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Effect of Barite Concentrations on Oil Based Drilling Mud Density and Rheology

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Abstract**—** *Drilling fluid is an essential element to the drilling process as most drilling challenges can be traced to the condition of the drilling mud used. Density and rheology are among the basic properties of drilling fluid usually defined by a well program and closely monitored during drilling operation. The sustainability of the density of drilling fluid is a key factor that needs deliberate monitoring to ensure that its density is higher than the formation density, so as to avert unexpected complications. Hence this research was aimed at investigating the effect of barite concentration on oil base drilling fluid density and rheology. Formulations and testing procedures were conducted in accordance with American Petroleum Institute (API) specifications. Experimental results showed that the increase of drilling mud is a direct function of increase in concentration of barite. It was also observed that when the barite concentration was 0%, the plastic viscosity decreased as the temperature increased meaning that the drilling mud sagged whereas an increase in barite concentration to 10% revealed an opposite relationship, the plastic viscosity increased as the temperature increased. The yield point at 0% barite concentration gave the least yield point; this signifies that the barite concentration aids in the carrying capacity of the drilling mud. It was also observed that the barite concentration can be used to make the fluid more pseudo-plastic in nature. The consistency index (K) increases as the barite concentration is increased, which indicated that the fluid becomes more viscous when barite concentration is increased. Therefore, results have showed that concentration of barite affect the density of drilling mud as well as rheological properties.*

***Keywords*— Density, Plastic Viscosity, Barite, Consistency Index, Pseudo-plastic.**

I. INTRODUCTION

Hydrocarbon recovery requires constant research and new ways of improvement of drilling based mud concentrating more effort towards researches that will enhance drilling optimization. One of the ways of enhancing drilling operation is through having good knowledge and application of drilling fluid (mud). Drilling fluid is an essential element to the drilling process as most drilling challenges can be traced to the condition of the drilling mud used. Premium is usually place on the selection of drilling fluid during drilling operations because the success of completion of oil and gas wells as well as production of hydrocarbon from reservoir depends to a considerable extent on the properties of the drilling fluids. Selective designing of the drilling fluids holds a strong place of concern in achieving economic project results in the oilfields and should be strongly emphasized, so as to achieve shortening of the non-productive time during operations hence, reaching the target depths (pay zones) in good time. In fact, without drilling mud and their additives, corporations would find it difficult if not impossible to drill for oil and gas and we would hardly have any of the fuels and lubricants considered essential for modern industrial civilization. Davies and Kingston (1992) stated that mud additives contribute to the specific functions and properties to the drilling fluid especially in case of weighting properties, which in turn attains multiple roles in the wellbore. Drilling fluid is simply defined as heterogeneous mixture of either water or oil and chemicals referred to as additives; it is an influential component in the drilling process, which brings about varied functions into play. Drilling fluids are multifunctional mixture which primary objective is to remove the rock cuttings from the borehole during drilling of the well.In addition, during drilling activities, drilling mud is usually used to prolong bits life, minimize fluid loss, and control well pressure and lots more. Drilling mud should be able to impose sufficient hydrostatic pressure, normally in the range of 250psi to 450psi higher than the formation pressure. Failure to produce the expected hydrostatic pressure will initiate the influx of formation fluid - a phenomenon known as kick, which may lead to blowout. According to Black*et al.*, (1985) and Juhari and Isham(1998), blowout will only occur if well kick could not be controlled/killed in a relatively short period. In modern drilling practices it is necessary to identify operations that could make drilling cost reduction possible (Bilgesu, 1997). Drilling fluid offer a complex array of interrelated properties; five basic properties are usually defined by the well program and are closely monitored during drilling. They are – Rheology, Density, Fluid loss, Solid content and Chemical properties. For any type of drilling fluid, all five properties may to some extent, be manipulated using additive, however, the resulting chemical properties of a fluid depends largely on the types of mud chosen, and this choice rest on the types of well, the nature of the formation to be drill and the environmental circumstances of the well (Baker Hughes 2011). To ensure proper functionality, an appropriate drilling fluid is to be designed and selected. Understanding the factors affecting the working of the drilling fluid is very much critical. The drilling fluid is related with most of the drilling problems. If the drilling fluid does not perform the above mentioned functions and according to the expectations of the bore hole conditions, then situations might arise leading to abandoning of the well. Since the additives and chemicals used are expensive, it is to be kept in mind that the drilling fluid be maintained in a good condition and at a lowest possible cost.

