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Article

Evaluating the Rheological Models of Formulated Neem Oil-Based Drilling Fluids

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Abstract: This study presents a comparison of several major rheological models to select the best one which precisely represents the relationship of shear stress and shear rate of the fluid solutions. These models are the Bingham Plastic, Power-law and Herschel-Buckley. The shear stress versus shear rate data is plotted for determining which rheological model best fit the behavior of the fluid system. Six different samples of oil based drilling fluids were formulated. For each sample, varying amount of weighing materials (Barite, Calcite and Haematite) were added as additives to increase the mud density of the formulated oil based fluids. The rheological properties of these drilling muds were measured by using an automated viscometer . The dial readings of the viscometer were then converted to stresses by applying standard conversion factors and different non-Newtonian Models were used in computing the stress values. The regression analysis (value of R^2- value) between the measured and calculated shear to determine the correlations of the best fitted model. The model that gives the highest R^2-squared and RMSE value was selected as best drilling fluid.

Keywords: Rheological models, Neem Oil, Newtonian Fluid and Non- Newtonian Fluid, Drilling Fluids, RMSE and R^2-squared

Nomenclature

YP	Yield Point
PV	Plastic Viscosity
n	Flow Behavior index
k	Consistence index

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k_H Hershel Buckley Consistency index

n_H Hershel Buckley Flow index

τ_{OH} Hershel Buckley Yield Stress

Symbols

τ Shear Stress

μ Viscosity

γ Shear Rate

τ_o Yield Stress

Abbreviations

BPRM: Bingham Plastic Rheological Model

HBRM:Hershel-Buckley Rheological Model

PLRM:Plastic Law Rheological Model

1. Introduction

A number of rheological models, based on mathematical equations relating shear stress and shear rate in laminar flow condition, have been developed in order to predict fluid behavior at shear rates other than those actually tested (Adewale et al., 2017). However most drilling fluids are too complex to allow a single set of equations to be used in determining their behavior under all conditions. Therefore the utilization of the appropriate rheological model together with shear stress/shear rate data obtained from a suitable instrument allows accurate determination of the fluid behavior under varying flow conditions found in the oilfield (Adewale et al., 2017).

The ability of any drilling fluid to perform the better functions is greatly vested on its rheology. Generally, fluids can be classified into, a Newtonian fluid whereby the shear stress is directly proportional to the shear rate and a single parameter known as viscosity characterizes the fluid and a non-Newtonian fluid whereby the shear stress is a function of prevailing shear rate (Adewale et al., 2017).

Weighing materials such as Barites are used as additive in drilling mud formulation. The used of Local Nigerian Barite found in some part of the country can help to reduce the rate of importation of Barite in the oil and gas sectors. This weighing material increases the mud weight of the drilling mud which will balance abnormal pore pressure in depleted matured reservoir.

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There is a need to look inward in harnessing the local resources in providing solutions to challenges obtainable in the oil industry. This would help in reducing the importation of materials and conserving financial resources for the indigenous oil companies. The Nigerian Local Content Development Act was signed into law in 2010 with the singular purpose of encouraging the use of Nigerian local resources and content in providing benefits and solutions to the problems confronting the Nigerian oil and gas industry (Ayonmike and Okeke, 2015).

It has been shown that Diesel oil is always used as base oil in formulating oil-based drilling fluid which is environmentally hazardous because of its high toxicity and aromatic content. Vegetable oil will substitute diesel oil because it can be developed locally, environmentally friendly (Agwu et al., 2015).

The (Herschel-Buckley) rheological model accurately predicts mud rheology and offers many advantages over the Bingham plastic and power law rheological models because it more accurately characterizes mud behavior across the entire shear rate (Adewale et al., 2017). Though the concept of yield stress in Hershel-Buckley model has been challenged because a fluid may deform minutely at stress values lower than the yield stress (Mahmudur, 2018).

This study presents a comparison of several major rheological models to select the best one which precisely represents the relationship of shear stress and shear rate of the fluid solutions. These models are the Bingham Plastic, Power-law and Herschel-Buckley. The shear stress versus shear rate data is plotted for determining which rheological model best fit the behavior of the fluid system using Correlations Analysis.

2. Materials and Methods

The major materials used in this research work are: Barite, Haematite, Calcite, Gum Arabic, Poly anionic cellulose, Wyoming grade bentonitic clay, Sabon Gari Ngalda bentonite, Neem Oil and distilled water. Six (6) oil based drilling fluids Samples A, B. C, D, E and F respectively were formulated at variations of the weighing materials (Barite, Calcite and Haematite).

2.1. Mud Preparation

The following procedure was used in the formulation of the oil-based muds respectively:

i. Using the weighing balance, the various quantities of materials as shown in Table 1 below were measured.
ii. The quantities of oil were measured using the measuring cylinder.
iii. Using the Hamilton Beach Mixer, the measured materials were thoroughly mixed until homogenous mixture was obtained.

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Table 1: Mud Sample Composition (Bilal *et al.*, 2021)

Oil Sample	Neem Oil
Oil Volume	210mL
Bentonite	24.5g
Gum Arabic	2.0g
PAC	2.0g
Distil Water	140mL

2.2. Determination of Viscosity

The following procedures were used to determine the viscosity of the Formulated oil based mud using Fan viscometer.

i. The mud sample was poured into the mud cup of the fan viscometer and the rotor sleeve was immersed exactly to the fill line on the sleeve by raising the platform. The lock knot on the platform was tightened.
ii. The power switch located on the back panel of the viscometer was turned on.
iii. The speed knob was first rotated to the stir setting, to stir the mud for a few seconds, and it was rotated to 600RPM, waiting for the dial to reach a steady reading, the 600 RPM reading was recorded.
iv. The above process was repeated for 300RPM, 200RPM, 100RPM, 30RPM, 6RPM.and 3RPM
v. The value variation of the weighing materials were recorded (that is 0gram, 5grams, 10grams, 15grams, 20grams and 25grams respectively) for the formulated drilling mud. The plastic viscosity, apparent viscosity and yield point was determined using the formula respectively.

