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Evaluation of Effect of Different Concentrations of Shale on Rheological Properties of Water-Based Mud

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Abstract

Wellbore instability encountered while drilling shale formations is a worldwide problem. Despite much experience and considerable research, drilling and completion operations continue to be plagued by various hole problems attributed directly to shale formations. This results in substantial yearly expenditure for the drilling industry. There is utmost need to evaluate the concentration of shale contamination on mud that could result to these associated well instability problems. This study therefore was undertaken to evaluate the effect of different concentrations of shale on the rheological properties of water- based mud (WBM). This was done by contaminating 8.5PPG WBM with 1.0%, 2.0%, 4.0%, 7.0% and 10.0% respectively of typical shale sample from the Niger delta region of Nigeria. The rheological values were determined using viscometer and the Plastic viscosity evaluated as applicable. Test results indicated that the rheological values increased showing a spike as the shale concentration increased. The increase in rheological values were 9.5%, 42.9%, 52.4%, 66.7% and 114.3% respectively for the *various contaminations as indicated above. To avoid non-productive time resulting from hole instability problems caused by shale, when drilling is expected to encounter shale zones, proper design of the drilling fluids that will inhibit shale swelling as well as prudent step to avoid mud contamination by shale is imperative.*

Keywords: Shale, rheology, clay, drilling, mud, hydration, contamination.

Introduction

The art and science of drilling wells require the use of drilling fluids for several reasons including cuttings carrying and maintenance of wellbore stability. Drilling fluid selection is dependent on the behaviour of the formation to be drilled. Shale, the most abundant rock type in the earth interacts variably with the fluids used. The use of conventional WBMs in drilling shale formations results in the adsorption of water associated with the drilling mud onto the surface of shale[1]. Depending on the shale type, water adsorption may lead to various reactions such as swelling, cuttings dispersion, and increase in pore pressure[2] creating wellbore instability to varying degrees. Common failures that occur from shale instability using conventional WBMs include sloughing, caving, stuck pipe, bit balling and increased torque and drag. These failures can grow into massive expenses due to lost non-productive time. These are further compounded into mud treatment costs, difficulties in running casing and poor cement jobs. Overall, it is imperative that WBMs be formulated and tailored to the type of shale formation encountered. Shales are known to hydrate due to the hydrophilic nature of the clays present in their molecular structure. In particular, the montmorrillonite clay with a specific surface area of 800 m^2g^{-1} can adsorb water on many sites leading to severe wellbore instability issues. With the limited knowledge of shale-fluid interactions, water based mud design is predominantly experimental, on a shale by shale basis.

In general, drilling fluid weight and chemical compositions are the elements that are manipulated in order to control such instabilities. However, instabilities in shale may be caused by a complex mechanism of shale drilling fluid interaction ranging from mechanical to chemical reasons. Mechanical failure takes place when the stresses acting on the wellbore exceed the shale strength[3]. This occurs when the mud weight is either too low (compressive failure) or too high (tensile failure). Therefore proper selection of the drilling fluids to be used on a particular well site is an essential phase of any carefully planned drilling operation. When this drilling is expected to encounter shale zones, the selection of the fluid becomes even more important. To maintain a stable borehole through such zones, a carefully designed mud will be required. The design of successful fluids for this type of application depends largely on a knowledge of the physical and mineralogical characteristics of the shale and its behaviour when in contact with drilling mud. The use of conventional WBMs in drilling shale formations results in the adsorption of water associated with the drilling mud onto the surface of shale[4,5].

Shales and Associated Problems: Shales are low-permeability sedimentary rocks with small pore radii that characterized by low permeability, medium to high clay content, and medium porosity[6] in addition to other minerals, such as quartz, feldspar, and calcite[7]. Shale types range from soft Gumbo shale in offshore Louisiana, Gulf of Mexico to hard brittle shale in South Louisiana with each type presenting its own set of problems.

They account for over 75% of formations drilled all over the world and cause over 90% of wellbore instability problems. The distinguishing features of shale are its clay content and low permeability, which results in poor connectivity through narrow pore throats. Shales are also fairly porous and are normally saturated with formation water, with several factors affecting their properties, such as burial depth, water activity, and the amount and type of minerals present.

