Effect of Weighing Agent on Rheological Properties of Drilling Fluid

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Abstract: *Well planning and drilling for oil and gas cannot be done without proper drilling fluid planning and application. The execution of a good vertical, diverged and straight drilling depends largely on the Efficiency of the selected drilling fluid and the fluid additives properties. The practical implication of increase in barite loading, as a weighing agent on the fluid stability was investigated. An oil base mud was selected with diesel as the non-stop phase. The result shows that Barite loading at 20% gave the top result in the electrical stability, followed by 15%, 10%, and 5% respectively, while the drop experienced in electrical stability value at 25% barite loading demonstrate that at 9.4ppg mud weight or any further increment, the designed oil base mud became unstable.*
Key Words: *Drilling fluid, Polymer, Pneumatic, Viscosity and Wellbore*

I. Introduction

In geotechnical engineering, fluid for drilling is harnessed to initiate the boring of holes into the earth. It is also used in drilling for gas well and oil well, exploration drilling rig, and borehole of simpler forms, for example, water wells. It is also called liquid drilling fluid or drilling mud. Drilling fluids (muds) are intricate, varied fluids, made up of numerous additives. It is a useful technology deployed in the drilling of natural gas well and oil, as far back as since 1900. It is any fluid distributed through a well, to remove from a wellbore cuttings.

The fluids may have air, mist and foam in its constituent of the formulation and water or oil as their continuous phase. This mud functions act in conflicting ways (Chilingarian, et al, 2005) to ensure a safe, economical and successful drilling. Since too much filtrate can generate problems in borehole, and a kind of filtration control additive is usually added this is also because of the hydrostatic pressure which balances abnormal pore pressures, hence the need for the addition of weight materials like barite, and hematite for the density of the drilling fluid to increase (Baker Hughes INTEQ, 1999).

Generally, a good drilling fluid is simple and contains a minimal number of additives. This allows easier maintenance and control of properties. A mud system which is flexible and allows changes to be made to meet the dynamic requirements as they occur is a vital resource. And every change in the mud should be scheduled properly on time, as it is required. This will allow current treatment of the mud consistent with future requirements as it is a known that an incomplete mud plan will cost the operator many hours of rig time or lost time and may mean the differentiator of a productive and a non-productive well.

It was Fauvelle, a French engineer, in 1845 that conceptualised and named the pattern drilling fluids. It is a cover term for a broad category of fluids, both liquids and gases, harnessed in drilling operations to achieve specific purposes. They are designed as a solution to minimize many drilling problems. An understanding of these functions and uniqueness will enable the drilling supervisor effectively prepare a mud program, use proper additives, and diagnose trouble areas.

What should inform the design of the drilling-fluid program is the need to satisfy the highest-priority requirements for drilling the prospect well. Unfortunately, these prerequisites could create conflict and constraining demands, on the system. For example, a low-solids structure may be desirable for improved drilling rates band minimum formation damage. However, if the pressure, and activity shale are high and are drilled in a very high temperature range, oil muds or dispersed lignosulfonate systems may be easier to manipulate. The engineer must attempt to select a system that will achieve the following goals: satisfy the crucial items like pressure control, if possible, and satisfy all lower-priority requirements by avoiding the use unsatisfactory systems. For example, an unsatisfactory system might be using oil muds in formations that have historically proven non-productive due to emulsion blockage when oil muds are used (Neal, et al, 1985).

The consequence of barite on rheological properties (yield point, plastic viscosity and apparent viscosity) of mud must be studied because an upward-rise in the volume percentage of barite leads to an upward-rise in the yield point, plastic viscosity and apparent viscosity due to the upward-rise in solid content. The addition of solid material will necessitate an upward-rise in friction and attraction forces between the solid particles, so according to that, will result in an increase in yield point, plastic viscosity and apparent viscosity (M-I SWACO, et al, 2007).

Barite sag, the traditional weight material used in drilling fluids to increase the density remains a recurrent and potentially serious problem on many directional wells. It could cause a plethora of drilling problems like-lost circulation, well-control difficulties, low qulaity cement jobs, and stuck pipe. Nowadays, there are barites substitutes like: Micromax (manganese tetraoxide), Hematite, Calcium carbonate, Ilmenite (iron titanium oxide) among others. However, Barite is a vital and extensively used weight material which offers high density with wide availability, favourable economics, and it is environmentally friendly. Unfortunately, it proves to be quite a challenge for drilling industry.

