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Full Length Research Paper

Investigation into the rheological and filtration properties of drilling mud formulated with clays from Northern Nigeria

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Rheological properties of drilling mud formulated from ten samples of Nigerian clay and treated with sodium carbonate (Na_2CO_3) were determined. Four different formulations were made: A (22.5 g / 350 ml of mud + 0% Na_2CO_3), B (22.5 g / 350 ml of mud + 10% Na_2CO_3), C (25 g / 350 ml of mud + 10% Na_2CO_3) and D (28 g / 350 ml of mud + 10% Na_2CO_3). None of the samples tested in their natural state exhibited remarkable improvement in rheological properties. However, as the concentration of sodium carbonate in 22.5 g / 350 ml of mud increased to 10% in all the samples, the highest percent increase of 525% in shear stress at 1022 s^{-1} was observed. As clay concentration increased to 25 and 28 g / 350 ml at 10% sodium carbonate concentration, an additional increase in shear stress of 32 and 29% was observed respectively. This resulted in an increase in the apparent viscosity, plastic viscosity and yield point of the mud by 298, 32 and 29% in B, 205, 10 and 7% in C, and 9500, 90 and 61% in D respectively (on average basis for all samples). Four of the samples (NWY 013, 028, 033 and 053) showed strong promising flow properties and can be further improved to qualify as substitute for imported bentonite clay.

Key words: Clay, viscosity, sodium carbonate, beneficiation, flocculation, yield point, drilling, mud.

INTRODUCTION

Nigeria's economy is largely based on its oil resources and she is the largest oil producer in sub-Saharan Africa. In view of the fact that hydrocarbon and water beneath the ground could only be exploited through drilling wells, the petroleum industry especially has continued to make increasing use of clay which is the main constituent of drilling fluids. Research over the past several years has clearly shown that drilling activities in the petroleum and ground-water development industries in Nigeria have consumed, and are still consuming, large amounts of clays for drilling muds, all of which are imported despite the presence of large reserves of clay in Nigeria (Omole et al., 1989). Prior to the government's initiative to develop local content, the cost of importation of bentonite for drilling activities in Nigeria runs to millions of dollar annually which has been detrimental to the economy of the country considering that about 5 to 15% of the cost of drilling a well which ranges between $1 million to $100 million accounts for drilling fluids (Ben Bloys et al., 1994; http://www.wikipedia.com). Therefore, it is imperative to locally outsource these clay materials in order to conserve foreign exchange, create employment and to enhance Nigerian content development in the drilling component of oil and gas industry.

It was reported by Emofurieta (2010) at the international conference on "Modern Mining Processing" that Nigeria bentonite proven reserve has risen above four billion metric tons. Thus, its abundant reserve cannot be ignored because of increased revenue it will generate when fully exploited and more so as means of developing economy of the country through creation of more

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industries which will consequently lead to local skill transfer and man power development.

"The selection of the most suitable mud type and mud properties, and the efficient engineering support whilst drilling will help to ensure a safe and successful operation. Any problem where the mud fails to meet its requirements can not only prove extremely costly in materials and time, but also jeopardize the successful completion of the well and may even result in major problems such as kicks or blowouts" (Rabia, 2002).

Hence it is necessary to critically examine the suitability of Nigerian clays in regards to their rheological properties.

Objective of study

The objectives of this study are to investigate the rheological properties of Northern Nigeria clays beneficiated with sodium carbonate and compare them with imported bentonite using the API (American Petroleum Institute) specifications. Subsequently, prospective clays that qualify as substitute to the imported clay could be identified and recommended. This study will enable the performance of Nigerian clay to be benchmarked against the imported bentonite.

LITERATURE REVIEW

Effect of sodium exchange in clay minerals

It has been established that smectite has better swelling ability than all other clay minerals because of its crystal lattice; the tetrahedral sheet of one layer is adjacent to the tetrahedral sheet of the next, so that oxygen atoms are opposite oxygen atoms which make cleavage easy. A study of clay properties (Gray et al., 1980) has shown that the swelling ability of the smectite also depend on the loosely held cations (calcium, sodium, magnesium etc.) in its structure with the sodium cations having strong swelling pressure that makes the layers separate into smaller aggregates and even into individual unit layers. When calcium is the dominant cation or it enters the mud it will first produce flocculation and eventually aggregate the smectite (Figure 1). One reason for this effect is that the divalent characteristics of the calcium cations prevent the separation of the clay plates, therefore cause reduction in the surface area for water adsorption (Preston, 1974). Thus, Adam et al. (1986) has also found that it is often desirable to remove the calcium by chemical treatment.

Calcium cations can be replaced by higher concentration of sodium compound which is known as beneficiation. Beneficiation is a process where chemicals are added to low-quality clay to improve its performance. This is done to improve the properties of clay (Falode et al., 2008; http://www.wikipedia.com).

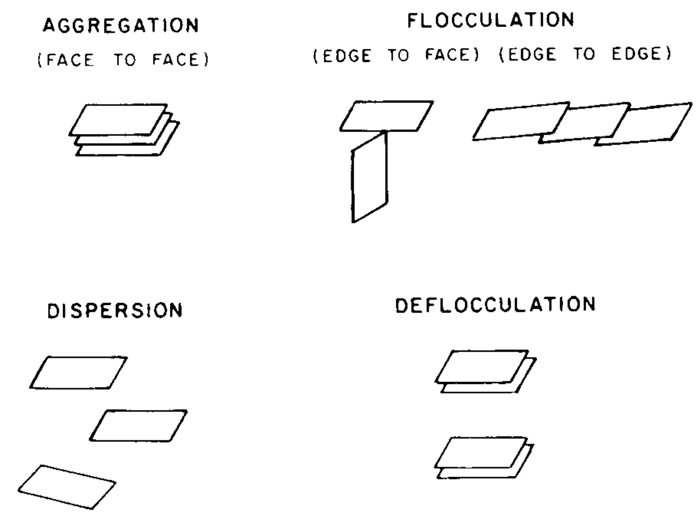

Figure 1. Association of clay particles (adapted from Adam et al., 1986).

Effect of increase in clay mineral on viscosity

The ability of the drilling mud to perform its function depends entirely on its viscosity. Without viscosity, all weighting materials and drill cuttings would settle to the bottom of the hole as soon as circulation is stopped. Viscosity in drilling is a structure built within the water or oil phase which suspends solid material (Rabia, 2002). In practice, when more viscosity is desired, it may be obtained by (1) adding bentonite, (2) flocculating the clay solids, and (3) adding polymers designed for the purpose. Preston (1974) has established the fact that when bentonite is used in fresh water, it increases viscosity rapidly with a small effect on mud weight. Clays are reactive solids in drilling muds because they develop plasticity when hydrated and it is added to fresh-water muds to boost its performance.

MATERIALS AND METHODS

Sample collection, handling and preparation

The samples used for this study represented a random sampling of clays from different localities, which occur within the main lithologic types in the sedimentary and basement complex terrains of Northern Nigeria. About 74 samples were collected from North West (Figure 2) by digging from surface and underground using shovel, digger and hoe at an average depth of 1.5 m. Table 4 shows location and some physical properties of the clay samples.

Each of the samples was packed in a bag and well labeled according to its flank and location. Afterwards they were processed to get clay content. Figures 3 and 4 depict the processes used.