2.3. Rheological Model Of Drilling Fluids

Several mathematical models have been developed to describe the shear stress/ shear rate relationship of drilling fluids. These models are used to characterize flow properties in an effort to determine the ability of a fluid to perform specific functions (Steffe, 1996). There are two basic models for describing the rheology of drilling fluids: The Newtonian model where the shear stress (τ) is directly proportional to the shear rate (γ) and the constant of proportionality is the fluid viscosity (μ) and the non-Newtonian model where the fluid viscosity is not constant but a function of the shear stress (Adewale et al., 2017). The following mathematical models are used to describe the rheology of non-Newtonian fluids. These are:

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a. Power Law Model
b. Bingham Plastic Model
c. Hershel Buckley Model

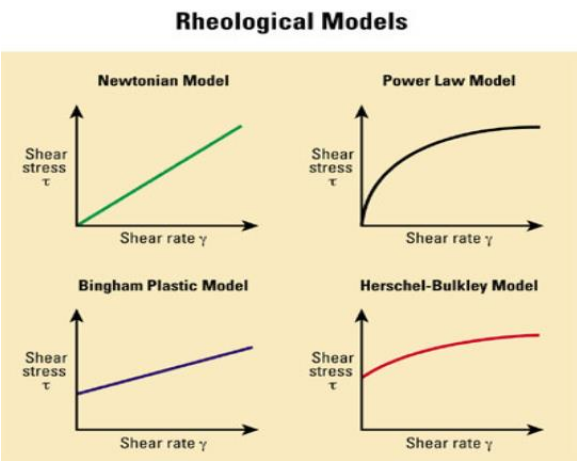

Figure 1: Shear stress versus shear rate for various rheological models (Adewale et al., 2017)

The power law model is expressed as:

$$\tau = k\gamma^n \qquad (1)$$

Where n is the fluid flow behaviour index which indicates the tendency of a fluid to shear thin and it is dimensionless, and k is the consistency coefficient which serves as the viscosity index of the system and the unit is lb/100ft^2 which can be converted to Pa.s^n by multiplying by a factor of 0.51 (Lauzon et., al 1979).

When n < 1, the fluid is shear thinning and when n > 1, the fluid is shear thickening (Adewale et al., 2017).

The parameters k and n can be determined from a plot of logτ versus log γ and the resulting straight line's intercept is log k and the slope is n.

The k and n parameters can be obtain from taking the logarithmic function of equation (1) as follows:

$$\log \tau = \log k + n\log \gamma \qquad (2)$$

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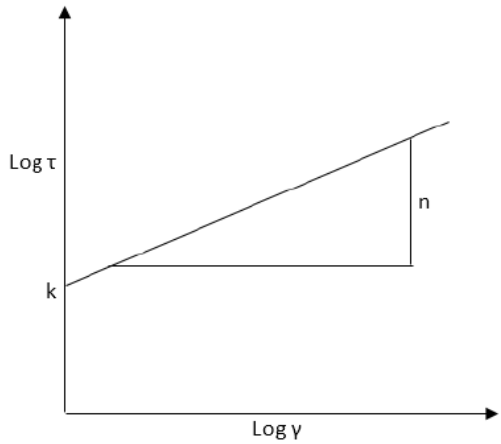

Figure 2: Power law Logarithmic graphical Representation ((Adewale et al., 2017))

The Bingham plastic model is a two parameter model that is widely used in the drilling fluid industry to describe the flow characteristics of many type of muds. Mathematically, it can be represented as:

$$\tau=\tau_0+\mu_p \qquad (3)$$

Where τ_o is the yield point and the unit is lb. /100ft^2 or Pa.s^n and μ^p is the plastic viscosity and the unit is mPa.s (cp). The two parameters τ_O *and* μ_p can be determined from equations 4 and 5 respectively. Fluids that exhibit Bingham Plastic behaviour are characterized by a yield point (τ_o) and plastic viscosity (μ_p) that is independent of the shear rate.

$$YP = \theta_{300} - PV \qquad (4)$$

$$PV = \theta_{600} - \theta_{300} \qquad (5)$$

The Hershel- Bulkley Model is an extension of the Bingham Plastic model to include shear rate dependence.Mathematically, it is expressed as:

$$\tau= \tau_{0H} + k\gamma^{nH} \qquad (6)$$

Where γ is the shear rate (s^{-1}), τ is the shear stress (Pa), n^H is the flow behaviour index (dimensionless) and k^H is the HRBM consistency index in (Pa.s^n) and τ_{oH} is the HBRM yield stress (Pa).

If the yield stress of a fluid sample is known from an independent experiment, the parameters k_H and n_H can be determined by linearizing Equation (Adewale et al., 2017) as follows:

$$\log(\tau - \tau_{oH}) = \log k + n\log(\gamma) \qquad (7)$$

And a plot of log ($\tau - \tau_{oH}$) versus log (γ) will result in a straight line with intercept log k and slope n_H respectively.

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The Yield stress is normally taken as the 3 rpm reading.

2.3.1. Measured shear stress

The shear stresses and shear rates were estimated using equations (8 and 9) as function of viscosity (Mahmudur, 2018).

$$\boldsymbol{\gamma} = \mathbf{1.703}\boldsymbol{v} \quad (8)$$

$$\boldsymbol{\tau} = \mathbf{1.069}\boldsymbol{\theta} \quad (9)$$

2.3.2. Correlations analysis

Correlation analysis involves identifying the relationship between a dependent variable and one or more independent variables. A model of the relationship is assumed and estimates of the parameter values are used to develop an estimated regression equation using Microsoft Excel 2010. The regression analysis (value of R^2- value) between the measured and calculated shear to determine the correlations of the best fitted model. The model that gives the highest R^2-squared and RMSE value is the best one for a given drilling fluid (Mahmudur, 2018).

3. Results and Discussion

3.1. Correlations Analysis

From the Tables 2, 3 and 4 respectively, the Rheograms parameters for the rheological models were shown that is the R^2, Adj. R^2 and RMSE. The Rheograms parameters for Bingham Plastic Law model show clearly that the Bingham plastic fit is not appropriate for all the formulated drilling fluid samples. The R^2 value range from 0.6956 to 0.862. While higher value of RMSE value was obtained in which the least is 29.9963. But the R^2 Adj. values are not higher enough and closer to 1 to make it a better fit.

