IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 7 Issue 3, March 2020
ISSN (Online) 2348 – 7968 | Impact Factor (2019) – 6.248
www.ijiset.com

Measurement of the Potentials of Terminalia Mantaly Gum as A Viscosifier For Drilling Mud Formulation

Inemugha, O.,[a] **Uyigue, L.,**[a*] **Chukwuma F.,**[a] **and Akaranta, O.,** [b]
[a]Department of Chemical Engineering, World Bank Africa Center of Excellence, Center for Oilfield Chemicals Research, University of Port Harcourt, Nigeria.
[b]Department of Industrial Chemistry, World Bank Africa Center of Excellence, Center for Oilfield Chemicals Research, University of Port Harcourt, Nigeria

*Email of the Corresponding author: uyique@yahoo.com

ABSTRACT
The focus of this study is on determining the potentials of Terminalia mantaly (TM) gum to serve as viscosifier (or fluid loss control agent) in drilling mud formulation. The idea is to further enhance the drive for local content materials which can support the oil and gas industry in Nigeria positively. Samples of the TM gum were pre-treated, and used for drilling mud formulation in line with standard practice. Other viscosifiers (such as xantha gum and polyanionic cellulose) were equally used for formulating other mud samples. The results obtained from the rheological measurements showed enhanced values of yield stress and plastic viscosity in the mud formulation with TM gum than the mud formulations with other viscosifiers. The rheological properties of the mud formulation with TM gum also showed strong dependence with TM gum quantity, such that as the mass concentration of TM gum increases (0.5 to 2.0 %) in the formulation, the rheological parameters were also increased by 23.1% (apparent viscosity); 25% (plastic viscosity); and 25.6 % (yield point). In addition, the mud formulation with TM gum also showed good level of thermal resistance. This was evident in the rheology such that as mud temperature increases (26 to 60 ^oC), the rheological properties of the formulation slowly decreased, except plastic viscosity which had sharp decreases. The Herschel-Bulkley model adequately fitted the rheological data for all mud formulations with TM gum. The model had the least RMSE and RSS values of less than 0.2 and 0.6 respectively, and the highest R^2 value of 0.997. Thus, the TM gum has strong potentials to serve as viscosifier or fluid loss control agent for water-based drilling mud.

Keywords: Rheological property; Terminalia mantaly; Drilling Mud; Viscosifier and Natural polymer

1. INTRODUCTION

Water based drilling mud are still preferred more, than the oil-based mud because of the negative impact of oil based mud on the environment. In recent years, some reports have been conducted on the effective use of water-based mud in drilling fluid (Abduoa et al, 2016; Udoh and Okon, 2012; Behnamanhar et al, 2014). A good number of these reports have revealed the uses of polymers in water-based mud to improve viscosity and control fluid loss (Akeem et al., 2018). Experimental examination at several API standards, temperature and pressure are used to explain the practical behaviour of polymers in the mud.

The composition of water based drilling mud contains a base fluid, suspended solid particles and chemicals. The suspended solid particles react chemically with the base fluid to control the properties of the mud (Annis and Smith, 1996). Some of the major additives like polymers are used in water-based mud to improve the rheological properties (apparent viscosity, plastic viscosity, yields point) or control the loss of fluid in the mud. These rheological properties are used to define the flow behaviour of the mud.

The molecular size and shape of polymers are responsible for their ability to absorb water and turn viscous. (Nwosu and Ewulonu, 2014). The viscosity in a solution is influenced by polymer chain entanglement and polymer solvent interaction which can be described by hydrodynamic volume (HDV). HDV of a polymer is determined by the polymer structural parameters such as chain toughness, chain length and polymer-solvent interactions and polymer associations or repulsions which depend on the concentration, temperature, molecular weight and deformation rate of the polymer (Kong and Ziegler, 2014).

Terminalia mantaly gum is a non-food agricultural waste gotten from the incised of the bark of the tree. It is seen as an agricultural waste because its economic values are less than processing it for human benefit. The aim of this work is to study the effect of the concentration and temperature on the rheological properties of drilling mud formulation with terminalia mantaly gum and compare with mud formulation with conventional polymers such as Xanthan gum and Polyanionic cellulose.

Some literature reports have revealed the use of terminalia mantaly gum as a binding agent in pharmaceutical industries, the reason for its application as binding agent is that its molecular structure contains highly branched polysaccharides consisting of galacturonic, glucuronic and 4-O-methylglucuronic acids, as well as galactose, arabinose, rhamnose, mannose and xylose, but it neutral sugars and total uronic acid content may vary with different type of Terminalia gum (Oluyemisi et al., 2012; Michael et al., 2017). The physicochemical characteristics is presented in Table 1.