The physics of the phenomenon is deceptively complex, and certain problems arising from it are often unanticipated without any known solution universally. Albeit, fresh innovations in drilling processes have emerged, thereby engendered greater numbers of directional wells. These wells are successfully limiting the application of ordinary approaches to mitigate sag.

Sag is not truly understandable since it is a consequence of many parameters and their interactions are difficult to quantify. While the significances of mud rheology are well known, efforts to come up with the key rheological parameters have not been successful. Additionally, annular velocity, density of drilling fluid, eccentricity, and rotation speed of drill-pipe clearly impact the barite sag, but there is not a correlation that combines these parameters. Furthermore, lack of industry standards to measure and report barite sag has inadequate availability of usable field data. Sound engineering strategies and guidelines have helped, but clearly more developments are necessary (Tan, 2006).

1.1 Types Of Drilling Fluid
Drilling fluids are three spectra or classifications (Baroid Drilling Fluids, 1998)
• Pneumatic
• Oil-Based
• Water-Based

1.1.1 Oil-Based Fluids
This refers to any drilling fluid having oil as the continuous phase. Oil-based fluids are commonly deployed for drilling troublesome shales and also to advance hole firmness. They find applicability in drilling extremely deviated holes. This is because of their great degree of lubricity and capacity to checkmate hydration of clays. They may also be selected for

Because of their special applications in extreme temperature/high pressure wells, minimizing formation damage, and native-state coring, they are often selected. The fluid also has resisting ability to formation contaminant.

1.1.2 Water-Based Fluids
Water based fluids have water as the continuous phase and they are the most used drilling fluids. They are not difficult to build, cost-effective to maintain, and can be formulated to overcome most drilling problems. In order to have a better understanding of the ranges of water-based fluids, they are delineated into three major sub-classifications: Inhibitive, Non-inhibitive, Polymer.

For drilling depleted zones areas where abnormally low formation pressures may be encountered Pneumatic (air/gas based) fluids are used. Its leverage over liquid mud systems is the increased penetration rates. Also, the significant pressure differential makes it that cuttings are literally blown off the cutting surface. While formation fluids emanating from permeable zones flow into the wellbore due to the pressure differential which may be high.

1.2 Drilling Fluid Selection
Specific drilling fluid with favourable quality for the job are selected by the engineers in charge of drilling. The rheological properties control most of the drilling fluid functions. A drilling fluid specialist or a "Mud Engineer" is often on site to take care of, and revaluate these properties as drilling proceeds. Some of the deciding variables which inform the choice of drilling fluids are; the nature and type of drilling formation, its temperature range, strength permeability and pores fluid pressure, shown by the formation (Annudeep, 2012).

Thus, the choice of the drilling fluid can also be inferred through consideration of other factors such as; Cost, Application and Performance, Production Concerns, Logistics, Exploration Concerns, Environmental Impact and Safety. (Amoco Drilling Fluid Manual, 2004)

II. Methodology

2.1. Experimental Method

This study is within the experimental frame, in order to examine the outcome of increase barite (barium sulfate) loading in selected mud properties. And this was designed to adhere with the strict laboratory testing procedures and best quality assurance and control elsewhere in the universe. The drilling fluid type used in this experiment was oil-base mud with diesel as its continuous phase. One mud sample was employed by increasing the barite percentage of the entire sample.

The Hamilton Beach mixer was operated equal speed and time throughout the whole formulation for different barite loading. The continuous phase fluid was exposed to the same shear and mixing time prior to testing.

