An Investigation on the Free Swelling Volume and Beneficiation Properties of Clay Samples from Wilberforce Island, Bayelsa State, Nigeria.

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Abstract
This research investigates the swelling volume of clay locally sourced from Wilberforce Island, Nigeria. The aim of this research was achieved through the underpinned objective of evaluating the swell volume of clay when beneficiated with chemicals. It was however observed from the reviewed literatures that the clay samples experimented from the northern part of Nigeria was most suitable for ceramics other than drilling purposes. In addition, the clay deposit at Wilberforce Island has not been researched for its suitability for drilling fluid performance. Furthermore, the study relied on the use of measuring cylinders and tables were used to analyze the data obtained. This study observed that the clay samples falls in the kaolinite family and thus, it's unsuitable for drilling intermediate intervals, except the drilling fluid is beneficiated with some additives.

Keywords: *Drilling Fluids, Clay, Swelling Volume, and Beneficiation.*

1.0 The Background of Study

Since the exploration of crude oil into deeper subsurface, clay has been a major constituent in the formulation of drilling fluid used in drilling successful and economic wellbore to the targeted pay-zone. In drilling fluid technology, clay swelling is an important characteristic of drilling fluid as it enables the fluid to form a thixotropic gel which suspends the drilled cuttings during work over and pipe tripping. Hence, understanding the mechanism by which clay swells is an important part of controlling drilling mud characteristics and anticipating problems. Swelling volume refers to the ratio of the measure of yield of clay in water when a given volume of water is poured in a given volume of clay over a period of time, usually between 24 to 96 hours. The swelling volume of clay examines the tendency of clay to hydrate within a given period of time. This test is to determine the value of the swelling volume of the clay samples, to obtain its swelling ability for drilling mud preparation (Ajugwe *et al.*, 2012). Iheagwara (2012) also referred to swelling volume as the analysis done to examine the tendency to swell (hydrate) over a period of time. Iheagwara presented this formula for calculating the swelling volume of clay, as shown in equation 1.1.

Swelling volume = ………………… 1.1

Using the principle of equation 1.1, clay minerals are classified as 1:1 or 2:1 ratios depending on its structure. A typical 1:1 ratio classification of clay contains one tetrahedral sheet and one octahedral sheet. Similarly, a 2:1 ratio classification of clay is made up of an octahedral sheet sandwiched between two tetrahedral sheets. Examples of these classes of clay include the kaolinite, and montmorillonite respectively. Clays that have high swelling abilities have an expanding crystal lattice in a 2:1 ratio. Examples of these classes of clay include the kaolinite, and montmorillonite respectively. Clays that have high swelling abilities have an expanding crystal lattice in a 2:1 ratio. The phenomenon of swelling is associated with the hydration of clay. However, not all clays swell upon hydration. Those of the kaolinite group, for example exhibit little or no swelling on hydration. Sodium montmorillonite, on the other hand, characteristically swells in water to many times its dry volume as compared to calcium montmorillonite because the calcium cation is strongly adsorbed compared to the sodium cation. In the presence of water, the adsorbed cation can exchange with cation of another species, and it's therefore known as exchangeable cation. This swelling ability of bentonite has made researchers in Nigeria to investigate the clay domicile in Nigeria for its suitability in the formulation of drilling fluid. However, if it is to be used as drilling fluid, further investigation needs to be carried out. Hence, clay minerals can be classified as 1:1 or 2:1 depending on their structure. A typical 1:1 classification of clay contains one tetrahedral sheet and one octahedral sheet. Similarly, a 2:1 classification of clay is made up of an octahedral sheet sandwiched between two tetrahedral sheets. Consequently, a comparative study of bentonite and clay samples from Adiabo in cross River state of Nigeria was carried out by Abuh *et al.* (2014) and the conclusion was reached that although the swelling volume of the Adiabo clay attained a level of 48% after been mixed with distilled water and allowed to stand for 24hrs, it is still below the recommended standard for use as drilling fluid as compared to bentonite. Similarly, clay samples from Akokwa, Akperhe-olomu as reported by Ajugwe (2012) were sampled to investigate its swell volume, and the conclusion was reached that the local clay samples do not possess any appreciable swelling. However, the blend of the local clays with little concentration of imported bentonite can improve its swelling ability. Furthermore, Falode (2008) argued that clay samples obtained from pindiga in Borno state had a swell volume of 64% when beneficiated with Na_2CO_3. Falode concluded that beneficiated pindiga clay gives a good promise for drilling purposes at optimum additives concentration.

