Performance Evaluation of Local Cassava Starch Flour as a Secondary Viscosifier and Fluid Loss Agent in Water Based Drilling Mud*

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Abstract

The success of any rotary drilling process depends on the type of drilling mud selected to achieve a particular task. The main function of drilling mud is to remove cuttings during drilling process. Viscosity is by far, the most needed property of the drilling fluid to aid it perform its needed task. The viscosity property of the mud helps in well cleaning and also aid in the suspension of drilling cuttings when circulation of the fluid is put on hold. It is important to monitor and continuously adjust the viscosity of the drilling fluid. Series of investigations have been carried out to discover less expensive and high performance viscosifiers. Cassava starch flour with bentonite in controlling viscosity and fluid loss in Water Based Mud (WBM) was investigated in this study. Various mud samples were formulated consisting of different masses of cassava starch flour (2 g, 4 g, 6 g and 8 g) and an additional one being the control bentonite (0 g of cassava starch flour). Fluid loss and rheological tests were carried out to determine the plastic viscosity, yield point, gel strength among others. Results from this investigation showed that, increasing the amount of cassava starch flour in the WBM increased the viscosity of the mud samples due to its swelling ability. Mud samples with cassava starch flour exhibited greater suspension ability (gel strength) of cuttings than that of the control sample with the exception of 6 g and 8 g of cassava starch at 80 °C for the 10 minutes gel strength. At the end of the fluid loss test, mud sample with cassava starch flour concentration of 2 g recorded a filter cake thickness of 2 mm while that of 4 g, 6 g, and 8 g gave 3 mm thickness. In conclusion, introduction of cassava starch flour into the mud samples from concentrations of 2 g to 8 g reduced its fluid loss by an average of 8 %. Based on the analyses, starch flour prepared from freshly uprooted local cassava has the potential to improve viscosity and also control fluid loss in WBM.

Keywords: Bentonite, Drilling Fluid, Fluid Loss, Rheology, Water Based Mud (WBM), Viscosifier

1 Introduction

Drilling fluids are the fundamental demand in majority of drilling operations. Most wells are drilled with clear water for faster penetration rates, until a depth is reached where hole conditions dictate a need for a fluid with special properties (Dankwa *et al*., 2018). Enhancers such as clay as filtrate reducers, viscosifying agents and dispersants for rheology control have to be added to the drilling fluids. The main requirement of any drilling fluid to removing cuttings from the wellbore to the surface. For the effectiveness of the fluid to be able to remove cuttings, the fluid has to have some viscosity (Neff *et al*., 2005). Therefore, it is important to monitor and continuously adjust the viscosity of the drilling fluid during drilling process to achieve the purpose the mud is designed for (Okumo and Isehunwa, 2007). Aside removing cuttings from the well, the mud should be capable of forming a thin seal preventing fluid from and to the formation otherwise, it will cause stuck pipe and loss of circulation, an influx or a kick that may graduate to a blowout, formation damage just to mention but few (Igbani *et al*., 2015).

Water based mud has a wide application because it is easy to formulate, environmentally friendly (Dankwa *et al*., 2018) and while nearly 5-10 % use oil-based muds (Sifferman *et al*., 2003). The frequent use of water based mud has led to the development of three distinct types; inhibitive; non-inhibitive and polymer water based mud (Reza, 2015). For the purpose of this study, much emphasis will be place on polymer water based fluid. These fluids contain polymers to viscosify, control filtration, deflocculate and provide high-temperature stabilization. Polymer fluids generally contain only minor amounts of bentonite to build viscosity. Polymer fluids also reduce cuttings dispersion and stabilize the well bore through encapsulation (Amorin, 2014).

Drilling fluid is linked directly or indirectly to most drilling problems, there is no particular drilling fluid that could serve as a solution to all drilling problems yet still, it is a tool that is used to solve most drilling problems. Commonly used drilling fluids should contain a minimum number of additives, this helps to preserve and check the properties of the drilling fluid. It is beneficial to have a mud system that is easy for an adjustment to meet the development demands as drilling

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problems arise (Annis and Smith, 1974). Today, various polymers, which can be in the form of natural (e.g. starch), synthetic, and/or modified (e.g. Carboxymethyl Cellulose or CMC) polymers, are used in order to control the fluid loss and viscosity oil and gas industry (Nasiri *et al*., 2012; Winson, 2012; Samavati *et al*., 2016).