2.1.1 Equipment Used for the Experiment

- Hamilton Beach Mixer
- Electronic Balance
- Fan Viscometer
- Mud Balance
- Stop watch
- Measuring cylinder
- Syringe
- Electrical stability meter

TABLE 2.0: Sample Additives, Concentration, Spin Time and Functions

S/N	ADDITIVE(S)	CONCENTRATIONS (%)	MIXING TIME (MINUTES)	FUNCTION(S)
1	Diesel Oil	198mls	1	Continuous phase
2	Organophilic Clay	6g	30	Fluid loss control, gelling agent and Viscosifier
3	Lime	5g	5	Alkalinity adjustment/Salinity source
4	Soltex	4g	3	Shale stabilizer
5	$CaCl_2$	0.30g	2	Weighting agent
6	Water	88mls	3	Discontinuous phase
7	Primary Emulsifier	6mls	3	Emulsifier
8	Secondary Emulsifier	3mls	2	Emulsifier
9	Barite	17.5g	15	Weighting agent

Weight of Barite Loading, W_b Calculation.

➢ The percentage increment for each barite loading is 5%

Therefore; W_b = % increment × volume of mixture (350ml)

i.e. $W_b = \frac{5}{100} \times 350ml = 17.5g$

<u>NOTE</u>: 17.5g of barite was added at each increment, and W_b is the weight of barite loading for each percentage.

2.2 Oil-Based Mud Mixing/Formulation Procedure

198mls of diesel oil was measured and poured into the Hamilton mixing cup. 6grams of organophilic clay was added and prehydrated for 30 minutes under stirring condition. After 30 minutes, 5 grams of lime, 4grams of soltex were addeded into the mixing cup. These with prehydrated mud was blended for 8 minutes before 0.30grams $CaCl_2$ was added together with 88 mls of water to form a brine then added and turned for another 5 minutes, 6 mls of primary emulsifier was placed into it, shook vigorously for 3 minutes, 3 mls of secondary emulsifier was added and blended for 2 minutes then finally different amount of barite was added and

the mixture was stirred further for 15 minutes for homogeneity before ascertaining the rheological readings with Fan Viscometer. Below are the equipment and materials used for this formulation.

Fig.2.1: Some of the mixing materials used during experiment

Fig2.2: Electronic balanced and

Fig. 2.3: Hamilton Beach Mixer

Fig.2.4: Mud Balance

2.2.1   Test Procedures

Procedures for Density experiment (Mud Weight):
*   The mud balance was calibrated with freshwater by adjusting the balancing screw to ascertain a reading of 8.33 lb/gal or 62.3 lb/ft^3 (1.0 g/cm^3)
*   The mud balance base was placed on a flat level surface.
*   A dry mud balance cup, cleaned, was filled with the tested mud sample and the cup's cap was spinned, till it sat firmly. Some of the mud was expelled through the hole in the cap to free trapped air or gas.
*   The cup outside was washed or wiped to remove the expelled base oil.
*   The beam or balance arm was positioned on the support base and balanced by moving the rider along the graduated scale until the level bubble was balanced on the center line.
*   The density of the mud was noted and recorded beside the rider toward the knife edge.

Procedures for Plastic Viscosity (PV) and Yield Point (YP):
*   2/3 of mud sample was filled in a thermo cup and place on the viscometer stand.
*   The thermo cup was raised and immersed the rotor sleeve exactly to the scribed line, and locked the cup stand by turning locking screw.
*   The sleeve was allowed to rotate, thereby, stirring the mud sample for a minute before ascertaining the readings, which were taken at different speeds by shifting the position of the red knob.
*   With the sleeve rotating at 600 RPM, and the dial reading was read at a steady value (10 seconds) through the top window of VG meter. The dial reading at 600 RPM was recorded.
*   The red knob was shifted to 300 RPM with the dial reading, read at a steady value through the top window of VG meter. The dial reading at 300 RPM was also recorded. Reading at 600, 300, 6, and 3 RPM dial readings were taken and recorded accordingly.

Procedures for Gel Strength:
*   The mud sample was placed in position as above and it was stirred at extreme speed for 60 seconds.
*   The knob was then shifted to 3 RPM and the mud was allowed to stand uninterrupted for 10 sec with the motor on and the maximum deflection was noted and recorded (lb./100ft^3) as the gel strength at 10 seconds.

<u>NOTE:</u> The maximum reading attained after a rotation at 3 RPM is the initial gel strength.
*   The mud sample was re-stirred at an extreme speed for 60 seconds, and the speed was set at 3 RPM.
*   The mud was allowed to stand uninterrupted for 10 minutes and the maximum deflection recorded as the 10 minutes gel (lb/100ft^2).