The sustainability of the density of drilling fluid is a key factor that needs deliberate monitoring to ensure that its density is higher than the formation density, so as to avert unexpected complications. To achieve effective balance pressure, the mud should be design light to prevent lost circulation if the formation pressure is low. In trying to enhance the properties of drilling fluid through the addition of additives, critical analysis of the impact of the different conditions on the mud must be done so as to avert unexpected complications. The mud density is considered in relation to the hydrostatic pressure (HP) imposed on the hole. At a given depth, large mud density results in large pressure. When this pressure in the bottom hole is examined, in the face of the formation pressure acting on opposite direction to it, the net effect is called Differential Pressure, - that is the difference between the HP and the Formation Pore Pressure. It is this Differential Pressure that affects drilling rate when mud density is considered. High Differential Pressure opposes cuttings removal thus causing regrinding of drill cuttings and retardation of Penetration Rate. It also leads to the strengthening of the rock and causes Chip- Hold – Down (Onyia1991). Mud weight is calculated by sum of weights over sum of volumes. It is increased by adding solid materials and decreased by adding water, oil or aerating the fluid (Baker Hughes 1991; Gatlin 1960) thus, many mud properties vary with its solids content.

Akgun (2002a and b) stated that the selection of mud weight is a challenge one faces during drilling operations. Penetration rate is decreased by increasing plastic viscosity, solid content and mud weight. Furthermore, the increase of barite in the drilling fluids has a bad effect on other 85 well completions and logging processes. For example, it tends to attenuate the intensity of the emitted gamma rays from the different geological formations, especially those enriched by shale and clay minerals. This tends to give low counted rate of the gamma rays and hence erroneous estimate of some important reservoir properties, such as shale volume, effective porosity, and fluid saturations, will arise (Schlumberger, 1986, 1991 and 1995; Lashinand Abd El-Naby, 2014; Lashin, *et al*. 2011, 2016). Therefore, it is necessary to select the proper mud density, which have the best functions of drilling operations, and achieve minimum non-productive time during drilling and completion of oil and gas well.

Rheological properties are basis for all analysis of well bore hydraulics and to assess the functionality of the mud system. Rheological characteristics of drilling mud also include yield point and gel strength. It is critical to control and maintain rheological properties as failure to do so can result in huge financial and time loss, and in extreme cases, it could result in the abandonment of the well (Darley and Gray, 1988). Physical and chemical properties of the drilling fluids largely depend on the type of solids in the mud. These solids are categorized as either *active* or *inactive* solids. The *active* solids are those that react with water phase and the dissolved chemicals. On the other hand, the *inactive* solids are those that do not react with the water and chemical to a significant degree (Azar and Samuel, 2007). Some examples of the inactive solids include - Barite and Hematite, these are added to drilling fluids as weighing agents. Examples of inactive fluids include - clays, polymers and other chemicals, which are viscosity enhancers. There are three different types of drilling fluid namely; Oil-Based Mud or Non-Aqueous Muds; Water Based Muds and Gaseous Drilling Fluid.

Inability to control and maintain rheological properties of drilling fluid can result in unexpected complication during well drilling and completion operations; density being one of the key rheological properties of drilling fluid is controlled with barite. Therefore, this research is aimed at investigating the effect of barite concentration on oil based drilling fluid density and rheology.