Interests in the design of water-based muds (WBM) have escalated due to wellbore instability issues that arise from the abundance of problematic shales encountered while drilling. Conventional water-based muds (WBMs) that are used to drill through water sensitive shale formations cause a high degree of wellbore instability. Consequently, oil based muds (OBMs) were adopted to solve the wellbore instability problems due to their superior shale stabilization properties[8]. Unfortunately, high costs, environmental restrictions, cuttings and used mud disposal difficulties, and safety have largely limited the use of Oil base muds. Consequently, WBMs that have the ability to effectively reduce shale instability problems have once again come under the lime light to replace the OBMs. The limited availability of models to adequately describe shale fluid interaction has hindered the growth of inhibitive WBM development. Models based on chemical potential and hydraulic pressure had been developed[9,10]. They have indicated the complexity of theoretical analysis of driving forces and mechanisms that govern shale stability in the borehole. As a result, the design of such WBMs is mostly experimental. To avoid non-productive time resulting from hole instability problems caused by shale, when drilling is expected to encounter shale zones, proper design of the drilling fluids that will inhibit shale swelling as well as prudent step to avoid mud contamination by shale and other contaminants is imperative[11]. The design of successful fluids for this type of application depends largely on a knowledge of the physical and mineralogical characteristics of the shale and its behaviour when in contact with drilling mud. Interests in the design of water-based muds (WBM) have escalated due to wellbore instability issues that arise from the abundance of problematic shales encountered while drilling. Conventional water-based muds (WBMs) that are used to drill through water sensitive shale formations cause a high degree of wellbore instability. Consequently, oil based muds (OBMs) were adopted to solve the wellbore instability problems due to their superior shale stabilization properties[11].

Cement is a mixture of complex compounds, the reaction of cement with water leads to setting and hardening. All the compounds present in the cement are anhydrous, but when brought in contact with water, they get hydrolyzed, forming hydrated compounds. Since water helps to form the strength, the quality of water is to be critically monitored and controlled during the process of cement making as the water universally the most abundant and naturally available solvent, can contain large number of impurities ranging from less to very high concentration of them[12]. The process of hydration could take several days or even weeks at low temperatures. However, at high temperatures, maximum strength is attained after a few hours. The rate at which hydration occurs when water is mixed with cement and mud can be altered as a result of impurities[13].

Material and Methods

341grams of water was measured and poured into the Hamilton mixing cup. 4.0grams of bentonite was added and prehydrated for 30 minutes under stirring condition. After 30 minutes, 0.2grams of xanthan gum, 0.4grams of Pac-R, 0.6grams Pac-L respectively were added to the mixing cup. These with prehydrated bentonite was stirred for 15 minutes before 0.25 grams of soda ash was added and stirred for another 10 minutes. Then 13.0 grams of barite was finally added and the mixture was stirred further for another 20 minutes for homogeneity before taking the rheological readings and (10 seconds/minutes) gel strength using VG meter.

The mixing procedure was repeated using the grounded sample of shale. Different concentrations of the sample by weight of the formulated mud (0.7%,2%,4%,7%,10%) respectively were added. The rheological readings and (10 seconds/minutes) gel strength values were recorded as well. The plastic viscosity and yield point values were evaluated.

The shale sample was grounded to powder form in a mortar and weighed. The shale sample was transferred into an oven at 120^0C and after 4 hours, it was weighed again to get the new weight. The native moisture of the shale sample was calculated using appropriate procedure.

Results and Discussion

Table-1 shows the composition of the 8.5PPG mud recipe and various functions of the additives. Results of the formulated mud recipe is reflected on table-2 while table -3 details the result for the shale composition, indicating a native moisture content of 13.83% and cation exchange capacity of 2.92Meg/100g. The 13.83% moisture content indicates high presence of expandable clays with the ability to store moisture easily.

