EVALUATING THE IMPACT OF RHEOLOGICAL PROPERTY OF LOCAL VISCOSIFER ON HOLE CLEANING

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Abstract

Hole cleaning is an important factor for a good drilling program. Effective and efficient wellbore cleaning is achieved by adequate cuttings transportation from bottom hole to surface through the annulus, but this cutting transport in the annulus is a complex problem. Effective removal of drill cutting from the wellbore is one major factor in preventing various drilling challenges associated with cuttings transportation. These challenges result to loss of drill time, higher operating cost and reduced production. Consequently, it is necessary to optimize the parameters influencing wellbore cleaning. This work evaluated the cuttings carrying capacity of drilling fluids developed with local viscosifer (biopolymer- Irvingia Gabonensis) and compared it with the performance of existing mud prepared with conventional viscosifer (polyaionic cellulose PAC polymer). Power law model was used to evaluate viscosity while modified power law model was used for estimation of slip velocity of the drilling fluids. The result of the study showed that the effectiveness of circulating fluid in removing drilled cuttings depends on the rheology among other factors. The rheolgy of the biopolymers compared favorably based on the viscosity and flow curves. Samples F6 to F8 had higher yield stress than the conventional muds , this is a good indication of good hole cleaning. Equally the biopolymer exhibited good transport ratio. Drilling fluids with high transport ratio are very good candidates for wellbore cleaning.

Keywords: Rheology, local viscosifer, hole cleaning, biopolymers, transport ratio, drilling fluid

1.0 Introduction

The drilling mud is essentially used in the oil and gas well drilling basically to carry out the drill cuttings and to lubricate the bit for fast and effective penetration of the formation. Cuttings removal is a function of the mud rheology, wellbore size and the subsurface conditions prevailing while drilling. The rheological properties of the desired drilling mud must be suitable to perform this function and also sustain the ecosystem of the environment at a low cost. It becomes imperative to use environmentally friendly drilling mud that will be non-toxic, biodegradable and locally sourced, as viscosifer in the preparation of water based mud. In this work, several domestically used seeds were used to prepare viscosifers used in place of the conventional viscosifers. Amongst the material are irvingia gabonensis (ofo), Barchystegia eurycoma (achi), Mucuna Sloanei (Ukpo) and deuterium Senegalense (ogbono). Drilling high angle or large diameter holes impose some severe demands on the rheological properties of drilling mud. Drilling mud must have high cutting carrying capacity and hole cleaning capability. The desired rheology includes high shear thinning viscosity with a high ratio of yield point to plastic viscosity and relatively high gel strength. Modified natural polymers like xanthan gum, guar gum and carboxyl methyl cellulose (CMC) have been used successfully with bentonitic clay to achieve good carrying capacity in water base mud (WBM). The problem with these conventional polymers is adverse effect on the environment, especially the mud-filtrate pollutes and contaminates aquifer and the spent mud must be disposed with caution. Therefore the development of new set of viscosifers derived from grains and tress are attracting the interest of researchers. These new set of viscosifers must be biodegradable and less costly, which can be used as fertilizer after drilling activities.

It is equally necessary to evaluate the hole cleaning ability of these suggested new viscosifers. Adequate hole cleaning is important goal in the drilling industry to eschew the operational problems that arise if sufficient wellbore cleaning is not achieved. The operational challenges includes but not restricted to excessive over pull on trips, hole pack-off, excessive equivalent circulating density (ECD), formation break down, slow rate of penetration and difficulty in removing casing. The difficulty in removing cuttings is caused by the interaction of the drilling mud with the cuttings bed to form cutting bed gel. Drilling fluid composition can be designed to minimize gel formation in the cuttings bed. One of the major functions of the drilling mud is to remove the cuttings generated by the drill. Therefore, the drill fluid properties should be optimized to ensure a sufficient shear stress on the cuttings for adequate cuttings removal. The carrying capacity of a drilling fluid is its ability to transport the cuttings up the casing-pipe annulus to the surface. Poor wellbore cleaning results to operational challenges which culminate to reduction in revenue derived because of non-productive time, higher operating costs and impaired production. This study is intended to use power law model to evaluate the impact of rheological properties on effective wellbore cleaning when local viscosifers are used while drilling. This assesses the cuttings carrying capability of the new formulations.