Free swell volume determination

Free swell volume experiments (Figure 5) were conducted for each sample to determine the optimum concentration of Sodium

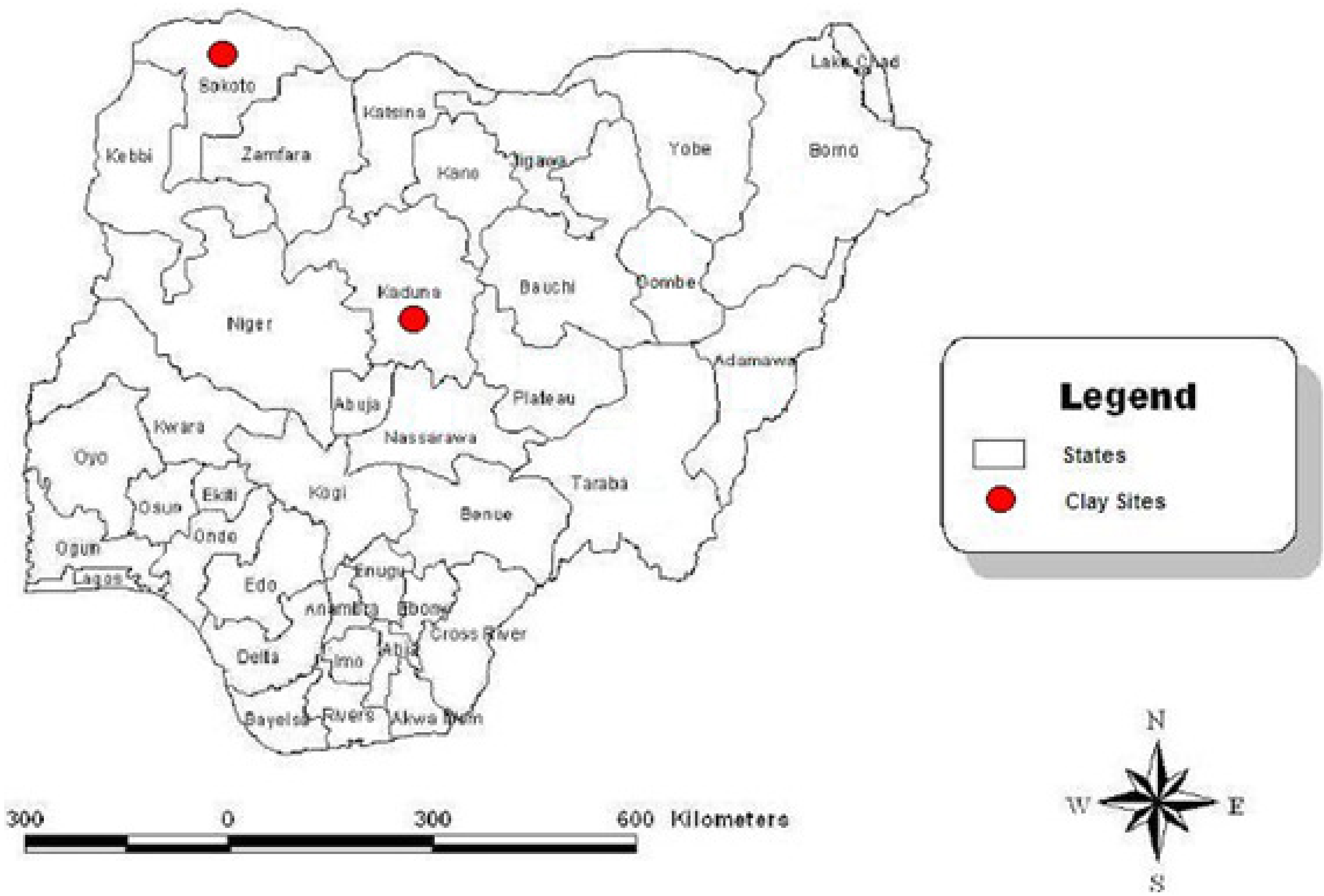

Figure 2. Map of Nigeria showing states where samples were collected.

Carbonate required for beneficiation. 2.5 g of the sample was measured each into eight measuring cylinders containing 50 ml of de-ionized water after which 0, 1, 2, 4, 6, 8, 10 and 12% of sodium carbonate was added to each measuring cylinder. Then each sample was mixed and allow to swell for 24 h and the levels of the clay were recorded (Table 1). These experiments were conducted for all the samples.

Rheological parameters determination

To determine the rheological properties, four (4) different combinations of clay and sodium carbonate were prepared as shown in Table 2.

The Baroid (Model 286) Rheometer was used to determine multi-point viscosities. It is a coaxial cylindrical rotational viscometer with fixed speeds of 3 (GEL), 100, 200, 300 and 600 RPM (revolution per minute) that are switch selectable with the RPM knob.

The following rheological properties were calculated from the experimental data.

$$Plastic\ Viscosity\ (PV) = 600\ RPM\ reading - 300\ RPM\ reading \quad (1)$$

$$Apparent\ Viscosity\ (AP) = \frac{600\ \text{RPM reading}}{2} \quad (2)$$

$$Yield\ Point\ (lb/100\ ft^2) = 300\ RPM\ reading - PV \quad (3)$$

Gel strength measurement

A third property to describe the attractive forces while the mud is static is called gel strength. It can be thought of as the stress required to get the mud moving. The gel strength is measured using the viscometer. The 3-rpm speed is used for gel strength determination at 10 s and 10 min. The gel strength appeared on Table 3 as two figures (for example, 04/05). The first being the initial gel and the second is the 10 min gel.

Filtration properties determination

The test is made using standard cell under the API condition of 100 psi for 30 min at room temperature. Filter press used for filtration tests consists of six independent filter cells mounted on a common frame as shown in Figure 6. The mud cell is detached from filter press frame and bottom of filter cell is removed to place filter paper in the bottom of the cell. Afterwards mud to be tested is introduced

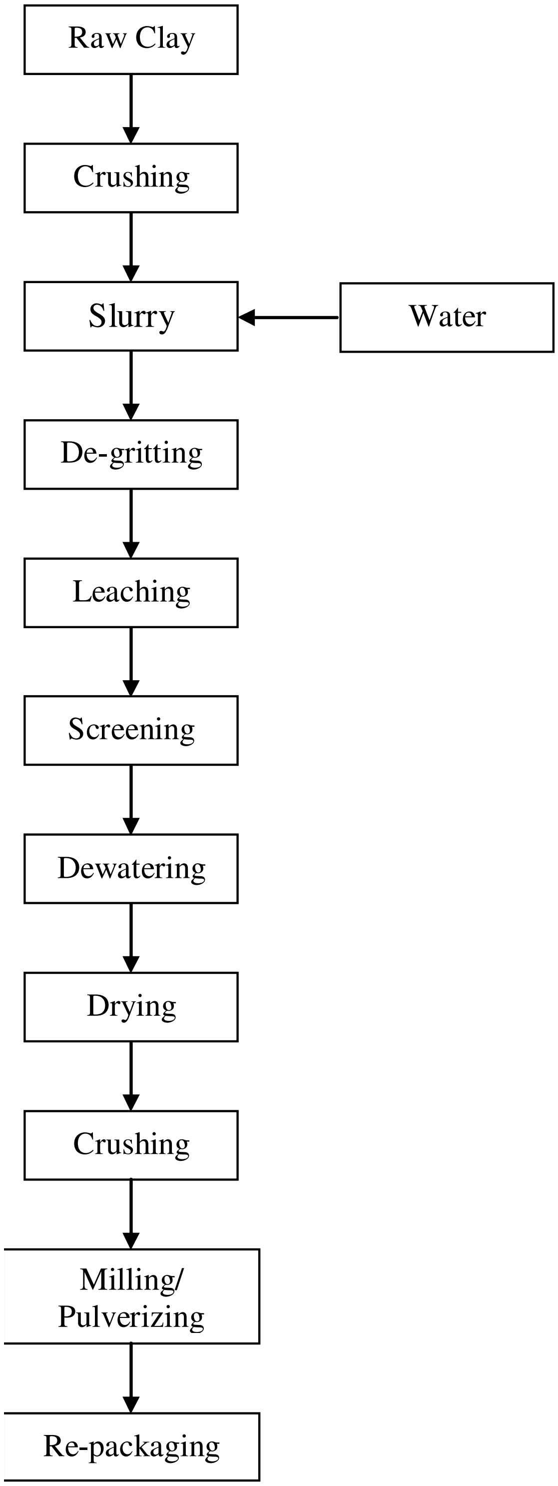

Figure 3. Flow chart for clay processing.

into the cup assembly. With the air pressure valve closed, the mud cup assembly is clamped to the frame while holding the filtrate outlet end finger tight. A graduated cylinder is placed underneath to collect filtrate. Pressure valve is opened for gas to flow in and timing start at the same time. Filtrate collected after 30 min is recorded in cc as showed in Table 4.