Although at the moment, the industry makes use of semi-synthesized viscosifiers such as tendrillar carbonaceous material (TMC), polyanionic cellulose (PAC), carboxy methylcellulose (CMC), hydroxyl ethylcellulose (HEC), xantha gum etc., for which these materials are either prepared locally at high cost or are imported, hence will impart on operations cost. Therefore, this study will seek to evaluate the potentials of terminalia mantaly gum as drilling mud viscosifier. This gum is a water soluble natural polymer which is locally available, renewable and requires very little processing cost. In this study, different drilling mud samples will be formulated separately with Terminalia mantaly gum and other gums. These samples will be subjected to rheological evaluations while their performance will be compared.

Table 1: Physicochemical characteristics of Terminalia mantaly exudate (Michael et al, 2017).

Parameters	Terminalia mantaly exudates
Particle diameter (μm)	263.10
Angle of repose (°)	57.80
Particle density	1.32
Bulk density (g/cm^3)	0.090
Tapped density (g/cm^3)	0.139
Hausner's ratio	1.54
Carr's index	35
Swelling index	8.4
Water absorption capacity	10.71

2. MATERIALS AND METHODS

2.1 Purification of Terminalia Mantaly Gum

The purification of TM exudates was first reported by Michael et al (2017). TM gum was collected from the incised of the tree and allowed to dry for five days. 100.0g of dried gum was washed with deionized water to remove the initial foreign bodies from its body surface. The washed gum was kept in a hot air oven at a temperature of $50^{O}C$ for 50 h. The gum was hydrated in a double strength chloroform and water mixture in the ratio of 0.5%:95.5% for 5 days to soften and extract the mucilage. A straining exercise was carried out with use of a white muslin cloth to further remove the remaining viscous mucilage from the gum. Precipitation of the gum was conducted with use of an absolute ethanol for extra purification process. 100ml of Dimethyl ether was used to wash the precipitated gum after that the gum was kept at a temperature of $50^{O}C$ in a hot air oven for 10 h. The precipitated gum was pulverized with the use of blender into powdery form. 50.0g of the powdery TM gum was stored in an air tight container.

2.2 Drilling mud formulation

Formulations of water-based mud with few additives were performed in this section. The following additives were used for the water-based drilling mud formulation: Pre-hydrated bentonite, soda Ash, caustic soda, terminalia mantaly gum, xanthan gum, potassium chloride, low viscosity polyanionic cellulose and barite.

Table 2 presents the drilling mud formulation components and their functions. Water-based mud were formulated according to API (American Petroleum Institute) standard.

Table 2: Component of drilling mud formulation

Component	Functions
Deionized water	Base fluid
Pre-hydrated Bentonite	Viscosifier, Filtration Control
Soda Ash	Treat contamination
Caustic Soda	Alkalinity control
Xanthan gum	Viscosifier
Terminalia mantaly gum	Viscosifier (under this study)
Potassium chloride	Inhibition Source of K+ion
PAC L	Viscosifier and Filtration control
Barite	Weighing material

2.3 Rheological measurement

Rheological properties were performed to describe the flow behavior of the mud at different concentrations and temperature. In the preliminary step for the mud formulation, 22.5 g of bentonite was put in a weighing plate and weighed with electronic balance. The weighed material was added to a 350 ml of deionized water in a mud cup. Hamilton beach mixer was used to stir the suspension for 20 minutes in which a spatula was used to scrap the mud on the walls of the cup making sure that proper mixing is carried out. The same procedure was used to prepare two other pre-hydrated mud samples. Pre-hydrated mud functions better in the presence of salt (Annis and Smith, 1996).

Actual Water-based drilling mud formulation was carried by first adding 155.6 ml of pre-hydrated bentonite (PHB) in a mud cup containing 194.4 ml of deionized water and stirred for five minutes using Hamilton beach mixer, to formulate three separate mud samples: A, B and C.. Soda Ash and caustic soda of 0.1g each were added to the respective mud samples at every five minutes to reach 0.5g amidst frequent mixing. Xanthan gum, PAC L and TM gum of 1.7g each were also added in the order presented in Table 3, alongside with 10.5g of potassium chloride, and 19g of Barite.

In order to check the effect of other factors (such as quantity of TM gum in mud and temperature) on the rheology of the mud formulation sample B (Mud B), as well as fit the appropriate model describing the rheology, varied quantity of TM gum in terms of mass were added in the order: 0.5 %, 1%, 1.5% and 2%, to form different mud formulations for sample B.

Table 3 Different drilling mud formulation

Mud A	Mud B	Mud C
Deionized water	Deionized water	Deionized water
Pre-hydrated Bentonite	Pre-hydrated Bentonite	Pre-hydrated Bentonite
Soda Ash	Soda Ash	Soda Ash
Caustic Soda	Caustic Soda	Caustic Soda
Xanthan gum	**Terminalia mantaly gum**	**PAC L**
Potassium chloride	Potassium chloride	Potassium chloride
Barite	Barite	Barite

The rheological properties were calculated from 600 and 300 rpm readings from a Rotational Fann Viscometer (Model 35) using the following equations 1, 2 and 3 from API Specification for drilling fluid material.