1.1 Review Mud Rheology

Several investigators (Sifferman and Becker, 1992: Zeidler, 1970 and Walker and Li 2000) had worked on influence of mud rheology on cuttings transport. Sifferman and Becker (1992) reported that cutting transport efficiency increased as fluid viscosity increased. The study revealed that more cuttings are transported (85% - 90%) in a laminar flow while in a turbulent flow cuttings removal is about 75% of the theoretical value. Zeidler (1970) had a contrary result. The work claimed that viscosity is not a major factor in cutting transport. Hussain et al (1983) investigated cutting transport with 3 different drilling fluids. Their work evaluated the effect of annular fluid velocity and yield point and concluded that these parameters had positive influence on cutting transport hence had efficient well bore cleaning. Fluid rheology plays important role in cutting removal, an optimum result may be achievable when the low viscosity fluid is used in turbulent flow (Walker and Li, 2000), because turbulent flow will induce turbulent slip velocity hence laminar flow in the annulus would result to more efficient transport (Pigott 1941). Another important concept is evaluation of fluid density to viscosity ratio which could be applied to control drilling through sensitive formations. A small increase in the fluid density to viscosity ratio causes a rapid decrease in the transport ratio (Belavadi and Chukwu, 1994). Also an increase in the drag coefficient on the cuttings results to a big increase in the transport ratio.

Interaction of mud rheology, particle size and drill pipe movement while drilling has been found to contribute immensely to cutting removal. Experiments conducted with different cutting sizes have shown that smaller cuttings are more difficult to be removed than larger cuttings in water as drilling fluid but when tested with polymers smaller cuttings were easier to be transported (Doan et al., 2000). More over the investigation also reported that pipe rotation and fluid rheology are key factors in controlling small cuttings transport (Doan et al., 2000). Studies on critical re-suspension velocity (CRV) and critical deposition velocity (CDV) of sand particles have shown that CDV is almost 2 – 3 times grater than CRV for given sand size and fluid properties (Doan et al., 2000). This indicates that water will be more effective than low-concentration polymers for bed erosion while polymer drilling fluids will be more needful than water in preventing cutting bed formation.

Suspension of cutting in the drilling mud is favoured by the rotation of drill pipe especially when drilling is not in progress Ozbayoglu, 2007, Belavadi and Chukwu, 1994, sifferman and Becker, 1992, Walker and Li, 2001,

Different models have been developed to predict cuttings carrying capability of the drilling fluid. A mathematical model developed to predict the volumetric cuttings concentration (Zedler, 1970) has shown that predicted concentration of cuttings is high at low fluid velocities during drilling. Studies have been conducted to evaluate the minimum fluid transport velocity for vertical inclined and horizontal wells (Larsen 1994). Three parameters were found to affect the determination of minimum fluid velocity; inclination, rate of penetration and mud density.

A two layer (Gavignet and Sobbey, 1989; Martins and Santana 1992 and Cho etal 2001) and a three layer (Hyun etal 2000) mathematical models have been develop to predict cuttings transport. It is assumed that the cuttings had fallen to the lower part of the inclined wellbore and had formed a bed that slides up the annulus, above this bed is a region where the cuttings are in suspension (Martins and Santana, 1992). Several models have been developed to evaluate and predict the wellbore cleaning ability of the drilling fluid. Most of these models estimated the minimum fluid transport velocity. For instance Larsen (1990) and Gavignet and Sobey (1989): developed two and three layer models to evaluate cutting transport while Martins and Santana 1992, Hyun etal 2000 and Cho etal 2001 considered the slippage between drilling fluid and cuttings. Hence the models could be used to predict cuttings bed height as a function of drilling fluid flow rate.

2.0 Materials and Method

In the rheological property test, the performances of the locally sourced products were compared with the standard water base formulation. The study considered two sets of laboratory test. The first considered the work on combination of different local materials and the second obtained from the works of Onyeukwu and Ihuoma (2012) on the use of irvingia Gabonensis as a viscosifer.

2.1 First set of laboratory test- case 1

Data used here was obtained from an experimental test carried out on samples A to G. sample A here is used as control test for case 1 and shows composition of a standard water based mud. Table 1 shows the composition.

