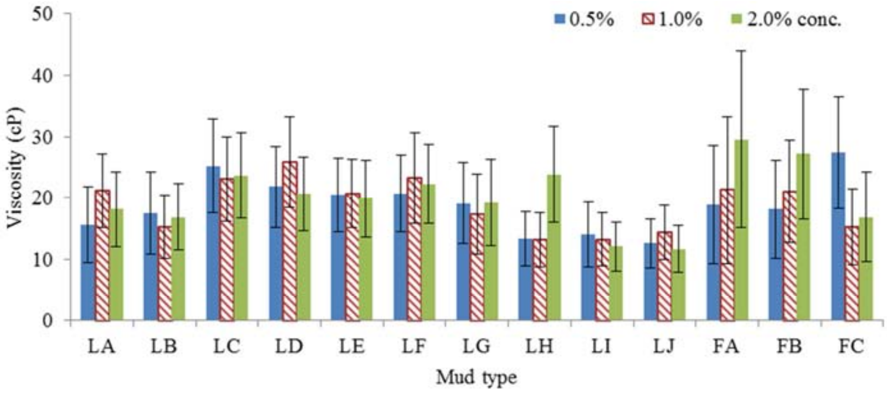

Figure 9. *Effects of polymer concentration on bentonite mud before aging.*

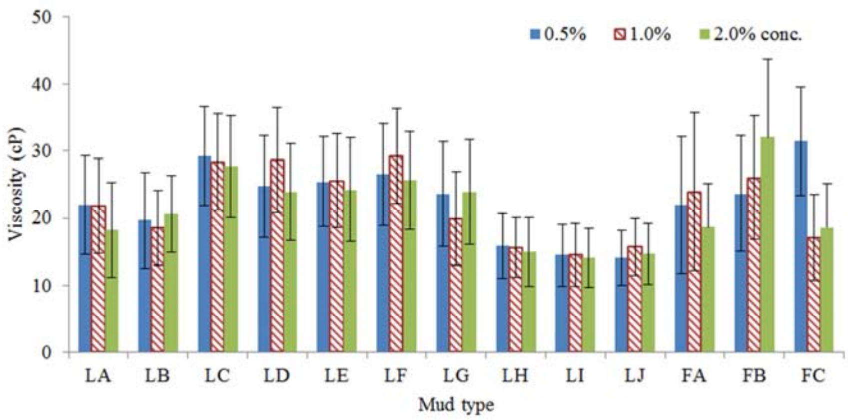

Figure 10. *Effects of polymer concentration on bentonite mud after aging.*

The highest viscosity after 16 hours aging was Mud FB with 2.0 percent polymer, followed by Mud FC with 0.5 percent polymer and Mud LC with 0.5 percent polymer. Like the mean viscosity before aging, Mud FC with polymer concentration above 0.5 percent was relatively low. Though there was reduction in mean viscosities of the Mud LC with increase in concentration, the range was low. The performance of Mud LH, LI and LJ were comparably low, just like they were, before aging. Muds LA, LC, LH and FC were at their best at 0.5 percent polymer presence. Muds LD, LE, LF, LI, LJ and FC were at their best at 1.0 percent polymer concentration, while Muds LB, LG and FB were at their best at 2.0 percent. From the result, for both before and after mud aging, the optimum concentrations of the polymers as bentonite mud viscosifier were 0.5 percent (industrial starch), 1.0 percent (PAC), and 2.0 percent (XG). However, for the local cassava starches optimum concentration ranged between 0.5 and 1.0 percent.

3.5. Effect of Temperature on Viscosity of Bentonite-Polymer Mud

For muds treated with the local cassava polymers and the commercial polymers, viscosities increased with increase in temperature. Most of the mud viscosity profiles in Figures 3 to 8 showed slight drops in viscosities at 150°F, then an increase at 190°F. The starch granule hydrates and swells when heated in water. As the temperature increases, the double helices hydrogen bond in the starch gets ruptured, such that the starch molecule lost its crystallinity and continues to swell [33]. This accounted for the impressions in viscosity at about the 150°F. Previous report [15] also noted a change in viscosity profile of mud enhanced by starches at temperatures above 62^{o}C (143.6°F). This is known as gelatinization temperature. Omojala *et al*. [34] stipulated that gelatinization causes viscosity to increase. After gelatinization, starch continues to swell in water and increase the weight. The polymer weight gain contributed to the viscosity of the bentonite drilling fluid. The local starch modified muds, LC, LD and LF exhibited better performance than two of the controls, Mud FA and Mud FC.