The parameters for the Herschel-Buckley and plastic law model looks similar and appear to fit the data very well. The R^2 and R^2 Adj. values are quite high and similar. The values are very closer to 1. But the RMSE value obtained are also similar, smaller and are less than one which imply a better model fit. The Bingham Plastic model fits are not as good as the power law and Herschel-Buckley fits. A high value for R^2 can be misleading and means only that the fitted curve came close to the observed data points, not necessary that the model is good or meaningful. So, R^2 gives no insight for chosen the best model (Spiess and Neumeyer, 2010).

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Table 2: Rheograms Parameter for Power Law Models of Formulated fluid Samples

Plastic Model Equation						
Samples	**Mud Weight (g)**	**K (Pa.S^2)**	**n**	**R^2**	**Adj. R^2**	**RMSE**
A	25	0.0031	2.1267	0.9831	0.9789	0.0643
	20	0.0106	1.9262	0.9772	0.9715	0.0220
	15	0.0120	1.9320	0.9802	0.9752	0.0765
	10	0.0167	1.9195	0.9838	0.9798	0.0697
	5	0.0149	2.0214	0.9717	0.9646	0.0871
	0	0.0168	2.0632	0.9725	0.9657	0.0840
B	25	3.8010	0.6578	0.9929	0.9912	0.0589
	20	3.0711	0.6776	0.9937	0.9921	0.0575
	15	2.6430	0.6878	0.9913	0.9892	0.0683
	10	2.1145	0.7096	0.9897	0.9871	0.0767
	5	1.9311	0.6873	0.9865	0.9832	0.0851
	0	1.0889	0.7499	0.9830	0.9787	0.1047
C	25	3.5800	0.6993	0.9766	0.9707	0.0788
	20	3.0711	0.6776	0.9937	0.9921	0.0575
	15	2.6430	0.6878	0.9913	0.9892	0.0683
	10	2.1145	0.7096	0.9897	0.9871	0.0767
	5	1.9311	0.6873	0.9865	0.9832	0.0851
	0	1.8000	0.5873	0.9830	0.9787	0.1047
D	25	8.3138	0.5558	0.9797	0.9746	0.0848
	20	7.4216	0.5620	0.9813	0.9767	0.0822
	15	4.9716	0.6105	0.9816	0.9770	0.0886
	10	2.5427	0.6878	0.9868	0.9835	0.0844
	5	1.7555	0.7119	0.9858	0.9821	0.0910
	0	1.0595	0.7604	0.9858	0.9822	0.0969
E	25	12.9390	0.4966	0.9325	0.9156	0.1418
	20	8.6020	0.5530	0.9790	0.9738	0.0858
	15	7.3621	0.5533	0.9846	0.9807	0.0735
	10	6.2216	0.5496	0.9927	0.9909	0.0500
	5	5.7359	0.5270	0.9922	0.9902	0.0496
	0	5.4175	0.4964	0.9909	0.9886	0.0505
F	25	3.2969	0.6892	0.9882	0.9852	0.0800
	20	2.8210	0.7026	0.9902	0.9877	0.0742
	15	2.5556	0.6969	0.9926	0.9908	0.0638
	10	1.8824	0.7312	0.9930	0.9913	0.0650
	5	1.6676	0.7229	0.9925	0.9907	0.0666
	0	1.2912	0.7193	0.9899	0.9874	0.0771

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Table 3: Rheograms Parameter for Bingham Plastic Models of Formulated fluid Samples

Bingham-Plastic Model Equation						
Samples	**Mud Weight (g)**	μ_p (mPa.s)	τ_0 (Pa)	R^2	Adj. R^2	**RMSE**
A	25	0.02193	109.14	0.7408	0.6760	69.2223
	20	0.0194	108.08	0.7447	0.6809	66.3240
	15	0.0148	102.51	0.7201	0.6501	64.8801
	10	0.0102	97.92	0.7535	0.6919	54.2469
	5	0.0092	72.42	0.6957	0.6196	45.8040
	0	0.0061	64.26	0.6956	0.6194	38.3648
B	25	0.0199	107.61	0.8598	0.8247	52.9936
	20	0.0117	103.02	0.8629	0.8286	48.4450
	15	0.0102	99.45	0.8360	0.7949	47.7139
	10	0.0087	87.21	0.8101	0.7627	45.1020
	5	0.0066	67.32	0.7955	0.7444	35.6359
	0	0.0046	56.61	0.7782	0.7228	31.0595
C	25	0.0209	111.18	0.7044	0.6305	75.5622
	20	0.0184	109.14	0.8629	0.8286	48.4470
	15	0.0158	104.04	0.8360	0.7949	47.7139
	10	0.0117	99.96	0.8101	0.7627	45.1020
	5	0.0092	92.31	0.7955	0.7444	35.6359
	0	0.0071	77.01	0.7782	0.7228	31.0595
D	25	0.0189	108.12	0.7379	0.6724	69.8494
	20	0.0163	103.53	0.7488	0.6860	63.9158
	15	0.0138	100.47	0.7872	0.7340	55.4525
	10	0.0107	86.7	0.8077	0.7596	45.7965
	5	0.0071	69.36	0.7975	0.7469	37.6187
	0	0.0051	60.18	0.8016	0.7520	31.2408
E	25	0.02142	110.16	0.7215	0.6519	72.2596
	20	0.0204	108.63	0.7524	0.6905	68.8097
	15	0.0184	92.82	0.7611	0.7013	58.8592
	10	0.0148	83.13	0.8169	0.7712	44.3348
	5	0.0102	69.36	0.8048	0.7560	36.8800
	0	0.0077	56.10	0.8150	0.7687	28.3856
F	25	0.0184	114.24	0.8224	0.7780	63.0584
	20	0.0168	110.67	0.8474	0.8092	55.3841
	15	0.0143	103.53	0.8705	0.8382	45.9900
	10	0.0112	95.88	0.8621	0.8277	43.1341
	5	0.0087	78.08	0.8488	0.8110	36.2081
	0	0.0056	59.67	0.8222	0.7778	29.9963

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Table 4: Rheograms Parameter for Herschel-Buckley Law Models of Formulated Fluid Samples