Accordingly, researches have been carried out in different parts of the country to test for the free swell volume of the indigenous clays. Nmegbu (2014) investigated clay samples collected from three different geographical locations namely; Egbamini, Afam Street and Oboboru in Rivers State. A measuring cylinder was filled with water to the 100ml mark, and 2g weight of all three samples was transferred in small amounts (about 2.5g) unto the surface of the water (sample in powdered form) using a thin spatula. This process was done repeatedly without stirring until the 2g powdered clay had completely disappeared into the water. Nmegbu pointed out that clays which are suitable for use as drilling mud would have a swelling volume increase to the 12-16ml mark on the measuring cylinder. However, if clays have swelled only to the 4-6ml mark, it will not effectively coat the side of the wellbore during drilling and therefore should not be used as the thickening agent. All three samples did not meet the swelling test criteria of 12-16ml mark on the measuring cylinder. At the end of the test period, sample C recorded the highest swelling volume attaining the 5ml mark. While samples A and B read an increase in volume of 4ml and 3ml respectively on the measuring cylinder. Similarly, Abuh *et al.* (2014) carried out an experimental study on Adiabo clay sample collected from Calabar, Cross River State. 10g of the sample was mixed with distilled water and allowed to stand for 24hrs. At the end of the 24hrs the swelling volume was read to be 48%. which is less than half its volume required for use as bentholitic clay in drilling operations. Abuh concluded that, though Adiabo clay cannot be used as drilling mud, nevertheless, it has other properties suitable for industrial applications. Likewise, Akokwa clay sample, Akperhe-olomu clay sample and Bariod Nig Ltd, all from Delta and Imo state were investigated by Ajugwe *et* al. (2012) and a comparative analysis was done with the foreign commercial bentonite. These clay samples were tested to obtain the free swell volume over a period of 96hrs (4days). At the end of the testing period, Akokwa clay sample measured an increase in volume of 0.75, 0.85, 1.76, 1.21%. Akperhe-olomu read an increase of 0.78, 1.0, 1.08, 1.21%. Bariod Nig Ltd clay sample read a volume increase of 1.26, 3.5, 4.4, 5.4% and the foreign aqua gel benonite clay sample read an increase of 5.7, 3.0, 37.0 and 105%. Ajugwe concluded that the local clays do not possess any appreciable swelling as compared with the foreign aqua gel bentonite which had a very high swell volume on the 2^{nd} and 4^{th} days respectively. However, the blend of local clays with little concentration of foreign aqua gel clay can improve its swelling properties. Furthermore, Nweke *et al*. (2015) compared clay samples from Abakaliki formation with commercial bentonite clay. Nweke reported that the clays are composed predominantly of little and mixed layer clays, with presence of montnorillonite which is responsible for the swelling potential of the clay, Ranging from 20-30%. However, the range present in the clay is significantly low when compared with Wyoming bentonite which has a range of 35-85%. The presence of kaolinite in Abakaliki clay could lead to poor rheological properties since such type of clay has low swelling capabilities (Apugo-Nwosu *et al.*, 2011). Therefore, the free swell values of Abakaliki clays are generally below 63%, whereas the standard bentonite clays all have a free swell volume above 700%. Nweke concluded that Abakaliki clays showed very low swelling capability. However, with beneficiation, its swelling potential will remarkably improve. Hence, it is imperative to locally outsource these clay materials in order to enhance Nigerian content development in the drilling component of oil and gas industry.