3.6. Effect of Mud Aging on Viscosity of Bentonite-Polymer Mud

The aging of mud has effect on the viscosity of the mud. This could be due to the change in chemical properties of the composition of the mud. Except for Mud FA, the viscosities for all the mud types increased after 16 hours aging, which was in agreement with previous report [15] on mud modified with starches at 16 hours aging. The molecular weight or polymer chain length was reported to determine the affect fluid viscosity [5]. The higher the molecular weight the more viscous the fluid. Polymer molecules hydrate and swell in water with time. Hydrated molecules add to the polymer weight as well as the viscosity of the fluid. Starch and cellulose base polymers in solution decompose with time, due to breaking apart of the molecules which lowers the molecular weight. In such case the viscosity is lowered. PAC degraded performance in bentonite mud after 16 hours aging was as a result of decomposition of the molecule.

3.7. Effect of Polymer on Fluid Loss

API maximum requirement for fluid loss for bentonite mud is 15ml [25]. Bentonite mud used for this study had a fluid loss of 18ml, which is above the API maximum. The polymers, PAC (Mud FA), XG (Mud FB), industrial starch (Mud FC), TMS 98/0581 (Mud LC) and M98/0068 (Mud LD) reduced the fluid loss of bentonite from 18ml to 15ml and below at different polymer concentrations (0.5, 1.0 and 2.0 percent) as shown in Figure 11. At 0.5 percent polymer concentration, XG (Mud FB) and industrial starch (Mud FC) reduced fluid loss by 16.67 percent. XG (Mud FB) performance in fluid loss control sharply decreased with increase in concentration from 1.0 to 2.0 percent. Mud performance was best at 1.0 percent polymer concentration for Mud FA (11ml fluid loss), Mud FC (12.2ml) and Mud LD (14ml). Fluid losses for Mud LC decreased with increase in concentration - 0.5 percent (14.4ml), 1.0 percent (14.2ml) and 2.0 percent, (14.0ml). TMS 96/1632 polymer (Mud LF) only reduced bentonite fluid loss to just above the API maximum. NR8082 (Mud LG) and TME 419 (Mud LH) had little impact on enhancing the fluid loss property of bentonite.

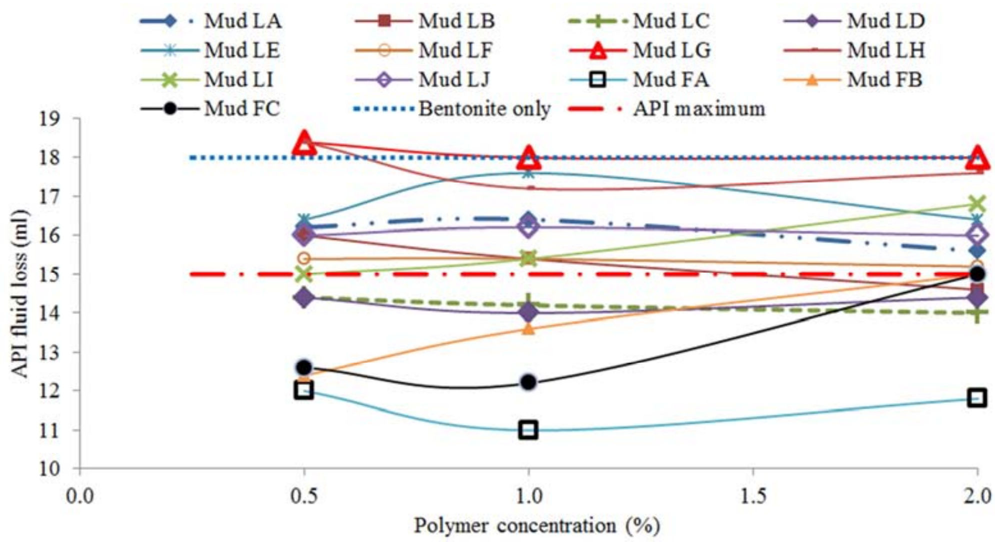

Figure 11. *API fluid loss of bentonite muds at different polymer concentrations.*

3.8. Mud Viscosity and Fluid Loss Models

3.8.1. Mud Viscosity Model

The model equations for viscosity of bentonite mud with local cassava polymer with a satisfactory goodness of fit and statistically significant coefficients are expressed as:

Before aging,

$$Y = 27.79 - 0.84X_1 + 0.03X_2 + 0.98X_3 - 6.63X_4 + 3.26X_5 - 52.67X_6 + 12.54X_4^2 + 900.96X_6^2 - 5.03X_7^2 - 106.22X_8^2 + 2.38X_9^2 \quad (3)$$

$R^2 = 0.910$, R^2 (adjusted) = 0.900, $p<0.01$. All predictors coefficients were significant at $p<0.01$.