Figure 4. Acts of processing clay samples (clockwise).

Mud density determination

The mud density is measured with a mud balance. The density of the mud is read at the left hand edge of the sliding weight and recorded in Table 4.

pH determination

The pH test is a measurement of the concentration of hydrogen ions in aqueous solution. This is done by a special pH meter after calibration. Its probe is simply placed in the mud sample (with and without sodium carbonate) and the reading taken after the needle stabilizes (the probe is washed clean before re-use). The meter gives a more accurate result as tabulated in Table 4.

RESULTS AND DISCUSSION

Rheological properties

Table 1 shows the results of free-swell volume in which samples NWY 014, 026, 033 and 050 attained the highest swelling level at 8% of Na_2CO_3 added. However, it was observed that increase in sodium carbonate concentration above this percentage tends to have adverse effect on clays' swelling ability. Similarly, samples NWY 011, 013, 028, 030B, 053 and 057 reached optimum swelling levels at 10% of Na_2CO_3 and any increase in sodium carbonate concentration above 10% rather reduces swelling ability of the clays. For this reason ten percent (based on mode) analytical-grade

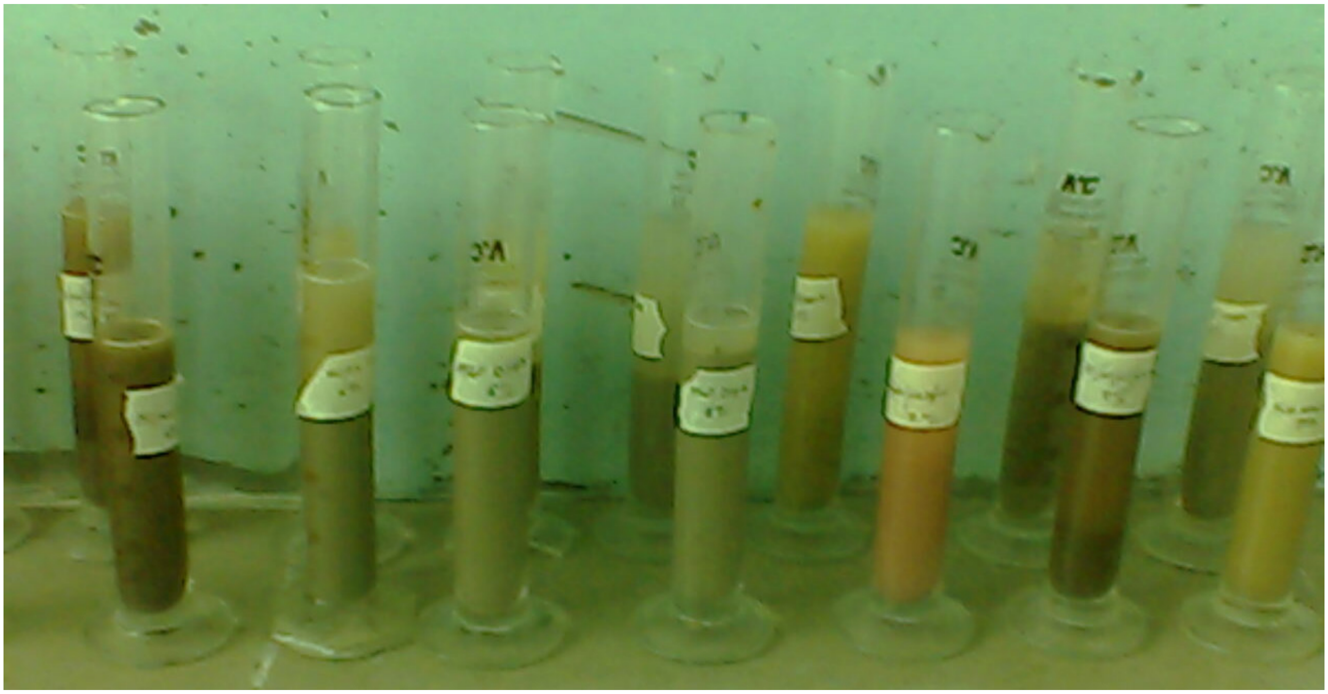

Figure 5. Free swell volume determination.

Table 1. Percentage Increment of free swell volume with addition of Na_2CO_3.

	% of Na_2CO_3 in sample (by weight)							
Sample No	**0**	**1**	**2**	**4**	**6**	**8**	**10**	**12**
NWY 011	100	300	580	780	1100	1340	1500	1260
NWY 013	120	340	500	700	980	1260	1620	1500
NWY 014	80	380	620	740	1060	1300	1220	1220
NWY 026	140	480	700	860	1260	1620	1580	1380
NWY 028	100	540	740	900	1140	1340	1620	1500
NWY 030B	80	500	660	860	1140	1380	1540	1380
NWY 033	140	660	1020	1260	1580	1780	1780	1700
NWY 050	160	380	420	540	900	1020	1020	1000
NWY 053	160	420	740	980	1420	1700	1740	1660
NWY 057	80	460	580	720	740	980	1260	1180

Table 2. Mud preparation for laboratory experiment.

A	B	C	D
22.5 g/350 ml	22.5 g/350 ml	25 g/350 ml	28 g/350 ml
+	+	+	+
0% of Na_2CO_3	Na_2CO_3 (10% of 22.5 g of clay)	Na_2CO_3 (10% of 25 g of clay)	Na_2CO_3 (10% of 28 g of clay)

sodium carbonate was used for beneficiation. It could be deduced that the free swell volume has revealed the cation exchange capacity of each sample.

The readings recorded from the rheometer were converted to shear stress and shear rate. Consistency curves were plotted for all the formulations (Table 2) and

Table 3. Bentonite requirements for API specification (adapted from Gray and Darley, 1980).

Moisture, as shipped from point of manufacture:	10% maximum
Wet screen analysis, residue on U. S. Sieve (ASTM) no. 200: 4% maximum	
Properties of a suspension of 22.5 g of bentonite (as received) in 350 cm^3 of distilled water; stirred 20 min; allowed to stand overnight; re-stirred 5 min.	
Viscometer dial reading at 600 rpm: 30 minimum	
Yield point, lb/ 100 ft^2: 3 * plastic viscosity, maximum	
Filtrate: 13.5 cm^3, maximum	
Tests to be made as stated in API RP-13B, "Standard Procedure for Testing Drilling Fluids"	

Figure 6. Experimental determination of static filtration.

are compared with the behavior of imported bentonite.

