Journal of Polymer and Biopolymer Physics Chemistry, 2014, Vol. 2, No. 3, 50-54
Available online at http://pubs.sciepub.com/jpbpc/2/3/2

DOI:10.12691/jpbpc-2-3-2

Rheological Behaviour of Eco-friendly Drilling Fluids from Biopolymers

O.U. Nwosu[1], C. M. Ewulonu[2,*]

[1]Department of Environmental Engineering/Industrial Safety, Imo State Polytechnic, Umuagwo, Nigeria
[2]Department of Polymer and Textile Engineering, Nnamdi Azikiwe University, Awka, Nigeria
*Corresponding author: cm.ewulonu@unizik.edu.ng

Received May 14, 2014; Revised August 24, 2014; Accepted August 27, 2014

Abstract The rheological properties of drilling fluids modified with three biopolymers – carboxylmethyl cellulose (CMC), xanthan gum polysaccharide (xanplex D), and polyanionic cellulose (PAC-R) have been studied. The effect of concentration of the biopolymers on the drilling fluid was also reported. The modified drilling fluids were found to obey Herschel-Bulkley rheological model. The fluids were also found to be pseudo-plastic with shear thinning behaviour. Polyanionic cellulose showed the highest shear rate and shear stress than carboxylmethyl cellulose and xanplex D. This can be attributed to the straight open long chain structure of PAC-R and its ability to interact with water, solids and with itself. It also acted as a better viscosifier because of the more negative charge it carries. Also, the formulation of biopolymer drilling fluid with bentonite has proven to improve the viscosity than that encountered in normal conventional drilling fluids.

Keywords: *rheology, biopolymers, drilling fluids, natural polymers, Herschel-Bulkley model*

Cite This Article: O.U. Nwosu, and C. M. Ewulonu, "Rheological Behaviour of Eco-friendly Drilling Fluids from Biopolymers." *Journal of Polymer and Biopolymer Physics Chemistry*, vol. 2, no. 3 (2014): 50-54. doi: 10.12691/jpbpc-2-3-2.

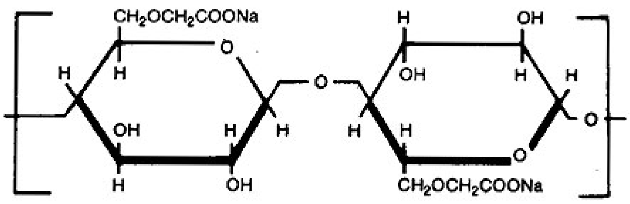
1. Introduction

Drilling fluids properties are very important for the success of any drilling operation. The fluids were originally designed to ensure that rotary drilling of subterranean formations is possible and economical. The drilling fluids achieve this by (i) moving drill cuttings to the surface, (ii) cooling and cleaning the drill bit, (iii) reducing friction, (iv) maintaining wellbore stability, and (v) preventing pore fluids from prematurely flowing into the wellbore. In addition, the drilling fluids are essentially designed to build a filter cake, which is basically intended to decrease filtrate loss to the formation, be thin and hold the drilling fluid in the wellbore [1]. One of the most critical functions of drilling fluids is to minimize the amount of drilling fluid filtrate entering the hydrocarbon bearing formation which can lead to formation damage because of rock wettability changes, fines migration, drilling fluid solids plugging and formation water chemistry incompatibilities [2].

