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Utilisation of Sweet Potato (*Ipomoe batatas*) and Rice Husk (*Oryza sativa*) Starch Blend as a Secondary Viscosifier and Fluid Loss Control Agent in Water-based Drilling Mud

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Abstract

The drilling mud plays an important role in ensuring the success of any drilling operation as it remove cuttings from the wellbore regions. The viscosity of the drilling mud must be constantly monitored and adjusted during drilling to enable it suspend the cuttings when mud circulation is halted. Starch is frequently applied in drilling fluid technology due to its solubility in water, viscosity and water retention capacity. This study evaluated the use of sweet potato (*Ipomoe batatas*) and rice (*Oryza sativa*) husk starch blend as a viscosifier and fluid loss control agent in water based drilling mud. The mud samples were prepared according to th API 13B-1 specifications. The rheological and fluid loss tests were also according to the API 13B-1 specifications. The plastic velocity, yield point and gel strength of the drilling mud increased with increasing starch content (0 – 8g). From the study of temperature effects (25 – 80ºC), higher temperatures were detrimental to the mud's plastic viscosity and had a positive effect on yield point and gel strength. This shows a clear positive effect of the starch blend as a viscosifier. The starch blend was also shown to reduce mud fluid loss by 8% due to its water retention capacity.

Keywords: *Drilling mud; Viscosifier; Rheology; Fluid loss control; Starch.*

1. Introduction

Drilling is considered to be an important aspect of any oil and gas sector due to the fact that it creates access to the hydrocarbons underground [1]. For a drilling operation to be carried out successfully, a drilling fluid with appropriate specifications needs to be used [2]. To enable penetration rates at a faster pace, majority of wells are drilled with clear water until a considerable depth is attained where the hole conditions would determine if a drilling fluid with special properties is required [3]. The basic function of the drilling fluid is to remove cuttings from the wellbore regions to the surface [4]. For the fluid to remove cuttings effectively, the fluid has to have a good measure of viscosity [5]. The viscosity of the drilling fluid must be continuously monitored and adjusted during the course of drilling in order for the mud to achieve the designed requirements [6]. Water based mud has a variety of applications due to its ease of formulation [3]. There are different types of water based mud namely; inhibitive, non-inhibitive and polymer water based mud [7]. Polymer-water based mud was used for the Purpose of this research.

Polymer fluid generally comprises of small amounts of bentonites that would improve viscosity, reduce cuttings dispersions and also help in well bore stabilization through the process of encapsulation. Additives should be added to drilling fluids to preserve and evaluate the drilling fluid properties[8]. In contemporary times, several polymers mostly natural polymers e.g. starch, synthetic or modified polymers are used for controlling fluid loss and enhancing viscosity in the oil and gas industry[9-11]. Starch is frequently applied in drilling fluid technology in modified forms because it is soluble in water [11]. Starch is frequently applied as an effective colloid due to its ability in increasing the viscosity of drilling fluids and the vital role it plays in the reduction of loss of the drilling fluids due to its swelling capacity and its ability to increase its volume (as a result of free space water absorption).

Starch comprises of amylose and amylopectin polysaccharides, the amylose contained in starch swells up aiding in fluid control loss [12]. Sweet potato (*Ipomoe batatas*) is an important food crop cultivated in Africa with Nigeria being the highest producer having an annual production output of 3.56 million metres tonnes [13]. Sweet potato starch is a polysaccharide polymer and the amylose present in sweet potato enables its starch to portray unique characteristics such as improving viscosity and reducing fluid loss [14]. Rice (*Oryza sativa*) starch is amongst the varieties of cereal starch with well-known characteristics [15]. Starch is the main component of rice and accounts for about 80% of its total constituents [16]. Rice has a high amylose content which enhances its pasting abilities and also its capacity to retain water [15].

In recent years, the substitution of locally produced materials for imported drilling fluid additives have been reported. Ademiluyi, Joel [17] indicated that the filtration control properties of local materials were better than their imported counterparts and yielded better results. Egun and Achadu [18] revealed that cassava starch improves the water retention capacity of drilling fluids. A study was conducted by Igbani, Peletiri [19] on improving the density of drilling fluid using cassava starch, and the results were positive. The study by Olatunde, Usman [1] and Udoh and Okon [4] indicated that some local materials such as soda ash, sweet potato and Gum Arabic have the capacity to act as a good substitute for imported additives. It was observed by Saboori, Sabbaghi [20], that core-shell nano composites can serve as a good substitution to control mud cake thickness whilst preserving other mud properties. The use of starch form rice husk and sweet potato is unreported and scarcely studied in open literature. This study attempts to fill this gap in knowledge. This study is important as viscosifiers used in the oil and gas industry in Nigeria are very expensive and not always available. Nigeria has the capacity to formulate water based drilling fluids from local materials but little research has been conducted to investigate the potential of using starch derived from a combination of sweet potato and rice husk to formulate a drilling fluid that would serve as a secondary viscosifying agent and a fluid control agent. Therefore, it is of utmost importance to investigate the basic characteristics of the combination of sweet potato and rice husk to formulate a drilling mud that will perform the same functions as the imported additives. This study is aimed at appraising the performance of a combination of sweet potato and rice husk blend as a viscosifier and fluid loss control agent in water based drilling mud.