Beneficiation is a process where chemicals are added to low-quality clay to improve its performance. This is done to improve the properties of the clay (Falode *et al*., 2008). Clay samples were sampled randomly from different localities in Northern Nigeria as reported by Omole *et al*. (2013). A total of 10 samples were collected by digging from surface and underground using shovel, digger and hoe at an average depth of 1.5m. Each of the samples were packed in a bag and well labeled according to its flank and location. Free swell volume experiments were conducted for each sample to determine the optimum concentration of sodium carbonate required for beneficiation. The samples were labeled as NWY and 2.5g weight was measured each into 8 measuring cylinders containing 50ml of de-ionized water after which different percentages of sodium carbonate was added to each measuring cylinder. Then each sample was mixed and allowed to swell for 24hrs and the levels of the clay were recorded. The results of this experiment showed that samples NWY 014, 026, 033 and 050 attained the highest swelling level at 8% of sodium carbonate (Na_2CO_3) added. However, it was observed that increase in sodium carbonate concentration above the percentage tends to have adverse effects on clays' swelling ability. Similarly, six samples reached optimum swelling levels at 10% of Na_2CO_3 above 10% rather reduces swelling ability of the clays. It could be deduced that the free swell volume has revealed the cation exchange capacity of each sample. In another study, four clays (A, B, C and D) were taken from different locations in Sokoto State as investigated by Ihom *et al*. (2012). The sampling method was that for each deposit, 5 samples were taken at different locations and mixed together. Each of the clay was then sampled for determination of its swelling volume. The samples were washed and dried in the oven at 110^oC. 2 cylinders were filled with water and kerosene respectively to the 90ml mark, and 10g of the clay sample was introduced into each of the cylinders. This was done for the 4 clays. The entrapped air was removed by gently shaking and stirring with a glass rod. The samples were allowed to stand for 24hrs. It was observed that the clay specimen in the kerosene filled cylinder read no swell increase as kerosene is a non-polar liquid. The clay volume was the same as the original sample volume. While the clay specimen in the water filled cylinder read an increase of 25, 60, 10 and 40% respectively. Ihom *et al.* (2012) concluded that these clays are suitable for moulding.

The literatures reviewed show that, all the experimental procedures followed the same trend of testing for volume increase by the test tube method, which show that high value of sodium montmorillonite accounts for higher swelling capacity. Also, the literatures disclosed that clay deposits from the Northern part of Nigeria are most suitable for ceramics other than drilling purposes. Furthermore, clay deposits samples depth ranged from 1 to 2.5m. Therefore, Nigerian clays can be used as drilling fluid upon beneficiation was reached. Hence, it is imperative to undertake free swell and beneficiation studies of clay samples from Wilberforce island in order to upgrade the properties if need be, to that of the standard commercial bentonite for drilling fluid formulation.

Therefore, this research is aimed at investigating the swelling volume of clay in Wilberforce Island, south-south Nigeria for its application as drilling fluid; based on the underpinned research objectives: to investigate the free swell volume of local clay and when beneficiated with chemicals and to determine the optimum concentration of chemicals required for beneficiation. Significantly, this research will evaluate the swelling volume of clay in Wilberforce Island beneficiated with sodium carbonate (Na_2CO_3), sodium chloride (NaCl) and Zec-modified starch. The results from this investigation will enable the performance of Nigerian clay from the south-south region to be benchmarked against the imported bentonite.

1.3 Definition of Keywords

1.3.1 Clay

Clay is a fine grain natural rock or soil material that combines one or more clay minerals with traces of metal oxides and organic matter. Clays are plastic due to their water content and become brittle and non-plastic upon drying or frying. Clay is composed of silica (SiO_2), Alumina (Al_2O_3) and water (H_2O) plus appreciable concentration of oxides of iron, alkali and alkaline earth, and contains groups of crystalline substances known as clay minerals such as Quartz, Feldspar, and Mica. Depending on the content of the soil, clay can appear in various colors, from white to dull gray or brown to a deep orange-red. There are three main groups of clay; Kaolinite, montmorillonite, smectite and illite. Among this groups of clay "montmorillonite" a subclass of smectite is the most important and useful in the oil and Gas-drilling industry as it's a major component of drilling mud, making the mud slurry viscous, which helps in keeping the drill bit cool and removing drilled cuttings.

1.3.2 Swelling volume

The phenomenon of swelling is associated with the hydration of clays. However, all clays do not swell upon hydration. Similar to many other types of clay, montmorillonite swells with the addition of water. However, some montmorillonite expand considerably more than other clays due to water penetrating the interlayer molecular spaces. The amount of expansion is due largely to the type of exchangeable cation contained in the sample. The presence of sodium as the predominant exchangeable cation can result in the clay swelling to several times its original volume.

1.3.3 Beneficiation

Beneficiation can be referred to as a blend of chemicals to low-quality clay to improve its properties. In the petroleum industry, the most common chemicals used in this process include sodium chloride, sodium carbonate, starch, potash, just to mention but few.

1.0 Materials and Methods

1.1 Materials

The materials used in conducting these experiments include the following: hand auger, 50ml measuring cylinders, spatula, weighing balance, masking tape, foil paper, stirring rod, desiccant, and polyethene bags; others are hand-mixer, 20-liter buckets, centrifuge, distilled water, oven, thermometers, electrical grinder, mortar pestle, Zec-modified Starch, and 75µm sieve.