Figure 7 shows very low shear stress of the unbeneficiated (native state) samples at 22.5 g / 350 ml clay concentrations. Sample NWY 014 has the lowest shear stress of 7.7 while sample NWY 033 has the highest shear stress of 23 both at 1022 s^{-1}, with about 81 and 94% below imported bentonite respectively. This was due to the dominance of calcium in Nigerian clays.

However, there was slight increase in the shear stress when the samples were beneficiated. From Figure 8, samples NWY 030B has the lowest improvement in shear stress of 129% while sample NWY 028 has the highest improvement in shear stress of 525% at 1022 s^{-1}.

In order to boost the rheology of the mud, clay concentration was increased to 25 g / 350 ml as shown in Figure 9. As a result of beneficiation with increase in clay concentration, there were broken edges, and sides of the clay structure with clay in suspensions were mechanically sheared, exposing unsatisfied valences of positive or negative, which tends to hold and orient individual clay particles in random structures. Samples NWY 014 and 030B recorded the lowest shear stress of 56.21 at 1022 s^{-1} while sample NWY 028 and 053 have the highest shear stress of 81.76 at 1022 s^{-1} translating to 32% increase.

Further improvement was observed when the clay concentration was increased to 28 g / 350 ml (Figure 10). It was observed that samples NWY 011 and 014 have the lowest shear stress of 76.65 at 1022 s^{-1} while sample NWY 053 has the highest shear stress of 104.76 1022 s^{-1}. On the contrary in percentage increment, sample NWY 028 has the lowest percentage of 19% while sample NWY 053 has the highest percentage of 41% and the total average increase is 29%.

Generally, it was observed that addition of clay has proportionate effect on the muds. By comparison, the consistency curves revealed that beneficiation caused improvement in the ability of the clay particles to flocculate which resulted to better flow properties of the mud.

The reason for increase in shear stress when sodium carbonate and clay concentration were increased could be attributed to three reasons. Firstly, cation exchange - converting calcium smectite to sodium smectite, thereby

Table 4. Location and some properties of the clay samples.

Sample No.	Co-ordinates	Elevation (m)	Clay (%)	Conc. (g/350 ml)	G.S. lbs/100 ft^2	Density (ppg)	Filtrate loss (ml)	pH
NWY 011	12° 56′ 51″ N 005° 12′ 01″ E	307	51.31	22.5 22.5* 25* 28*	00/00 00/00 01/1.5 03/04	8.75 8.75 8.76 8.78	94.7 44.1 37.4 30.3	8.3 10.1 10.01 10.01
NWY 013	12° 29′ 30″ N 007° 59′ 13″ E	-	43.80	22.5 22.5* 25* 28*	00/00 00/01 01/02 4.5/05	8.83 8.83 8.83 8.84	111.2 35.4 29.1 25.6	8.13 11.01 11.01 11.01
NWY 014	12° 55′ 48″ N 005° 18′ 11″ E	310	58.72	22.5 22.5* 25* 28*	00/00 00/00 00/00 03/3.5	8.76 8.76 8.77 8.78	102.5 45.7 38.3 30.4	7.77 10.81 10.81 10.81
NWY 026	12° 52′ 36″ N 005° 16′ 56″ E	314	66.33	22.5 22.5* 25* 28*	00/00 00/00 01/02 04/05	8.76 8.76 8.76 8.77	93 41.5 35.5 29	7.98 10.00 10.00 10.00
NWY 028	12° 52′ 19″ N 005 20′ 10″ E	294	55.61	22.5 22.5* 25* 28*	00/00 01/02 1.5/2.5 05/6.5	8.87 8.80 8.81 8.82	80.5 35 28.5 25	8.92 10.01 10.01 10.01
NWY 030B	12° 50′ 36″ N 005° 21′ 04″ E	314	53.67	22.5 22.5* 25* 28*	00/00 00/00 00/01 03/04	8.76 8.76 8.76 8.76	82.9 44.5 38.1 29.3	8.11 10.7 10.7 10.7
NWY 033	13° 06′ 44″ N 005° 16′ 32″ E	274	70.28	22.5 22.5* 25* 28*	00/00 00/01 02/2.5 04/5.5	8.76 8.76 8.76 8.77	78.5 38.8 31.6 27.3	7.97 10.53 10.53 10.53
NWY 050	13° 44′ 42″ N 005° 39′ 24″ E	345	60.15	22.5 22.5* 25* 28*	00/00 00/00 1.5/02 03/04	8.76 8.76 8.78 8.82	83.9 37.6 33 28.1	7.89 10.05 10.05 10.05
NWY 053	13° 45′ 31″ N 5° 36′ 48″ E	341	63.38	22.5 22.5* 25* 28*	00/00 01/2.5 03/04 07/08	8.78 8.78 8.79 8.81	80.5 33.8 28 24	8.13 10.83 10.83 10.83
NWY 057	13° 45′ 11″ N 05° 38′ 49″ E	331	61.55	22.5 22.5* 25* 28*	00/00 00/00 01/02 04/05	8.78 8.78 8.79 8.81	95.1 39 34.7 29.5	8.67 10.00 10.00 10.00

[1]*beneficiated with 10% sodium carbonate, G.S. = Gel Strength.

C.E.C. – Cation exchange capacity, M – moderate, MH – moderately high, W – weak, NE – non expandable, EX – expandable

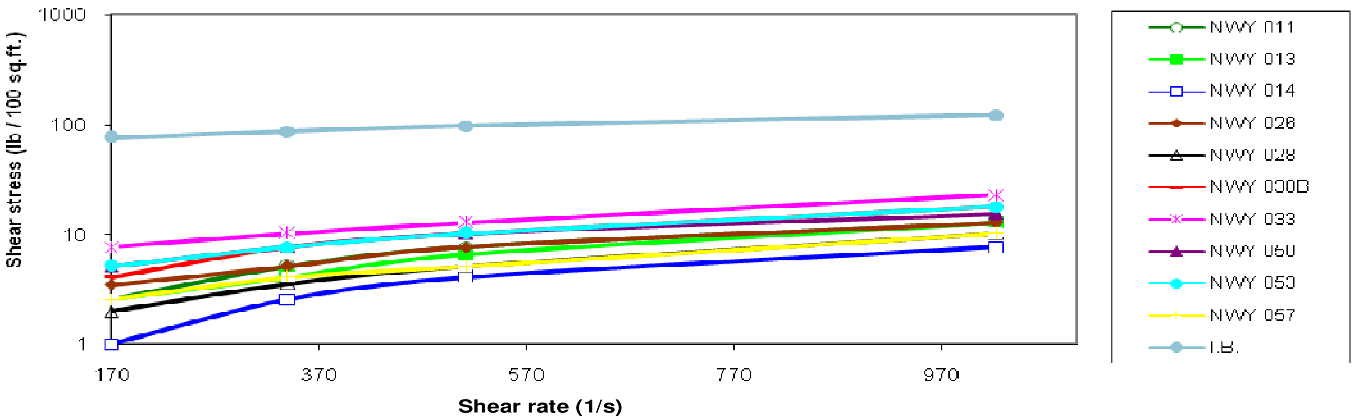

Figure 7. Rheological behaviour of unbeneficiated samples investigated at 22.5 g / 350 ml of clay concentration with imported bentonite (I.B.) as control at 22.5 g / 350 ml. NWY: Represent cardinal points where the samples were taken (N-North, W- West and Y is just to complement the name).