2. Methodology

2.1. Preparation of sweet potato and rice husk starch granules

A local variety of sweet potato (*Ipomoe batatas*) called "Dan Izala" was used for this experiment. Sweet potato tubers weighing 10 kg were flaked and cut into uneven smaller shapes, the reduced slices of sweet potato were then thoroughly washed and soaked using distilled water. The soaked potato was the ground using an electric grounder to yield a paste. Distilled water was used to dilute the paste and then it was discharged into a cloth and it was then firmly squeezed whilst the filtrate was collected. The filtrate was left to settle for 30 h and the water suspended was removed while the starch settled at the base of the wooden container. The moist starch was spread on a large metallic tray and sundried for 15 days. The sample was then oven dried at 80°C for 12 h. The starch was ground and sieved through mesh size 0.425 mm. The sweet potato then underwent the process of pre-gelatinization to a temperature range of about 60°C–80°C in order to break the amylose-amylopectin chains affecting its solubility in water. The rice (*Oryza sativa*) husk was carefully sorted out to remove the stones and other particles and weighed to be about 5 kg. The husk was washed using distilled water and sun dried for 10 days. The dried husk was then pulverized to powder using and electric grinder. It was then sieved with a sieve of mesh size 0.425 mm. The sweet potato flour was then mixed with the rice husk powder using an electric mixer to form a mud flour (denoted as SPRH) to be used in the study.

2.2. Preparation of the water based mud samples

The methodology applied in this study abided by the API 13B-1 [21] standard for preparation of and evaluation of drilling fluid. The ratio of 350 ml distilled water to 22.5 g of bentonite were used for every system setup according to the API specification for drilling fluid preparation. For the study, Bentonite of about 112.5 g was mixed with 1750 mL of distilled water. About half of the total volume of water was poured into a container after which the bentonite was added. The resulting mixture was hen stirred thoroughly using a hand-held mixer for about 5 minutes. Subsequently, the left over water was then added and the mixture was stirred thoroughly until there were no visible lumps. Five samples of the bentonite mud were used for the study, one of which was a control sample without the addition of the SPRH flour. 2g, 4g, 6g and 8g of the SPRH flour were added to the bentonite mud to prepare the remaining four samples. All four samples were vigorously stirred using a hand-held mixer until there were no visible lumps of the SPRH flour. The test analysis was carried out following the 16 hours of the aging process at room temperature.

2.3. Test of rheology and fluid loss

The two main properties that play a significant role in determining the viscosity properties of good drilling fluids are plastic viscosity (PV) and yield point (YP). The plastic viscosity, yield point, gel strength of approximately 10 seconds and 10 minutes were carefully recorded at structural dial readings of 600 rpm, 300 rpm, 200 rpm, 100 rpm, 60 rpm, 30 rpm and 3 rpm as specified in API 13B-1 [21] for measurement of drilling fluid properties. Following the completion of the experiments at 25°C, thermos-cup was used to heat the mud samples at 40°C, 60°C and 80°C after which the test was repeated. Equations 1 and 2 were used to compute the viscosity properties of the developed mud [22]. Equation 1 was applied to calculate the plastic viscosity (PV) in mPa.s.

$$PV = \theta_{600} - \theta_{300} \qquad \text{Eqn. 1}$$

Equation 2 was applied to calculate the yield point (YP) in kg/m^2

$$YP = \theta_{300} - PV \qquad \text{Eqn. 2}$$

where θ_{600} is the 600 rpm dial reading and θ_{300} is the 300 rpm dial reading.

Following the completion of the rheology test, the fluid loss was determined by pouring the control and the bentonite mud with distinctive weights of SPRH starch into the API filter press mud cell. The pressure was then increased to 100 psi as recommended in API 13B-1.

3. Results and discussion

The analysis of the results from the experiments carried out were compared to the control bentonite, including previous works done by other researchers. The range of numerical values for estimating the quality of the properties of water based drilling mud which is very fundamental to ensuring a successful drilling operation is outlined in Table 1. The dial readings, estimated plastic viscosities, yield point values, gel strength at a time value of 10 seconds and 10 minutes of mud samples with distinct concentrations (0g, 2g, 4g, 6g, 8g) of SPRH flour at different temperatures of 25°C, 40°C, 60°C and 80°C min SI units are illustrated in Table 2. An outline of how the fluid loss from the different experimental samples increased with time is also depicted in Table 3. The filter cake measurements at the completion of the fluid loss test is outlined in Table 4.