II. MATERIALS AND METHODS

This study was achieved with the aid of the following experimental materials and apparatus such as: measuring cylinder, Hamilton beach mixer, mud cup, 6-speed viscometer (35 Model), thermometer, weighing balance, continuous medium, viscosifier,primary emulsifier, secondary emulsifier, alkalinity agent, salinity source, fluid loss control and weight agent of 4.0 specific gravity (barite)

2.1 Formulation of Oil Based Drilling Mud

The formulation of oil based drilling mud and experiment were conducted in accordance with the American Petroleum Institute (API) specification.210.00ml of continuous mediumwas introduced into a Hamilton beach mixer cup and allowed to stir for a minute and 15.00 grams of viscosifier was added and was stirred for 5 minutes. Thereafter, 12.00 ml of primary and secondary emulsifiers were added intermitted and allow to stirfor 5 minutes respectively; 2 grams of alkalinity agent was added and allow to stir for 5 minutes; 20.00 ml of salinity source was added was added was stir for 5 minutes; 5.00 grams of fluid loss control was introduced and allow to stir for 5 minutes and finally 74.00 grams of weight agent was added and the mixture mixed vigorously for 1 hour for homogenous mixture.The cement slurry was ready for analysis. Mudweight was taken and transferred to a consistometer for different temperatures regulations at 120 ºF, 150 ºF and 190 ºF while 80 ºF was taken without a consistometer at room temperature. After each regulations, the slurry was transferred to the rheometer were rheological readings were taken and recorded.

2.2 Rheological Properties Determination

i. About 150ml of the cement slurry was transferred into the rheometer cup and stirred for 10 seconds and heated to a working temperature (80).
ii. The motor was started by placing the switch in a high-speed position. Readings were taken at 600RPM. The gear of the motor was changed while the motor was running to try for other speeds (300, 200, 100, 60, 30, 6, and 3 RPM).
iii. Step 2 was repeated at 120, 150, and 190.
iv. Readings were taken to determine: Plastic viscosity (cP), Yield point (lb/100ft2), Gel strength (lb/100ft2).

2.3 Results and Discussion

In order to investigate the effect of barite concentrations on density and rheology, oil based drilling fluid was formulated. The results for these experiments are tabulated in tables 4.1 to 4.3, followed by the graphical representations and discussed below.

Table 1: Rheology and Density @ 0% Barite Concentration

RPM	80^0F	120^0F	160^0F	190^0F
600	49	45	39	21
300	36	30	27	19
200	28	22	18	13
100	23	18	16	11
6	19	15	13	9
3	14	12	12	7
PV	13	15	12	2
YP	23	15	15	17
10Secs	11	9	7	4
10Mins	13	10	10	7
Mud weight, ppg	8.37	-	-	-

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Table 2: Rheology and Density @ 10% Barite Concentration

RPM	80^0F	120^0F	160^0F	190^0F
600	102	96	91	85
300	91	81	69	53
200	84	76	66	46
100	57	41	37	30
6	20	18	15	11
3	17	14	11	9
PV	11	15	22	32
YP	80	66	47	21
10Secs	15	11	10	7
10Mins	17	12	12	10
Mud weight, ppg	8.5	-	-	-

Table 3: Rheology and Density @ 20% Barite Concentration

RPM	80^0F	120^0F	160^0F	190^0F
600	151	142	126	93
300	101	97	91	64
200	95	91	88	60
100	71	62	60	49
6	26	21	18	14
3	19	17	15	12
PV	50	45	35	29
YP	51	52	56	35
10Secs	22	19	16	14
10Mins	25	24	22	17
Mud weight, ppg	9.2	-	-	-