Starch used in drilling operations are basically derived from corn, potato and other cereals. Corn starch was discovered to be an effective material for fluid loss control in 1937 and is the first polymer to be used for bentonite drilling fluid (Ademiluyi *et al.,* 2011). Starch is mostly used as effective colloids, because of its ability to decrease fluid loss and increase the viscosity of drilling fluids. These are caused by its swelling capacity which increases its volume due to free space water absorption (Rupinski *et al*., 2009). Starch contains amylose and amylopectin polysaccharides, the amylose in starch swells up and helps in controlling fluid loss. Cassava starch is a polysaccharide polymer and the amylose present in cassava enables its starch to exhibit similar functions as some of the imported viscosity and fluid loss polymers used in formulating drilling fluids (Harry *et al.,* 2016).

Cassava is a root crop cultivated in various parts of the world. Global production of cassava was estimated to be 278 million tonnes in 2017, with Nigeria being the world's largest producer with annual production of 20 % of the world's output (Chuasuwan, 2018). Ghana produces approximately 18 million tons of cassava annually (Anon, 2017a). Among the several varieties of cassava cultivated in Ghana, the type known as "Abrabopa" exhibits high starch content (40% dry matter content) which aids in the production of high quality flour for industrial products such as alcoholic beverages, flour for bakery, glue for lumber, as well as industrial alcohol and pharmaceutical products (Anon, 2015).

The use of locally produced materials as a substitute for imported drilling fluid additives have gained much attention over the years due to the high cost of the imported mud additives. Research conducted by Olatunde *et al*. (2012) and Undoh and Okon (2012) revealed that local materials such as gum Arabic, soda ash and sweet potato have the potential to serve as a substitute for imported drilling fluid additives in formulating water based mud. Ademiluyi *et al*. (2011) investigated the use of local cassava starch as substitute for imported sample in viscosity and fluid loss control in water based mud. Their results indicated that the local had similar or better filtration control properties that imported sample, however, the viscosity of the drilling fluid produced from local starch were lower than that of the imported type. Igbani *et al*. (2015) also conducted a research using cassava starch and found out that it can improve the density of the drilling fluid. Similarly, Harry *et al*. (2016) did a comparative analyses on local cassava starch with imported starch for drilling fluid formulation, the local cassava starch had structural properties considerably close to the imported starch. They concluded that imported starch could be substituted with local cassava starch as drilling fluid additive.

In the Ghanaian oil industry, materials used as viscosifiers and fluid loss agents are mostly imported therefore expensive and not readily available. However, Ghana has the necessary materials to produce locally based drilling fluids, hence this has led to research into several local materials such as yam, cocoyam and corn cob cellulose that could be used as substitute for commercial additives in mud formulation (Ossai, 2015; Nyande, 2017; Ashikwei and Marfo, 2016). Yet, little or no research have been conducted in an attempt to investigate the potential use of locally produced cassava in formulating drilling mud to serve as a secondary viscosifier and a possible fluid loss control. Therefore, it is imperative that comprehensive research be conducted into the local cassava, to study their characteristics and formulate mud that can perform the same function as those with imported additives. This will reduce the cost of some expensive viscosifiers and fluid loss agents that are being imported and will create employment as well (Undoh and Okon, 2012). This study therefore evaluates the performance of Ghana's local cassava as viscosity enhancer and a fluid loss agent in water base drilling mud.

2 Resources and Methods Used

2.1 Cassava Starch Flour Preparation

Local cassava variety called "Abrabopa" was purchased in Tarkwa, Ghana. 10 kg of the cassava roots were peeled and cut into irregular smaller sizes, these reduced sizes of the cassava were washed and soaked with distilled water and ground using electric grinder to produce a paste. The paste was diluted with distilled water and then poured into a porous cloth and squeezed tightly whiles the filtrate (suspended starch and distilled water) was received in a bucket. The residual cake in the cloth was discarded in an environmental friendly manner. The filtrate was then allowed to settle down for 20 hours and the suspended water was removed whiles the solid starch settled at the bottom of the bucket. The solid starch was then spread in a pan and dried in the sun for 13 days and oven dried to remove the moisture content. The dried starch was then grounded using mortar and pestle which was later sieved with a 0.425 mm sieve and stored in a container for drilling mud preparation and testing.