Procedures for Electrical Stability:
*   A well stirred mud sample was positioned in a dry, clean container.
*   The mud sample was either heated or cooled to $120\pm5°F$ ($50\pm2°C$).
*   The electrode (first cleaned) was immersed into the mud.
*   It was hand stirred with the electrode for approximately 10 seconds and the electrode was held motionless without touching the sides or bottommost of the container.
*   The direct reading electrical stability meter was depressed and held down button until the displayed value stabilized. The displayed values on the screen were recorded and the mean values of each barite loading were recorded as the electrical stability (volts).

III. Results And Discussions
TABLE 3.0: Experimental Results

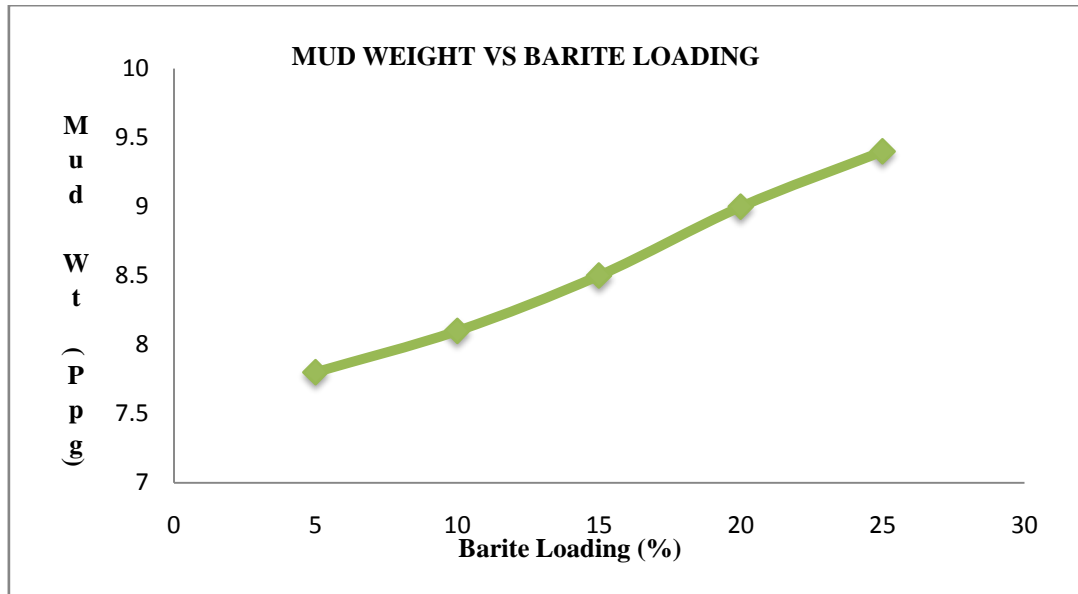| % of barite	600 RPM (cP)	300 RPM (cP)	200 RPM (cP)	100 RPM (cP)	6 RPM (cP)	3 RPM (cP)	10 sec (lb./100ft^2)	10 min(lb./100 ft^2)	PV (cP)	YP (lb./100ft^2)	Mud Wt. (ppg)	Elect. stability (volt)
5	122	90	75	58	34	31	32	35	32	58	7.8	121
10	130	95	81	65	38	35	34	36	35	60	8.1	146
15	134	98	84	68	39	35	35	37	36	62	8.5	183
20	140	102	87	69	39	37	36	38	38	64	9	245
25	146	105	88	71	40	37	37	38	41	64	9.4	194

Fig 3.1: Graph of Mud Weight (ppg) against Barite Loading (%)

Fig.3.1 above depict that the mud density of the designed oil base mud increases as the percentage of barite loading increases from 5% to 25% barite loading. This increase in mud weight can be attributed to:
- An increase of the hydrostatic head of the mud column.
- Increases the carrying capacity of cuttings but also reductions in settling rate in the mud pit.