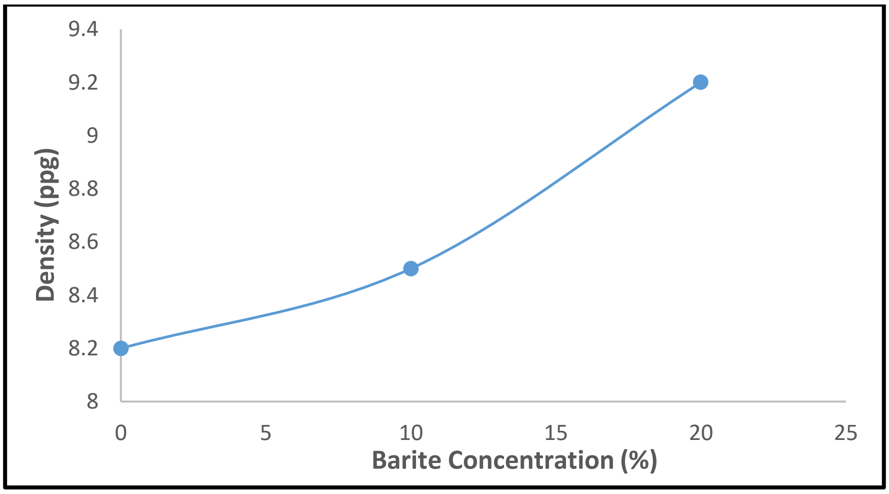

Fig.1: Barite Concentration (%) against the Density of the mud (ppg)

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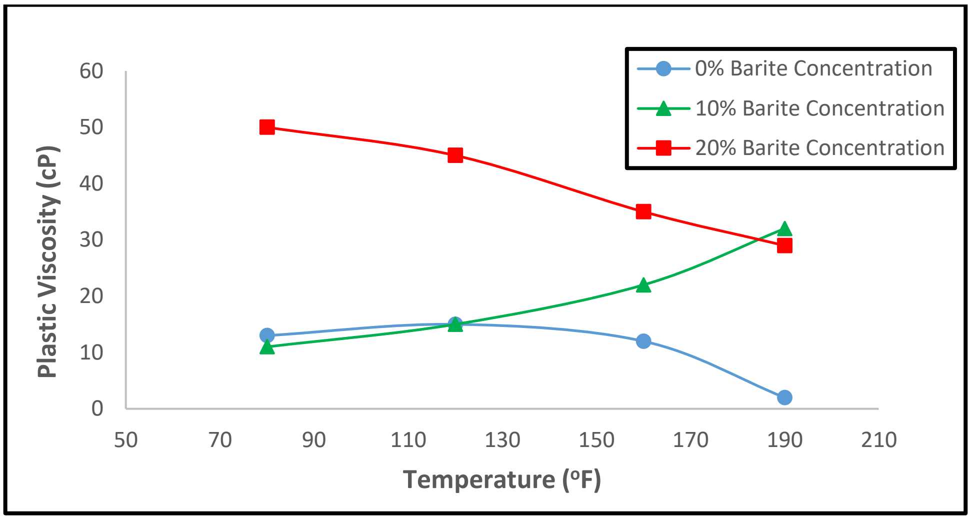

Fig.2: Temperature (°F) against Plastic Viscosity (cP) for different Barite Concentration

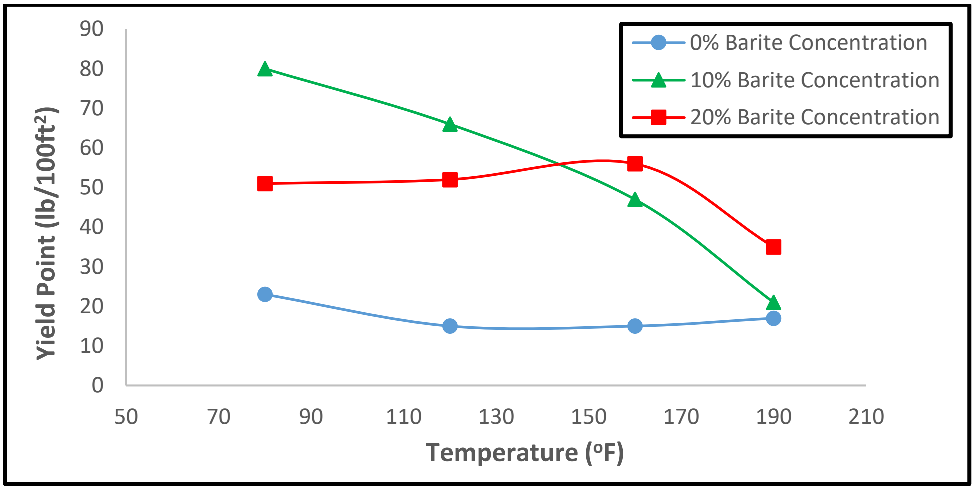

Fig.3: Temperature (°F) against Yield Point (lb/100ft²) for different Barite Concentration