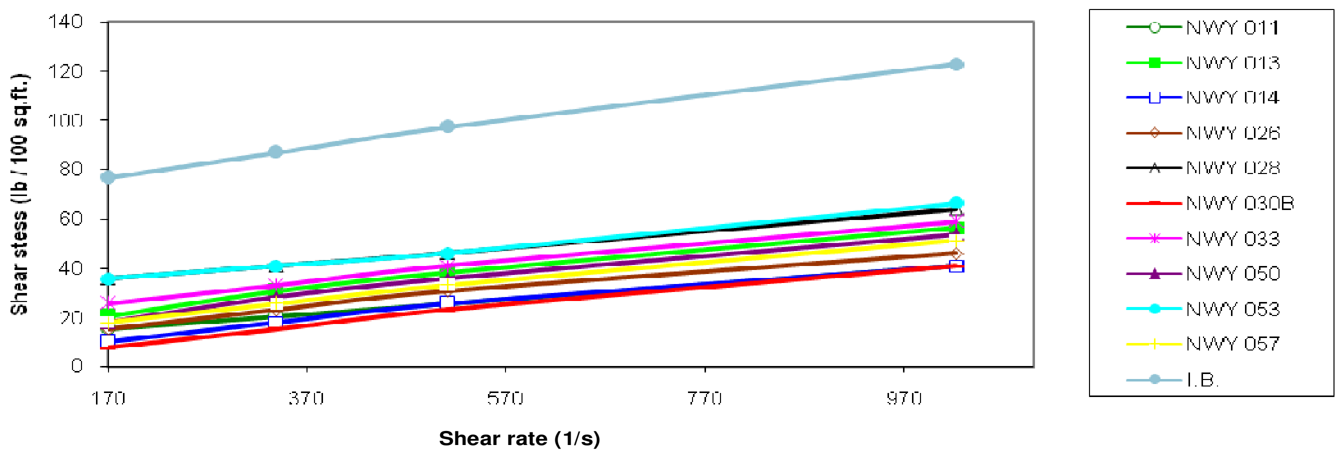

Figure 8. Rheological behaviour of beneficiated samples investigated at 22.5 g / 350 ml of clay concentration with imported bentonite (I.B.) as control at 22.5 g / 350 ml. NWY: Represent cardinal points where the samples were taken (N-North, W- West and Y is just to complement the name).

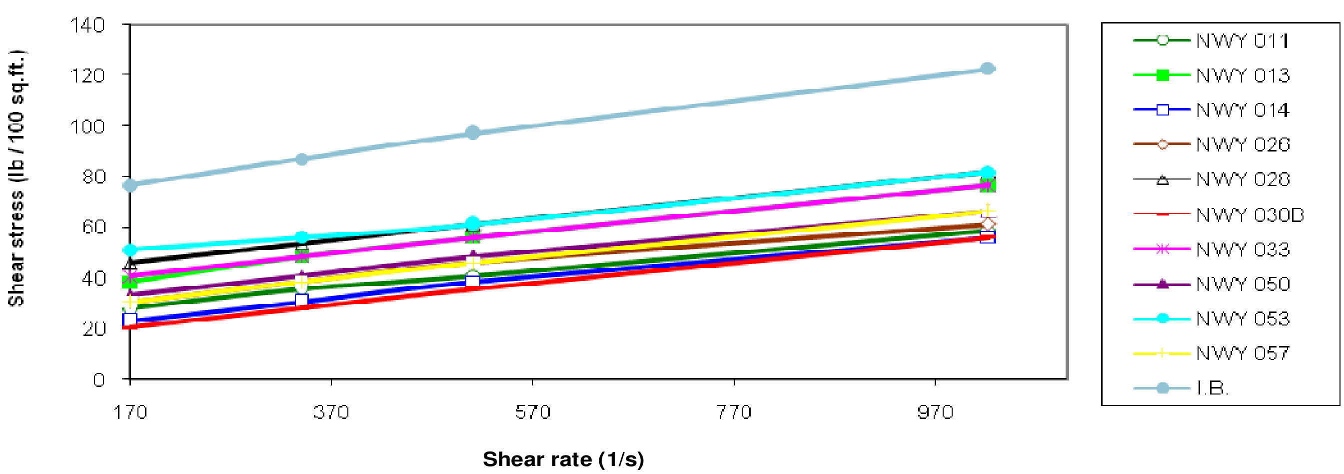

Figure 9. Rheological behaviour of beneficiated samples investigated at 25 g / 350 ml of clay concentration with imported bentonite (I.B.) as control at 22.5 g / 350 ml. NWY: Represent cardinal points where the samples were taken (N-North, W- West and Y is just to complement the name).

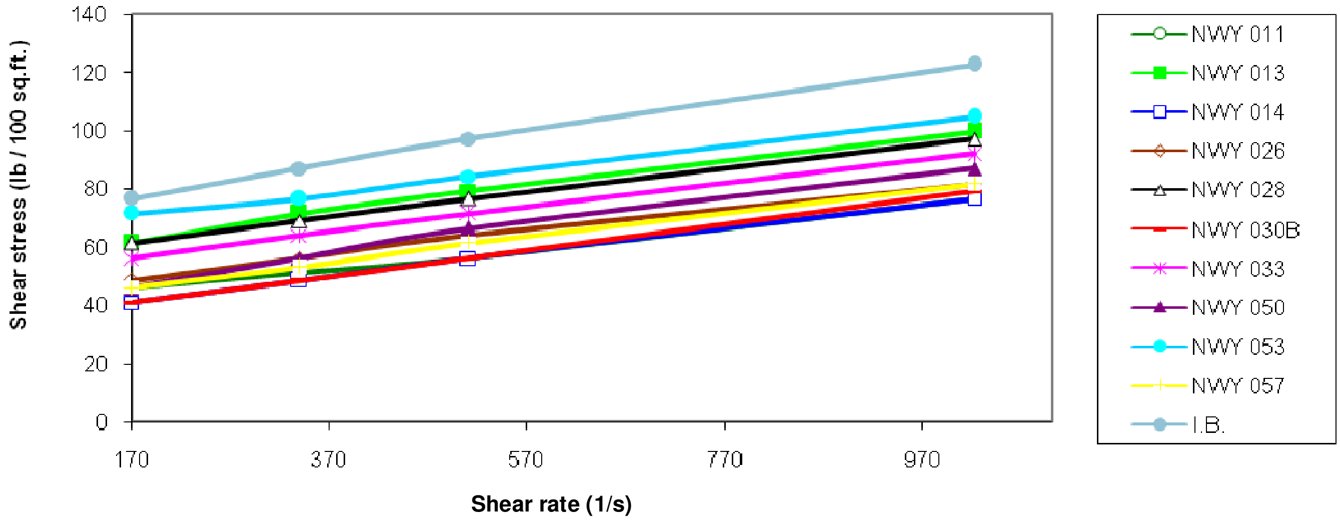

Figure 10. Rheological behaviour of unbeneficiated samples investigated at 28 g / 350 ml of clay concentration with imported bentonite (I.B.) as control at 22.5 g / 350 ml. NWY: Represent cardinal points where the samples were taken (N-North, W- West and Y is just to complement the name).

Table 5. Summary results of cations exchange capacity and estimated mineral composition of investigated clays.