While 20% barite loading increment, the designed oil base drilling mud has a mud density of 9.0ppg. This mud density is the standard for the density of oil base mud for deep well drilling operation (HTHP condition) and it is accepted as the minimum standard percentage barite loading requirement to design oil base mud. Though, the mud density can be more than 9.0ppg, but any well designed oil base mud to for the purpose of drilling operation must have at least 9.0ppg mud density for it to serve its purpose.

TABLE 3.1: Rheological properties using different barite loading

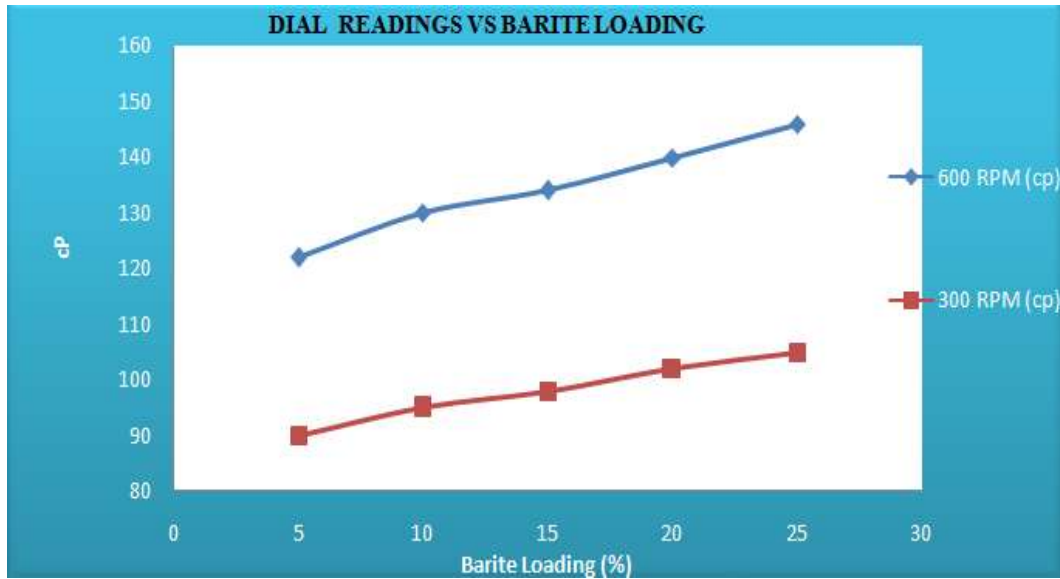| % of barite	600 RPM (cP)	300 RPM (cP)	200 RPM (cP)	100 RPM (cP)	6 RPM (cP)	3 RPM (cP)	10 sec.(lb/100ft²)	10 Min.(lb/100ft²)	PV (Cp)	YP (lb./100ft²)
5	122	90	75	58	34	31	32	35	32	58
10	130	95	81	65	38	35	34	36	35	60
15	134	98	84	68	39	35	35	37	36	62
20	140	102	87	69	39	37	36	38	38	64
25	146	105	88	71	40	37	37	38	41	64

Fig 3.2: Graph of 600RPM (cP) and 300RPM (cP) against Barite Loading (%)