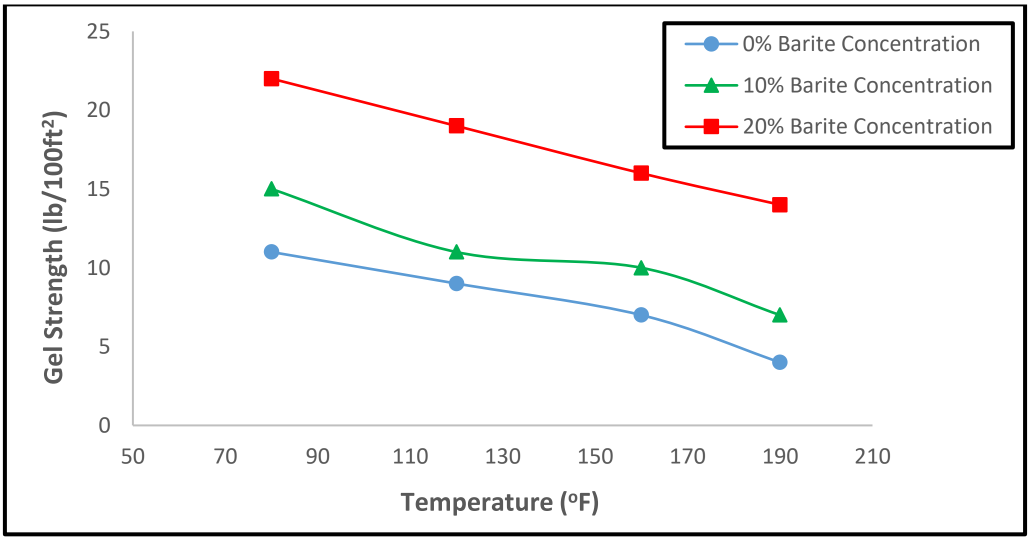

Fig.4: Temperature (°F) against 10 sec Gel Strength (lb/100ft²) for different Barite Concentration

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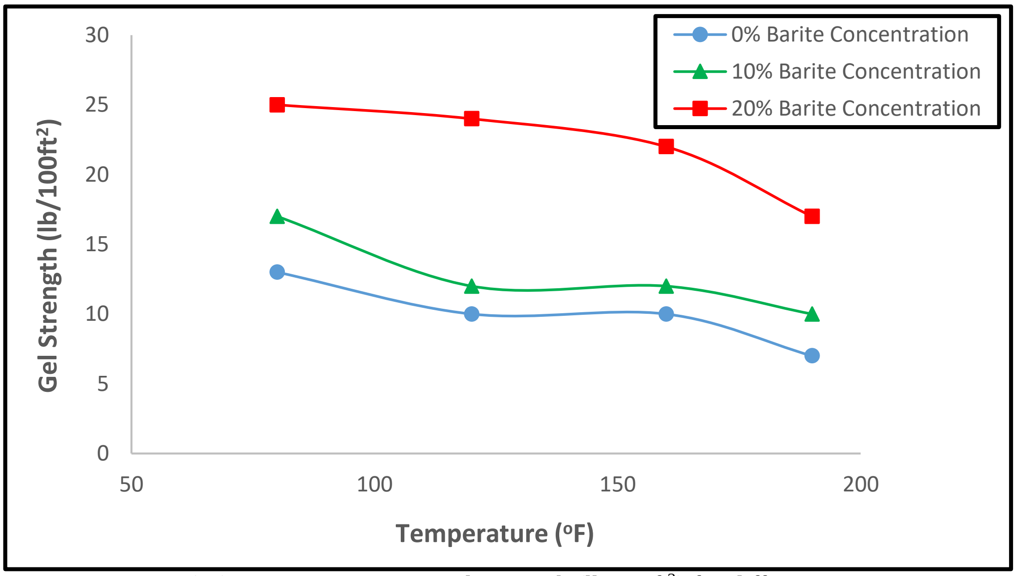