Table 1. API Standard Range of Numerical Values Specifications for Drilling Grade Bentonite

Mud Properties	Specification (SI units)	(Oilfield units)
Plastic viscosity (PV)	<65 (mPa.s)	<65 (cP)
Yield point (YP)	73.5-220.5 (kg/m²)	15-45 (lb/100ft²)
Gel strength @ 10 seconds	14.7-98	3 - 20 (lb/100ft²)
Gel strength @ 10 minutes	39.2 - 147 (kg/m²)	8 - 30 (lb/100ft²)
API Fluid loss	15.0 ml (max)	15.0 ml (max)

Table 2. The results for PV, YP, Gel Strength and Dial Readings of the Samples of Mud gotten from the Laboratory Test

Sample	Parameter	Temperature			
		25°C	40°C	60°C	80°C
WBM + 0g SPRH	θ_{600}	24	27	24	25
	θ_{300}	20	22	20	22
	PV (mPa.s)	4	5	4	3
	YP (Kg/m²)	77.3	71.8	77.8	82.1
	Gel Strength @ 10secs (Kg/m²)	15.8	15.8	18.7	40.9
	Gel Strength @ 10mins (Kg/m²)	54.8	62.9	77.5	94.2
WBM + 2g SPRH	θ_{600}	27	25	28	32
	θ_{300}	22	20	24	28
	PV (mPa.s)	5	5	4	4
	YP (Kg/m²)	76.7	76.7	92.8	108.5
	Gel Strength @ 10secs (Kg/m²)	28.5	35.6	54.3	79.2
	Gel Strength @ 10mins (Kg/m²)	67.4	76.7	104.9	142.7
WBM + 4g SPRH	θ_{600}	25	27	32	35
	θ_{300}	20	24	28	31
	PV (mPa.s)	5	3	4	4
	YP (Kg/m²)	94.7	106.9	119.3	104.8
	Gel Strength @ 10secs (Kg/m²)	37.1	29.6	38.5	85.1
	Gel Strength @ 10mins (Kg/m²)	76.3	86.1	96	145
WBM + 6g SPRH	θ_{600}	33	38	33	38
	θ_{300}	25	33	26	31
	PV (mPa.s)	8	5	7	7
	YP (Kg/m²)	101.4	126.2	126.2	135.7
	Gel Strength @ 10secs (Kg/m²)	39.2	56.1	69.8	99
	Gel Strength @ 10mins (Kg/m²)	84.1	115.9	106.3	168.2
WBM + 8g SPRH	θ_{600}	39	36	34	39
	θ_{300}	31	30	29	34
	PV (mPa.s)	8	6	5	5
	YP (Kg/m²)	104.7	115.2	138.6	151.9
	Gel Strength @ 10secs (Kg/m²)	50.2	61.8	72.4	90.2
	Gel Strength @ 10mins (Kg/m²)	83.7	120.1	132.3	157.6

Table 3. Results for the Fluid Loss Test

Time (mins)	Fluid loss (mL)				
	0g SPRH	2g SPRH	4g SPRH	6g SPRH	8g SPRH
1	1	1.4	1.6	1.4	1.4
3	3.2	2.8	3.2	3	3
5	4.6	4.4	4.2	4.8	4.8
7	5.2	5.2	5.8	5.6	5.6
9	6.4	6.8	6.8	6.3	6.6
10	7.1	7.4	6.8	6.8	6.8
11	7.4	7.4	7	7.2	7.4
13	8.6	8.4	8.2	8	7.8
15	9	8.4	8.2	8.2	8.2
17	9.4	9	8.8	9.2	9.2
19	10	9.4	9.4	9.4	9.6
20	10.4	10	9.6	10	10
21	11	10.2	10	10.4	10
23	11.4	11	10.6	10.8	10.8
25	12.2	11.6	11.6	11.2	11.6
27	12.6	11	10.8	11.6	11.6
29	13	12.6	11.8	12.6	12.6
30	13.2	12.3	12	12.2	12.2

Table 4. Measurement of the filter cake

Mud sample with SPRH starch granules	Thickness of the filter cake (mm)
0g of SPRH starch	2
2g of SPRH starch	2
4g of SPRH starch	3
6g of SPRH starch	3
8g of SPRH starch	3

3.1. The effect of SPRH starch on mud plastic viscosity

There is an increase in the PV of a water based drilling fluid in response to an increase in its solid content. However, the PV of a water based drilling mud decreases with an increase in temperature. It can be observed from Figure 1 that at a temperature of 25°C, an increase in the SPRH flour concentration led to an increase in the PV of the drilling mud samples, by that performing as a secondary viscosifying agent. Contrastingly, as the temperature of the drilling mud increased from 25°C to 80°C, a decrease in PV was observed. The plastic viscosity of the 8g concentration of SPRH flour mud decreased steadily with its temperature increasing. The latter's pattern aids in reducing the suspension of molecules in the drilling mud while the drilling operation is ongoing.