Apparent Viscosity (AP), $\mu_a = \frac{1}{2}\,\theta600$ (1)

Plastic Viscosity (PV), $\mu_p = \theta600 - \theta300$ (2)

Yield point (YP) = $\theta300$ – PV (3)

Shear stress (SS), $\tau_y = \theta300 - \mu_p$
(4)

Where, Apparent Viscosity in equation (1) is measured in centipoise (cp)

Plastic Viscosity in equation (2) is measured in centipoise (cp)

Yield Point (or Yield Stress) in equation (3) is measured in $lb/100ft^2$

Note: $\theta600$ is the dial reading at 600 rpm and $\theta300$ is the dial reading at 300 rpm

2.4 Rheological Models Application

The measured data for shear stress and shear rate for the different mud formulations were fitted into the following rheological models in order to measure the unknown parameters of the models. The models considered in this work are presented: Bingham plastic model, Power law model and Herschel-Bulkley model.

Bingham plastic model
The Bingham model is a 2-parameter model that describes flow characteristics of many types of drilling mud. This model can be expressed mathematically as;

$$\tau = \tau_o + \mu_p \gamma \quad (5)$$

where, τ is the shear stress in lb/100ft^2, τ_o is the yield point with the unit lb/100ft^2, $\mu_p$is the plastic viscosity in (centipoise (cp)) and the γ is the shear rate (or strain rate) in sec^{-1} (per second).

Power law model
The Power law model (also called Ostwald-De-Weale model) is another 2-parameter model which describes fluids rheology with pseudo-plastic behavior in which the relationship between the shear stress and shear rate of a fluid is presented:

$$\tau = K\gamma^n \qquad (6)$$

Where, 'K' and 'n' are consistency and flow indices respectively, τ is the shear stress and γ is the shear rate in sec^{-1}. The logarithm of the equation is shown as linear equation, given as follows,

$$\log\tau = \log K + n\log\gamma \qquad (7)$$

For a graph plot of log τ versus log γ for the drilling mud formulations, n = slope and log K = intercept

Herschel-Bulkley Model
The Herschel-Bulkley describes the behaviour of pseudo-plastic fluids using 3-parameter model expression.

$$\tau = \tau_o + K\gamma^n \qquad (8)$$

Where, τ is the shear stress, τ_o is the yield stress, K is the consistency index, γ is the shear rate, n is the flow index.

2.5 Test for response of drilling mud rheology to temperature
Drilling mud formulation with TM gum of different mass concentration (0.5%, 1%, 1.5%, 2%) in the mud were subjected to viscosity measurement at different temperatures between 27 and 60 ^oC. The mud sample of each concentration was poured into the viscometer cup to the mark inscribed inside the cup. The viscometer cup was kept inside a thermocouple and placed on the viscometer stand and lifted to immerse the rotating spindle. The thermometer was inserted into the viscometer cup, allowed to heat up to the specified temperature. Thereafter, the respective dial reading for each temperature was recorded.

3 RESULTS AND DISCUSSION

3.1 Rheological Characterization
The shear stress and shear rate plot is presented in Fig. 1. From the figure, there was an initial increase in shear stress as shear rate increases, which later reduced as the shear rate continues to increase. This type of behavior indicates a pseudo-plastic fluid behavior as described by the Herschel-Bulkley model. Fluids that allow initial high shear stress to kick-start the flow at low shear rate, but will reduce at increased shear rate are described by Herschel-Bulkley model which was also corroborated by Nwosu and Ewulonu (2014); Khalil and Jan (2012).

IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 7 Issue 3, March 2020
ISSN (Online) 2348 – 7968 | Impact Factor (2019) – 6.248
www.ijiset.com

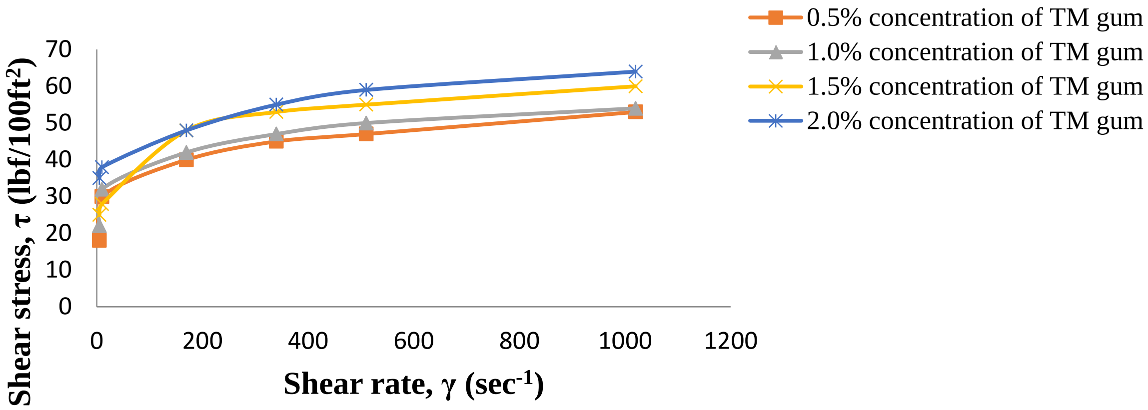

Figure 1: Plots of shear stress versus shear rate for mud formulation with TM gum