After aging,

$$Y = 34.04 - 0.89X_1 + 1.21X_3 - 7.56X_4 + 6.01X_5 - 75.87X_6 + 13.14X_4^2 + 1432.5X_6^2 - 5.41X_7^2 - 179.17X_8^2 + 3.64X_9^2 \quad (4)$$

$R^2 = 0.963$, R^2 (adjusted) = 0.960, $p<0.01$. All predictors coefficients were significant at $p<0.01$. The effect of temperature was not significant to the viscosity model after aging.

Where, Y - represents viscosity (centipoise) or fluid loss (mililitre) for mud system treated with local cassava starch. X_1 represents centred concentration, X_2 represents centred temperature, X_3 represents centred starch content, X_4 represents centred solubility index, X_5 represents centred amylose content, X_6 represents centred water absorption capacity, X_7 represents centred swelling power, X_8 represents centred pH, X_9 represents centred amylopectin

From the equations (3) and (4), the increase in viscosity mostly depends on the increase in temperature, starch content, amylose content, solubility index and amylopectin of the local cassava starches. However, increasing the starch concentration, water absorption and swelling power would decrease the viscosity. It was stated in previous report [35] that increase in pH increased the rheological properties of mud systems. These properties are also critical to the viscosity of the mud, because when they are below certain values, the viscosity of the mud would depreciate. It was postulated [3] that non-Newtonian behaviour increased with increase in starch content or amylose content.

3.8.2. Mud Fluid Loss Model

The model equation for fluid losses of bentonite muds at 80°F in terms of concentration and the cassava starch physicochemical property is expressed as:

$$Y = 16.25 - 0.13X_1 - 1.13X_3 + 1.16X_4 - 0.75X_9 - 2.4X_4^2 + 103.29X_6^2 + 1.09X_7^2 - 20.54X_8^2 \quad (5)$$

$R^2 = 0.884$, R^2 (adjusted) = 0.840, $p<0.01$. Except for concentration, all the predictors coefficients were significant at $p<0.01$.

From equation 5, the fluid loss would decrease with increase in starch content, amylopectin content, solubility index and pH respectively. High WAC and swelling power increases the fluid loss in mud formulated with local cassava starch. Though amylose content also contributed to bentonite mud filtration property, previous report [9] revealed that the API fluid loss of mud with 25 percent amylose content starch was lower than 0, 50 and 75 percent amylose content. The improvement of filtration property of the starch was attributed to effective swelling. Swelling is a property of amylopectin molecule [3]. Ademiluyi *et al.* [6] observed the influence of amylose content and water absorption capacity of cassava starch on the viscosity and filtration property of drilling mud, however, a combination of the physicochemical properties of cassava starch contributed to their suitability as drilling fluid additive.

4. Conclusion

Local cassava starches used in treating bentonite muds acted differently in the performance of the muds. Starches from TMS 98/0581, TMS 96/1632, M98/0068 and TMS 97/0057 performed comparably with commercial polymers, as viscosity enhancer and fluid loss control agents, in bentonite drilling mud. The different properties of the cassava starches have attributed to their performance. Viscosity increased with increase in rotational speed. Increased shearing increased polymer swelling which gave rise to increased viscosity of the mud types. The industrial starch optimum concentration before and after aging was 0.5 percent, while the optimum concentrations for local cassava starches were between 0.5 and 1.0 percent. PAC optimum concentration in bentonite mud was between 1.0 and 2.0 percent, while XG performed best at 2.0 percent. For all the mud types, viscosity initially increased with increase in temperature, then either decrease from 150°F or increase again at 190°F. For the starch treated muds, this behaviour was as a result of granules hydration and swelling when heated in water, a process known as gelatinization. The viscosities of bentonite muds treated with polymers were found to increase after 16 hours aging, except for PAC mud. The highest mean viscosities for all speeds, concentrations and temperatures in this study, were mud types formulated with TMS 98/0581 > XG > TMS 96/1632 > M89/0068 > TMS 97/0057 > PAC > NR-8082 > industrial starch > TMS 30572 > TMS 98/0505 > TME 419 > TMS 97/4779 > TMS 01/1412 in decreasing order. The physicochemical properties of local cassava starches had influence on the performance of the bentonite muds as drilling fluid.

Acknowledgements

The authors are grateful to the support of the World Bank African Centre of Excellence for Oil Field Chemicals Research, University of Port Harcourt, Nigeria and the National Root Crop Research Institute, Umudike, Nigeria. We also wish to thank Mrs. Bimbo Ayanbode for assisting with the cassava processing.