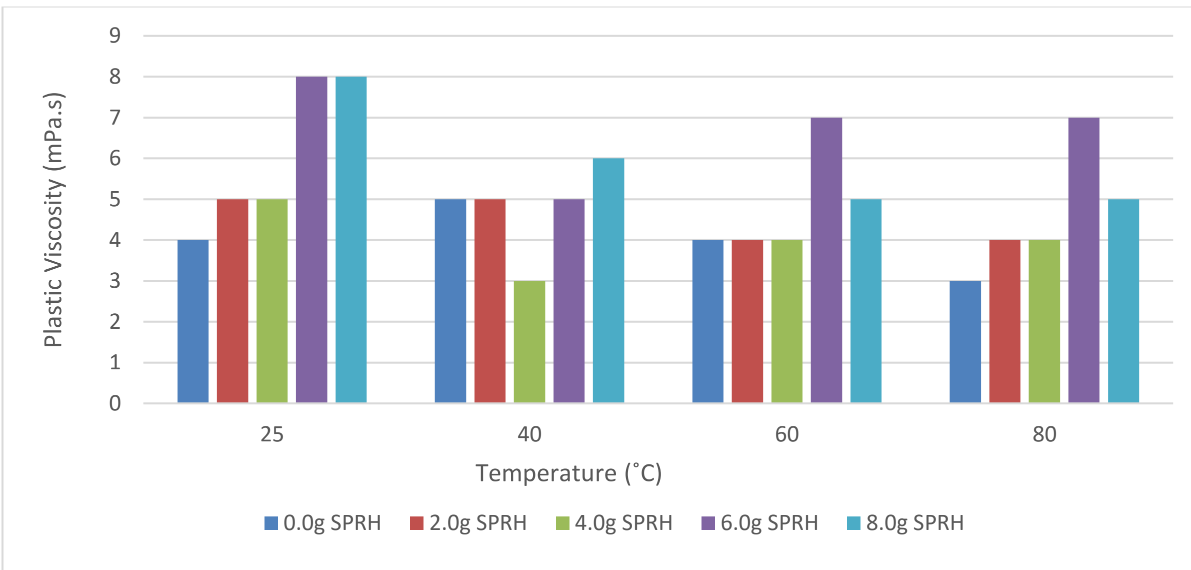

Figure 1. Plastic viscosity of the SPRH composition at different temperature

In 2g SPRH starch flour concentration, it was observed that the PV was decreased with the temperature increasing from 25°C to 40°C. Although, no further increase in plastic viscosity was observed when the mud temperature was increased to 80°C. A similar pattern was observed for the mud sample with 4g of SPRH starch except that an increase in the temperature of the mud to 80°C comparatively resulted in an increase in the plastic viscosity. A decrease in the plastic viscosity of the mud sample having 6g of SPRH starch flour was observed as the temperature increased starting from 25°C and the temperature stabilized between 60°C and 80°C.

The decrease in the plastic viscosity of the mud sample emanates from the basis that, when the temperature of the mud sample is increased, it brings about a decrease in the liquid phase of the drilling mud and causes a thermal degeneration of starch as a result of the dissociation of the polymer chains present in starch. This pattern was also observed in previous studies by Ademiluyi, Joel [17] and Akintola and Isehunwa [23] albeit for other viscosifier types. When the plastic viscosity is low, it indicates that the mud has the capacity of speeding up the rate of drilling because the mud flowing out of the bit has a low viscosity. Typically, alterations in the temperature affected the plastic viscosity of the mud because it is an important factor of viscosity. Taking into account, the rheological analysis of the water based fluid that is depicted in Figure 1, the results gotten for plastic viscosity were found to be in approved ranges required for successful drilling operations. This confirms that the drilling mud developed with a combination of sweet potato and rice husk flour can adequately carry cuttings to the wellbore surface with slight alterations.

3.2 The Effect of SPRH starch on mud yield point

The yield point can be seen as a determinant of the attractive forces present in a drilling mud that is under specified flow. The yield point is commonly seen as the force of attraction in colloidal particles or fragments present in drilling fluids. An increase in temperature and contaminants present in drilling muds (i.e., CO_2, salt, anhydrites and other particles) during the process of drilling results to an increase in the yield point of water-based mud. With increasing SPRH concentrations, the yield point noticeably increased from 25°C to 80°C due to water loss through the process of evaporation. Evaporation results from the increased temperature during the process of thickening the drilling mud.

It can be closely observed in Figure 2 that the temperature and concentration of SPRH granules have symbolic aftermaths on the yield point of the drilling mud. Essentially, the yield point also illustrates the capacity of the drilling mud in carrying cuttings to the wellbore surface. If the yield point of a drilling fluid is low, the drilling fluid will flow rapidly and the cuttings will be left in the wellbore. The performance observed in correlation to the resulting effects of temperature on the yield point of the drilling mud apparently indicates verge limits in which further addition of SPRH starch granules would lead to negative consequences on the properties that affects the yield point of a drilling mud. This can be attributed to the fact that a high yield point will amount to a high pressure loss during mud circulation. On the other hand, assuming the yield point of the mud is on a high level, it notifies the mud engineer that in order to use a mud of that attributes, a higher pumping pressure needs to be applied to enable the mud flow properly, this is earnestly required in the oil & gas industry.