Table 3.2 and Fig. 3.2 above shows the 600RPM and 300RPM dial reading rheological properties of the designed oil base mud, which depict that increase barite loading generate increase in 600RPM and 300RPM viscosity dial readings. Thus, any further increase in barite loading beyond the experimental data may lead to an increase in the dial readings at 600RPM and 300RPM.
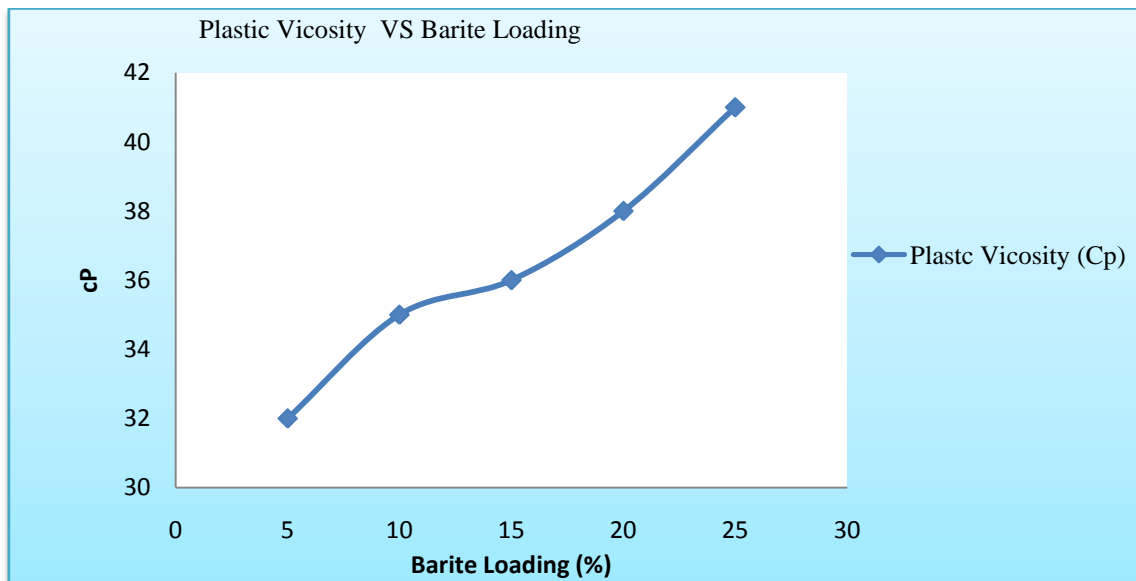

Fig. 3.3: Graph of PV (cP) against Barite Loading (%).

Fig. 3.3 above depict that increase barite loading increases the plastic viscosity of the designed oil base mud, which is an indicator of high shear-rate viscosities. Consequently, it gives idea about the expected behaviour of the mud at the bit down hole. An important design criterion is to minimize the high shear-rate viscosity and this can be accomplished by minimizing the plastic viscosity of the mud. That is, a decrease in plastic viscosity signals a corresponding decrease in the viscosity at the bit. The consequence is higher penetration rate. Thus, an increase in the plastic viscosity is not an appropriate means of increasing the hole-cleaning ability of a mud. In fact, the rise in pressure drops down the drill string, caused by an increase in PV, would reduce the available flow rate and offset any increase in lifting ability. Generally, a plastic viscosity which is high is not appropriate, and should be manged to the bearest minimum practicable. The viscosity of the liquid phase and the volume of solids contained in a mud necessitated plastic viscosity. This viscosity of the liquid phase is made to rise by addition of any soluble material.
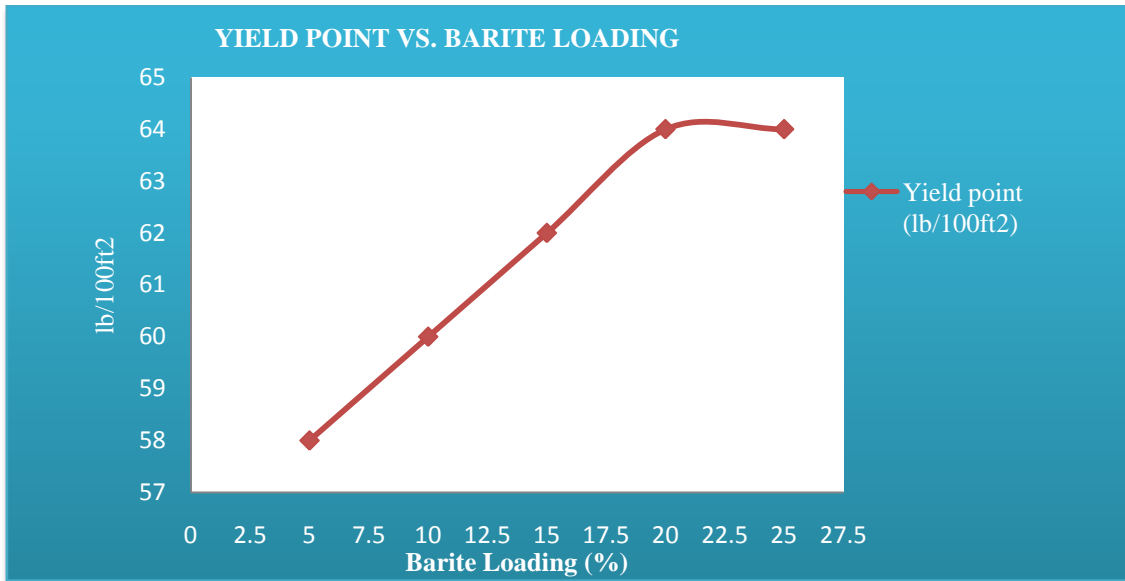
Fig. 3.4: *Graph of YP (lb/100ft^2) against Barite Loading (%).*