Table 1: Mud composition

Additives	Concentration
water	342.65ml
NaoH	0.5g
Soda ash	0.5g
Nacl	109g
Aldacide	A drop
Xanthan gum	10g

Table 2: sample composition

Mud mixtures	samples
Xanthan gum	A
Water/achi	B
Water/bentonite/ofor	C
Water/bentonite/ogbono	D
Water/bentonite/ogbono/achi	E
Water/bentonite/ogbono/ukpo	F
Water/Ogbono/ofor	G

A barrel of the mud was made with 350ml of water. All rheological test additives were 10g in 350 ml of water. The viscosifers were formulated with the Hamilton bench mixer for 15 minutes. The same concentration of additives used in sample A was used in preparing samples B to G. Rheological test was carried out at 120^{o}F. The result is shown in Table 3.

2.2 Case 2 Data comparing rheology of conventional viscosifer and Irvingia Gabonensis

The mixing procedure and the sample concentration can be found in Onyeukwu and Ihuoma, (2012).

Table 3: Rheological properties of the samples in case 2 (Onyeukwu and Ihuoma 2012)

RPM	Samples					
	F1	F2	F4	F6	F7	F8
600	59	90	73	60	93	138
300	42	59	49	54	77	100
200	36	33	43	36	62	82
Pv	17	31	24	6	16	38
Yp	25	28	25	48	61	62

3.0 Results and Discussion

Table 4: Rheological properties of the samples in case 1

RPM	Samples						
	A	B	C	D	E	F	G
600	40	10	9	16	10	11	10
300	31	9	8	12	8	9	8
200	27	8	6	9	5	7	6
Pv	9	1	1	4	2	2	2
Yp	22	8	7	8	6	7	6

Table 5: Power law indices for case 1 samples

	Pv	**Yp**	**600 RPM**	**300RPM**	**n**	**k**
A	9	22	40	31	0.368	3.124
B	1	8	10	9	0.152	3.488
C	1	7	9	8	0.170	2.771
D	4	8	16	12	0.415	0.902
E	2	6	10	8	0.322	1.074
F	2	7	11	9	0.289	1.484
G	2	6	10	8	0.322	1.074

Table 6 Power law indices for case 2 samples

	Pv	**Yp**	**600 RPM**	**300RPM**	**n**	**k**
F1	17	25	59	42	0.49	1.978
F2	31	28	90	59	0.61	1.314
F4	24	25	73	49	0.57	1.401
F6	6	48	60	54	0.15	21.190
F7	16	61	93	77	0.27	14.296
F8	38	62	138	100	0.46	5.677

3.1 Impact of Rheology on Wellbore Cleanings

The analysis of influence of rheology on wellbore cleaning was done using excel spreadsheet to compute parameters which affects cutting carrying capacity of the drilling fluid. Seven parameters were considered to demonstrate the impact of rheology on wellbore cleaning such as plastic viscosity (Pv), yield point (y_p), yield point to plastic viscosity ratio, the laminar flow consistency factor (k), the laminar flow behavior index (n), shear stress to shear rate ratio and the viscosity of the drilling fluid. Yield point is the major rheological parameter that improves the cutting carrying capacity of the fluid. Drilling fluids with very high yield point and very low plastic viscosity values have been found to have optimum wellbore cleaning capability. Yield stress controls annular hole cleaning during drilling. From table 6 drilling fluid samples F6, F7, and F8 have higher yield stress compared to F1, F2 and F4. The result of the rheological test in case 1 showed that the control fluid A, has the highest yield point followed by samples B, C and F, and E and G. higher yield stress is good indication of good hole cleaning. From table 4 samples B and C had the lowest plastic viscosity. Based on the flow behavior of water based drilling fluid, the power law model was used to evaluate the relationship between shear stress and the shear rate.

Moreover, drilling fluids with very low power law index (n) and high laminar flow consistency factor (K) values exhibited high degree of shear thinning and were adequate for wellbore cleaning. Tables 5 and 6 show the results of the power law model for the two cases. Based on case study 2, the power law index value ranges from 0.1 to 0.6. Standard value of n for non dispersed drilling fluid is between 0.4 and 0.7 and for highly dispersed fluid the range is between 0.7 and 0.9 (Mian 1992). If n is less than 1the fluid show sufficient shear thinning, if n is 1 the fluid is a Newtonian fluid while n values greater than 1 shows shear thickening fluid. Since all the values of n for both of the local polymer materials and conventional polymers are less than 1, the samples are shear thinning fluid. Shear thinning is the decrease in viscosity with increase in shear rate. These values were applied to study wellbore cleaning in well x. In case 1 the control sample A had better rheological properties followed by sample D and others as shown in figures 1 to 4.