Also noticed in Table 3 and Fig. 2 was that as the quantity of TM gum increased in the mud formulation, the yield stress (or yield point), apparent viscosity, plastic viscosity of the drilling mud gradually increased by 23.1%, 25%, and 25.6% respectively. This concentration-dependence behavior of the mud rheology with TM gum is mostly attributable to polymer-mud interaction resulting in increased chain entanglement density and gel formation. It is also related to increased resistance to mud flow. This observation is an indication that the TM gum is a potential mud viscosifier.

Table 3 Rheological Properties of drilling mud formulation with TM gum based on Herschel-Bulkley model.

Quantity of TM gum in mud	0.5 %	1 %	1.5 %	2 %
Apparent Viscosity (cp)	24	27	29	31
Plastic Viscosity (cp)	4	4	5	5
Yield Point (lbf/100ft^2)	26	27	30	32
Flow index, n	0.48	0.459	0.407	0.013
Consistency index, K (lbf/100ft^2)	0.61	0.811	1.24	179.97

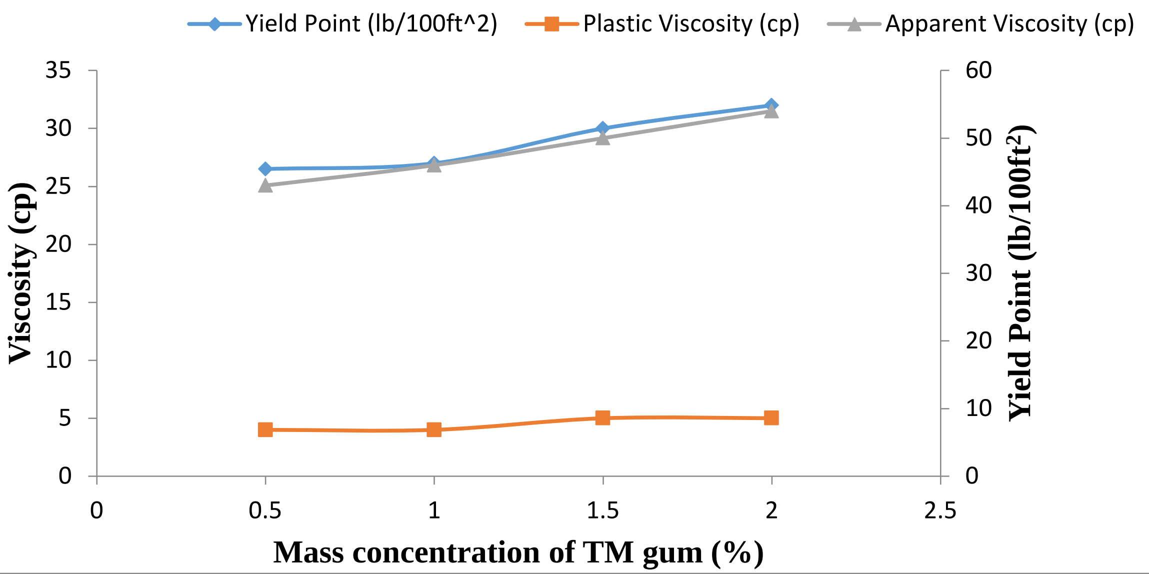

Figure 2: Plots of drilling mud rheological Property against mass concentration of TM gum

ISSN (Online) 2348 – 7968 | Impact Factor (2019) – 6.248
www.ijiset.com

3.2 Effect of temperature on the rheology of drilling mud with TM gum

Figures 3 to 5 showed the effect of temperature on the rheological properties of drilling mud formulated with TM gum. It was observed that all rheological properties of the mud slowly decreased as temperature is increased. Thus, an increase in temperature of the mud formulation can cause increase in the intermolecular distance of polymer molecules in the mud. This can cause degradation of the polymer in the mud due to the heat applied. This is assertion is corroborated by Makinde et al (2012) which stated that thermal degradation of polymer in the mud can cause the clay platelets to dehydrate and link each other so closely, thereby making the attractive forces dominate, resulting in a state of dispersion with edge-to-face contacts of the platelets. This can cause flocculation of clay platelets and decreased flow properties.

However, the general response of the rheology of mud formulation with TM gum to temperature, and as evident in Figures 3 to 5 are that apparent viscosity and yield stress showed favorable thermal resistance, while plastic viscosity showed low thermal resistance.