The yield point values of the oil base mud increases quickly as the barite loading increases from 5% to 20%, and becomes constant at a further 5% increment as evident in Fig.3.4 above. Therefore, there is a tendency that at any further barite loading increment, the yield point value may either be steady or reduces, or increases. The high yield point values helps to increase the hole cleaning capacity and this depends on high mud weight.
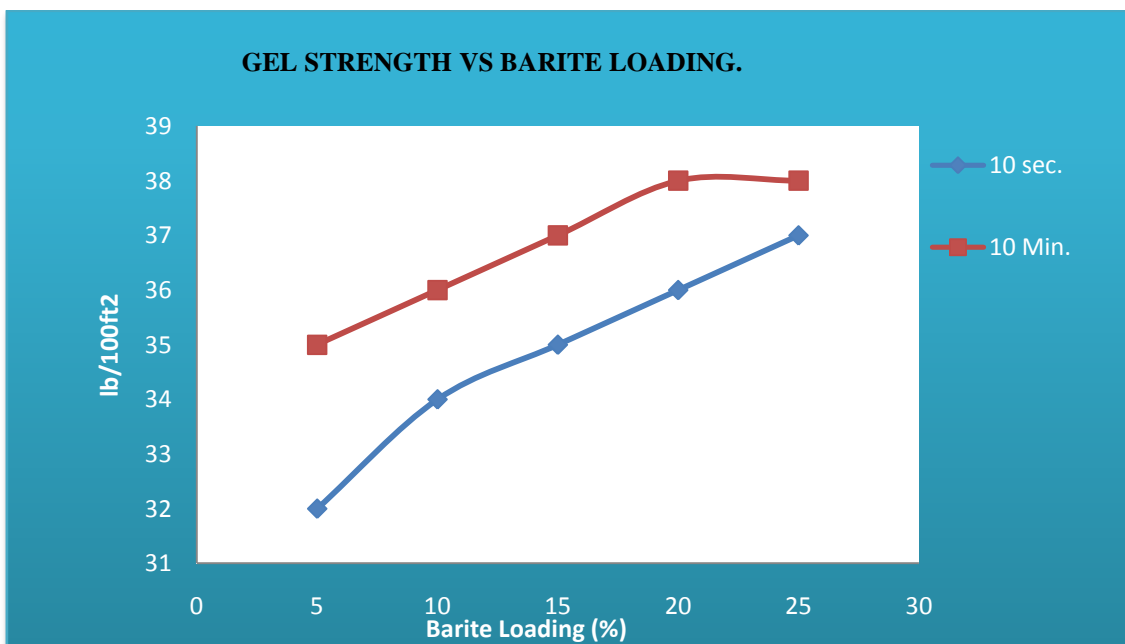

Fig.3.5: Graph of Gel Strength at 10sec (lb/100ft^2) and 10min (lb/100^2) against Barite Loading (%).

The gel strength at 10 seconds and 10 minutes of the designed oil base drilling mud increases as the barite loading increases from 5% to 25% as evident in Fig. 3.5 above. Thus, this designed oil base mud has the tendency of suspending barite, since 'gel strength' is the ability of drilling mud to halt or pause barite and cuttings when circulation is altered.

Also, it can be deduced from Fig. 3.5 that the gel strength value at 10 minutes rapidly increases from 5% to 20% barite loading increments. Above 20% barite loading, the gel strength value of the designed oil base mud tends to be constant/steady. Thus, any further barite loading increase beyond 25% may either make the gel strength value to remain constant or drop, or rise.

TABLE 3.2: Electrical stability readings of an oil based mud.