2.2 Water Based Mud Samples Preparation (Bentonite and Cassava Starch Flour Mud)

The experimental procedures used in this study followed the API 13B-1 standard for drilling fluid preparation and testing as follows.

(i) 22.5 g of bentonite and 350 ml of fresh water were used in each of the set-up according to API requirement for preparing drilling fluid.
(ii) A total of 112.5 g of bentonite was weighed with a mass balance and 1750 ml of fresh water was measured with a measuring cylinder.
(iii) Firstly, half of the water was poured into a container and the bentonite was added. The mixture was then stirred with a handheld mixer for a while (5 minutes).
(iv) Later, the remaining water was added and stirred for about 5 minutes till all the lumps became invisible. In all, five samples of mud were required for this investigation which included one control sample with no cassava starch flour.
(v) The remaining four samples of mud were prepared by adding 2 g, 4 g, 6 g and 8 g of cassava starch flour to the bentonite mud separately into different cups and were stirred vigorously with the aid of the handheld mixer until lumps of cassava disappeared;
(vi) Test were conducted after the 16 hours of aging at room temperature

2.3 Rheology and Fluid Loss Test of the Formulated Mud Samples

The viscosity properties of drilling fluid are made up of two main variables: Plastic Viscosity (PV) and Yield Point (YP). These parameters, as well as timed gel strength of 10 seconds and 10 minutes were recorded with Fann Viscometer Model 3500 at dial readings of 600, 300, 200, 100, 60, 30, 3 rpm as indicated in API 13B-1 for measuring drilling mud properties. After the experiments were carried out at room temperature (25 ºC), the mud samples were heated with the aid of a thermos-cup at 40 ℃, 60 ℃, and 80 ℃ and the test repeated. The viscosity properties of the formulated mud samples were computed using Equations 1 and 2 (Caenn *et al*., 2016).

The Plastic Viscosity (PV) in mPa.s was calculated using Equation 1:

$$\mathrm{PV} = \theta_{600} - \theta_{300} \tag{1}$$

The Yield Point (YP) in kg/m^2 was calculated using Equation 2:

$$\mathrm{YP} = \theta_{300} - PV \tag{2}$$

where; θ_{600} = dial reading at 600 rpm; θ_{300} = dial reading at 300 rpm; rpm is revolution per minute.

After the rheology test, the control bentonite and the bentonite with respective weight of cassava starch was poured into the API filter press mud cell and pressurized to 100 psi to determine the fluid loss as prescribed in API 13B-1 reference manual (Anon, 2017b).

3 Results and Discussion

3.1 Results

The results of the experiment conducted would be compared with the control bentonite as well as previous work by researchers. Table 1 presents numerical value range for assessing the quality of water based drilling mud properties necessary to ensure optimum drilling. Table 2 presents the dial readings, calculated plastic viscosities, yield point values, gel strength at 10 seconds and 10 minutes of mud samples with different concentrations (0 g, 2 g, 4 g, 6 g and 8 g) of cassava starch flour at varying temperatures of 25 °C, 40 °C, 60 ℃ and 80 °C in SI units. Table 3 shows how fluid loss from the tested samples changed with increasing time while Table 4 shows the filter cake measurements at the end of the fluid loss test.