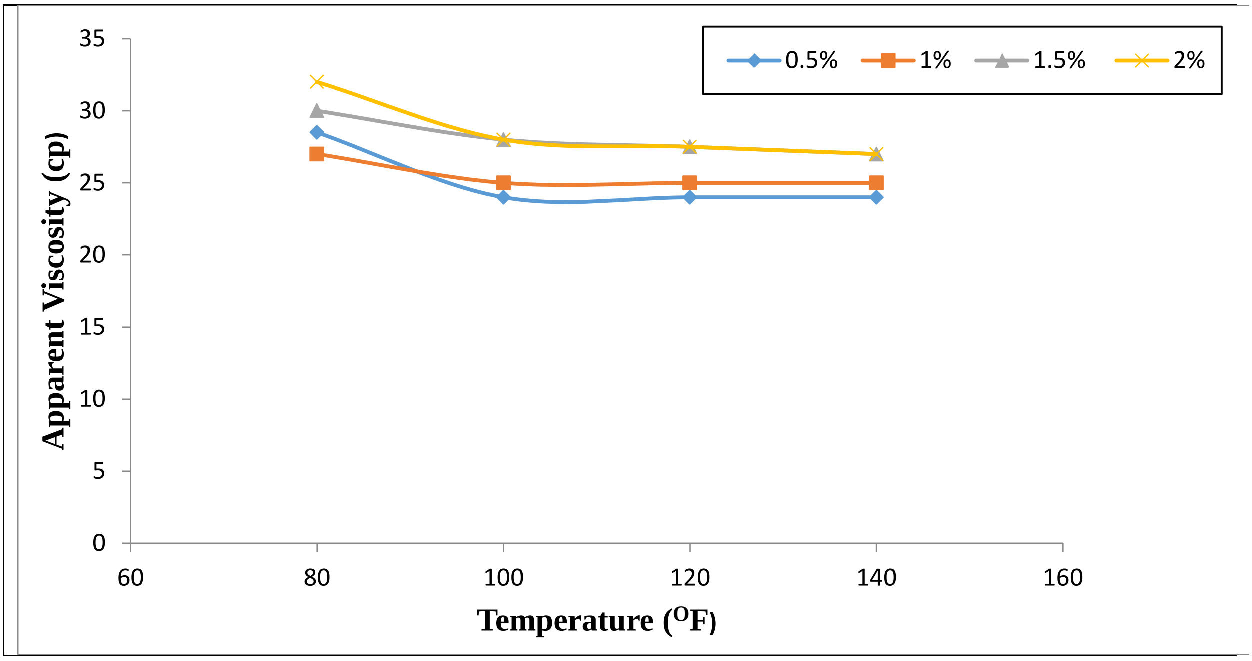

Figure 3: Effect of temperature on the apparent viscosity of drilling mud with TM gum

IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 7 Issue 3, March 2020
ISSN (Online) 2348 – 7968 | Impact Factor (2019) – 6.248
www.ijiset.com