Table-4 gives results with contaminations with different shale concentrations. Looking at table-4 and figures 1-5, with 1.0%, 2.0% , 4.0%, 7.0% and 10.0% shale contamination respectively and considering the 600rpm reading, test results indicated that the rheological values increased progressively showing a spike as the shale concentration increased. The increase in rheological values were 9.5% (from 21 to 23 Cp), 42.9% (from 21 to 30 Cp), 52.4% (from 21 to 32 Cp), 66.7% (from 21 to 35 Cp) and 114.3% (from 21 to 45 Cp), respectively for the various contaminations as indicated above. This agrees with previous findings on this phenomenon. The use of conventional WBMs in drilling shale formations results in the adsorption of water associated with the drilling mud onto the surface of shale[1].

Figure- 6 shows the plastic viscosity result of the mud with different concentrations of the shale. The test result indicated that as the concentration of shales increased, the plastic viscosity increases, the plastic viscosity is an indication of the solid particles; but solids such as clay, which hydrate, will further increase the plastic viscosity as their volume is increased by hydration. This makes the hydration and dispersion of shale particles particularly detrimental. Models based on chemical potential and shale hydration had been developed[9,10]. They have indicated the complexity of theoretical analysis of driving forces and mechanisms that govern shale stability in the borehole.

Figure-7 showed the yield point results with the different concentrations of shale. The highest shale concentration gave the least yield point value. This is an indication of dispersion and settling tendency of the solid particles in the mixture. Depending on the shale type, water adsorption may lead to various reactions such as swelling, cuttings dispersion, and increase in pore pressure[2] creating wellbore instability to varying degrees.

There was noticeable increase in the 10 seconds and 10minutes gel strength reading as shown in figure-8. This is an indication of gelling tendency with shale contamination. Common failures that occur from shale instability using conventional WBMs include sloughing, caving, stuck pipe, bit balling and increased torque and drag that could be attributed to increase in static gel strength of shale formation when mud is allowed to be static in the wellbore. To avoid non-productive time resulting from hole instability problems caused by shale, when drilling is expected to encounter shale zones, proper design of the drilling fluids that will inhibit shale swelling as well as prudent step to avoid mud contamination by shale is imperative.

Table-1
Additives and Functions

S. No.	Additive (S)	Function (S)
1	Water	Base fluid
2	Soda Ash	Calcium precipitant and pH reducer in cement contaminated mud
3	Bentonite	Viscosity and Filtration control
4	XCD	Viscosity and Filtration control
5	Par R	Fluid loss control and Viscosifier
6	Par L	Fluid loss control and Viscosifier
9	Barite	Weighting agent

Table-2
Rheological properties of formulated mud(8.5PPG)

S. No.	RPM	Dial Reading
1	Ø600	21(Cp)
2	Ø300	14(Cp)
3	Ø6	2(Cp)
4	Ø3	2(Cp)
5	Plastic Viscosity	7(Cp)
6	Yield Point (lb/100Ft^2)	7
7	10Sec Gel strength(lb/100Ft^2)	1
8	10Mins Gel strength(lb/100Ft^2)	2

Table-3
Shale Components

S. No.	Parameter	Result
1	Native moisture content %	13.83
2	Cation Exchange Capacity Meq/100g	2.92

Table-4
Rheology results for the shale/mud mixture at different concentrations

Mix	600rpm (Cp)	300rpm (Cp)	6rpm (Cp)	3rpm (Cp)	10s/gel Cp	10m/gel Cp	PV (Cp)	YP lb/100ft^2
Mud+0.7% shale	23	15	2	1	1	1	8	7
Mud+2.0% shale	30	18	2	1	1	2	12	6
Mud+4.0% shale	32	21	5	3	4	7	11	10
Mud+7% shale	35	25	11	10	10	10	10	10
Mud+10% shale	45	24	12	11	11	13	21	3