Fig.5: Temperature (ºF) against 10 minute Gel Strength (lb/100ft²) for different Barite Concentration

From Figure 1, it was observed that the barite concentration had a positive effect on the density of the mud. Thus the increase in barite concentration caused corresponding increase in the mud density. Figure 2 showed the effect of temperature on the plastic viscosity at various barite concentrations. It was observed that when the barite concentration was 0%, the plastic viscosity decrease as the temperature increased. Increase in barite concentration to 10% revealed an opposite relationship, the plastic viscosity increased as the temperature increased. Further increase in barite concentration to 20% showed similar pattern as when the barite concentration was 0% but higher plastic viscosity was observed at 20% compared to 0%. It was observed that the barite concentration tends to increase the plastic viscosity of the fluid at higher barite concentration. It was also observed that at temperature above 170ºF the plastic viscosity for barite concentration of 10% and 20% were relatively close. Figure 3 showed the effect of temperature on yield point at various barite concentrations. The graph revealed that at 0% barite concentration, as the temperature increased the yield point of the fluid decreased. This pattern was also observed when barite concentration was 10% and 20%. The yield point at 0% barite concentration gave the least yield point; this signifies that the barite concentration increases the yield point of the fluid. It was observed that at lower temperature the yield Point of the fluid for the different barite concentrations differed significantly, but at temperature of 190ºF, the yield point for the different barite concentration were relatively close. Figure 4 showed the effect of temperature on the gel strength of the fluid at different barite concentration. There was a clear relationship between the three variables, it was observed that increase in temperature of the fluid tend to reduce the gel strength of the fluid and increase in the barite concentration tend to increase the gel strength of the fluid. The lowest gel strength was observed when the barite concentration was at 0% while the highest gel strength was observed when the barite concentration was at 20%. The gel strength of the fluid can be reduced by increasing the temperature of the fluid and reducing the temperature of barite concentration. Similar trend was also observed in Figure 5, which showed the relationship between temperature and 10 minute gel strength at different barite concentration.

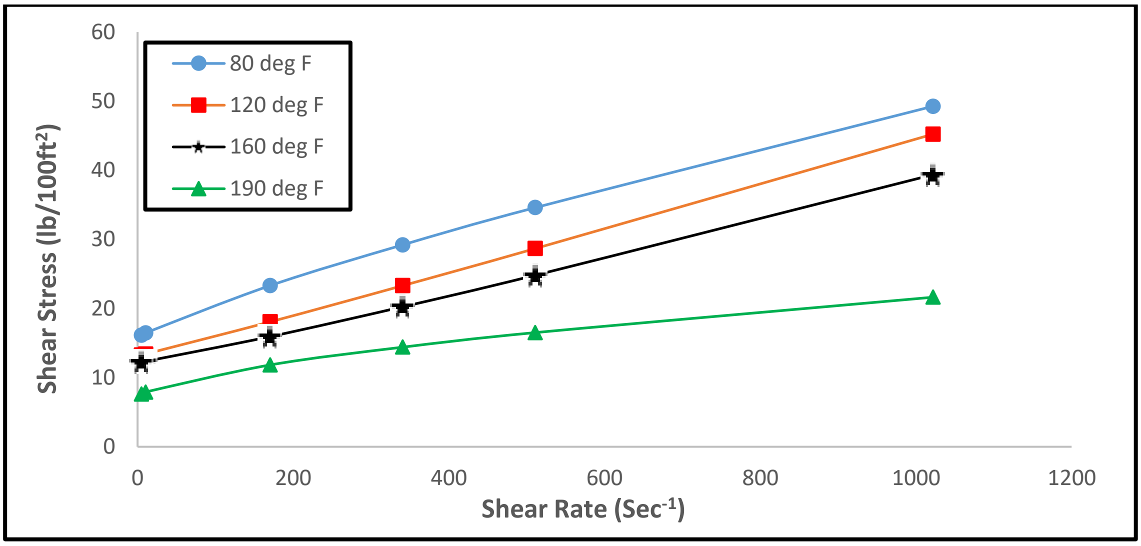

Fig.6: A graph of shear rate against shear stress for different temperature for 0% Barite Concentration