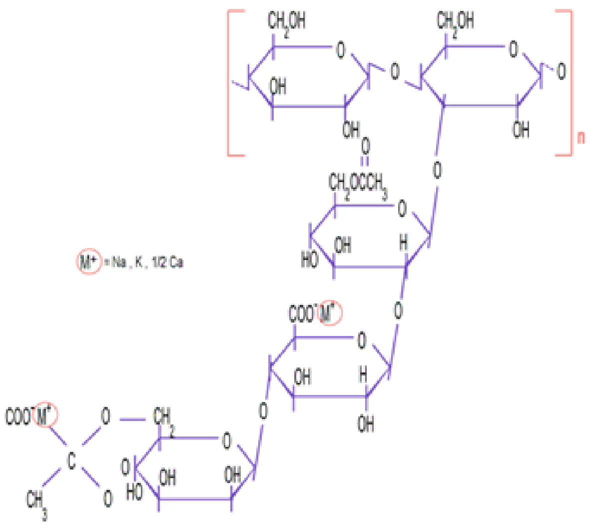
Rheological behaviour of drilling fluids is vital in their proper selection for any well. Rheological properties of drilling muds are important because they are used to characterize properties of the mud such as its well cleanses, erosion preservation, cutting material removal, hydraulic calculation, and pump system [3]. The rheological principles can be used to determine the dynamic performance of a drilling fluid behaviour in solving problems of cleaning hole, suspension of cuttings, hydraulic calculations and mud treatment [4]. The success of any drilling operation depends significantly on the performance and cost effectiveness of the drilling fluid employed [5,6,7]. According to Douglas et al [8,9,10], drilling fluids are generally classified into:(i) air or foam-based fluids which are used where liquid drilling fluid is not the most desirable circulating medium; (ii) oil-based fluid, and (iii) water-based fluid. Based on environmental and cost considerations, water-based fluids offer attributes that are generally preferred over that of oil-based fluids [11]. Drilling fluids should be environmentally friendly and contain the lowest possible amount of pollutants. Therefore, care should be taken in the selection and formulation of raw materials [12]. Nowadays, 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 of drilling fluids.

In oil-drilling, these polymers reduce filtrate, modify rheological properties, stabilize shale and reduce drag, and can be used in advanced oil recovery (EOR) processes [13,14]. The influx of the liquid phase, known as filtrate, in productive zones can cause a significant reduction of permeability and hence lower well productivity [15,16]. The incorporation of natural gums and starch-based materials in drilling fluids compositions was the primary solution to control this phenomenon [6]. A number of studies on polymers and their use in water-based drilling fluids have been carried out [6,17,18,19]. Gray and Darly, [6] studied the use of polymers like guar gum, carboxymethyl cellulose (CMC), and hydroxypropyl starch as filtration control agents and as drilling fluids. They concluded that filtration parameters like sorptivity and diffusivity of these polymers are dependent on temperature. Sorptivity is a measure of the resistance against the fluid flowing through the filter cake, while diffusivity is a measure of the rate of flow of fluid [20].

The effect of polymers on the rheological properties of KC1/polymer- type drilling fluids was studied by Kok and Alikaya, [19]. This study focused on the effect of addition of polymers on consistency index, flow behaviour index, and shear stress. The authors observed that consistency index increased as polymer concentration increased. Consistency index is a measure of the overall thickness of a fluid, while flow index is a measure of the degree of flow behaviour of a fluid [17,21]. The resistance of the fluid to the applied rate of shear or force is called the shear stress, which in oil field terms is analogous to the pump pressure [19,22,23].



Structure of sodium carboxymethyl cellulose



Structure of xanthan gum polysaccharide

In the present paper, the effects of adding various quantities of different biopolymers (Polyanionic cellulose, carboxymethyl cellulose and xanthan gum polysaccharide) to a drilling mud sample containing bentonite will be reported. The rheological properties of the drilling fluids will be determined and comparison made. Xanthan gum is an anionic polysaccharide polymer with high molecular weight generated by starch after fermentation of xanthomonas campestris. Carboxymethyl cellulose (CMC) is a semi-flexible anionic cellulose ether polymer [27] that is produced by reacting alkali cellulose with sodium monochloroacetate under rigidly controlled conditions. It is a chemical derivative of cellulose where some of the hydroxyl groups (-OH) are substituted with carboxymethyl groups ($-CH_2COOH$) while polyanionic cellulose (PAC) is a kind of anionic cellulose ether of high purity and high degree of substitution, prepared with natural cellulose through chemical modification. Its sodium salt is often utilized. The primary difference between the CMC and PAC production processes is in the radicalization step and the high degree of substitution in PAC. The structures of the biopolymers used are illustrated below. As is well known for CMC, PAC and other cellulose ethers, the characteristics of these materials can be varied by having different average numbers of substituents per glucose unit and different molecular weights [28].

2. Theory

The concepts of shear stress and shear rate and their measurement enable the mathematical description of the flow of drilling muds. The amount of force applied to a fluid determines the shear rate, which in oil field terms is determined by the flow rate of the fluid through a particular geometric configuration. Flow models are plots either of flow pressure versus flow rate or of shear stress versus shear rate.The Power law and Herschel –Bulkley models are described here and used forthe characterization of the drilling fluids studied.