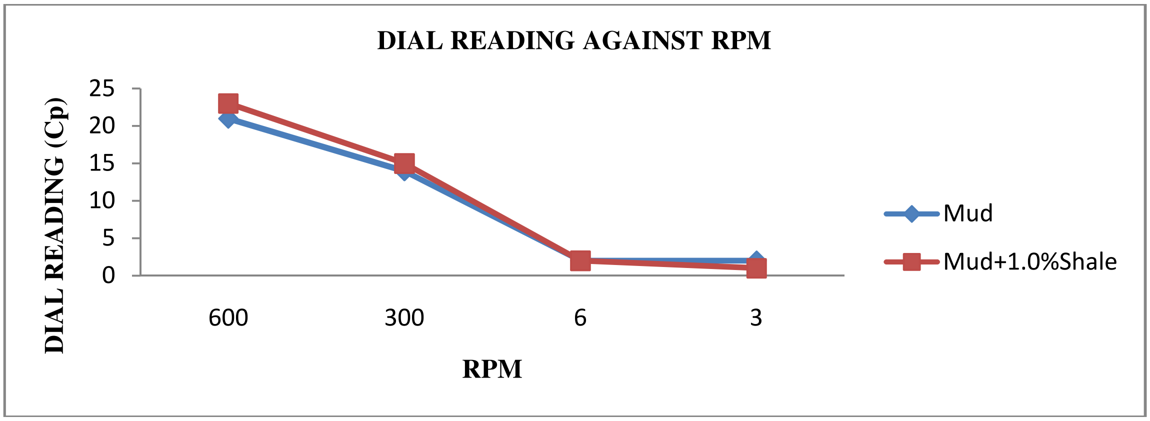

Figure-1
Dial Reading against RPM

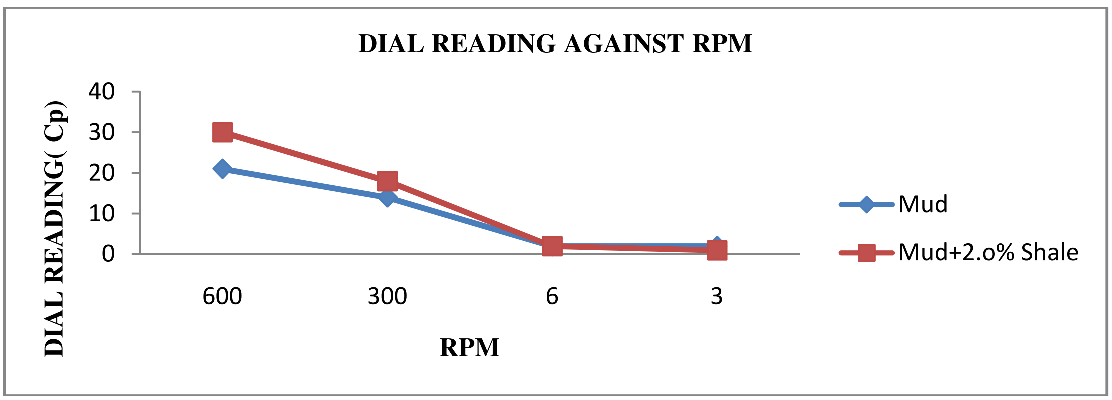

Figure-2
Dial Reading against RPM

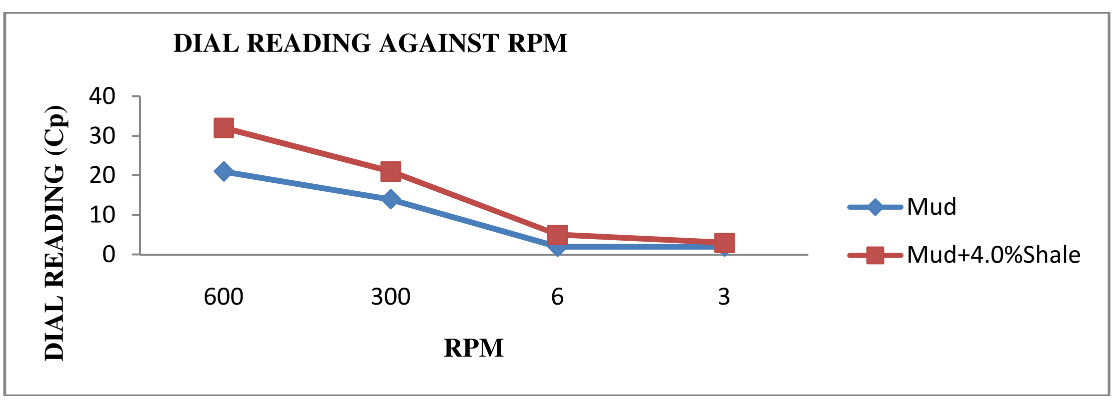

Figure-3
Dial Reading against RPM

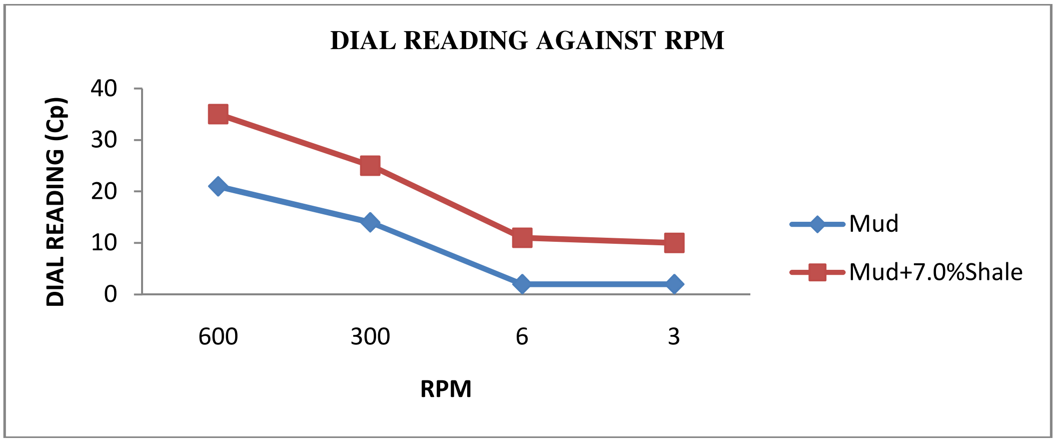

Figure-4
Dial Reading against RPM

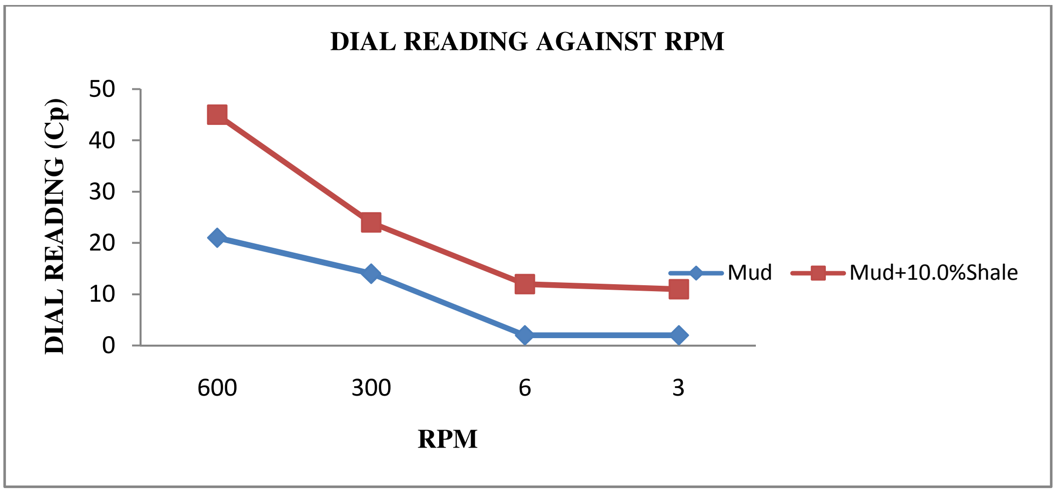

Figure-5
Dial Reading against RPM

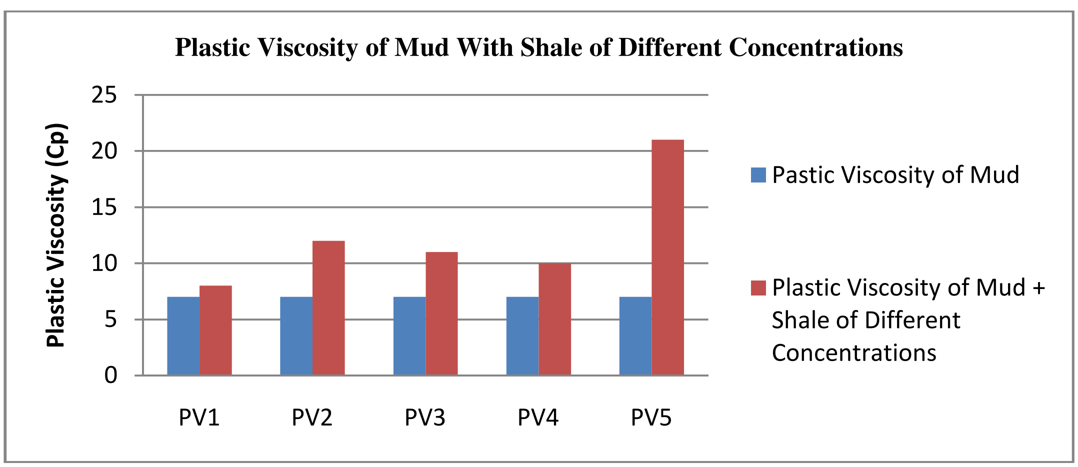

Figure-6
Plastic Viscosity of Mud with Shale of Different Concentrations