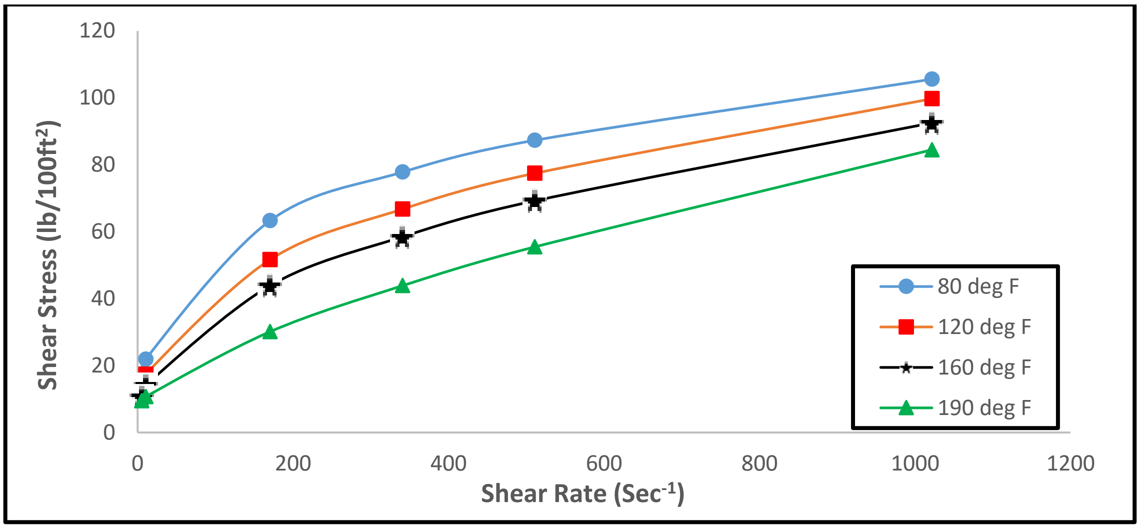

Fig.7: A graph of shear rate against shear stress for different temperature for 10% Barite Concentration