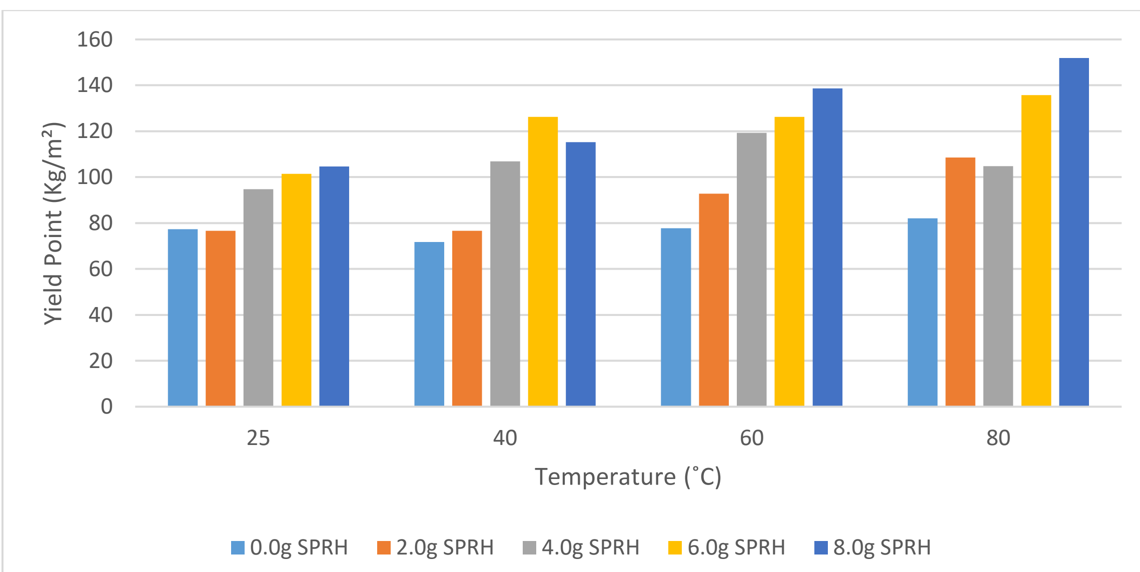

Figure 2. Yield point of SPRH starch mud compositions at different temperature

3.3. The effect of SPRH starch on mud gel strength

It can be observed from Figure 3 that all the samples of drilling mud with SPRH starch exhibited the same temperature trend, the gel strength of the mud were directly proportional to its weight, and increasing with increasing temperature. At a temperature of 40°C, the mud sample having 4g of SPRH starch granules was observed to have decreased for the 10 seconds gel strength. With regards to the 10-minute gel strength illustrated in Figure 4, the drilling mud samples with SPRH starch granules composition was found to have a similar trend of increase according to increased temperature. Although at a temperature of 80°C of mass 6g and 8g SPRH starch granule mud, 168.2 and 157.6 kg/m^2 were recorded respectively which is not acceptable for a successful drilling operation.

This pattern is associated to the degrading of the polymer bonds present in the mud samples when the temperature increased from a level of 25°C to 80°C. it can be concluded from the analysis gotten from the experiments carried out, that temperature had a very high effect on the gel strength of the drilling mud samples. The gel strength plays a vital role in determining the properties of the drilling fluid because it increases the capacity of the drilling mud to suspend the colloidal particles when the process of mud circulation is stopped. In a scenario where the gel strength of the mud is high, a high pressure pump will be required to enable the dissociation of the fixed bonds after the mud has previously stopped circulation.