Table 1 API Standard Numerical Value Requirement for Drilling Grade Bentonite

Mud Properties	Specifications (SI units)	Specifications (Oilfield units)
Plastic Viscosity (PV)	< 65 (mPa.s)	< 65 (cP)
Yield Point (YP)	73.5 – 220.5 (kg/m^2)	15 – 45 (lb/100ft^2)
Gel strength @ 10 seconds	14.7 – 98 (kg/m^2)	3 – 20 (lb/100ft^2)
Gel strength @ 10 minutes	39.2 – 147 (kg/m^2)	8 – 30 (lb/100ft^2)
API Fluid loss	15.0 ml (max)	15.0 ml (max)

Table 2 Dial Readings, PV, YP and Gel Strength of Mud Samples obtained from the Laboratory test

Samples	Parameters	Temperature 25 °C	40 °C	60 °C	80 °C
WBM + 0 g Cassava starch flour	Ө600 RPM	22	25	24	25
	Ө300 RPM	19	20	20	20
	PV (mPa.s)	3	5	4	3
	YP (kg/m^2)	78.4	73.5	78.4	83.3
	Gel Strength @ 10 secs (kg/m^2)	14.7	14.7	19.6	39.2
	Gel Strength @ 10 min (kg/m^2)	53.9	63.7	78.4	93.1
WBM + 2 g Cassava starch flour	Ө600 RPM	26	24	27	30
	Ө300 RPM	21	20	23	26
	PV (mPa.s)	5	4	4	4
	YP (kg/m^2)	78.4	78.4	93.1	107.8
	Gel Strength @ 10 secs (kg/m^2)	29.4	34.3	53.9	78.4
	Gel Strength @ 10 min (kg/m^2)	68.6	78.4	102.9	137.2
WBM + 4 g Cassava starch flour	Ө600 RPM	27	28	30	32
	Ө300 RPM	23	25	27	27
	PV (cP)/(mPa.s)	4	3	3	5
	YP (kg/m^2)	93.1	107.8	117.6	107.8
	Gel Strength @ 10 secs (kg/m^2)	39.2	29.4	39.2	83.3
	Gel Strength @ 10 min (kg/m^2)	78.4	88.2	98	147
WBM + 6 g Cassava starch flour	Ө600 RPM	35	37	35	37
	Ө300 RPM	28	31	30	32
	PV (mPa.s)	7	6	5	5
	YP (kg/m^2)	102.9	122.5	122.5	132.3
	Gel Strength @ 10 secs (kg/m^2)	44.1	53.9	68.6	98
	Gel Strength @ 10 min (kg/m^2)	83.3	112.7	107.8	166.6
WBM + 8 g Cassava starch flour	Ө600 RPM	37	34	37	38
	Ө300 RPM	29	29	33	35
	PV (mPa.s)	8	5	4	3
	YP (kg/m^2)	102.9	117.6	142.1	156.8
	Gel Strength @ 10 secs (kg/m^2)	53.9	63.7	73.5	93.1
	Gel Strength @ 10 min (kg/m^2)	88.2	122.5	137.2	156.8

Table 3 Fluid Loss Test Laboratory Results

Time (min)	Fluid Loss (ml) 0 g Cassava Starch Flour	2 g Cassava Starch Flour	4 g Cassava Starch Flour	6 g Cassava Starch Flour	8 g Cassava Starch Flour
1	1.2	1.6	1.4	1.2	1.2
3	3.4	2.6	3.4	3.2	3.2
5	4.8	4.8	4.6	4.6	4.6
7	5.8	5.8	5.6	5.8	5.8
9	6.6	6.6	6.6	6.5	6.8
10	7.4	7.2	7.0	7.0	7.0
11	7.6	7.6	7.2	7.4	7.6
13	8.4	8.2	8.0	8.2	8.0
15	9.2	8.8	8.6	8.6	8.6
17	9.8	9.2	9.0	9.4	9.4
19	10.4	9.8	9.8	9.8	9.8
20	10.8	10.4	10	10.2	10.2
21	11.4	10.6	10.2	10.6	10.4
23	11.8	11.0	10.8	11.0	11.0
25	12.4	11.4	11.2	11.6	11.4
27	13	11.8	11.6	12.0	12.0
29	13.4	12.4	12.2	12.4	12.4
30	13.6	12.7	12.4	12.6	12.6

Table 4 Filter Cake Measurement

Mud Sample with Cassava starch	Filter Cake Thickness (mm)
0 g of cassava starch	2
2 g of cassava starch	2
4 g of cassava starch	3
6 g of cassava starch	3
8 g of cassava starch	3