2.1. Power Law Model

Power law is a two – parameter model that relates shear stress to shear rate in a nonlinear manner [17,23]. The model does not consider an excess yield stress and states the relation as:

$$\tau = K\gamma^n \tag{1}$$

where k, and n are consistency and flow indices respectively, τ is the shear stress, and γ is the shearrate. Taking the logarithm of the equation, the following term is obtained:

$$\log\tau = \log K + n\log\gamma \tag{2}$$

Thus, n = slope and k = intercept.

2.2. Herschel-Bulkley Model

Herschel-Bulkley is a three-parameter model that describes the behaviour of yield-pseudoplatics fluids [21].

$$\tau = \tau_o + K\gamma^n \tag{3}$$

where τ is the shear stress, τ_o is the yield stress, k is the consistency index, γ is the shear rate, and n is the flowindex.

3. Materials

The xanthan gum polysaccharide used for this study was obtained from Baker Hughes Houston USA under the trade name of XAN-PLEX™. Polyanionic cellulose regular under the trade name DRISPAC from Yu Long Chemicals China was among the natural polymers used in this study. Bentoniteand carboxylmethyl cellulose were obtained from Global Oil Company Nigeria Limited. The equipment/apparatus used in this study include: Fan V-G meter 8 speed model viscometer; hamilton beach mixer;

stop watch; electronic weighing balance; spatula, viscometer cup and hamilton beach mixer cup; standardized weighing plate and thermometer.

3.1. Experimental Procedure

The suspension of bentonite samples were prepared by immersing 15g of bentoniteclay into 350cm^3 of deionized water. The mixture was stirred vigorously for 15 minutes to achieve homogeneity while intermittently dislodging any bentonite clinging to the wall of the mixing container. The bentonite suspension was then stored at room temperature in a sealed container for 24 hours to give room for aging. Polyanionic cellulose Regular (PAC-R)was added to the Bentonite suspension at varying concentrations (0.50 g, 0.75g, 1.0g) and the viscometric studies carried out to determine its rheological behaviour on the drilling fluid. Suitable amountsof sodium hydroxide (NaOH) and Potassium chloride (KCl) were added to the samples and mixed to adjust the pH and for inhibition respectively. The procedure was then repeated for Carboxylmethyl cellulose (CMC) and xanthan gum polysaccharide (Xanplex D)biopolymers respectively. The shear-stress was determined using the power law model which assumes that all fluids are pseudoplastic.

4. Results and Discussion

The rheological parameters such as plastic viscosity, yield stress, and apparent viscosity of all of the drilling fluids were calculated and presented in Table 1. Figures 1 – 3 illustrates the relationship between shear stress, and shear rate of the non-Newtonian fluids at different concentration of the biopolymers.

The pattern of these curves showed an initial high stress after which there was a less stress with increasing shear. This indicates that the fluids are pseudoplastics and obey the Herschel-Bulkley model. According to Hemphill et al. [24], Herschel-Bulkley fluid model requires a certain stress to initiate flow, but less with increasing shear.

Table 1. Rheological properties of the drilling fluids

Fluid Reference	PAC R			Xanthan			CMC		
	0.50 g	**0.75 g**	**1.00 g**	**0.50 g**	**0.75 g**	**1.00 g**	**0.50 g**	**0.75 g**	**1.00 g**
Plastic Viscosity (P)	1.4	1.8	2.8	0.9	0.9	1.3	0.7	0.4	0.6
Apparent Viscosity (P)	8.05	13.20	24.00	5.00	9.45	11.90	19.30	22.75	23.50
Yield Stress (dyn/cm^2)	13.3	22.8	42.4	8.2	17.1	21.2	37.2	44.7	45.8
Flow index, n	0.3098	0.2594	0.2248	0.2823	0.1797	0.2488	0.0918	0.0806	0.1203
Consistency index, k	4.9238	9.1201	17.7310	3.8038	9.7656	8.8757	26.6318	32.7190	28.3531

The three parameters of Herschel-Bulkley model, i.e., yield stress, fluid consistency, and fluid index were calculated by fitting the experimental data of shear stress as a function of rate of shear to the model in Equation 3. The results indicate that the increment of the amount of biopolymers, increase the yield stress of the final drilling fluid as the flow resistance is increased. This finding is in agreement with the results of Khalil and Jan [25]. The increase in yield stress with concentration resulted from an increase in shear stress required to break the gel structure of the mud before flow started. Furthermore, it could be considered that, at rest, the mud's chains were entangled and the gel formation resulted from the polymer network formed by the physical aggregation with region of local order acting as network junctions.