Sample name	Exchangeable cations (cmole/kg)					C. E. C. (cmole/kg)		Estimated clay mineralogy (%)	Suspected dominant clay minerals	Swelling tendency
	Na	K	Mg	Ca	H^+	Calculated	Class			
NWY 011	0.65	0.25	4.68	36.38	0.04	42.00	M	NE ≈ 62, EX ≈ 38	Ca-smectite	M
NWY 013	1.80	0.05	3.01	49.00	0.00	53.96	MH	NE ≈ 47, EX ≈ 53	Ca-smectite	M
NWY 014	0.82	0.19	6.01	26.73	0.01	33.76	M	NE ≈ 72, EX ≈ 28	Illite-chlorite-kaolinite	W
NWY 026	0.43	0.27	6.25	41.35	0.09	48.39	M	NE ≈ 55, EX ≈ 45	Ca-smectite	M
NWY 028	0.49	0.21	2.12	42.05	0.10	44.97	M	NE ≈ 59, EX ≈ 41	Ca-smectite	M
NWY 030B	1.07	0.18	4.67	43.75	0.02	49.69	MH	NE ≈ 52, EX ≈ 48	Ca-smectite	M
NWY 033	0.71	0.13	5.30	37.0	0.04	43.18	M	NE ≈ 61, EX ≈ 39	Ca-smectite	M
NWY 050	1.15	0.46	26.40	27.95	0.15	56.11	MH	NE ≈ 45, EX ≈ 55	Mixed	M
NWY 053	1.11	0.15	37.69	18.70	0.00	57.65	MH	NE ≈ 42, EX ≈ 58	Vermiculite	M
NWY 057	0.72	0.13	5.50	30.65	0.03	37.03	M	NE ≈ 69, EX ≈ 31	Illite-chlorite-kaolinite	W

increases the distance between the clay particles and hence increased flocculation of the clay. This could be attributed to the fact that sodium being a monovalent cation can associate with a charge deficient area such that dispersion in water will create separated sheets unlike calcium, a divalent cation which cannot effectively associate with two negative charges but centers on one sheet and thus bind two sheets together. Secondly, the higher proportion of expandable minerals in the samples and lastly the edges of the clay sheets formed by breaking the structure to form unsatisfied chemical bonds or charges. This could be justified by results of their free swell volume as shown in Table 1 and substantiated by their physico-chemical characteristics in terms of cation exchange capacity, expandable and non-expandable minerals (Table 5). It could also be as a result of differences in mineralogy influenced by depositional environment.

Summarily, the consistency curve plots of these samples exhibited non-newtonian behavior characteristic of a Bingham plastic model. Though, not ideal Bingham plastics but as normal drilling fluids, they deviated from linearity at low shear rates which could be as a result of concentration, size, and shape of the particles of each sample.

Figure 11 shows the plot of plastic viscosity calculated from all consistency curves using Bingham plastic model. It has been observed that increase in mass concentration and beneficiation has caused the plastic viscosity to increase moderately as a result of fair increase in

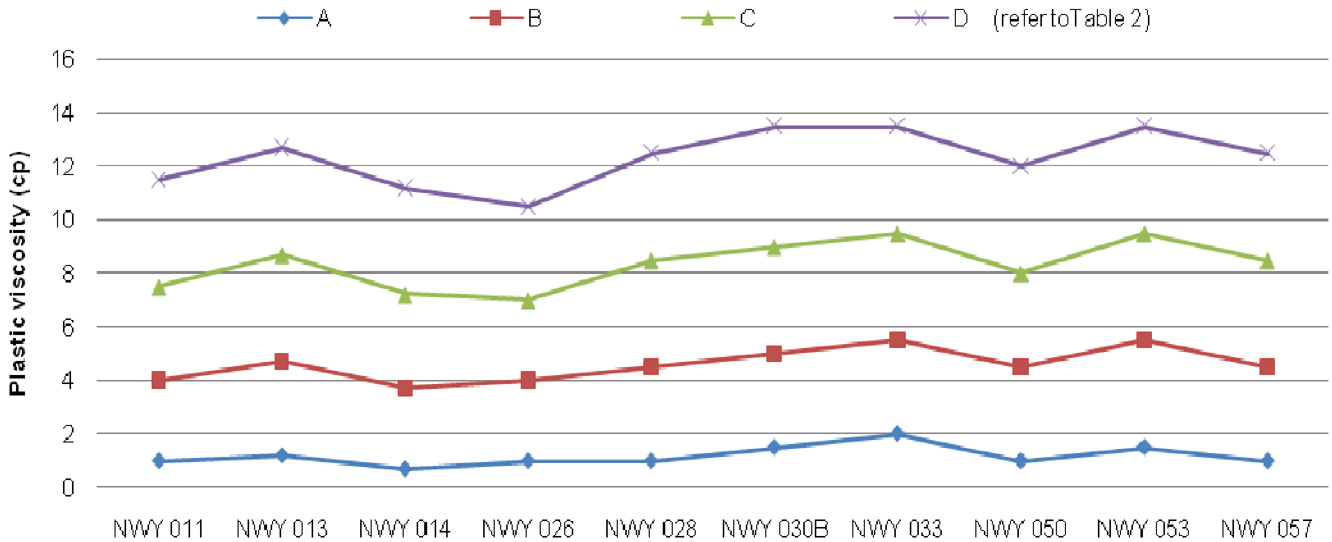

Figure 11. Effect of beneficiation and increase in clay concentrations on plastic viscosity. NWY: Represent cardinal points where the samples were taken (N-North, W- West and Y is just to complement the name). I.B: Imported Bentonite – represent commonly used drilling fluid by the industry. A, B, C, and D: Different composition of mud preparation for laboratory experiment (Table 2).

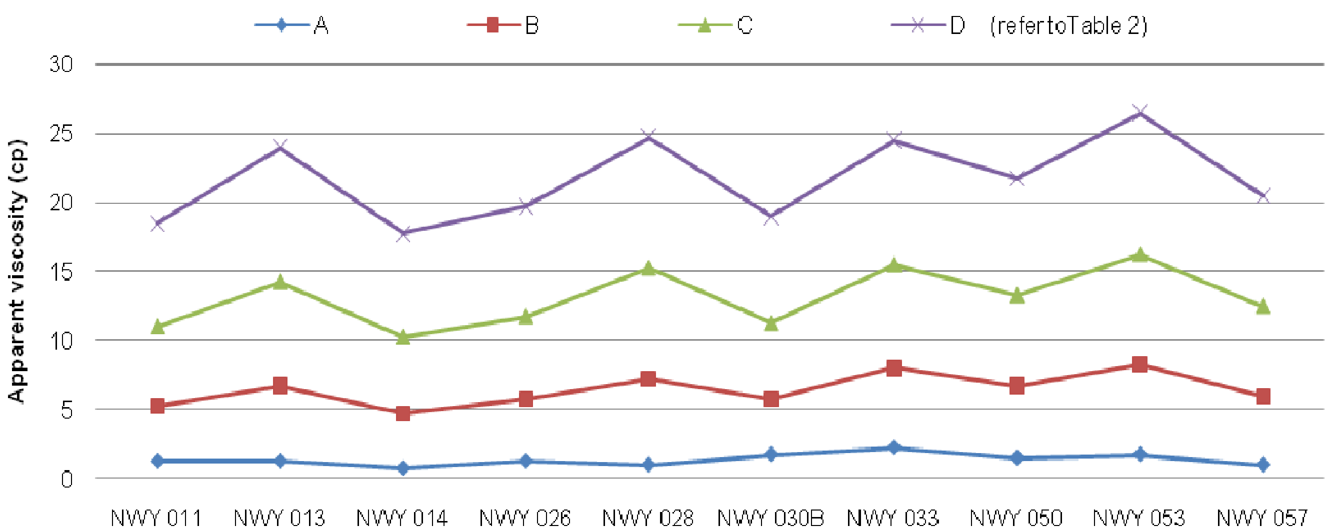

Figure 12. Effect of beneficiation and increase in clay concentrations on apparent viscosity at 600 RPM. NWY: Represent cardinal points where the samples were taken (N-North, W- West and Y is just to complement the name). I.B: Imported Bentonite – represent commonly used drilling fluid by the industry. A, B, C, and D: Different composition of mud preparation for laboratory experiment (Table 2).

dispersion initiated by increase in degree of ionization and particle friction hence, revealing the effect of mechanical forces of the solids in the mud. This is quantified by average 205, 10, and 7% increase in plastic viscosity for all samples at formulation B, C and D respectively (Table 2).