3.2 Discussion

3.2.1 Effects of Cassava Starch Flour on Plastic Viscosity

Plastic viscosity (PV) is defined as the resistance of a fluid to flow. Plastic viscosity of water based mud increases with the increase in solid content but decreases with increase in temperature. From Fig. 1, it can be seen that at 25 °C temperature, increase in cassava starch flour concentration resulted in increase in plastic viscosity of the mud samples, thereby acting as a secondary viscosifier. On the other hand, a decrease in plastic viscosity was observed as the temperature increased from 25 °C to 80 °C. The cassava starch flour with concentration of 8 g had its PV steadily decreasing with increasing temperature. This drift helps to reduce suspension of particles in mud during drilling process. In the sample with 2 g cassava starch flour concentration, it can be seen that, Plastic Viscosity decreased with increasing temperature (25 ℃ to 40 ℃), however, there was no further decrease in PV when the temperature was increased to 80 ℃. The same behaviour was observed for mud sample with 4 g starch flour as was done in 2 g sample except that increase in temperature to 80 ℃ rather increased the PV. Mud sample with 6 g starch flour showed a decrease in PV as temperature increased from 25 ˚C but remained steady at 60 ℃ to 80 ℃. The reason for the decrease in the PVs results from the fact that, increase in temperature increase tends to decrease the liquid phase of the mud and thermally degrades starch due to the breaking of polymer bonds in the starch. This trend is in agreement with earlier work done by Ademiluyi *et al.* (2011), Amani (2012) and Sarah and Isehunwe (2015). A low PV shows that the mud is capable of drilling rapidly because of low viscosity of mud flowing out the bit. Generally, the plastic viscosity was affected by the changes in temperature and cassava starch flour concentration as both are function of the PV. Considering the rheological evaluation of the water based mud illustrated in Fig. 1, all the plastic viscosity values are within acceptable range desired for optimum drilling. This affirms that mud formulated with cassava starch flour can effectively carry cuttings to the surface with some extra modifications.

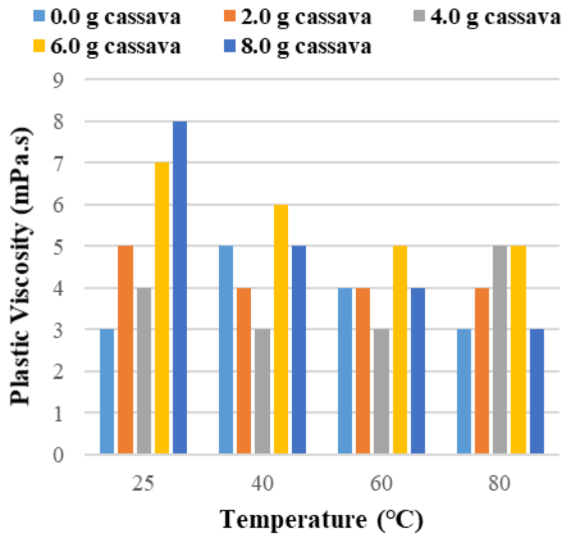

Fig. 1 Plastic Viscosity of Cassava Starch Mud Formulations at Different Temperature

3.2.2 Effects of Cassava Starch Flour on Yield Point

Yield point (YP) is a measure of the electrochemical or attractive force in the mud under flow (dynamic) conditions. It can be simply stated that the yield point is the attractive force among colloidal particles in drilling fluid. The yield point of water based mud increases with increase in temperature and contaminants such as carbon dioxide, salt, and anhydrite during drilling operations. From 25 ℃ to 80 ℃, Yield Point increased with increasing cassava starch flour concentrations. This is a result of loss of water by evaporation due to increased temperature making the mud thicker. It is worthy of notice in Fig. 2 that, temperature and concentration of cassava starch flour have significant effect on yield point. Basically YP also indicates the ability of the drilling mud to carry cuttings to surface. If a drilling mud sample has a very low yield point it will flow at a faster rate leaving the cuttings behind in the wellbore. The behaviour observed with the effect of temperature and concentration on the yield point clearly suggest a threshold limit at which any addition of cassava starch flour would have a negative impact on the yield point property. This is because higher YP will result in high pressure loss when the drilling mud is being circulated. In contrast, if the mud's yield point is too high, it informs the mud engineer that if such a mud is used to drill, it would require a high pumping pressure to cause the mud to flow, which is also undesirable in the industry.