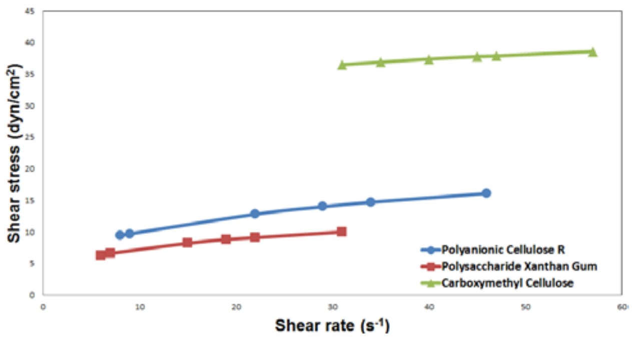


Figure 1. Plot of shear stress versus shear rate for bentonite gel modified with 0.5g of different biopolymers

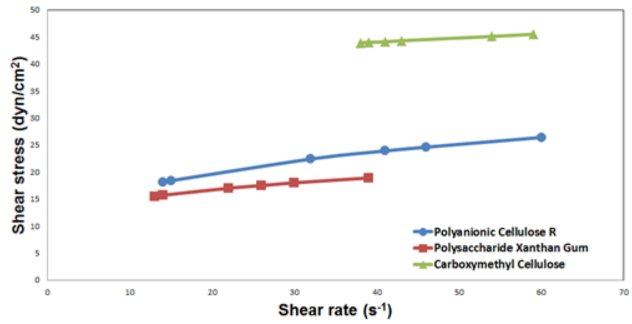


Figure 2. Plot of shear stress versus shear rate for bentonite gel modified with 0.75g of different biopolymers

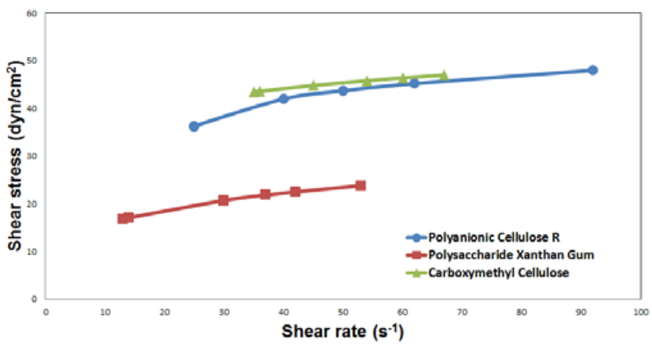


Figure 3. Plot of shear stress versus shear rate for bentonite gel modified with 1.0g of different biopolymers

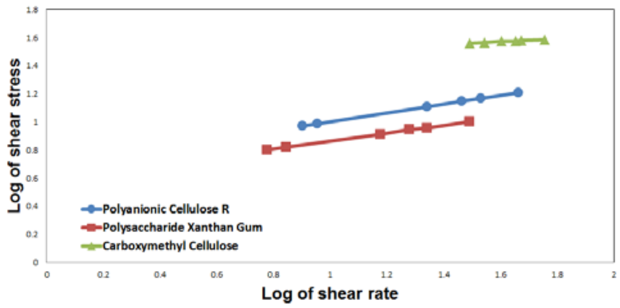


Figure 4. Plot of log of shear stress versus log of shear rate for bentonite gel modified with 0.50g of different biopolymers

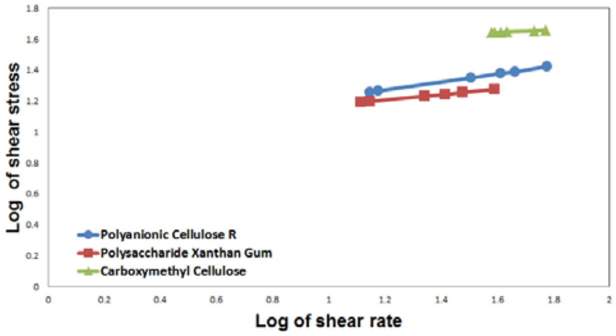


Figure 5. Plot of log of shear stress versus log of shear rate for bentonite gel modified with 0.75g of different biopolymers