Table 7: Rheological Properties of Drilling fluid used in Case 1

samples	Yp	Pv	RPM	Shear rate	Shear stress	viscosity	Yp/Pv
A	22	9	600	1022	40.012	0.039	2.44
			300	511	31.003	0.061	
			200	341	26.716	0.078	
B	8	1	600	1022	10.000	0.010	8.00
			300	511	9.000	0.018	
			200	341	8.460	0.025	
C	7	1	600	1022	9.000	0.009	7.00
			300	511	8.000	0.016	
			200	341	7.47	0.022	
D	8	4	600	1022	16.000	0.016	2.00
			300	511	12.000	0.023	
			200	341	10.15	0.03	
E	6	2	600	1022	10.00	0.010	3.00
			300	511	8.00	0.016	
			200	341	7.00	0.021	
F	7	2	600	1022	10.99	0.011	3.50
			300	511	9.00	0.018	
			200	341	8.01	0.023	

The flow curve is shown with figure 1, a relationship of the shear stress and shear rate for different fluid formulations. Both the base case fluid sample A and other samples show the same trend. The flow curve for sample A has better performance. Figure 3 shows the viscosity curve for all the samples. From the plots the samples exhibited good viscosity and therefore have good transportation ability and provide suspension of the cuttings. Good viscosity provides reduced radial slip velocity of the drilled and suspended cuttings during fluid flow. This may also eliminate cuttings agglomeration in the wellbore. Though the samples B to G did not match sample A effectively because equal weight of samples were used in the formulations. This shows that higher concentration of the sample B, C, D, and E may be used to obtain equivalent result in case 1.