Figure 12 shows considerable increase in apparent viscosities which were calculated from consistency curves at 1022 s^{-1}. Sample NWY 053 has the highest apparent viscosity of 10.25 cp (centipoises) in D. However the average increase in apparent viscosity for all samples at B, C and D were observed to be 298, 32 and 29% respectively.

The strength of interaction forces of the particles in each fluid increased which enhanced flocculation and consequently improved yield point significantly as shown on Figure 13. According to API specification (Table 3), it was only sample NWY 053 that did not meet yield point

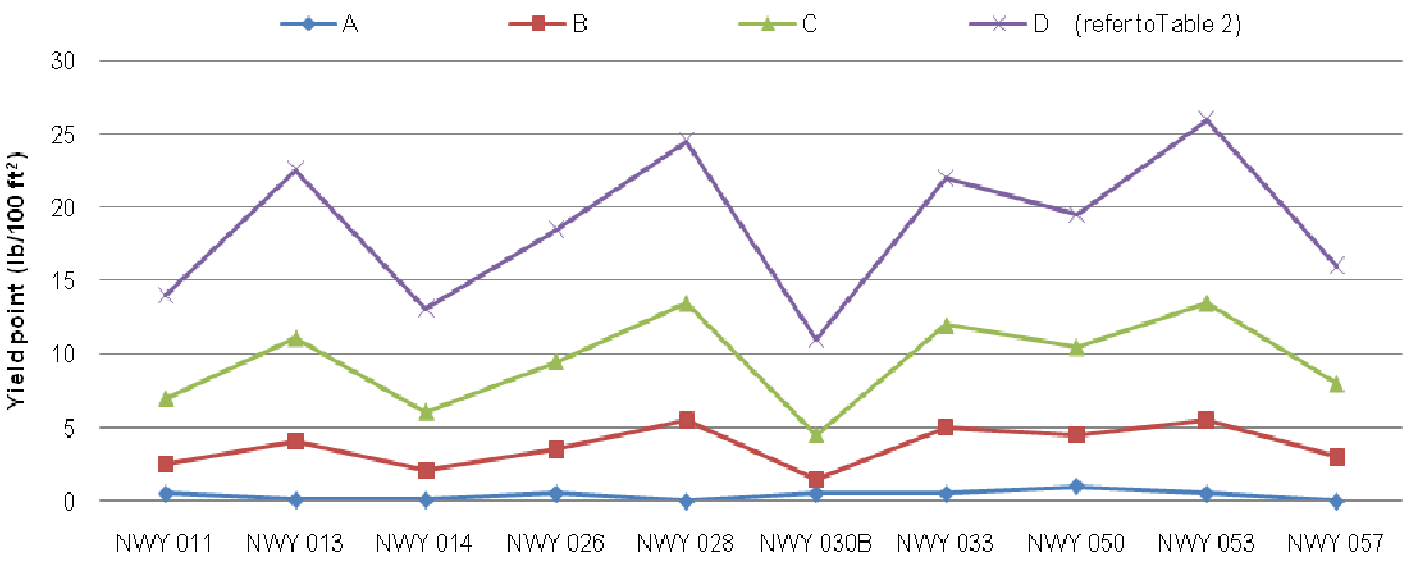

Figure. 13 Effect of beneficiation and increase in clay concentrations on yield point. NWY: Represent cardinal points where the samples were taken (N-North, W- West and Y is just to complement the name). I.B: Imported Bentonite – represent commonly used drilling fluid by the industry. A, B, C, and D: Different composition of mud preparation for laboratory experiment (Table 2).

specification at D. Between A and D, Sample NWY 030B increased by 600% (the lowest) while Sample NWY 053 increased by 1200% (the highest). Meanwhile average increase in yield point for all samples at B, C and D were observed to be 9500, 90 and 61% correspondingly.

The gel strength column on Table 4 shows gel strength data determined after 10 s and 10 min time. The gel strength determined on 22.5 g native clay samples were all 00/00 s, while it increased gradually as the carbonate was added and clay concentrations were increased with sample NWY 014 having the least value of 03/3.5 and sample NWY 053 having the highest value of 07/08 at D in that order. This could be ascribed to gel strength depending more on the presence of colloidal clays, and rearrangement of particles that occur with positive and negative charges at the broken edges of the clay structure, exerting an additional repelling or attractive forces.

Filtration properties

The effect of 10% Na_2CO_3 was much more reflected on the filtrate loss of those samples as filtrate loss reduced drastically ranging from 111.2 cc – 78 cc to 45.7 cc – 33.8 cc which amounted to 56% average reduction. However when the clay concentration was increased to 25 and 28 g with addition of 10% Na_2CO_3 there was further 15.5 and 16% decrease in filtrate loss respectively Figure 14. This is as a result of the particle size distribution, shape of the particles, and the compressibility of the filter cake influence on fluid loss properties of clay suspensions because the addition of carbonate on clay particles caused flocculation and these particles assume random positions with each other forming different clay associations. These randomly arranged particles of various micron sizes formed an effective seal when they are being compressed by pressure during filtration.

Mud density

It could be seen from Figure 15 that effect of increase in clay concentrations on density is relatively minimal. There were 0.08 and 0.17% average increase as clay concentrations was increased to 25 and 28 g respectively.

Effect of carbonate on $_{P}$H with reference to clay

Having treated each sample with 10% Na_2CO_3, the pH of each sample increased averagely by 27% as revealed by Figure 16. This apparently reflected on rheological properties of each sample because of its influence on creation of very strong attractive forces which speed up the movement of water molecules between clay platelets.

Conclusions

From the experimental results obtained, it could be deduced that beneficiation of drilling mud samples with sodium carbonate and increase in clay concentration influences the viscosity and affects the flow properties of