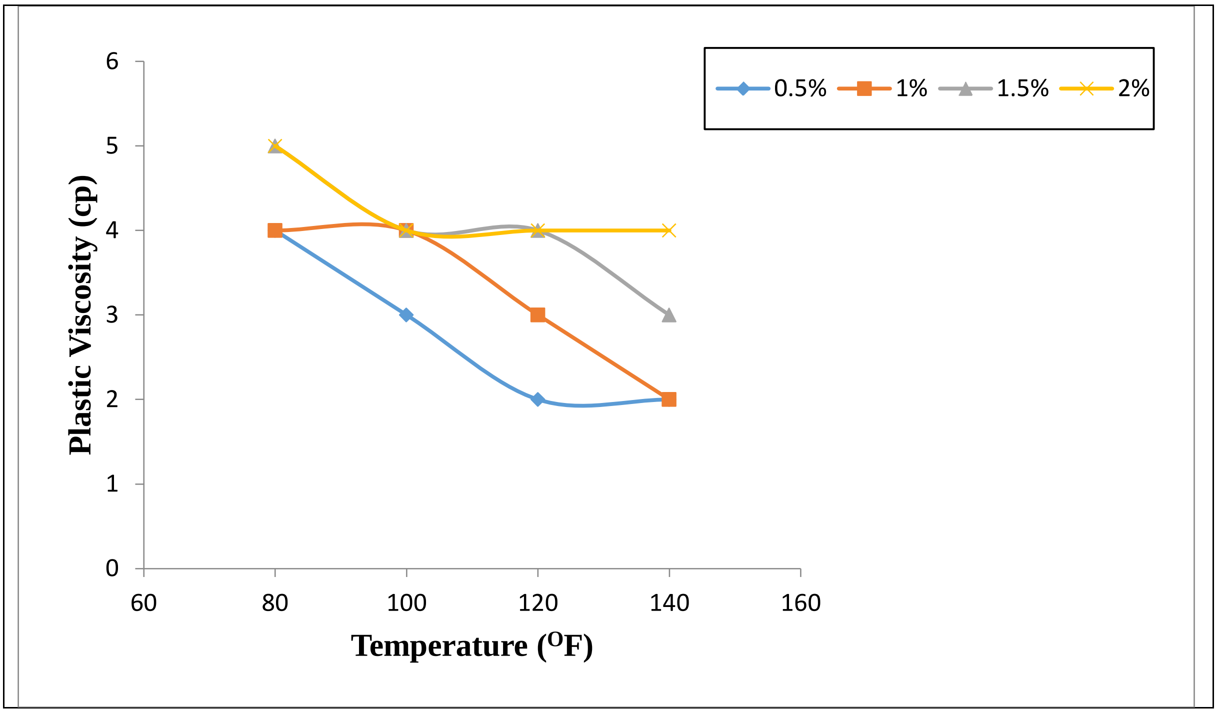

Figure 4: Effect of temperature on the plastic viscosity of tm gum drilling mud

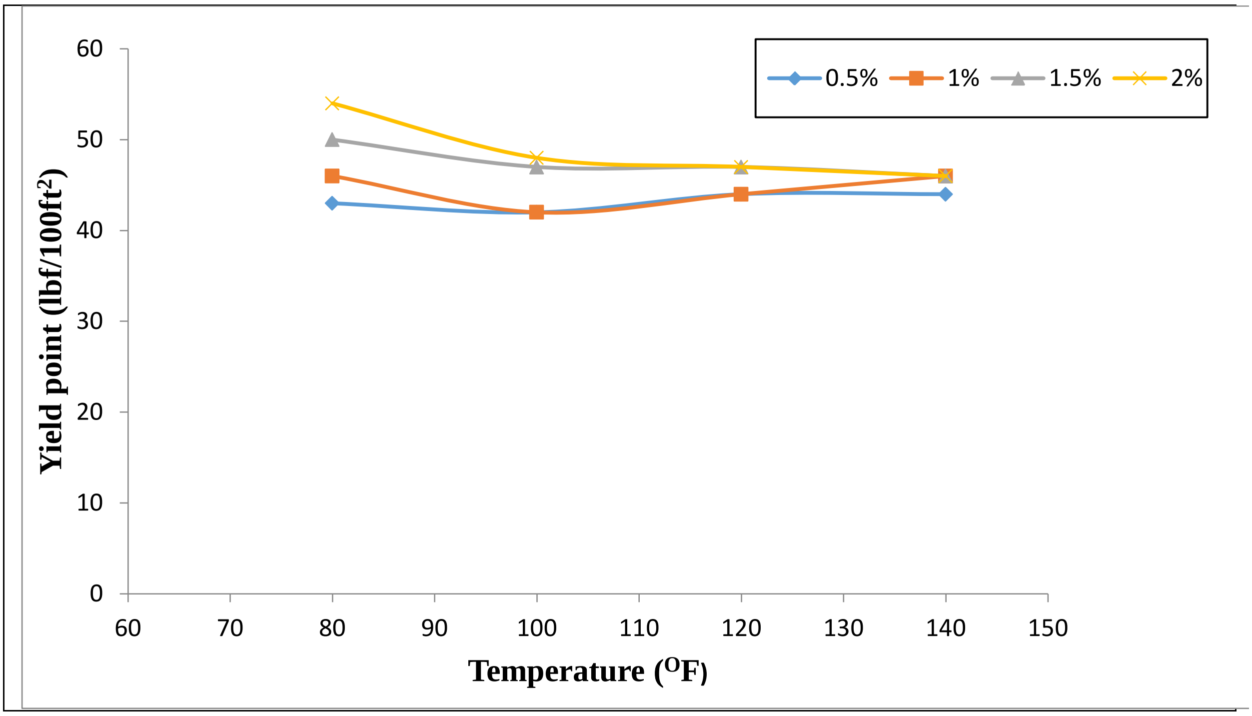

Figure 5: Effect of temperature on the yield point of tm drilling mud

3.4 Comparing the rheological properties of the different drilling mud formulation

In this section, the rheological properties of the three different mud categories (Mud A, B, and C) were compared based on the results shown in Fig. 6. Mud B had better rheological properties than Mud A and Mud C. This judgment is drawn based on the fact that TM gum used as additive in Mud B formulation acted as a better viscosifier and fluid control agent. In it, Mud B formulation showed lower plastic viscosity and a higher yield point.

In well drilling, the value of the plastic viscosity tells how the mud behaves around the bit. Higher plastic viscosity is never desirable because an increase in plastic viscosity can increase pressure drop down the drill string which can hinder the rate of flow and offset any increase in lifting ability. Higher yield point favors good hole cleaning and pressure control capability especially during the initial stages of drilling operation. This assertion is well corroborated by Al Sabagh et al (2014).