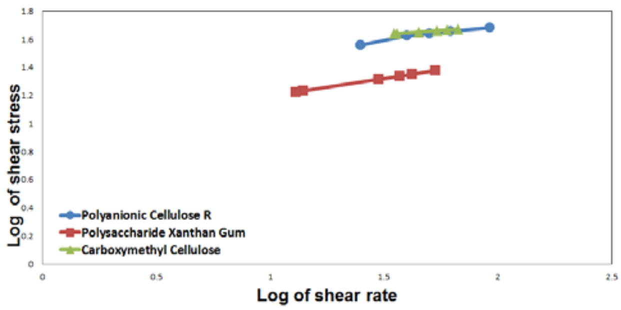


Figure 6. Plot of log of shear stress versus log of shear rate for bentonite gel modified with 1.0g of different biopolymers

The flow index, n, and consistency index, k, of the drilling fluids were analysed using Equation 2 andthis relationship is illustrated graphically in Figure 4 – Figure 6. The n values presented in Table 1 shows that the flow index, n, is less than 1 for each drilling fluid at the various concentrations of the biopolymers studied indicating a shear thinning behaviour. According to Mewis et al. [21], a fluid for which n valueis less than 1 ($n < 1$) is said to have pseudo plastic flow behaviour. Further examination of the table reveals thatthe flow index n, of the drilling fluid decreased with increasing concentration of polyanionic cellulose. This is contrary to the findings of Chike–Onyegbulaet al [26] who studied biodegradable polymer drilling mud prepared from Guinea corn starch. The consistency index, k, for the polyanionic cellulose modified drilling fluid was found to increase with increase in the concentration of the polymer in the fluid. The increase in consistency index, k, with polyanionic cellulose concentration resulted from the increase in the overall thickness of the fluid. In the case of drilling fluids modified with xanthan gum polysaccharide and caboxymethyl cellulose, the consistency index, K and flow index, n appears not to be affected by the quantity of the biopolymer. Contrarily, Khalil and Jan [25], found that the calculated fluid consistency of their drilling fluids appears to be strongly dependent on the presence of glass bubbles, xanthan gum, and clay. However, their fluid consistency appears not to be affected by the presence of starch.

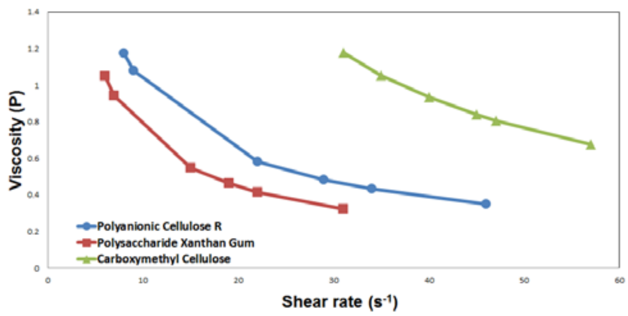


Figure 7. Plot of viscosity as a function of shear rate for bentonite gel modified with 0.50g of different biopolymers

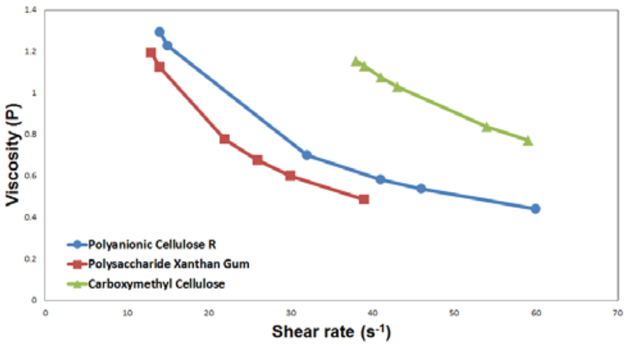


Figure 8. Plot of viscosity as a function of shear rate for bentonite gel modified with 0.75g of different biopolymers