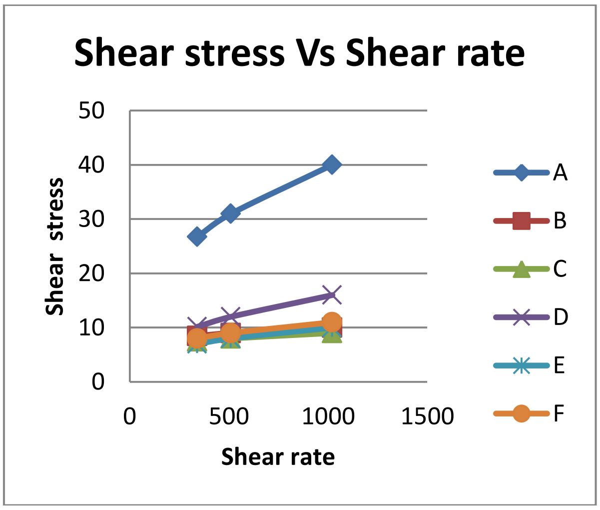

Figure 1: Flow curve of samples used in case 1

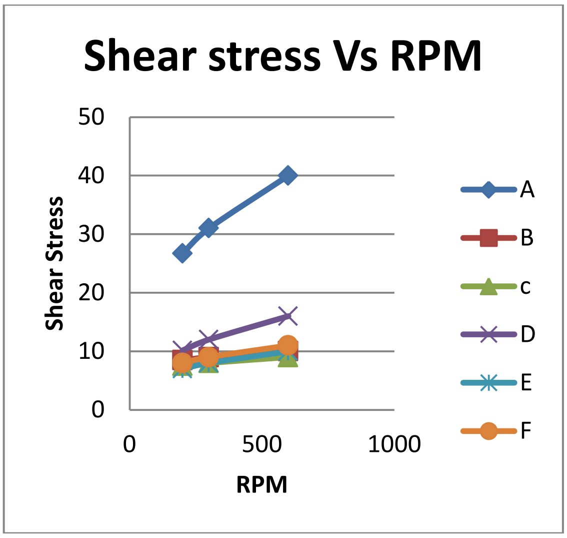

Figure 2: shear stress versus viscometer reading in rpm

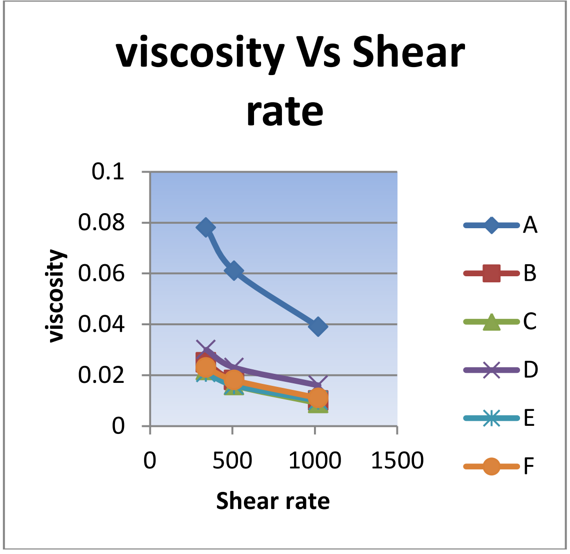

Figure 3: Viscosity curve for fluid samples used in Case 1

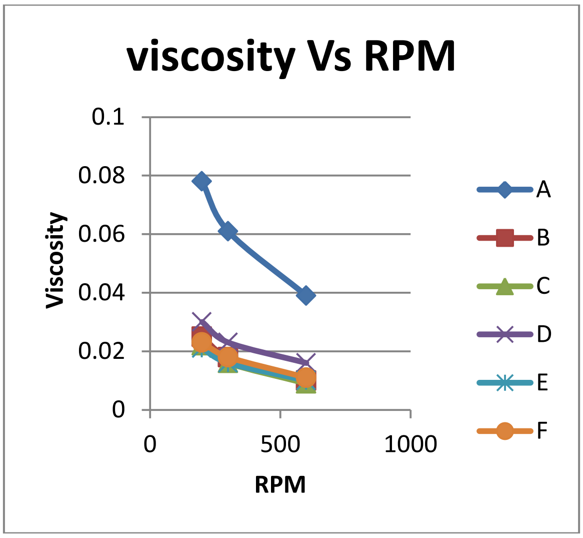

Figure 4 plot of viscosity against viscometer reading in rpm case 1

A better match was obtained in case 2 were PAC L was compared with Irvingia Gabonensis in the ratio of 1:1, 1:5, 1:7 and 1:10. The study done by Onyekwu and Ihuoma (2012) reported that 1ppb of PAC-L is equivalent to 7 ppb of Irvingia Gabonensis. Further investigation was done on the sample data as shown in table 8 and the results were plotted in figures 5 to 8. The analysis in this case 2 is based on formulation 4(10ppb of PAC-L) and formulation 7 (70 ppb of Irvingia). Figures 6 through figure 8 showed that samples F6, F 7 and F8 (local viscosifer – irvingia gabonensis) have better performance than samples F1, F2 and F4 (conventional viscosifer). Higher concentrations of the local viscosifer has higher viscosity, share stress, and yp/pv ratio.

Table 8: Rheological Properties of Drilling fluid used in Case 2

samples	Yp	Pv	RPM	Shear rate	Shear stress	viscosity	Yp/Pv
F1	25	17	600	1022	59.001	0.0577	1.471
			300	511	42.01	0.0822	
			200	341	34.457	0.101	
F2	28	25	600	1022	90.024	0.088	1.12
			300	511	58.984	0.1154	
			200	341	46.087	0.1352	
F4	25	24	600	1022	72.749	0.07118	1.042
			300	511	49.005	0.0959	
			200	341	38.998	0.1144	
F6	25	24	600	1022	59.917	0.0586	1.042
			300	511	54.0	0.1057	
			200	341	50.821	0.1490	
F7	61	16	6000	1022	92.847	0.0908	3.80
			300	511	77.0	0.1507	
			200	341	69.033	0.2024	
F8	62	38	600	1022	137.552	0.1346	1.632
			300	511	99.998	0.1957	
			200	341	83.021	0.2435	