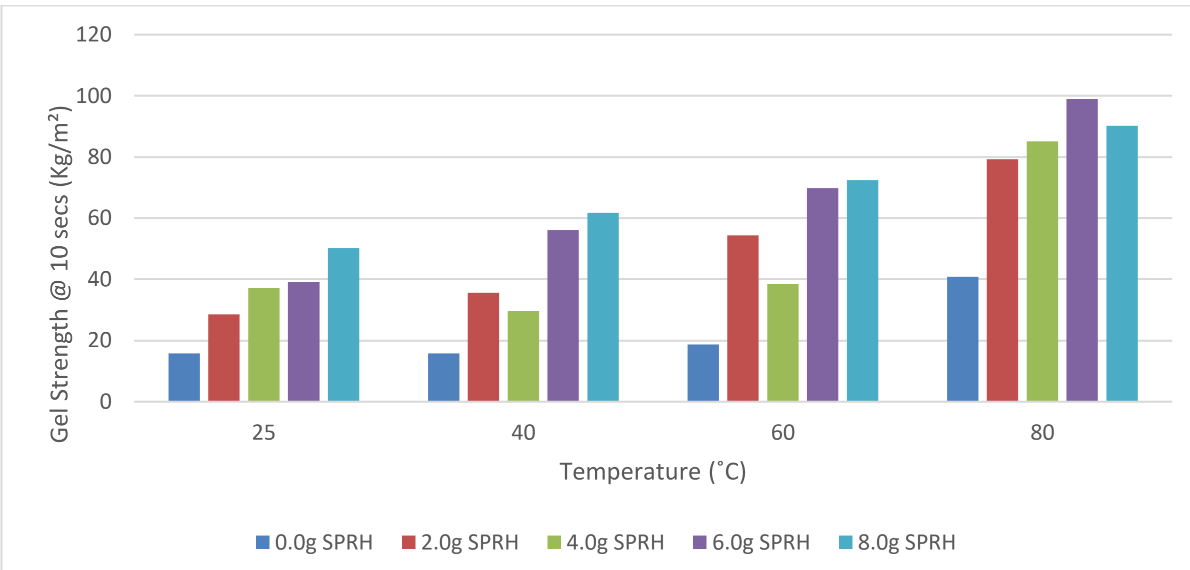

Figure 3. Ten seconds gel strength of SPRH starch mud compositions vs temperatur

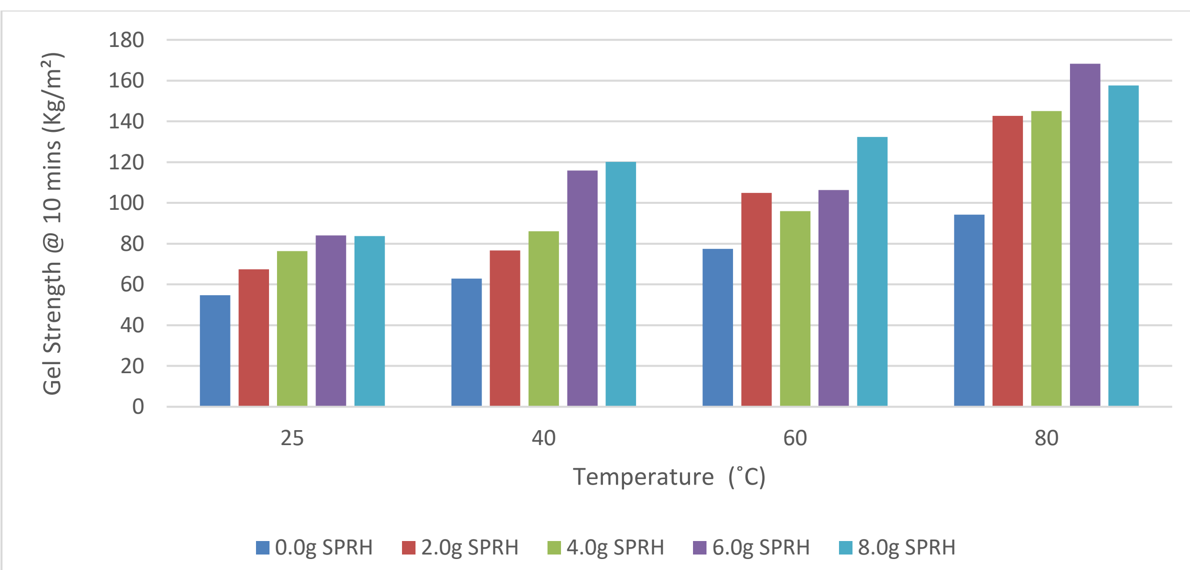

Figure 4. Ten minutes gel strength of SPRH starch mud compositions vs temperature

3.4. The effect of SPRH Starch on mud fluid loss

The correlation between fluid loss with time for SPRH compositions is illustrated in Figure 5. The fluid loss pattern differs from 1 min to 3 min with various volumes of SPRH starch granules. It was observed from Figure 5 that the fluid loss sample increased directly with time, although the 8g of SPRH starch granules contained in the drilling mud exhibited a marginally lower fluid loss that the set-out control bentonite (0g SPRH Starch granules). Furthermore, the mud sample having 2g concentration of SPRH flour at a lower time period of about (1-3 mins) recorded a lower value of fluid loss. This behaviour can be attributed to the high percentage of amylose present in sweet potato as stated in a similar project executed by [4]. The ratio of fluid loss can be considerably decreased by increasing the mass of SPRH starch granules in the drilling mud. It was observed using a filter cake that when the concentration of SPRH starch granules was increased, the thickness of the cake increased from 2 mm to 3 mm resulting in a thinner cake. A thinner cake is more desirable in drilling operations as it reduces the risk of pipe sticking hazards [20].