1.1 Methods

1.1.1 Clay Samples Collection and Mud Preparation

Clay samples were randomly sampled from Wilberforce Island, Bayelsa State, in south-south Nigeria, the locally sourced raw wet clay samples were excavated and collected at some average depths between 1.5m to 1.7m from six (6) different locations. From each of these locations, four (4) kilograms of the wet raw clay were bagged carefully in some labeled polyethene bags (see Table 2.1). Subsequently, in the petroleum drilling engineering laboratory, Niger Delta University; each of the raw sampled clays was dried in the sun rays at an average recorded temperature of 25^0C for 16 days. Consequently, these dried raw clay samples were ground to powdered form with an electrical grinder. Furthermore, 10 liters of de-ionized water were poured into 8 different buckets which had a capacity of 20-litre. And each of the dried powdered raw sampled clays was poured into each the buckets. The buckets' content was mixed rigorously with the hand mixer, to emulsify the mixture. The emulsified mixture of clay and water (mud) in each of the buckets were allowed to stand alone and age for 24hrs to settle out silts, sands and other weighting constituents present in the mud. The supernatants from each of the buckets were decanted into waste drains and the residues - which are the muds; were decanted and sieved with a 70µm sieve and the filtrate was allowed to settle down while continuously decanting the water. The concentrated clay was then transferred into centrifuge cups and set to rotate in the centrifuge at a revolution of 2000rpm for 20 minutes. The clay cake was then removed and spread on a pan then allowed to dry in an oven over a 50^oC temperature for 10 minutes. The dried clay cakes were allowed to cool for 1hr and were ground to fine sizes with mortar and pestle. After which the grounded prepared clay samples were sieve with a 75µm sieve. Each of these samples was placed in desiccants to prevent further moistening.

Table 2.1: Clay Samples from different field locations

Clay Sample Designation	WB1	WB2	WB3	WB4	WB5	WB6
Longitude /Latitude	6.11006 /4.97046	6.11587 /4.97108	6.1141 68 /4.9760 68	6.11589/4. 97108	6.10015 /4.96066	6.10794/ 4.97086

1.1.1 Experimental Procedure

The determination of the free swelling volume of clay investigated in this research, adopted and modified the methodology reported by Omole *et al.* (2013); Abuh *et al.* (2014); and Ihom *et al.* (2012). Consequently, from each of the six (6) prepared clay samples, 2.5g of clay was weighed into each of the (8) measuring cylinders – giving a total of 48 measuring cylinders. In addition 2g of modified starch (Zec) was added separately into a set of 8 measuring cylinders, respectively. However, 7 measuring cylinders were used for the modified starch beneficiation process and the remainder was left as a control to the experiment. Furthermore, de-ionized water was added to these measuring cylinders and each was stirred rigorously (figure 2.1). These beneficiation processes were aimed to identify which of the processes will yield or attain the highest swell volume after 24hrs, 48hrs, and 72hrs. The results were recorded and discussed accordingly.

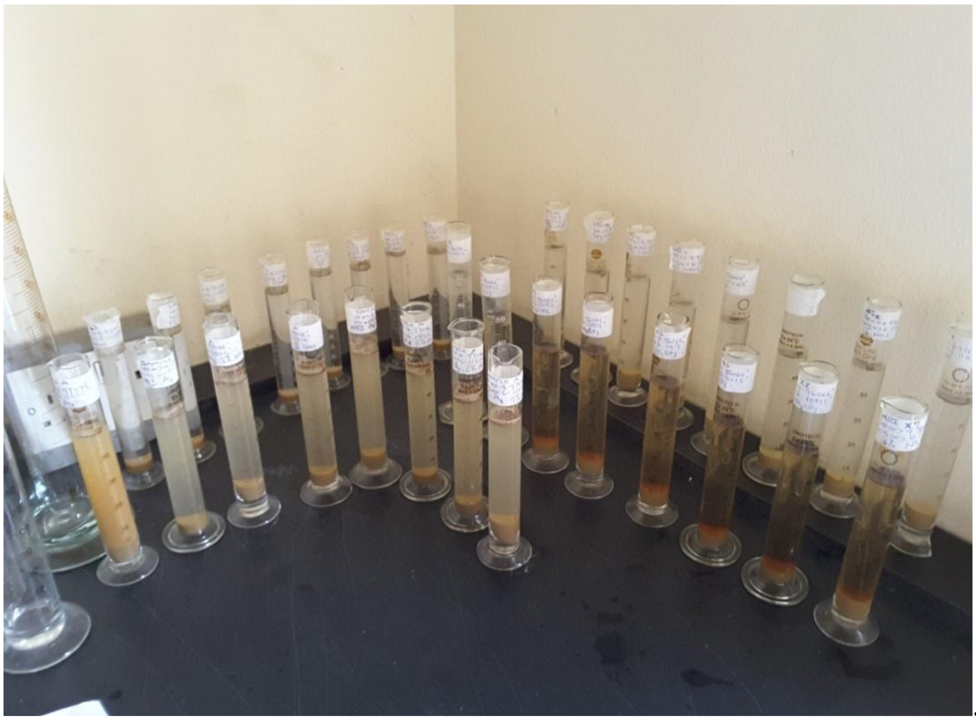.