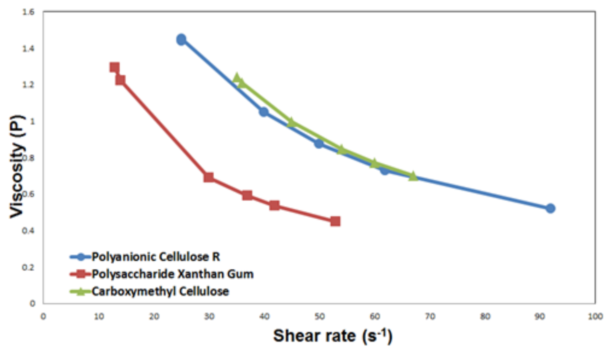


Figure 9. Plot of viscosity as a function of shear rate for bentonite gel modified with 1.0g of different biopolymers

The plot of shear rate as a function ofviscosity is shown in Figure 7 – Figure 9. It is observed from these figures that the viscosity of the drilling fluids decreased with increasing shear rate. This resulted from the fact that the entanglement of the fluid's chain at low shear rate impeded shear flow and the viscosity was high. The viscosity decreased as shear rate was increased, showing shear thinning behaviour of the drilling fluids. The viscosity of a polymer solution is related to the polymer concentration, the extent of polymer-solvent interaction, and the polymer structure such as molecular weight, shap, molecular flexibility, and molecular conformation [29]. Pseudo-plastics are known to resist flow with decreasing rate of shear stress. It was further observed that the concentration of xanthan gum polysaccharide and caboxymethyl cellulose in the drilling fluids did not have any effect on its viscosity whereas; increasing concentration of polyanionic cellulose increased the viscosity of the drilling fluid. Therefore increasing the concentration of polyanionic cellulose will increase its resistance to flow under certain levels of applied stress.

5. Conclusion

The Rheological properties of drilling fluids cannot be overemphasized because of their obvious contribution to the general successful drilling operations. This study has demonstrated the use of environmentally friendly biopolymers in the production of drilling fluids. The drilling fluids were found to be non-Newtonian and show pseudo-plastic behaviour. The shear stress, yield stress, and viscosity of the eco-friendly fluids are dependent on concentration and have higher values showing higher gel strength and flocculation for the new fluid than for the widely used fluids. The viscosity of the fluids decreases with increasing shear rate; therefore, the new fluids have a shear thinning behaviour. The new biopolymer fluids are therefore more suitable for exploration and exploitation of oil and gas in environmentally sensitive areas due to its high efficiency and purity. Polyanionic cellulose (PAC-R) showed the highest shear rate and shear stress than carboxyl methyl cellulose (CMC) and xanplex D. This was because of the straight open long chain structure of PAC-R and its ability to interact with water, solids and with themselves. It also acted as a better viscosifier because of the more negative charge it carries. Also, the formulation of polymeric drilling fluid with Bentonite has proven to improve the viscosity than that encountered in normal conventional drilling fluids.

References

[1] R. B. Watson, P. Viste, and J. R. Lauritzen, “The influence of fluid loss additives in high temperature reservoirs”, Society of Petroleum Engineers Conference Paper, 2012.

[2] B. K. Warren, T. R. Smith, K. M. Ravi, “Static and dynamic fluid-loss characteristics of drilling fluids in a full-scale wellbore”, Society of Petroleum Engineers Conference Paper, 1993.

[3] National Iranian Oil Company (NIOC) manual, “Drilling formation”, Department of Drilling Chemistry, Ahwaz, Iran, 2002.

[4] S. Z. Kassab, A. S. Ismail, and M. M. Elessawi, “Drilling fluid rheology and hydraulics for oil fields”, European Journal of Scientific Research, Vol. 57, Issue 1, p68, 2011.

[5] Deily et al., “New biopolymer low-solids mud speeds drilling operation”, The Oil and Gas Journal, vol. 65, No. 26, pp. 62-70, 1967.

[6] H. C. H. Darley, and G. R. Gray, “Composition and properties of drilling and completion fluids”, 5th ed. Gulf Professional Publishing, Houston, USA, pp. 66-67, 561-562, 1988.

[7] J. L. Lummus, and J. J. Azar, “Drilling fluids optimization: A practical field approach”, PennWell Books, Tulsa-Oklahoma, USA, pp. 3-5, 1986.