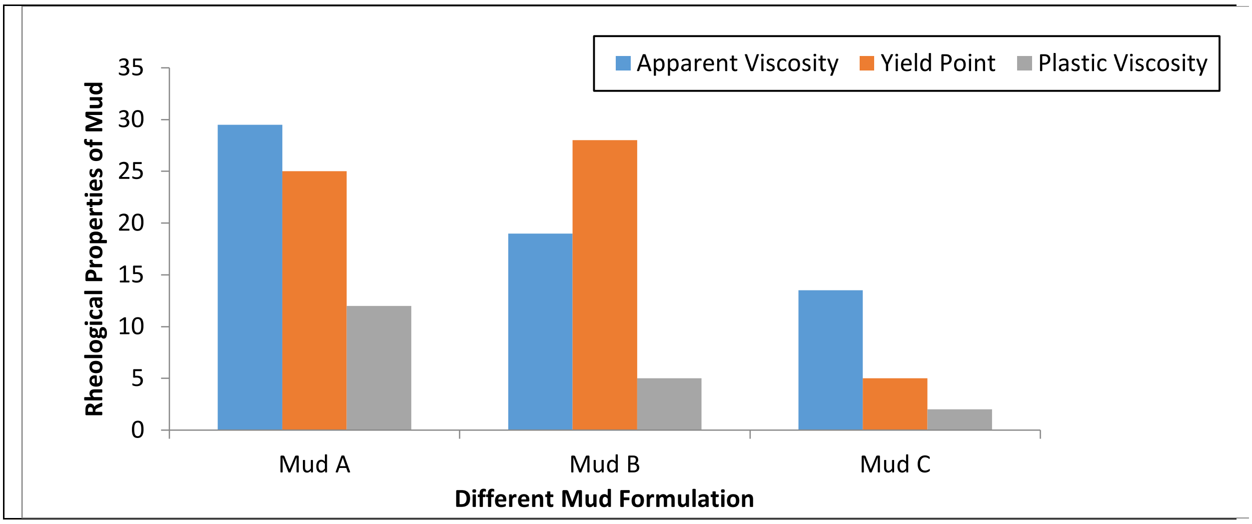

Figure 6: Rheological properties of mud formulations with different viscosifier

3.4 Rheological model analysis for drilling mud preparations with TM gum of different mass concentration

The measured rheological data for the drilling mud formulation (Mud B) with different mass concentration of the TM gum were fitted with three existing rheological models (Bingham plastic, Power law and Herschel-Bulkley), for which the unknown constant parameters of the models were measured, while the models goodness-of-fit were also estimated. The results of these analyses are shown in Tables 4 to 7. The Herschel-Bulkley model was observed to fit the measured rheological data better than the other tested models in all the mud formulations.

For instance, in the mud formulation with 0.5 % TM gum (Table 4), the Herschel-Bulkley model had the least root-mean-square-error (RMSE) and residual-sum-of-squares (RSS) values of 2.155 and 6.466, and the highest R-squared (R^2) value of 0.955. Similar observations were replicated in other mud formulations with TM gum as shown in Tables 5, 6 and 7. The RMSE and RSS are goodness-of-fit parameters which measures absolute fit of data to a model, while the R^2 parameter measures the relative fit. Thus, the lower the values of RMSE and RSS for a model, the more accurate are the model ability to predict the experimental measurement.

Table 4: Rheological model parameters and goodness-of-fit for mud formulation with 0.5% concentration of TM gum.

Model	Goodness-of-fit			Evaluated Parameter
	RMSE	**RSS**	**R^2**	
Bingham plastic	5.763	23.051	0.891	τ_o = 14.86 $lb_f/100ft^2$ μ_p = 0.015 $lb_fs/100ft^2$
Power Law	4.072	16.287	0.889	K = 9.998 $lb_fs/100ft^2$ n= 0.139
Herschel-Bulkley	2.155	6.466	0.955	τ_o = 11.76 $lb_f/100ft^2$ K = 0.61 $lb_fs/100ft^2$ n= 0.48

Table 5: Rheological model parameters and goodness-of-fit for mud formulation with 1% concentration of TM gum

Model	Goodness-of-fit			Evaluated Parameter
	RMSE	RSS	R^2	
Bingham plastic	8.12	32.49	0.869	τ_o = 16.16 $lb_f/100ft^2$ μ_p = 0.017 $lb_f s/100ft^2$
Power Law	4.98	19.90	0.923	K = 10.61 $lb_f s/100ft^2$ n = 0.146
Herschel-Bulkley	2.997	8.99	0.964	τ_o = 12.32 $lb_f/100ft^2$ K = 0.811 $lb_f s/100ft^2$ n = 0.459

Table 6: Rheological model parameters and goodness-of-fit for mud formulation with 1.5% concentration of TM gum

Model	Goodness-of-fit			Evaluated Parameter
	RMSE	RSS	R^2	
Bingham plastic	9.77	39.09	0.853	τ_o = 21.01 $lb_f/100ft^2$ μ_p = 0.018 $lb_f s/100ft^2$
Power Law	4.325	17.30	0.937	K = 14.66 $lb_f s/100ft^2$ n = 0.124
Herschel-Bulkley	2.492	7.475	0.972	τ_o = 16.114 $lb_f/100ft^2$ K = 1.24 $lb_f s/100ft^2$ n = 0.407

Table 7: Rheological model parameters and goodness-of-fit for mud formulation with 2 % concentration of TM gum.