References

[1] J. K. Fink, *Oil Field Chemicals*. Gulf Professional Publishing publications (an Imprint of Elsevier). 2003, pp. 1-44.

[2] R. C. A. M. Nascimento, D. S. Lira, L. V. Amorim, Influence of Aging of Drilling Fluids on the Risk of Differential Sticking. *21st Brazillian Congress of Mechanical Engineering Natal RN, Brazil*. October, 2011.

[3] J. BeMiller, R. Whistler, R. (2009). *Starch: Chemistry and Technology*, Academic Press. New York. 3rd Edition. 2009, pp. 200-350.

[4] Z. Xiuhua and M. Xiaochun, *Drilling Fluids*. Available from: jpkc.cugb.edu.cn/sy/zjy/book/DRILLINGFLUIDS.pdf. 2010, pp. 8-30.

[5] D. C. Thomas, Thermal Stability of Starch- and Carboxymethyl Cellulose-Based Polymers Used in Drilling Fluids. *Society of Petroleum Engineers Journal*. 1982, Pp. 171-180.

[6] T. Ademiluyi, O. F. Joel, A. K. Amuda, Investigation of Local Polymer (Cassava Starches) as a Substitute for Imported Sample in Viscosity and Fluid Loss Control of Water Based Drilling Mud. *ARPN Journal of Engineering and Applied Sciences*. 6(12). 2011, 43-48.

[7] F. F. Dias, Starch: Perspectives and Opportunities. *Journal of Scientific and Industrial Research.* 58. 1990, pp. 403-413.

[8] I. Ismail, A. K. Idris, The Prospect of Utilizing Local Starches as Fluid Loss Control Agents in the Petroleum Industry. *Regional Symposium on Chemical Engineering. Johor, Malaysia*. October, 1997.

[9] M. D. Amanullah, L. Yu, Superior Corn-Based Starches for Oil Field Application. CSIRO Petroleum, Australian Resources Research Centre. Available from: http://regional.org.au/au/asa/2004/poster/3/5/1010_amanullahm.htm 2004

[10] I. Okumo, and S. O. Isehunwa, Prediction of the Viscosity of a Water-Based Mud Treated with Cassava Starch and Potash at Varying Temperatures Using Factorial Design. *SPE 31st Nigerian Annual Conference and Exhibition, Abuja, Nigeria*. August, 2007.

[11] A. B. Oriji, O. F. Joel, (2012). Suitability of Beneficiated Local Starch under Elevated Temperature as a Fluid Loss Control Additive Used in Petroleum Industry. *Scientia Africana*. 11(1), 2012, pp. 77-83.

[12] I. L. Egun, and A. M. Abah (2013). Comparative Performance of Cassava Starch to PAC as Fluid Loss Control Agent in Water Based Drilling Mud. *Discovery*. 3(9), 2013, pp. 36-39.

[13] R. Samavati, N. Abdullah, N. K. Tahmasbi, S. A. Hussain, B. D. R. Awang, The Prospect of Utilizing a Cassava Derivative (*fufu*) as a Fluid Loss Control Agent in Water Based Drilling Muds. *International Journal of Chemical Engineering and Applications*. 5(2), 2014, pp. 161-168.

[14] R. Samavati, N. Abdullah, N. K. Tahmasbi, S. A. Hussain, B. D. R. Awang, Rheological and Fluid Loss Properties of Water Based Drilling Mud Containing HCl-Modified F*ufu* as a Fluid Loss Control Agent. *International Journal of Chemical Engineering and Applications*. 5(6). 2014, pp. 446-450.

[15] S. A. Akintola, S. O. Isehunwa, Temperature and Time-Dependent Behaviour of a Water Base Mud Treated with Maize (*Zea mays)* and Cassava (*Manihot esculanta*) Starches. *Journal of Scientific Research and Reports.* 5(7), 2015, pp. 591-597.

[16] B. Maziya-Dixon, A. A. Adebowale, O. O. Onabanjo, A. G. O. Dixon, Effect of Variety and Drying Methods on Physico-chemical Properties of High Quality Cassava Flour from Yellow Cassava Roots. *African Crop Science Conference Proceedings*. 7. 2005. Pp. 635-641.

[17] FAO, *Save and Grow: Cassava*. Available from: www.fao.org/publications, 2013.

[18] IITA-International Institution of Tropical Agriculture. Nigeria Gets Improved Cassava Varieties. *The Bulletin*. January, 2011.