Herschels-Bulkley Model Equation							
Samples	**Mud Weight (g)**	τ_0 **(Pa)**	**K** ($Pa.S^2$)	**n**	R^2	**Adj.** R^2	**RMSE**
A	25	14.28	7.68	0.5692	0.9723	0.9654	0.1019
	20	11.22	6.06	0.6002	0.9682	0.9602	0.1154
	15	10.2	5.12	0.6158	0.9705	0.9631	0.1139
	10	8.7	4.35	0.6206	0.9734	0.9667	0.1089
	5	7.7	3.86	0.5861	0.9583	0.9479	0.1297
	0	6.6	3.96	0.5727	0.9564	0.9455	0.1297
B	25	5.1	1.89	0.7684	0.9894	0.9867	0.0845
	20	4.6	1.46	0.7957	0.9928	0.991	0.0718
	15	4.1	1.23	0.809	0.9905	0.9881	0.0841
	10	3.06	1.04	0.8221	0.9849	0.9812	0.1079
	5	2.55	0.97	0.7967	0.9789	0.9736	0.1241
	0	1.53	0.56	0.8569	0.9745	0.9682	0.147
C	25	13.77	6.94	0.5895	0.9685	0.9606	0.1128
	20	12.75	0.11	1.2011	0.9757	0.9526	0.2169
	15	10.2	0.14	1.1504	0.9797	0.952	0.2017
	10	7.65	0.23	1.0615	0.9778	0.954	0.1657
	5	6.12	0.29	0.9913	0.971	0.9491	0.1575
	0	5.1	0.17	1.0457	0.9706	0.9329	0.2204
D	25	9.18	4.02	0.6688	0.9729	0.9661	0.1183
	20	8.16	3.63	0.6735	0.9737	0.9671	0.1175
	15	5.61	2.52	0.7179	0.9715	0.9644	0.1304
	10	3.57	1.24	0.8022	0.9817	0.9771	0.1162
	5	2.55	0.86	0.8261	0.9806	0.9758	0.1232
	0	1.53	0.55	0.8676	0.9776	0.9721	0.1392
E	25	9.18	7.17	0.5886	0.8989	0.8737	0.2093
	20	8.67	4.37	0.6586	0.9666	0.9582	0.1299
	15	8.16	3.34	0.6762	0.9771	0.9713	0.1099
	10	7.14	2.33	0.7023	0.9855	0.9819	0.0903
	5	6.63	1.82	0.7046	0.9882	0.9852	0.0818
	0	6.12	1.42	0.7029	0.9906	0.9883	0.0725
F	25	5.1	1.55	0.8088	0.9887	0.9859	0.9154
	20	4.59	1.3	0.8249	0.991	0.9886	0.0836
	15	4.08	1.19	0.8175	0.9933	0.9917	0.071
	10	3.06	0.9	0.8483	0.9921	0.9901	0.0801
	5	2.55	0.82	0.8372	0.9891	0.9864	0.931
	0	2.04	0.62	0.8362	0.989	0.9862	0.0935

3.1. Rheological Models of Drilling Fluids

The plots of the shear stress and shear rate show the rheological models of the different samples of the formulated drilling fluids as shown below in which the dial readings of the viscometer were then converted to stresses by applying standard conversion factors and different non-Newtonian models were used in computing the stress values.

From figures 5 to 20 repectively, shows the stress values predicted by the rheological modes for the formulated drilling muds. The model conformed to the models in figure 1 for various rheological model (Adewale et al, 2017). There is a linear relationship between the shear stress and the shear rate for drilling fluids that exhibit Bingham plastic behavior; such fluids do not flow until the shear stress

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supersedes a critical value known as the yield point. All the oil base muds formulated in this study show Bingham plastic behavior. It can be seen that the stress values predicted by the Bingham Plastic rheological model are lower at high rate conditions compared to the measured stress values but higher at lower shear rate conditions. This is attributed that Bingham Plastic model includes a yield point that is positive shear stress at zero shear rate (Folayan et al., 2017).

Also, the stress values of power law rheological model are higher than the measured values at low and higher shear conditions. This can be attributed to the partial rebuilding of the fluid microstructure broken down by pre-shear (Folayan et al., 2017). So therefore, Lauzon and Reid agrees with the results obtained by the power law rheological model because it cannot represent the behaviour of the drilling fluid accurately at very low shear rate in the annulus or at very high shear rate in the bite.

The stress values predicted by Hershel-Bulkey rheological model a wider agreement with that of the measured stress values. But the Hershel-Bulkey rheological model shows many advantages over the Bingham Plastic rheological model and Plastic Law rheological model because it accurately characterises mud behaviour over the whole shear rate range. This can be attributed that it accept the existence of a yield point as well as non-linearity of the shear stress to shear rate (Power law) (Folayan et al., 2017).

Also, figure 3 shows the plastic Law model of sample A (Barite Wyoming Formulation). It demonstrate the behaviour of a drilling fluid at low shear rates with no yield stress. As the shear rate increases, the slope of the graph decreases. That is, the apparent viscosity decreases with increase in shear rate. The drilling fluid(mud) is known as shear thickenning. The fluid can be describe as a dilatant fluid because the n (flow behavior index) is greater than one (Adewale et al, 2017). It forms a concave upward curve because the apparent viscosity increase as shear rate increases. The model gives better information at low shear rate but drawback at high shear rate condition.

Apart from figure 5, the plastic Law model for the formulated samples in figure 8, 10, 13, 15 and 19 repectively. It forms a concave downward curve at high shear rate with no yield stress.as the shear rate increases, the slope of the graph increases. The drilling fluid is known as shear thinning. The fluid is describe as a pseudo-plastic fluid because the flow behavior index is less than 1. It also shows that the viscosity of the fluid is constant.

As shown in figure 10, 12 and 18 respectively, that is Herschel-Bulkley model for sample C, D and F respectively of the formulated drilling fluid. The geographical representation does not conformed to the real model in figure 1 because at various variation of the weighing material, it shows no yield stress but the viscosity of the drilling fluid is not constant. This drilling fluid tends to behavior as a pseudo-plastic fluids. The yield stress breaks the interactive bonds among the particles (Adewale et al, 2017). Also, in that same sample C, the graphical presentation of the shear stress and shear rate at

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25grams of calcite added to the formulation a yield stress value of 25 Pa was observed. This rheological model predict accurately the fluids behavior across the low and high shear rate. Though the concept of yield stress in Hershel-Buckley model has been challenged because a fluid may deformed minutely at stress values lower than the yield stress (Folayan et al., 2017).