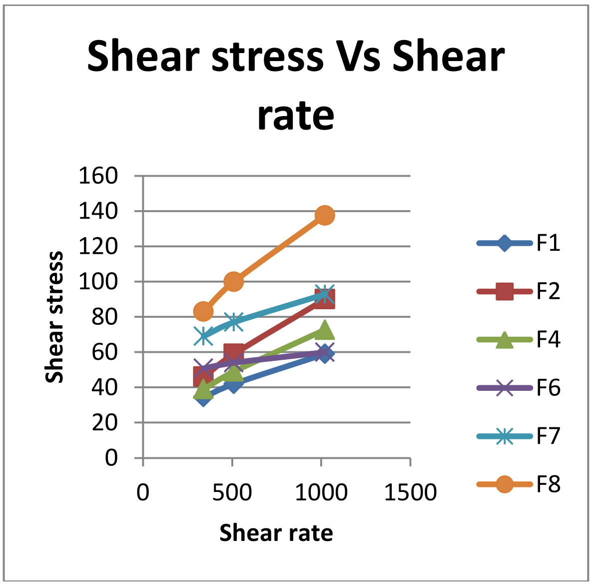

Figure 5: Flow curve of samples used in case 2

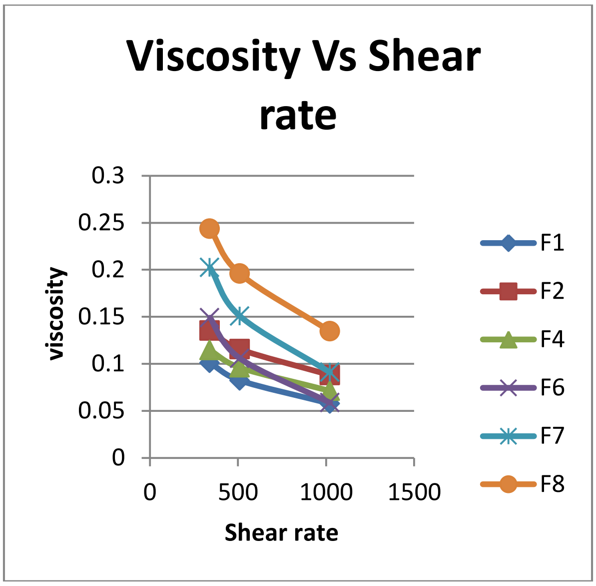

Figure 7: Viscosity curve for fluid samples used in Case 2

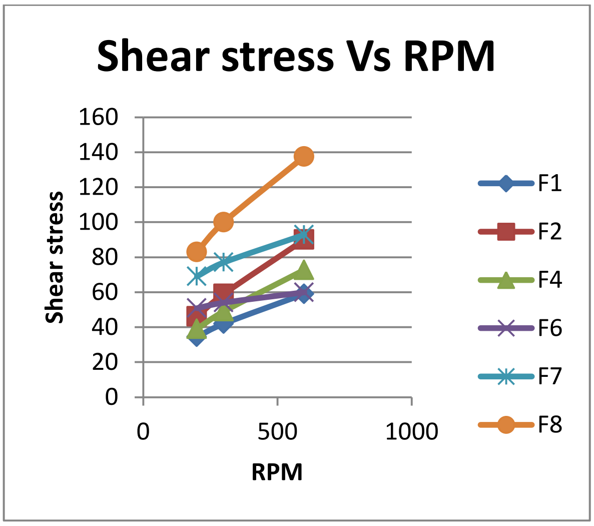

Figure 6: shear stress versus viscometer reading in rpm case 2

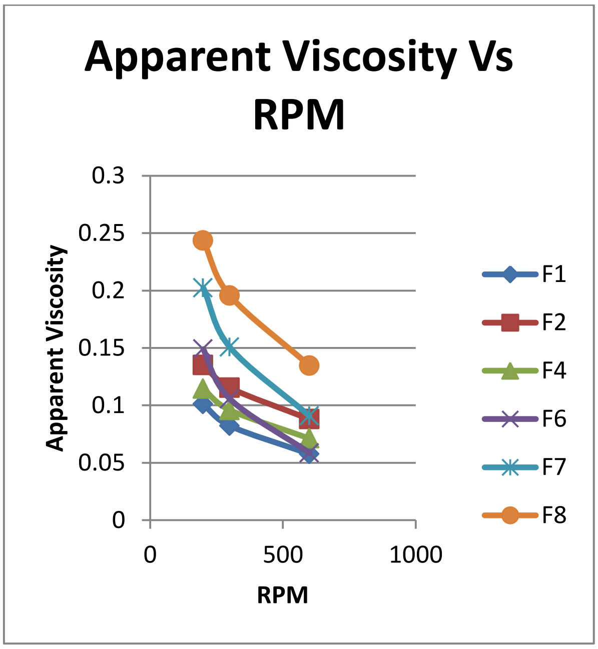

Figure 8 plot of viscosity against viscometer reading in rpm case 2

Table 9 (a): Evaluation of Average Annular Velocity (Va), Slip Velocity (Vs) and Transport Ratio TR For The Mud Samples A – G Case 1 using annular diameter of 4.5 inches