Figure 2.1: Part of the Experimental Setup of Free swelling volume determination

2.0 Results and Discussion

2.1 Results

The study to determine the swelling volume of clay was carried out and the results obtained are as follows:

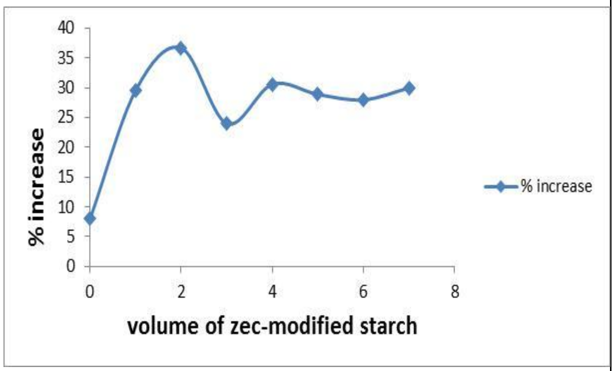

Figure 3.1 **WB1** percentage increase of free swelling volume of clay beneficiated with Zec-modified starch at 24hrs.

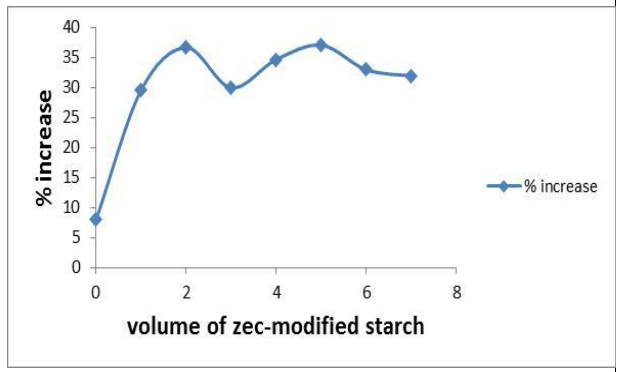

Figure 3.2: **WB1** percentage increase of free swelling volume of clay beneficiated with Zec-modified starch at 48hrs.

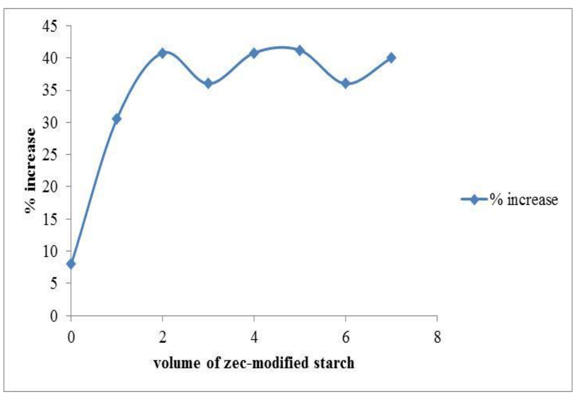

Figure 3.3: **WB1** percentage increase of free swelling volume of clay beneficiated with Zec-modified starch at 72hrs.