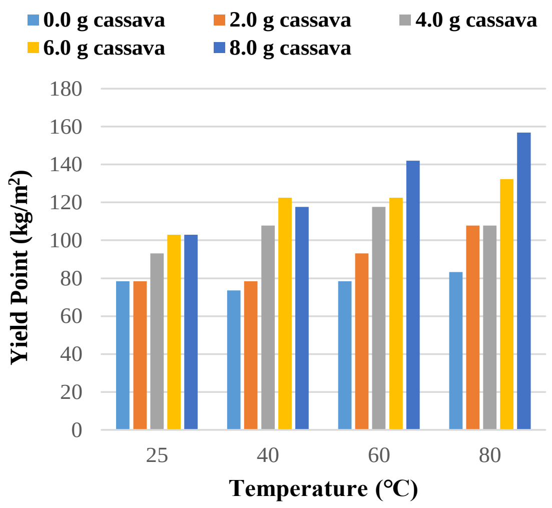

Fig. 2 Yield Point of Cassava Starch Mud Formulations vs. Temperature

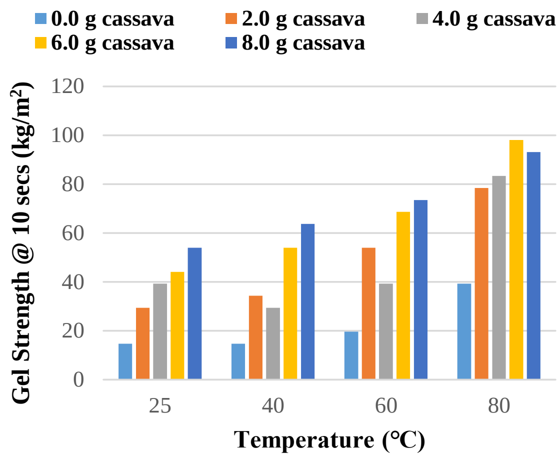

Fig. 3 Ten seconds Gel Strength of Cassava Starch Mud Formulations vs. Temperature

3.2.3 Effects of Cassava Starch Flour on Gel Strength (10 secs & 10 min)

From Fig. 3, it is observed that, all the mud samples with cassava starch flour formulations (2 g, 4 g, 6 g, and 8 g) increased with increasing temperature. However, mud sample containing 4 g of cassava starch flour at 40 ℃ tend to decrease for the 10 seconds gel strength. With respect to the 10 minutes gel strength in Fig. 4, mud samples with cassava starch flour formulations also showed the same pattern of increasing with increased temperature, however at 80 ℃ of 6 g and 8 g cassava starch flour mud which recorded values of 166.6 and 156.8 kg/m^2 respectively which is not favourable for ensuring optimum drilling. This can be attributed to the deterioration of the polymer bonds in the mud samples as temperature increased from 25 ℃ to 80℃. Therefore, from the results obtained at the end of the laboratory experiment, temperature was found to have undoubted huge effect on the mud samples. The gel strength is one of the important factor in drilling fluid properties because it gives the drilling fluid the ability to suspend drill solid and weighting material when circulation is halted. When drilling mud has a high gel strength, it will require high pump pressure in order to break the static bonds after the mud has been static for a long time.

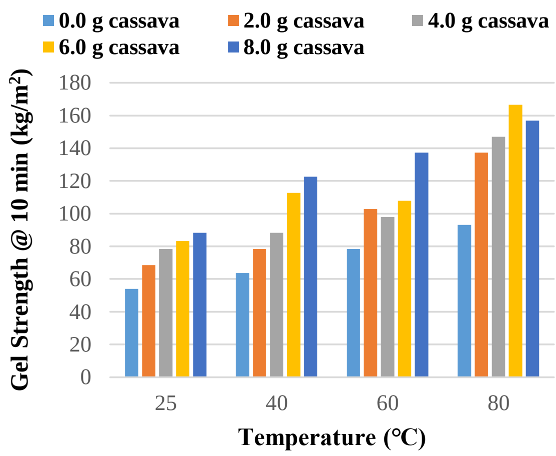

Fig. 4 Ten Minutes Gel Strength of Cassava Starch Mud Formulations vs. Temperature