% of barite	ES1 (volts)	ES2 (volts)	ES3 (volts)	ES MEAN (volts)
5	120	121	123	121
10	144	146	147	146
15	177	184	188	183
20	229	240	259	243
25	188	195	200	194

Table 3.2 and Fig. 3.5 show the result of electrical stability of an oil base mud for single formulation. The electrical stability (water in oil emulsion stability) of the designed oil base mud increases as the barite loading increases from 5% to 20%. But at a further 5% (from 20% to 25%) increments in barite loading, the electrical stability value of the oil base mud tends to drop, thereby, giving birth to the sagging /settling of the mud (i.e. inability of the oil base mud to suspends the solid particle present in it). Thus, any further increment in the barite loading beyond 25% of the design mud will generate lower electrical stability value of the mud and make the oil base mud to be unstable.
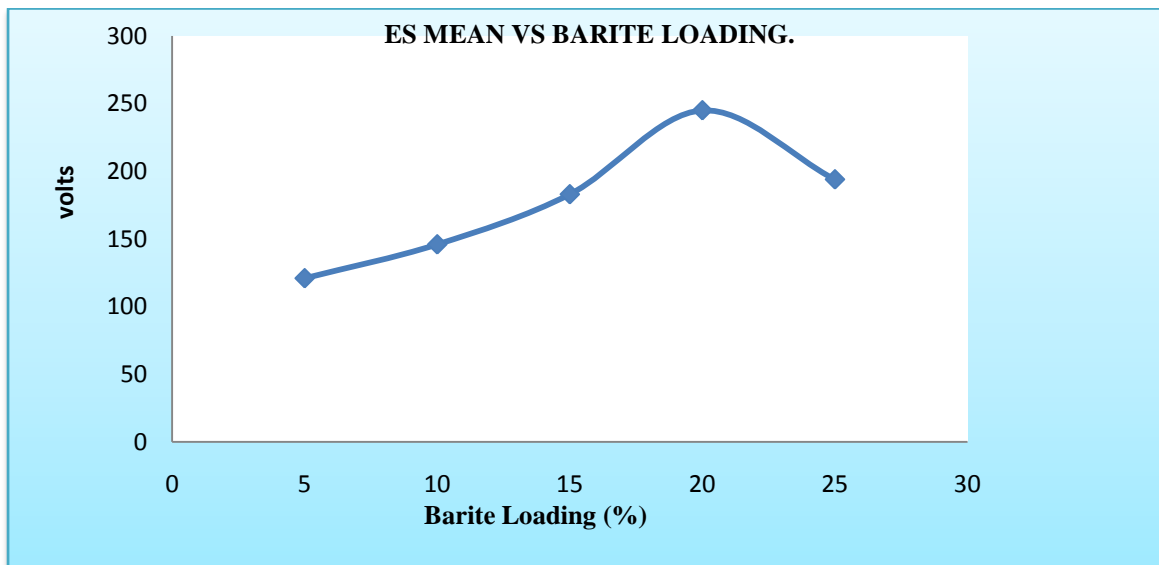

Fig.3.6: Graph of Electrical Stability (Volts) against Barite Loading (%).

IV. Conclusion And Recommedations
Barite as a weighting agent in drilling fluid does not only affects the rheology of drilling mud but also affect other properties like electrical stability, pH, etc. Understanding the consequence of increase barite loading in an oil base mud is a weighty and crucial aspect that cannot be undermine in an oil well drilling operation, therefore, optimizing the mud properties, and ensuring the efficiency of drilling operation on the field.

Electrical stability provides a means of understanding the emulsion stability and homogeneity of the mud, consistent routine check to know whether the designed oil base mud is stable or not (mud sagging) during the designing stage of the well drilling operation. Barite loading at 20% gave the best result in the electrical stability analysis, followed by 15%, 10%, and 5% respectively, while the drop experienced in electrical stability value at 25% barite loading prove that at this barite loading increment (where mud weight is equal to 9.4ppg) or any further increment, the designed oil base mud became unstable.

For mud weight (density), 20% barite loading gave the best oil base mud density (9.0ppg) result which is the stipulated specification range for a standard oil base mud density on the basis of its economics and efficiency during deep depth drilling operations.

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