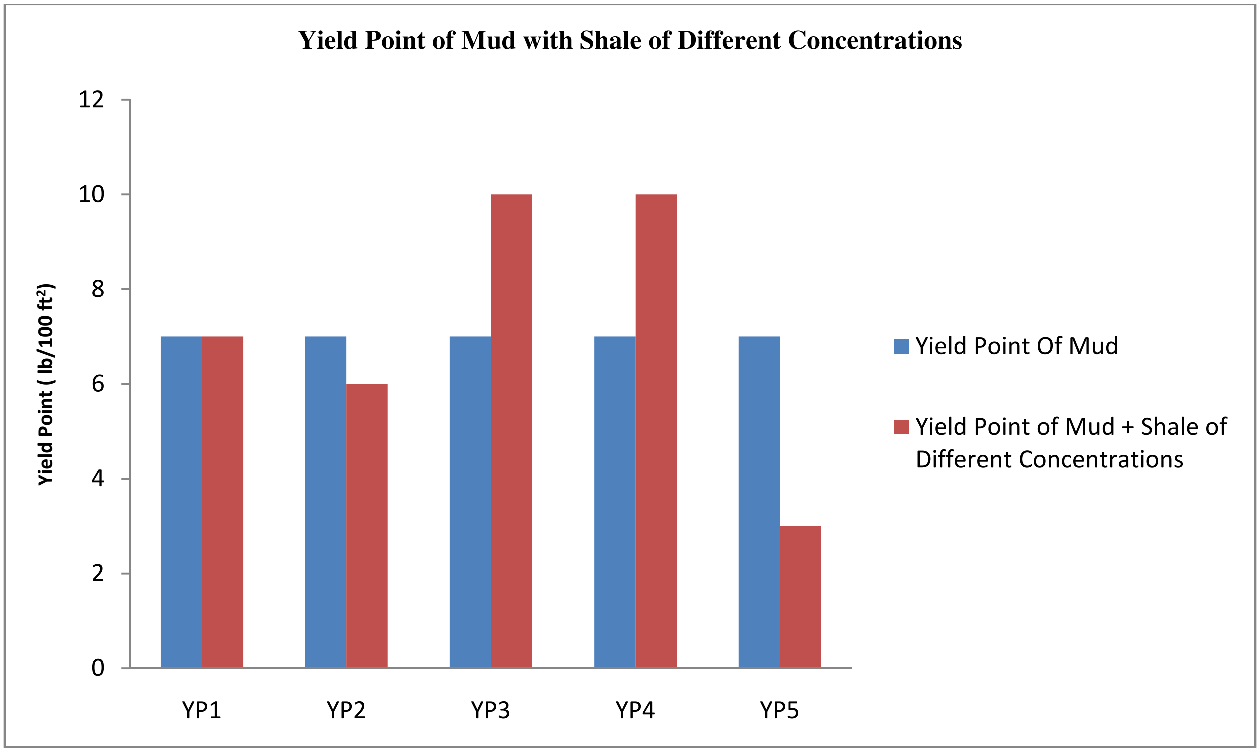

Figure-7
Yield Point of Mud with Shale of Different Concentrations

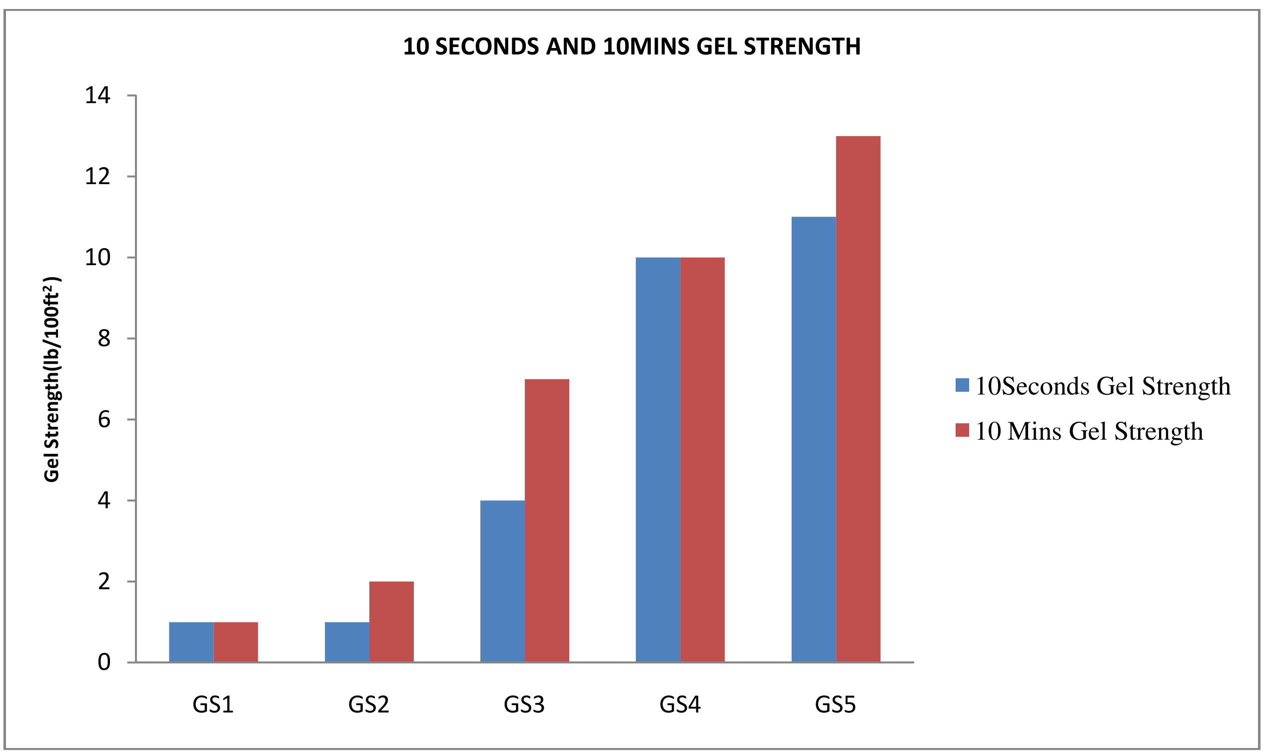

Figure-8
Gel Strength of Mud with Shale of Different Concentrations

Conclusion

The 13.83% moisture content in the shale indicates high presence of expandable clays with the ability to store moisture easily.

The rheological values increased progressively showing a spike as the shale concentration increased.

This agrees with previous findings on this phenomenon. The use of conventional WBMs in drilling shale formations results in the adsorption of water associated with the drilling mud onto the surface of shale[1].

The highest shale concentration gave the least yield point value. This is an indication of dispersion and settling tendency of the solid particles in the mixture. Depending on the shale type, water adsorption may lead to various reactions such as swelling, cuttings dispersion, and increase in pore pressure[2] creating wellbore instability to varying degrees.

To avoid non-productive time resulting from hole instability problems caused by shale, when drilling is expected to encounter shale zones, proper design of the drilling fluids that will inhibit shale swelling as well as prudent step to avoid mud contamination by shale is imperative.

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