3.2.3 Effects of Cassava Starch Flour on Fluid Loss

Fluid loss relationship with time for cassava starch flour mud formulations is shown in Fig. 5. The fluid loss trend varies from 1 minute to 30 minutes with different amount of cassava starch flour. Fig. 5 indicates that all the fluid loss samples increased with time; however, large amount of cassava starch flour (8 g) in the mud had a slightly lower fluid loss than that of control bentonite (0 g cassava starch flour). Moreover, mud sample with 2 g concentration ofcassava starch flour at lower times (1-3 mins) recorded, lower fluid loss value. This may be due to the high amylose content of cassava as reported in a similar work by Ademiluyi *et al* .(2011). The fluid loss may improve (decrease) by increasing the amount of cassava starch flour in the mud. The filter cake recorded for the mud samples with increasing cassava starch flour concentration from 2 g to 8 g increase in ranged from 2mm to 3mm, hence exhibiting a thinner cake. Thinner cake is preferable during drilling of oil and gas wells due to common risk of pipe sticking problems (Saboori *et al*., 2018).

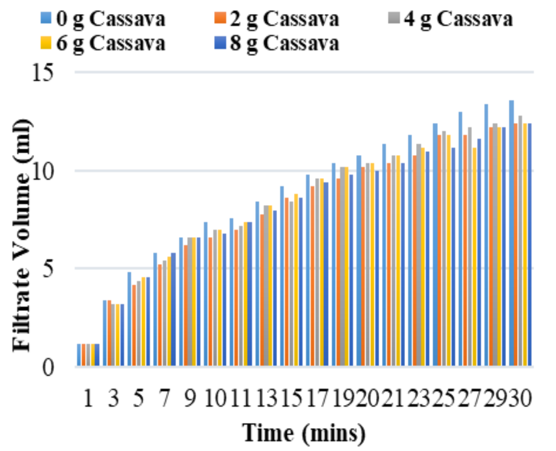

Fig. 5 Filtration Loss of Mud Samples vs. Time

3.2.4 Rheogram

It is evident from Figs. 6, 7, 8 and 9 that increase in the quantities of cassava starch flour in the mud samples increased their respective viscosities thereby increasing the shear stress of the mud. It can also be observed from the line graphs that, the nature of the curves for the various samples portray a non-Newtonian fluid behaviour. The main crystalline component in granular starch is amylopectin. The variation in the amount of amylose and amylopectin in starch changes the behaviour of the starch. The amylose component of starch controls the gelling behaviour of starch.