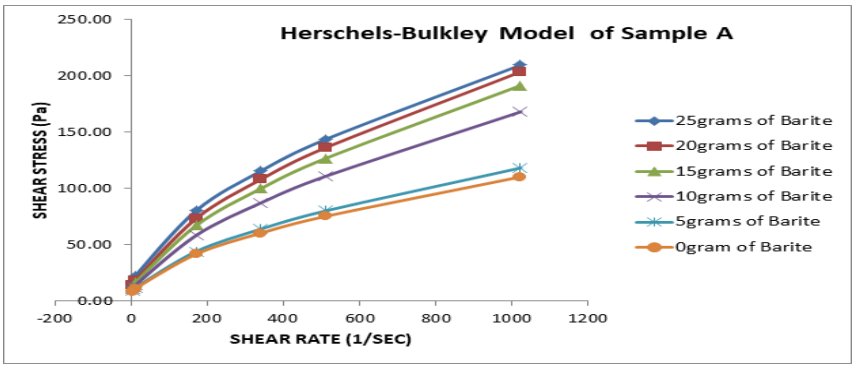

Figure 3: Herschel-Buckley Model of Sample A (Wyoming Bentonite and Barite Drilling Mud Formulation)

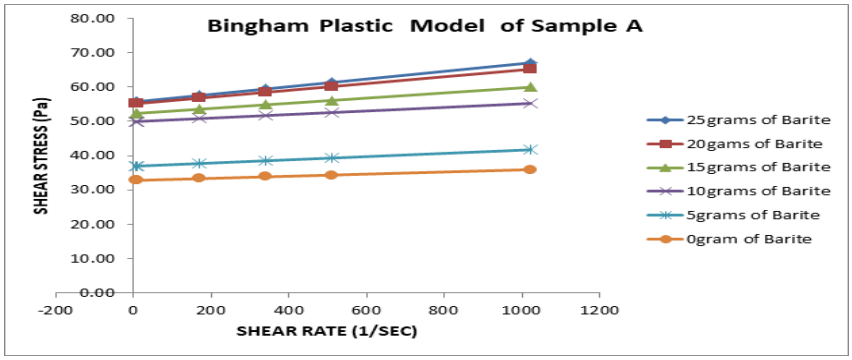

Figure 4: Bingham Plastic Model of Sample A (Wyoming Bentonite and Barite Drilling Mud Formulation)

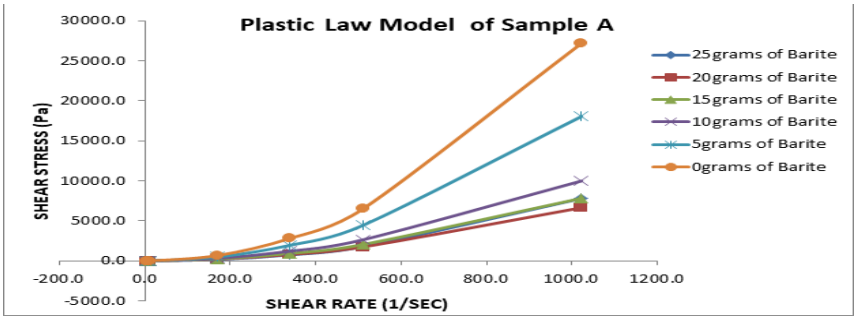

Figure 5: Plastic Law Model of Sample A (Wyoming Bentonite and Barite Drilling Mud Formulation)

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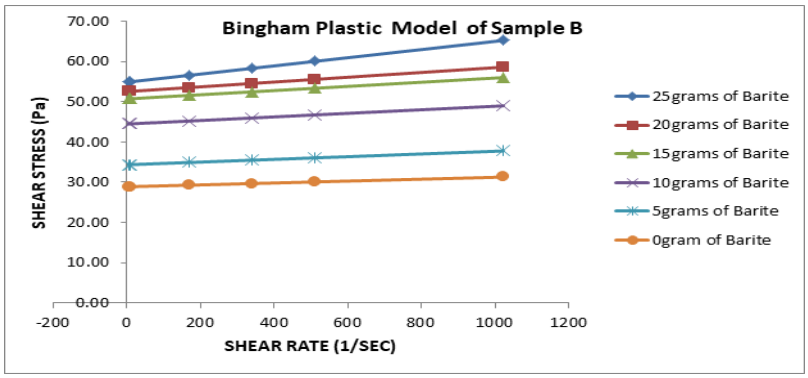

Figure 6: Bingham Plastic Model of Sample B (Sabon Gari Ngalda Bentonite and Barite Drilling Mud Formulation)

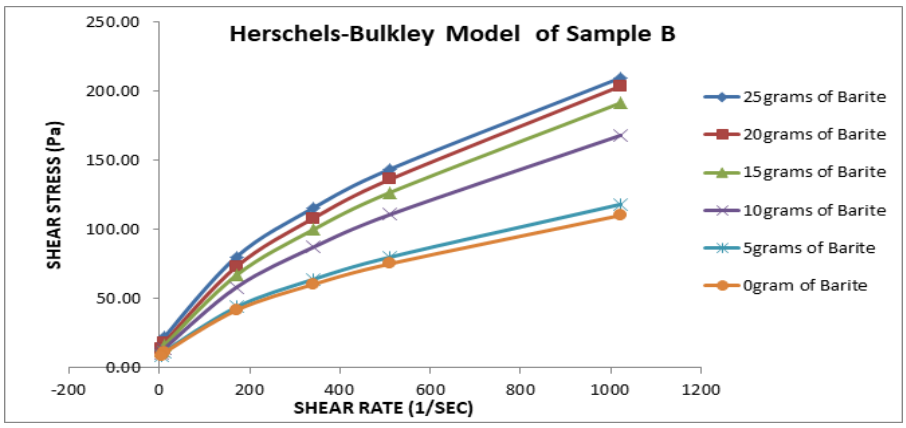

Figure 7: Herschel-Buckley Model of Sample B (Sabon Gari Ngalda Bentonite and Barite Drilling Mud Formulation)