Model	Goodness-of-fit			Evaluated Parameter
	RMSE	RSS	R^2	
Bingham plastic	10.54	42.16	0.693	τ_o = 10.61 $lb_f/100ft^2$ μ_p = 0.011 $lb_f s/100ft^2$
Power Law	0.72	2.88	0.981	K = 5.46 $lb_f s/100ft^2$ n = 0.194
Herschel-Bulkley	0.169	0.507	0.997	τ_o = 176.83 $lb_f/100ft^2$ K = 179.97 $lb_f s/100ft^2$ n = 0.013

4 CONCLUSION

This study has evaluated the potentials of Terminalia mantaly (TM) gum to serve as a viscosifier and fluid loss control agent in the formulation of water-based drilling mud. This is evident from the results obtained from experiments, wherein it showed more enhanced values of yield stress and plastic viscosity as compared to mud formulations with other viscofiers.

The rheological parameters of the mud formulation with TM gum showed strong concentration dependence with TM gum, such that as the mass of TM gum increases in the formulation, the rheological parameters were also increasing. In addition, the mud formulation with TM gum also showed good level of thermal resistance. This was evident in the rheology wherein as mud temperature increases, the apparent viscosity and yield stress of the mud formulation were slowly decreased as compared to plastic viscosity which had sharp decreases. The mud formulations with TM gum exhibited shear thinning behavior, for which the Herschel-Bulkley model fits the rheological data more accurately for all the formulations. Thus, the TM gum has strong potentials to serve as viscosifier and fluid loss control agent for water-based drilling mud.

REFERENCES

Abduoa, M. I., Dahab, A. S., Abuseda, H., Abdulaziz, A. M. and Elhossieny, M. S. (2016). Comparative study of using water-based mud containing multiwall carbon nanotubes versus oil-based mud in HPHT fields. *Egyptian Journal of Petroleum*, 25(4): 459-464.

Akeem, O. A., Olalekan, S. T., Salam, K. K., Omoloa, J. M. and Gafar, A. O. (2018). Potential evaluation and optimization of natural biopolymers in water-based drilling mud. *Journal of Chemical and Petroleum Engineering*, 52(1): 1-12.

Alsabagh, A. M., Abduoa, M. I., Khalil, A. A., Hamed, H. E. and Aboulrous, A. A. (2014). Investigation of some locally water-soluble natural polymers as circulation loss control agents during oil fields drilling. *Egyptian Journal of Petroleum*, 23(1): 27-34.

Annis, M. R. and Smith, M.V. (1996). Drilling Fluid Technology. *Revised edition, USA: EXXON COMPANY*.

Behnamanhar, H., Noorbakhsh, S. S. and Maghsoudloojafari, H. (2014). Environmentally friendly water-based drilling fluid for drilling of water-sensitive formations. *Journal of Petroleum and Gas Exploration Research*, 4(4): 60-71.

Collins, N., Kharitonov, A., Harliburton, C. T., Mitchell, R., Ahmadishin, F. and Tatneft, I. G. (2011). First application of new polymer viscosifier with a non-damaging drill-in fluid. *American Association of Drilling Engineers, National Technical Conference and Exhibition, Houston, Texas*, 1-8

Khalil, M. and Jan B. M. (2012). Herschel-Bulkley rheological parameters of a novel environmentally friendly lightweight biopolymer drilling fluid from xanthan gum and starch. *Journal of Applied Polymer Science*, 124,(1): 595-606.

Kong, L. and Ziegler, G. R. (2014). Molecular Entanglement and Electrospinnability of Biopolymers. *Journal of Visual Experiment*, (91): 1-7.

Makinde, F. A., Adejumo, A. D., Ako, C. T. and Efeovbokhan, V. E. (2011). Modeling the effects of temperature and aging time on the rheological properties of drilling fluids. *Journal of Petroleum & Coal*, 53(3): 167-182.

Michael, A. O., Babatunde, M. O. and Oluyemisi, A. B. (2017). Native and microwave-modified Terminalia mantaly gums as sustained-release and bioadhesive excipients in naproxen matrix tablet formulations. *Polymers in Medicine*, 47(1): 35-42.

Nwosu, U. O. and Ewulonu, C. M. (2014). Rheological Behavior of Eco-friendly Drilling Fluids from Biopolymers. *Journal of Polymer and Biopolymer Physics Chemistry*, 2(3): 50-54.

Oluyemisi, B. A., Oluwatoyin, O. A., Vivek, S. R. and Ruchita, K. (2012). Terminalia Gum as a Directly Compressible Excipient for Controlled Drug. *AAPS Pharmaceutical Science Technology*, 13(1): 16-23.

Udoh, F. D. and Okon, A. N. (2012). Formulation of Water-based Drilling Fluid Using Local Materials. *Asian Journal for Microbial Biotech Environmental Science*, 14(2): 167-174.