sample	**dc**	**n**	**k**	**ρ_m**	**Va**	**Vs (MS)**	**TR (MS)**
A	0.3	0.368	3.124	8.4	258.9915	7.023743	0.97288
B	0.3	0.152	3.488	8.3	166.112	96.19094	0.420927
C	0.3	0.17	2.771	8.3	163.9385	223.9375	-0.36598
D	0.3	0.415	0.902	8.35	216.4637	110.4921	0.489558
E	0.3	0.322	1.074	8.4	181.1716	268.9167	-0.48432
F	0.3	0.289	1.484	8.45	180.8811	166.4186	0.079956
G	0.3	0.322	1.074	8.35	181.8173	278.0987	-0.52955
A	0.2	0.368	3.124	8.4	258.9915	2.333779	0.990989
B	0.2	0.152	3.488	8.3	166.112	6.677887	0.959799
C	0.2	0.17	2.771	8.3	163.9385	20.62034	0.874219
D	0.2	0.415	0.902	8.35	216.4637	41.5925	0.807855
E	0.2	0.322	1.074	8.4	181.1716	76.33971	0.578633
F	0.2	0.289	1.484	8.45	180.8811	40.91566	0.773798
G	0.2	0.322	1.074	8.35	181.8173	78.94628	0.565793

Table 9 b Evaluation of Average Annular Velocity (Va), Slip Velocity (Vs) and Transport Ratio TR For The Mud Samples. A – G Case 1 using annular diameter of 3.5 inches

Sample	**dc**	**n**	**k**	**Δdiameter**	**ρ_m**	**Vs (MS)**	**Va**	**TR**
A	0.3	0.368	3.124	3.5	8.4	7.023743	274.0921	0.974375
B	0.3	0.152	3.488	3.5	8.3	96.19094	169.5814	0.432774
C	0.3	0.17	2.771	3.5	8.3	223.9375	167.8109	-0.33446
D	0.3	0.415	0.902	3.5	8.35	110.4921	231.1865	0.522065
E	0.3	0.322	1.074	3.5	8.4	268.9167	190.1229	-0.41444
F	0.3	0.289	1.484	3.5	8.45	166.4186	188.7246	0.118194
G	0.3	0.322	1.074	3.5	8.35	278.0987	190.8005	-0.45754
A	0.2	0.368	3.124	3.5	8.4	2.333779	274.0921	0.991485
B	0.2	0.152	3.488	3.5	8.3	6.677887	169.5814	0.960621
C	0.2	0.17	2.771	3.5	8.3	20.62034	167.8109	0.877122
D	0.2	0.415	0.902	3.5	8.35	41.5925	231.1865	0.820091
E	0.2	0.322	1.074	3.5	8.4	76.33971	190.1229	0.598472
F	0.2	0.289	1.484	3.5	8.45	40.91566	188.7246	0.783199
G	0.2	0.322	1.074	3.5	8.35	78.94628	190.8005	0.586237

Evaluation and analysis of transport ratio for the formulated and existing fluids were done using the modified stoke's law for slip velocity evaluation. In case 1 the mud viscosity of the samples are low. The transport ratio of sample A is better than samples Band D (local formulation) for the removal of cuttings as observe from Table 9a and 9b respectively. The local viscosifers performed well in removing cuttings with diameter of 0.2 mm. It was observed that the existing fluids F1, F2 and F4 for cutting diameter of 3 mm gave transport ratio of 0.33, 0.61 and 0.45 respectively while the value for the biopolymer (formulated) fluids F6, F7 and F8 are 0.99, 0.98 and 0.95, indicating that the formulated fluid (biopolymers) had better cutting carrying capacity than the existing fluids. A transport ratio of 1 means the cutting upward velocity is equal to the average annular velocity of the fluid in the annulus, meaning slip velocity is zero. The polymer fluids were more effective in removing small sized particles as shown in table 10 for particle sizes of 1mm and 0.5 mm. results show 97% to 100% cutting removal. The biopolymer mud is suitable for removal of small to large particles sizes. The difference in the performance of the local formulation in case 1 and case 2 is based on the concentration of the local formulation used. The study has equally show from tables 9 and 10 that cutting removal depends on fluid rheology, cuttings diameter and annular diameter amongst other parameters.