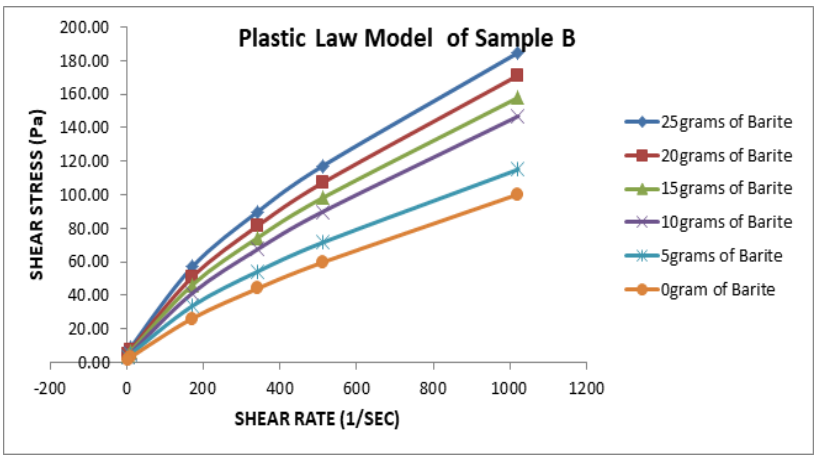

Figure 8: Plastic Law Model of Sample B (Sabon Gari Ngalda Bentonite and Barite Drilling Mud Formulation)

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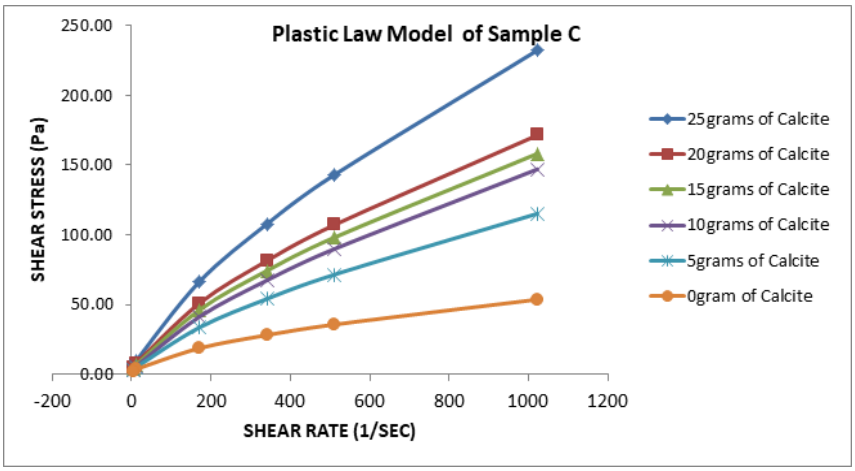

Figure 9: Plastic Model of Sample C (Wyoming Bentonite and Calcite Drilling Mud Formulation)

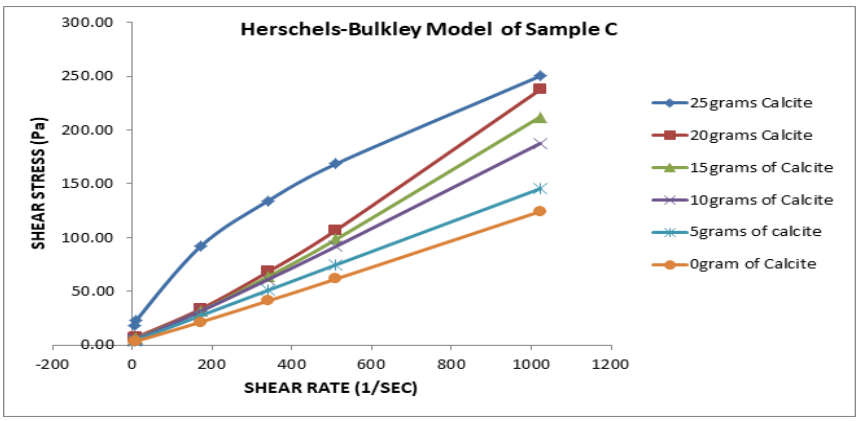

Figure 10: Herschel-Buckley Model of Sample C (Wyoming Bentonite and Calcite Drilling Mud Formulation)

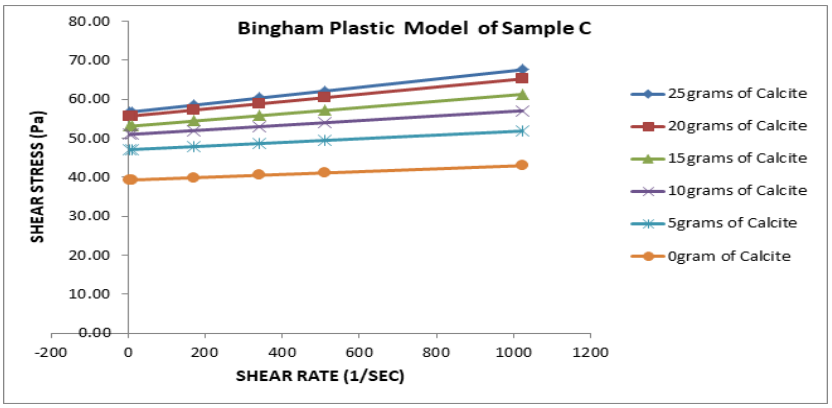

Figure 11: Bingham Plastic Model of Sample C (Wyoming Bentonite and Calcite Drilling Mud Formulation)

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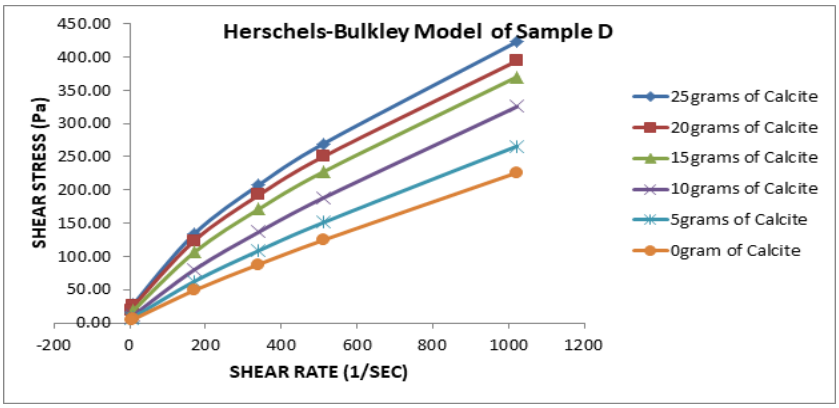