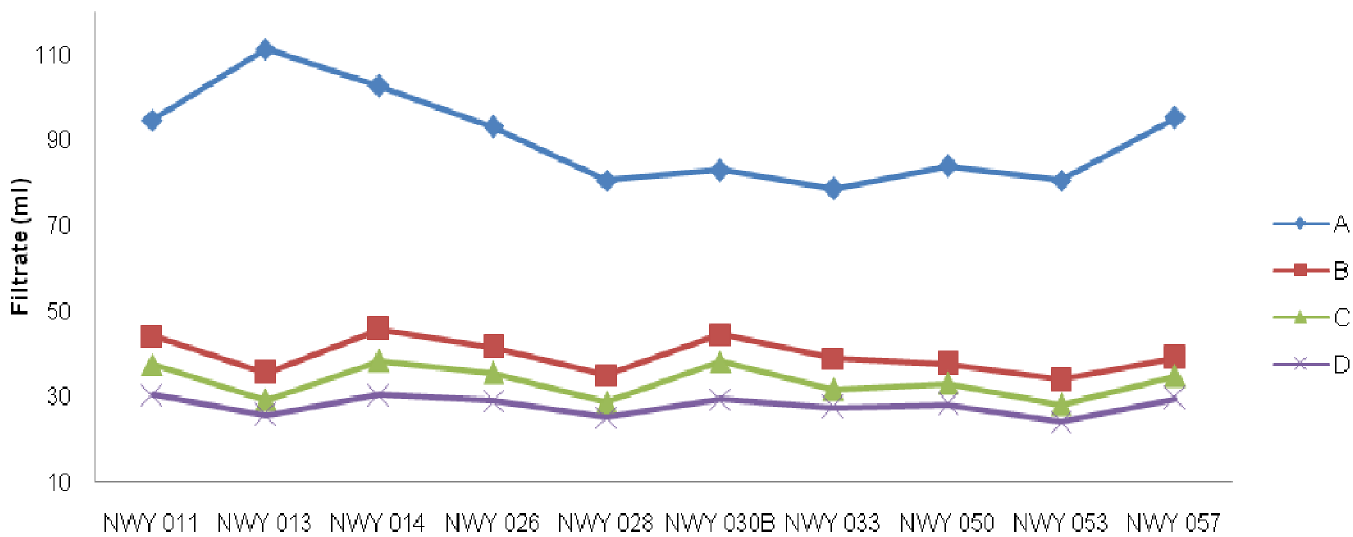

Figure 14. Results of carbonates and Increase in clay concentrations on filtration. NWY: Represent cardinal points where the samples were taken (N-North, W- West and Y is just to complement the name). I.B: Imported Bentonite – represent commonly used drilling fluid by the industry. A, B, C, and D: Different composition of mud preparation for laboratory experiment (Table 2).

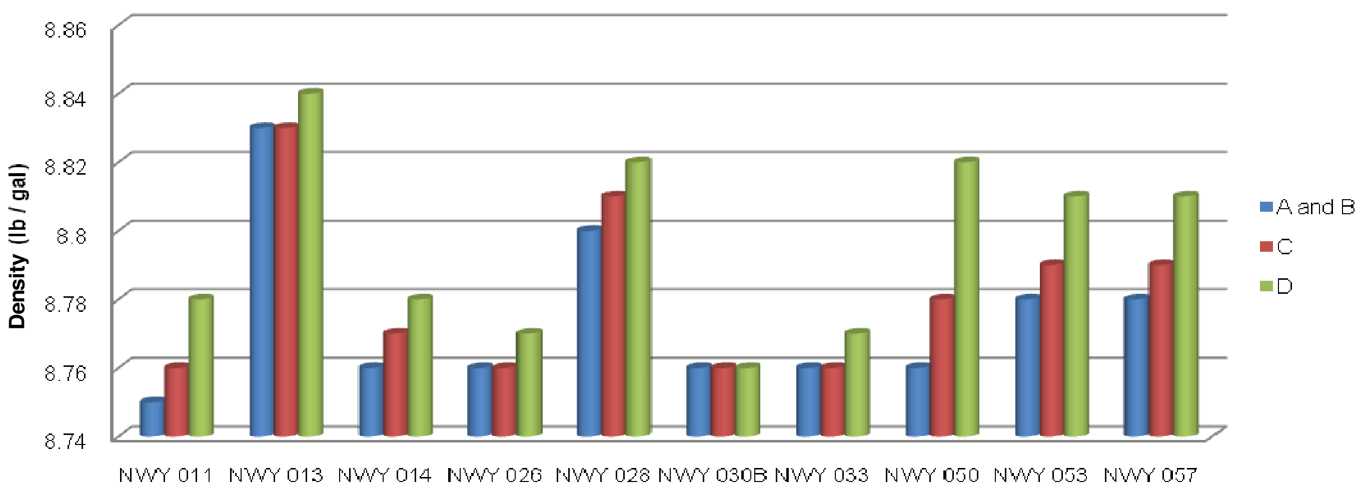

Figure 15. Effect of increase in clay concentrations on density. NWY: Represent cardinal points where the samples were taken (N-North, W- West and Y is just to complement the name). I.B: Imported Bentonite – represent commonly used drilling fluid by the industry. A, B, C, and D: Different composition of mud preparation for laboratory experiment (Table 2).

the mud samples and the following conclusions could be drawn:

(i) The samples that contained vermiculite as the suspected dominant clay mineral have swelling ability higher than those that contained calcium smectite / chlorite / illite / kaolinite / mixed minerals as their suspected dominant clay minerals.
(ii) Optimal average concentration of sodium carbonate needed to exchange sodium for calcium in the investigated northern clay samples is 10%.
(iii) Addition of 10% analytical grade of sodium carbonate increased the local clay plastic viscosities, yield points and apparent viscosities.
(iv) Increase in clay concentration by 11 and 24% of API specification (Table 3) also add to the improvement of the local clay plastic viscosities, yield point and apparent viscosities.
(v) Considering the API requirements for yield point (that is, $YP \leq 3 * PV$) only sample NWY 053 failed at 28 g / 350ml.
(vi) Samples NWY 033, 028, 013 and 053 are the most

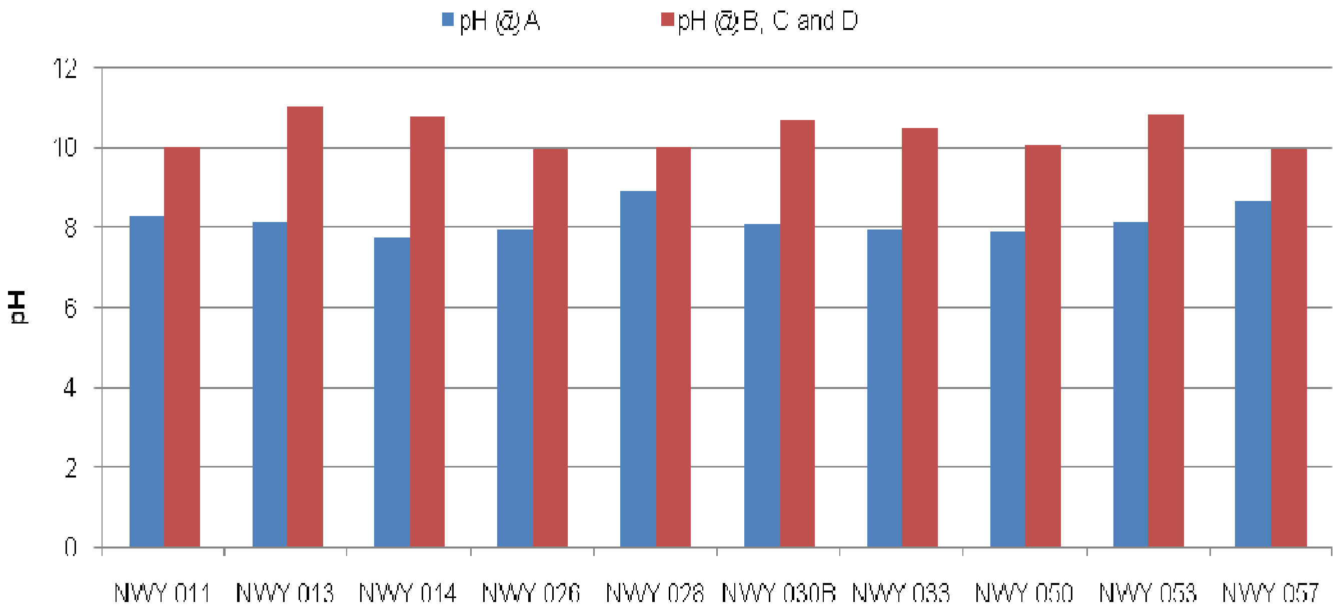

Figure 16. Effect of carbonate on pH of the samples. NWY: Represent cardinal points where the samples were taken (N-North, W-West and Y is just to complement the name). I.B: Imported Bentonite – represent commonly used drilling fluid by the industry. A, B, C, and D: Different composition of mud preparation for laboratory experiment (Table 2).

promising and have shown increase of 950, 1140, 1100 and 1200% in yield point properties respectively.

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