[8] J. F. Douglas, J. M. Gas-lorek, and J. A. Swaffield, “Fluid mechanics”, 3rd ed. ELBS with Longman, 1995.

[9] American Petroleum Institute, “Drilling fluid testing procedure manual”, USA, 2000.

[10] TEAP-ENIAgip Division, “Drilling fluid and waste disposal manual”, Nigeria, 2000.

[11] T. Hamida, E. Kuru, and M. Pickard, “Rheological characteristics of aqueous waxy hull-less barley (WHB) solutions”, Journal of Petroleum Science and Technology, 69, pp 163-173, 2009.

[12] T. Adam, Jr. Bourgoyne, E. C. Martin, F. S. Keithk, and Jr. Young, “Applied drilling engineering”, Society of Petroleum Engineers Text Book Series, Vol. 2, pp. 4082, 1991.

[13] L. M. Zhang, Y. B. Tan, and Z. M. Li, “New water-soluble ampholytic polysaccharides for oilfield drilling treatment: A preliminary study” Carbohydr. Polym.44, pp. 255-260, 2001.

[14] E. Lucas, C. Mansur, and L. Spinelli, Pure and Applied Chemistry, 81, pp. 473, 2009,

[15] A. Przepasniak and P. Clark, Society of Petroleum Engineers, Conference paper SPE-39461, Lafayette, EUA, 1998.

[16] A. Martins, A. Waldman, and D. Ribeiro, Society of Petroleum Engineers, Conference paper SPE-94287, Madrid, Spain, 2005.

[17] N. J. Alderman, D. R. Babu, T. L. Hughes, and G. C. Maitland, “Rheological properties of water-based drilling muds”, in 4th International Congress on Rheology, Sydney, 1988.

[18] M. V. Kok, T. Alikaya, “Rheological evaluation of polymers as drilling fluids”, Petroleum Science Technology, Vol. 21, Nos. 1-2, pp. 133, 2003.

[19] M. V. Kok, T. Alikaya, “Effect of polymers on the rheological properties of KCl/polymer type drilling fluid”, Energy Sources, 27: 405, 2005.

[20] F. H. D Outmans, “Mechanics of static and dynamic filtration”, Society of Petroleum Engineer Journal, 63: 210, 1963.

[21] J. Mewis, J. F. Willaim, A. S. Trevor, and W. B. Russel, “Rheology of suspensions containing polymerically stabilized particles”, Journal of Chemical Engineering Research Development, 19: 415, 1989.

[22] G. V. Chilingarian, and P. Varabutre, “Drilling and drilling muds” Development in Petroleum Science, 44, Elsevier, Amsterdam, 2000.

[23] M. N. Okafor, and J. F. Evers, “Experimental comparison of rheology models for drilling fluids”, SPE Western Regional Meeting, California, Paper ID. SPE-24086-MS, 1992.

[24] T. Hemphill, W. Campos and A. Pilehvari, "Yield-power law model more accurately predicts mud rheology”, Oil & Gas Journal, Vol. 91, No. 34, pp. 45-50, 1993.

[25] M. Khalil, and B. M. Jan, “Herschel-Bulkley rheological parameters of a novel environmentally friendly lightweight biopolymer drilling fluid from xanthan gum and starch”, Journal of Applied Polymer Science, Vol. 124, Issue 1, pp. 595-606, 2012.

[26] C. O. Chike–Onyegbula, O. Ogbobe, and S. C. Nwanonenyi, “Biodegradable polymer drilling mud prepared from guinea corn”, Journal of Brewing and Distilling Vol. 3, No. 1, pp. 6-14, 2012.

[27] C. W. Hoogendam, A. de Keizer, M. A. Cohen Stuart, B. H. Bijsterbosch, J. A. M. Smit, J. A. P. P. Van Dijk, P. M. Vander Horst and J. G. Batelann (1998). “Persistence length of carboxymethyl cellulose as evaluated from size exclusion chromatography and potentiometric titrations.” Macromolecules 31, 6297-6309.

[28] J. Kelly and J. John (1983). “Drilling fluid selection, performance and quality control.”Petroleum Technology, p889.

[29] B. L. Browning (1967). “Viscosity and molecular weight.”In Methods of wood chemistry, Vol. 2. B. L. Browning ed., Interscience Publishers, New York, Ch. 25, 519-557.