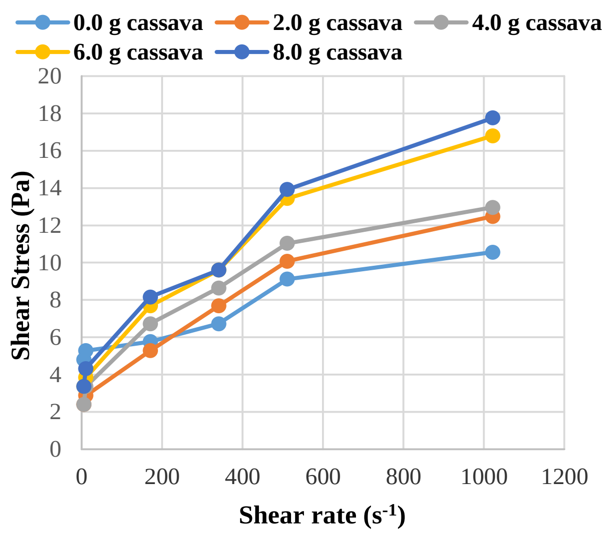

Fig. 6 Rheogram showing Fluid Behaviour at 25 °C

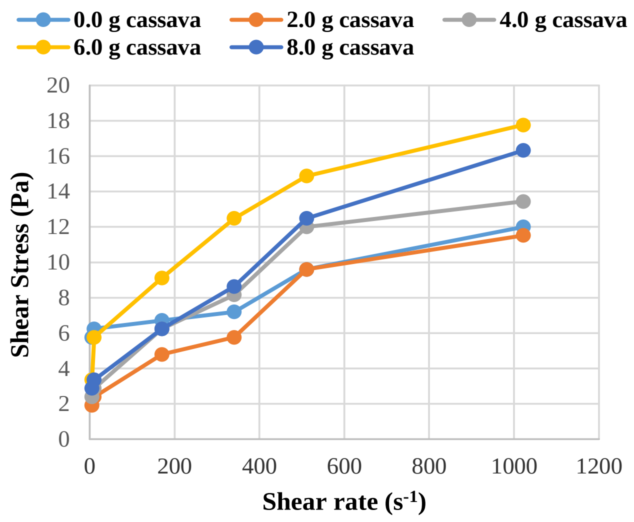

Fig. 7 Rheogram showing Fluid Behaviour at 40 °C

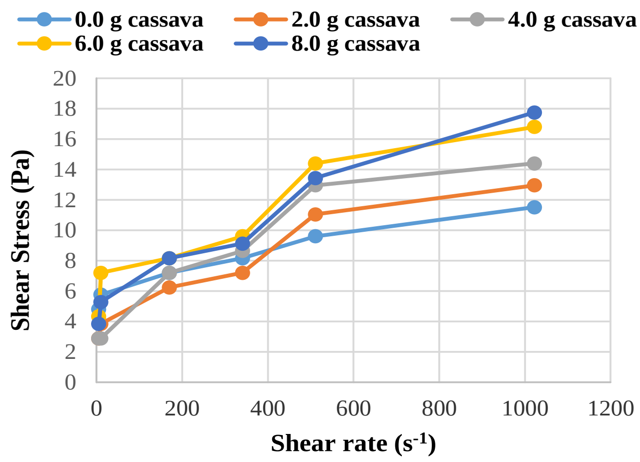

Fig. 8 Rheogram showing Fluid Behaviour at 60 °C

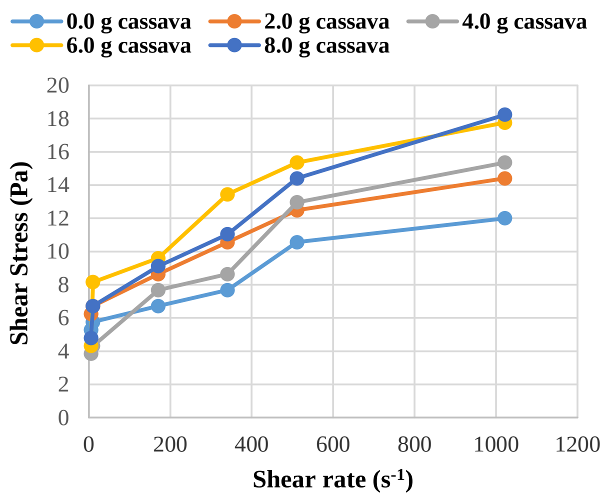

Fig. 9 Rheogram showing Fluid Behaviour at 80 °C

4 Conclusions

Results from this study have shown the potential use of Ghana's local cassava starch flour as a secondary viscosifier and fluid loss agent, hence the following conclusions can be drawn:

(i) Plastic Viscosity values of the mud samples with cassava starch flour ranged between 3 to 8 mPa.s which is acceptable for the mud in carrying cuttings.
(ii) Yield Point values of the mud samples with cassava starch flour ranged between 78.4 to 156.8 kg/m^2, which is favourable for aiding the mud for cuttings transport.
(iii) Mud samples with cassava starch flour exhibited greater suspension ability (gel strength) of cuttings than that of control sample (0 g cassava) with the exception of 6 g and 8 g of cassava starch at 80 °C for the 10 minutes gel strength;
(iv) Cassava starch flour at different concentrations increased the swelling ability of the starch thereby increasing the viscosity of the mud;
(v) Introduction of cassava starch flour from concentrations of 2 g to 8 g into the mud samples resulted in a thin filter cake thickness ranging from 2mm to 3mm, thereby yielding a reduction in fluid loss by 8 %. This gives an indication that a further increase in concentration of cassava starch would reduce the fluid loss significantly;

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