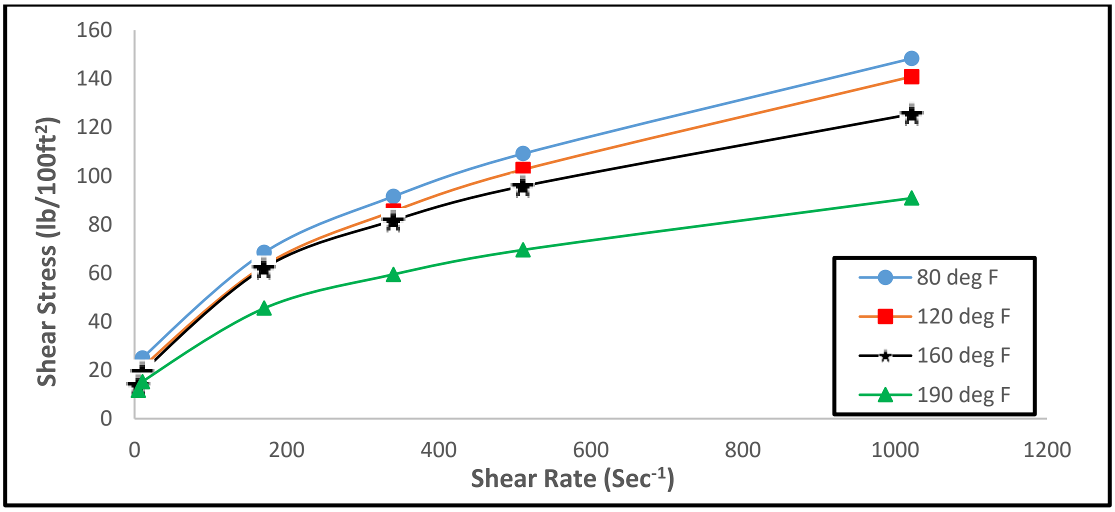

Fig.8: A graph of shear rate against shear stress for different temperature for 20% Barite Concentration

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Figures 6 to 8 showed graphs of the shear stress against the shear rate for various barite concentrations. The fluid exhibited a pseudo-plastic behaviour for all barite concentrations. This was confirmed in Table 4, as the flow index (n) was less than 1. Comparison of the Bingham plastic model and Herschel Bulkley model showed that the latter gave a better fit. The R^2 and RMSE error showed that the fluid exhibit a pseudo-plastic nature more than a Bingham plastic nature because of the higher R^2 values and lower RMSE error. It was also observed that the fluid becomes more pseudo-plastic when the amount of barite concentration was increased in the fluid. This was confirmed by the flow index (n) as shown in Table 4. It was observed that at 10% barite concentration the flow index decreased by more than 60% making the fluid more pseudo-plastic. This shows that the barite concentration can be used to make the fluid more pseudo-plastic in nature. The consistency index (K) increases as the barite concentration is increased, this indicated that the fluid becomes more viscous when barite concentration is increased.

Table 4: Rheology Model Parameter

Model Parameter	**0% Barite Concentration**				**10% Barite Concentration**				**20% Barite Concentration**			
	80^0F	**120^0F**	**160^0F**	**190^0F**	**80^0F**	**120^0F**	**160^0F**	**190^0F**	**80^0F**	**120^0F**	**160^0F**	**190^0F**
Bingham Plastic												
Ty	17.01	12.89	11.70	8.65	33.22	26.31	21.38	13.82	34.80	30.62	29.83	22.59
M	0.03	0.03	0.03	0.01	0.08	0.08	0.08	0.07	0.12	0.12	0.11	0.08
R^2	0.97	0.99	0.98	0.89	0.77	0.82	0.87	0.97	0.92	0.92	0.87	0.88
RMSE	1.84	1.16	1.40	1.69	16.16	13.43	10.50	4.51	13.16	12.73	14.34	9.85
Pseudo-Plastic												
K	0.11	0.02	0.01	0.19	31.96	8.76	4.81	0.69	4.99	4.66	9.45	6.34
N	0.83	1.05	1.11	0.63	0.21	0.35	0.42	0.68	0.48	0.48	0.38	0.38
R^2	0.98	0.99	0.98	0.93	0.98	0.96	0.98	1.00	0.99	0.99	0.99	0.99
RMSE	1.56	1.13	1.32	1.34	4.32	6.15	4.22	1.37	3.99	3.27	3.41	2.87

III. CONCLUSION AND RECOMMENDATION

3.1 Conclusion

Experimental investigation was conducted in the laboratory using API specified procedure for determining density and rheological properties of drilling fluid.

From the result of this study, the following observations were made;

- When barite concentration increased, the density of the mud also increased.
- When the barite concentration was 0%, the plastic viscosity decrease as the temperature increased; while an increase in barite concentration to 10% revealed an opposite relationship, the plastic viscosity increased as the temperature increased.
- The yield point at 0% barite concentration gave the least yield point; this signifies that the barite concentration increases the yield point of the fluid.
- The barite concentration can be used to make the fluid more pseudo-plastic in nature.
- The consistency index (K) increases as the barite concentration is increased, which indicated that the fluid becomes more viscous when barite concentration increases.

3.2 Recommendation

Since concentration of barite strongly affects density and rheology of drilling fluids, close monitoring must be adhered during drilling operation.

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