Table 10 : Evaluation of Average Annular Velocity (Va), Slip Velocity (Vs) and Transport Ratio TR For The Mud Samples.

sample	**dc**	**n**	**k**	**ρm**	**Mw**	**Va**	**Vs**	**TR**
F1	3	0.49	1.978	8.33	11	318.6657	183.7532	0.423367
F2	3	0.61	1.314	8.33	11	372.5422	128.8279	0.654192
F4	3	0.57	1.401	8.33	11	335.7162	161.8952	0.517762
F6	3	0.15	21.19	8.33	11	391.2135	3.39211	0.991329
F7	3	0.27	14.3	8.33	11	492.9516	8.466994	0.982824
F8	3	0.46	5.677	8.33	11	569.6465	26.09058	0.954199
F1	1	0.49	1.978	8.33	11	318.6657	6.507241	0.97958
F2	1	0.61	1.314	8.33	11	372.5422	7.091249	0.980965
F4	1	0.57	1.401	8.33	11	335.7162	7.853401	0.976607
F6	1	0.15	21.19	8.33	11	391.2135	0.000746	0.999998
F7	1	0.27	14.3	8.33	11	492.9516	0.048249	0.999902
F8	1	0.46	5.677	8.33	11	569.6465	0.798256	0.998599
F1	0.5	0.49	1.978	8.33	11	318.6657	0.790715	0.997519
F2	0.5	0.61	1.314	8.33	11	372.5422	1.138154	0.996945
F4	0.5	0.57	1.401	8.33	11	335.7162	1.163871	0.996533
F6	0.5	0.15	21.19	8.33	11	391.2135	3.67E-06	1.000000
F7	0.5	0.27	14.3	8.33	11	492.9516	0.001852	0.999996
F8	0.5	0.46	5.677	8.33	11	569.6465	0.08845	0.999845
F1	5	0.49	1.978	8.33	11	318.6657	868.633	-1.72584
F2	5	0.61	1.314	8.33	11	372.5422	496.0725	-0.33159
F4	5	0.57	1.401	8.33	11	335.7162	661.1362	-0.96933
F6	5	0.15	21.19	8.33	11	391.2135	170.3375	0.564592
F7	5	0.27	14.3	8.33	11	492.9516	93.59228	0.810139
F8	5	0.46	5.677	8.33	11	569.6465	132.0117	0.768257

Conclusion

The following conclusions were drawn from the results of this study.

1) This mud formulation is best for shallow drilling based on the temperature range of 60 ^{O}F to 120 ^{O}F used in this study. Also, the conventional mud formulated was a spud mud.
2) An excel spread sheet model was used to calculate the transport ratio of steady state flow in the annulus using power law model.
3) The drilling fluids formulated with local biopolymer have higher effective viscosity at 600 rpm reading, yield point and higher transport ratio which indicate a better cuttings carrying potential than the conventional mud used in the study.
4) Higher transport ratio provides better wellbore cleaning during drilling. Improvement of fluid rheology will enhance transport ratio at optimum annular velocity values.
5) Transport ratio depends on cutting diameter, cutting density, annular velocity and fluid rheology. Hence application of power law model in the slip velocity evaluation was done to show the effect of rheology and ensure good wellbore cleaning prediction.
6) This work has shown the impact of rheology of biopolymer Irvingia gabonesis on well bore cleaning at shallow depth and low temperature drilling.
7) There is need to refine the biopolymer to have equal measure of the conventional polymer, that is to use 1 g of biopolymer for 1g of conventional polymer. This is the reason for poor result in case 1

Recommendation

From the results of this work it is recommended that biopolymers could be used in drilling because it is environmentally friendly, has low cost, appreciable rheology and good cuttings carrying capacity. Further work should be done on the biopolymer to improve their rheological quality for high temperature high pressure drilling (deep well drilling).

Nomenclature

Dc	cutting diameter
N	laminar flow behavior index
K	laminar flow consistency factor
P_m	mud density
Va	annular velocity
Vs	slip velocity
TR	transport ratio
Yp	yield point
Pv	plastic viscosity
Rpm	revolution per minute
Mw	molecular weight

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