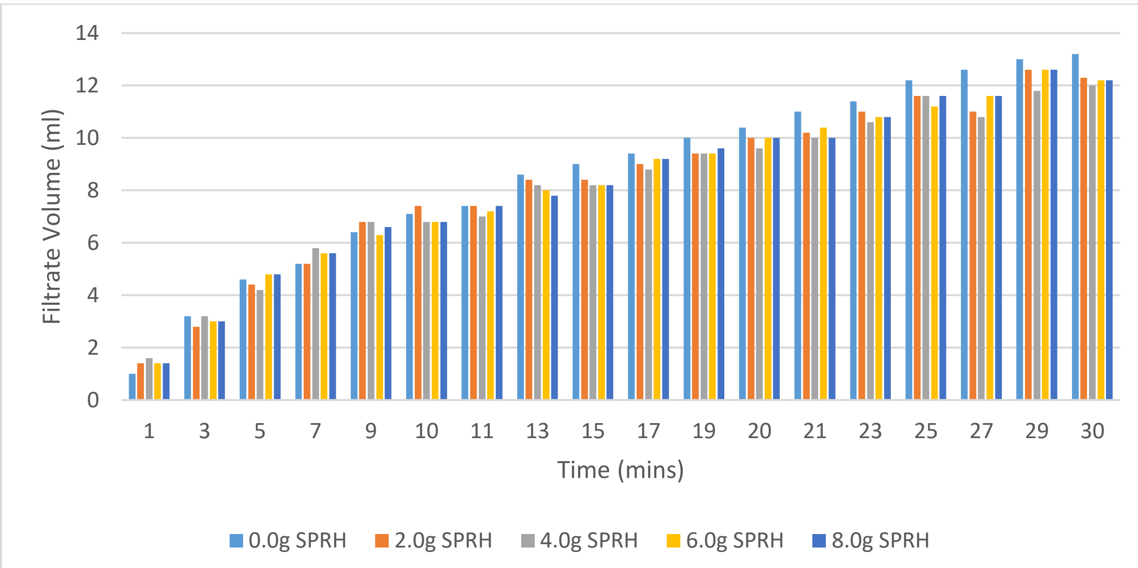

Figure 5. Filtration Loss of the Samples of Mud vs Time

3.5. Rheogram

It can be clearly deduced from Figures 6 - 9 that when the quantities of the SPRH starch granules is increased, there is a corresponding increase in their distinctive viscosities leading to an increase in the shear stress of the drilling mud. It can also be clearly deduced from the graphical representations that the pattern of the curves of the different samples illustrates the characteristics of non-Newtonian fluids. The basic crystalline compound contained in the granular starch is amylopectin. The disparity in the percentage of amylopectin and amylose present in starch alters the rheological nature of the starch. The gelling behaviour of starch is controlled by its amylose components.