Figure 12: Herschel-Buckley Model of Sample D (Sabon Gari Ngalda Bentonite and Calcite Drilling Mud Formulation)

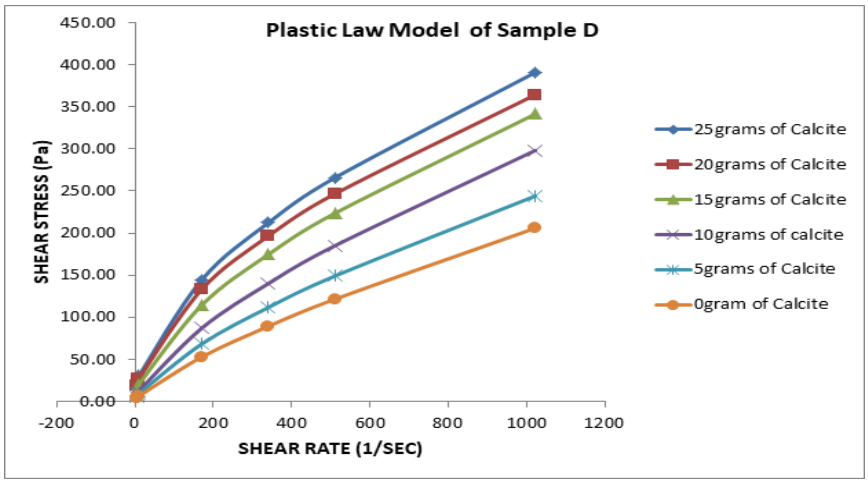

Figure 13: Plastic Law Model of Sample D (Sabon Gari Ngalda Bentonite and Calcite Drilling Mud Formulation)

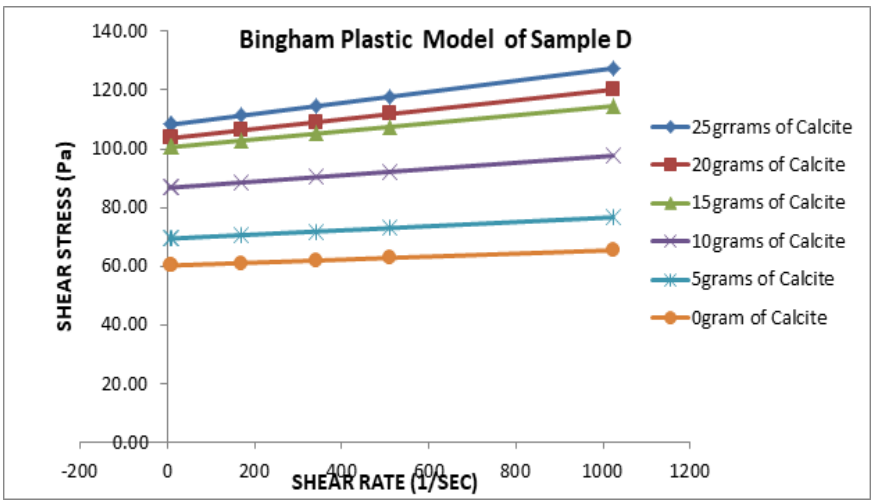

Figure 14: Bingham Plastic Model of Sample D (Sabon Gari Ngalda Bentonite and Calcite Drilling Mud Formulation)

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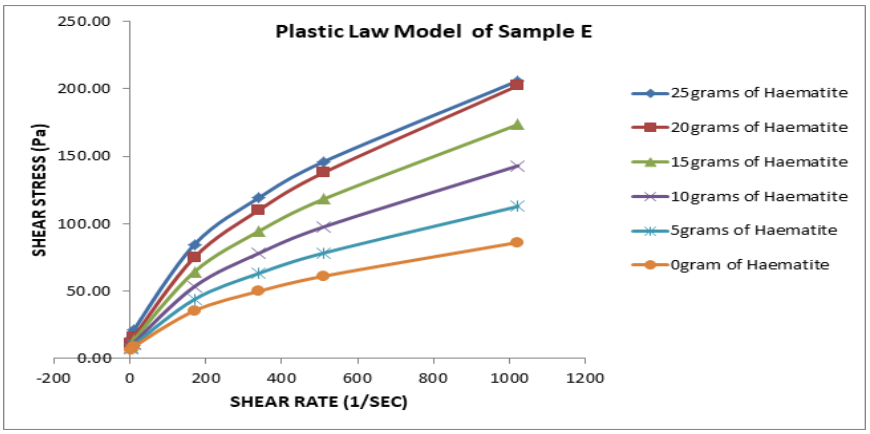

Figure 15: Plastic Law Model of Sample E (Wyoming Bentonite and Haematite Drilling Mud Formulation)

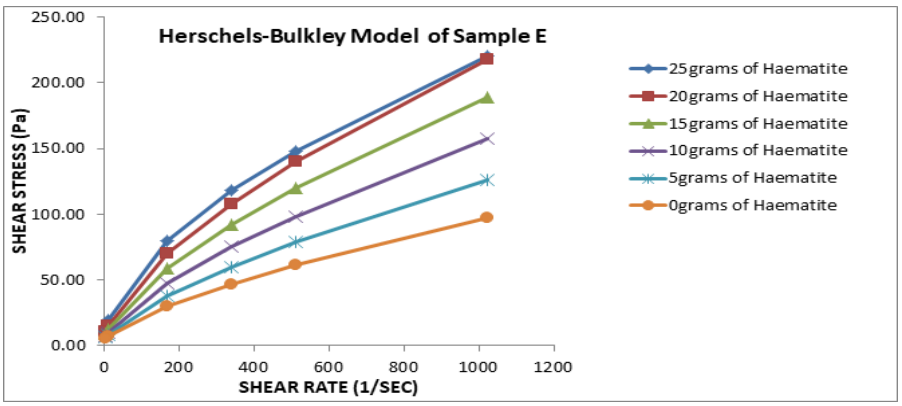

Figure 16: Herschel-Buckley Model of Sample E (Wyoming Bentonite and Haematite Drilling Mud Formulation)