[19] J. Eke, S. C. Achinewhu, L. Sanni, I. S. Barimalaa, B. Maziya-Dixon, A. Dixon, Seasonal Variations in Chemical and Functional Properties of Starches from Local and Improved Cassava Varieties in High Rainfall Region in Nigeria. *Journal of Food, Agriculture and Environment*. 5(3&4). 2007. Pp. 36-42.

[20] M. O. Onitilo, L. O. Sanni, L. Daniel, B. Maziya-Dixon, A. Dixon, Physiochemical and Functional Properties of Native Starches from Cassava Varieties in Southwest Nigeria. *Journal of Food, Agriculture and Environment*. 5(3&4). 2007, pp. 108-114.

[21] Ikegwu, O. J., Nwobasi V. N., Odoh, M. O. and Oledinma, N. U. (2009). Evaluation of the Pasting and Some Functional Properties of Starch Isolated from Some Improved Cassava Varieties in Nigeria. *African Journal of Biotechnology*. 8(10). 2310-2315.

[22] O. A. Ashaye, O. L. Sanni, B. E. Arowosafe, Physicochemical, Rheological and Consumer Acceptability of Cassava Starch Salad Cream. *Journal of American Science*. 6(1), 2010, pp. 65-72.

[23] R. M. Omodamiro, E. Oti, H. A. Etudaiye, C. Egesi, B. Olasanmi, U. J. Ukpabi, Production of *fufu* from Yellow Cassava Roots using the Odourless Flour Technique and the Traditional Method: Evaluation of Carotenoids Retention in the *fufu*. *Advances in Applied Science Research*. 3 (5), 2012, pp. 2566-2572.

[24] L. Ajala, O. L. Otutu, A. Bamgbose, Effect of Delayed Processing on Some Physicochemical properties of cassava starch. *American Journal of Food and Nutrition*. 2(2).2012, pp. 31-36.

[25] API 13A, Specification for Drilling Fluids – Specifications and Testing. API Specification 13A, 18th Edition., 2010.

[26] O. F. Joel, *Drilling Cement and Simulation Fluids*. Amethyst and Colleagues Publishers, 2010 pp. 1-52, 63-108.

[27] A. Mayyas, A. Qasaimeh, K. Alzoubi, S. Lu, M. T. Hayajneh, A. M. Hassan, Modeling the Drilling Process of Aluminum Composites Using Multiple Regression Analysis and Artificial Neural Networks. *Journal of Minerals and Materials Characterization and Engineering.* 11, 2012, pp. 1039-1049.

[28] D. Afshartous, R. A. Preston, Key Results of Interaction Models with Centering. *Journal of Statistics Education*, 19(3), 2010, pp. 1-24.

[29] C. Aniedu, R. M. Omodamiro, Use of Newly Bred β-Carotene Cassava in Production of Value- Added Products: Implication for Food Security in Nigeria. *Global Journal of Science Frontier Research Agriculture and Veterinary Sciences*. 12(10), 2012, pp. 10-16.

[30] S. C. Ubbor, E. N. T Akobundu, G. Onwuka, Functional Properties and Cyanide Content of Starch and Flour of Selected Cassava (*Manihot Esculenta Crantz*) Mosaic Disease (CMD) Resistant Varieties. *Journal of Raw Materials Research*. 3(2), 2006, pp. 4-15.

[31] S. J. Rao, R. Parimalavalli, Effect of Isolation Methods on Physiochemical and Functional Properties of Cassava Starch. *International Journal of Advanced Research in Science and Technology*. 3(2), 2014, pp.73-78.

[32] A. M. Alsabagh, M. I. Abdou, A. A. Khalil, H. E. Ahmed, A. A. Aboulrous, Investigation of Some Locally Water-Soluble Natural Polymers as Circulation Loss Control Agents during Oil Fields Drilling. *Egyptian Journal of Petroleum.* 23, 2014 pp. 27-34.

[33] A. L. Adejumo, A. F. Aderibigbe, S. K. Layokun, Cassava Starch: Production, Physicochemical Properties and Hydrolysation- A Review. *Advances in Food and Energy Security*. 2, 2011, pp. 8-17.

[34] M. Omojala, Tacca Starch: A Review of Its Production, Physicochemical and Properties, Modification and Industrial Uses. *African Journal of Food, Agriculture and Nutrition Development.* 13(4), 2013, pp. 7972-7985.

[35] R. Samavati, N. Abdullah, The Experimental Assessment and Study of *Ubi kayu* Starch as Fluid Loss Control Agent in Water Based Drilling Fluids. *International Journal of Scientific Research in Chemical Engineering*. 3(1), 2016, pp. 001-006.