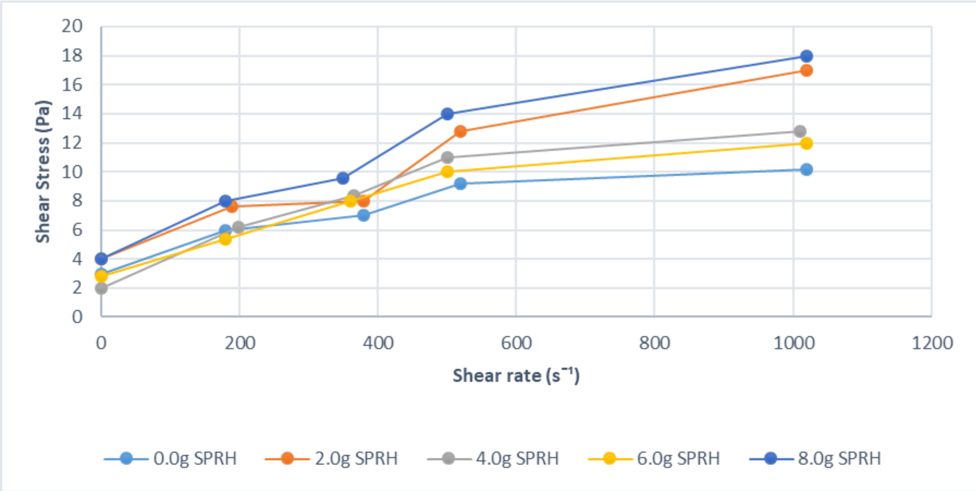

Figure 6. Rheogram illustrating the fluid behaviour at a temperature of 25°C

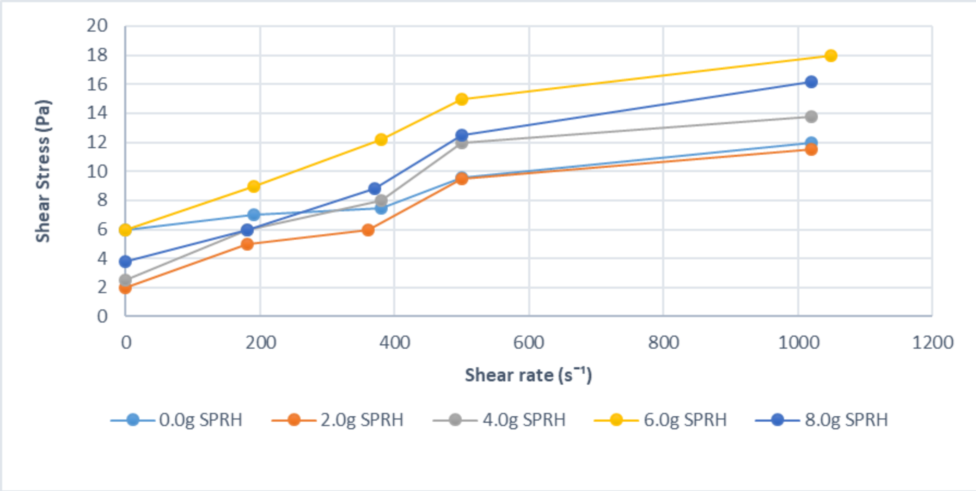

Figure 7. Rheogram illustrating the fluid behaviour at a temperature of 40°C

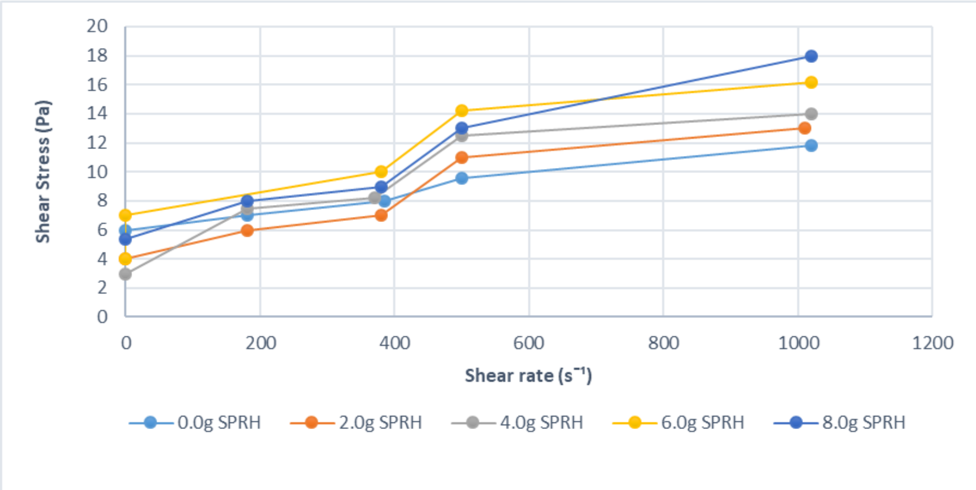

Figure 8. Rheogram illustrating the fluid behaviour at a temperature of 60°C

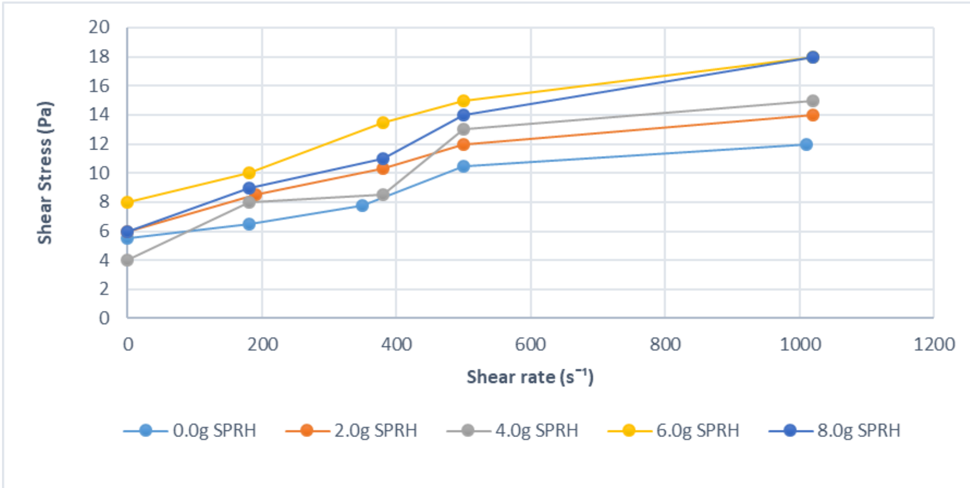

Figure 9. Rheogram illustrating the fluid behaviour at a temperature of 80°C

4. Conclusion

This study investigated sweet potato (*Ipomoe batatas*) and rice (*Oryza sativa*) husk starch blend as a viscosifier and fluid loss control agent in water based drilling mud. The plastic viscosity, yield point and gel strength of the drilling mud increased with increasing starch content. This showed a clear positive effect of the starch blend as a viscosifier. The decrease in the plastic viscosity of the mud sample with temperature is because higher temperatures brings about a decrease in the liquid phase of the drilling mud and causes a thermal degeneration of starch. From the study of temperature effect (25 – 80°C), higher temperatures were detrimental to the mud plastic viscosity and had a positive effect on yield point and gel strength. Several specific conclusions were drawn from the study.

1. The PV of the drilling mud sample with SPRH blend ranged from 3-8 mPa.s, which is ideal because it enables the drilling mud to carry cuttings to the well bore.
2. The yield point values of the drilling mud samples were in the ranges of 71.8- 151.9 kg/m^2 which is favourable for a successful drilling operation.
3. The samples of mud having concentrations of SPRH blend exhibited a greater gel strength than that of the control sample (0g SPRH Blend). Except for the 6g and 8g concentration of SPRH blend at a temperature of 80°C for the gel strength of 10 mins.
4. The SPRH starch blend at the different experimented concentration had a significant effect on the swelling capacity of the water based drilling mud as a result the viscosity of the drilling mud was significantly increased.
5. The introduction of the SPRH starch blends with concentration ranging from 2g to 8g affected the thickness of the filter cake leading to a thin filter cake with a thickness range of 2mm - 3mm, therefore resulting in an appropriate decrease in fluid loss by about 8%. This affirmed the basis that continuous increase in the concentration of the SPRH starch blend would significantly decrease fluid loss

Furthermore, the starch blend was also shown to reduce fluid loss from the drilling mud. The viscosifier was also shown to improve the viscosity of the drilling mud. The drilling mud also revealed the usual rheological characteristics of non-Newtonian fluids. This study has successfully utilised sweet potato and rice husk starch blend as a viscosifier and fluid loss control agent in water based drilling mud.

Disclosure statement

No potential conflict of interest was reported by the authors.

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List of symbols

PV	*Plastic Viscosity*	*YP*	*Yield Point*
Rpm	*Revolutions per minute*	Θ_{600}	*600 RPM dial reading*
SPRH	*Sweet Potato and Rice Husk*	Θ_{300}	*300 RPM dial reading*
WBM	*Water Based Mud*		

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