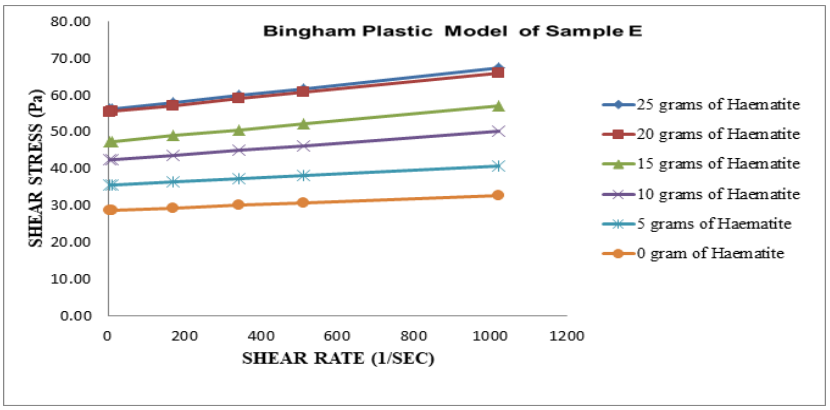

Figure 17: Bingham Plastic Model of Sample E (Wyoming Bentonite and Haematite Drilling Mud Formulation)

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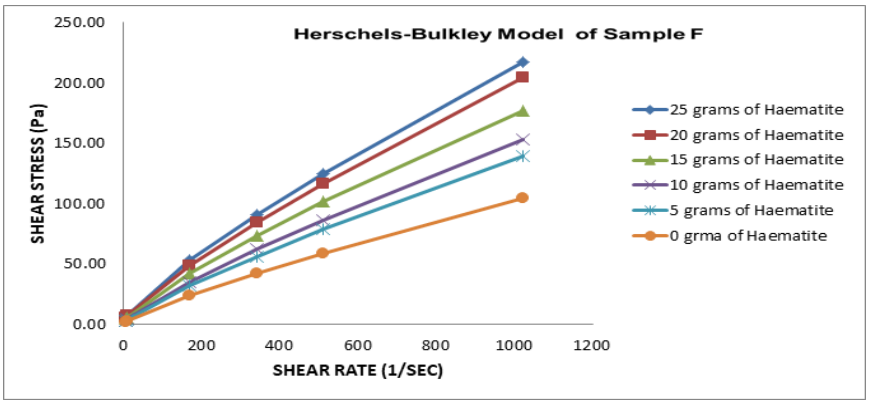

Figure 18: Herschel-Buckley Model of Sample F (Sabon Gari Ngalda Bentonite and Haematite Drilling Mud Formulation)

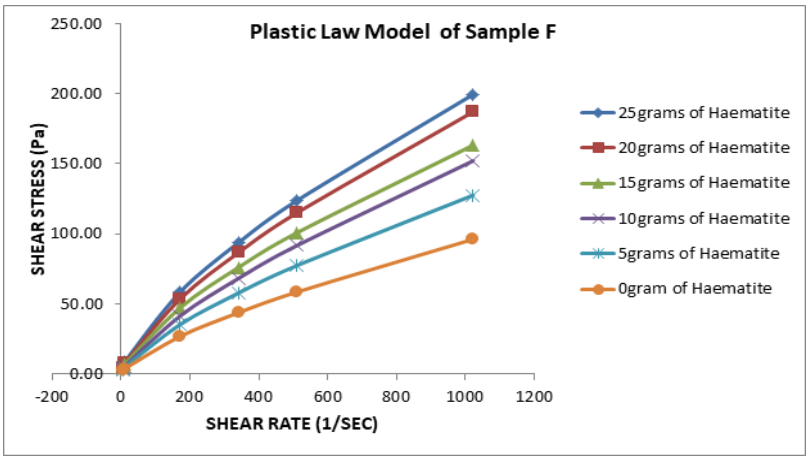

Figure 19: Plastic Law Model of Sample F (Sabon Gari Ngalda Bentonite and Haematite Drilling Mud Formulation)

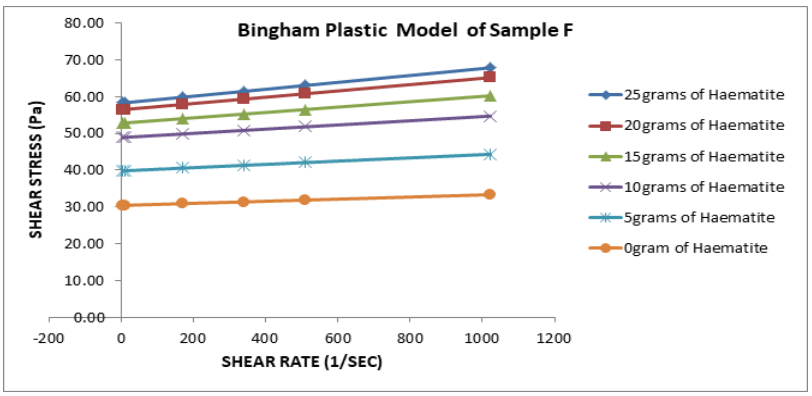

Figure 20: Bingham Plastic Model of Sample F (Sabon Gari Ngalda Bentonite and Haematite Drilling Mud Formulation)

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4. Conclusion

The following conclusions were observed and obtain during the research work:

a) The Hershel-Buckley rheological model accurately predicts mud behavior across the entire low and high shear rates.

b) The Bingham plastic model does not predict accurately the behavior of the drilling mud at very low shear rate as the case may be annulus and at very high shear rate and hence, a yield stress and plastic viscosity correction factors are required.

c) The power law rheological model gives better information at the onset of low shear rate condition but has a draw back at the start of high shear rate condition.

d) The curves produced by the various formulations shows that they are non-Newtonian fluids with the ability to form drilling fluids.

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