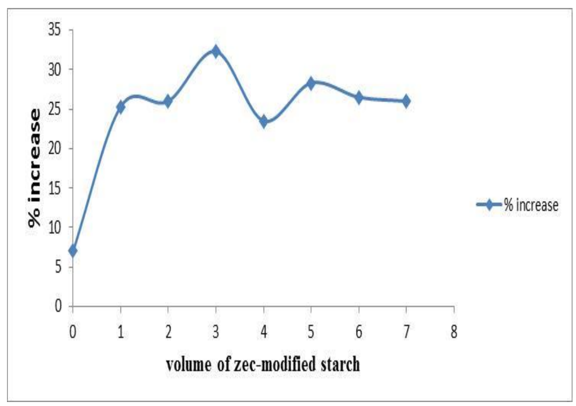

Figure 3.4 **WB2** percentage increase of free swelling volume of clay beneficiated with Zec-modified starch at 24hrs

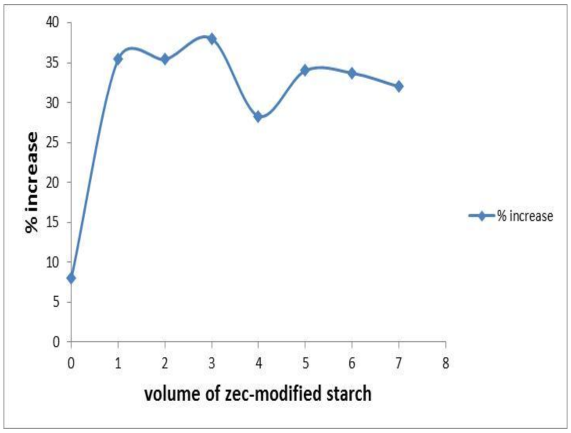

Figure 3.5 **WB2** percentage increase of free swelling volume of clay beneficiated with Zec-modified starch at 48hrs

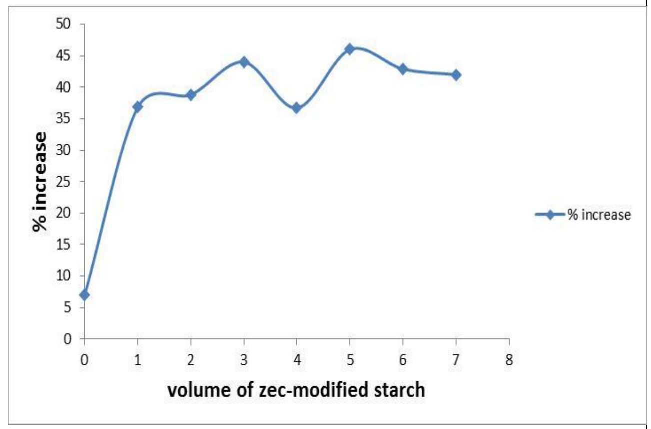

Figure 3.6 **WB2** percentage increase of free swelling volume of clay beneficiated with Zec-modified starch at 72hrs

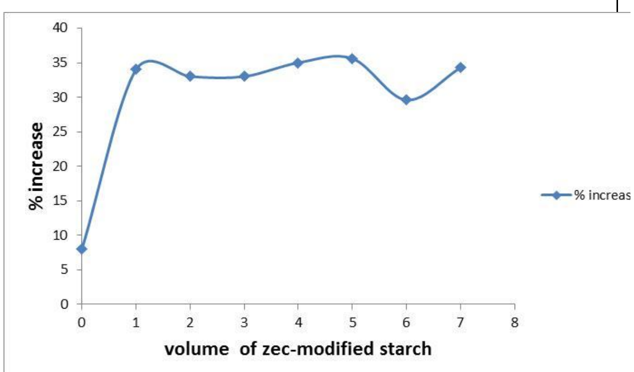

Figure 3.7 **WB3** percentage increase of free swelling volume of clay beneficiated with Zec-modified starch at 24hrs.

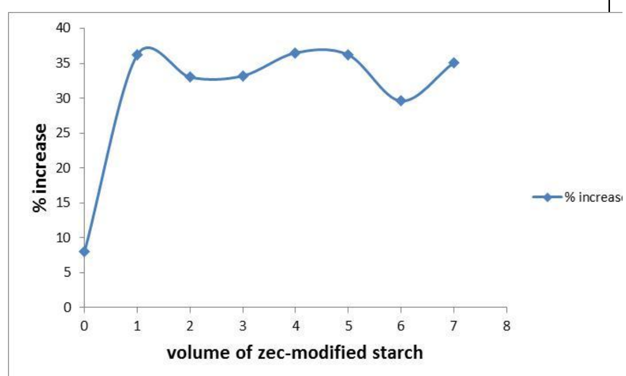

Figure 3.8 **WB3** percentage increase of free swelling volume of clay beneficiated with Zec-modified starch at 48hrs.

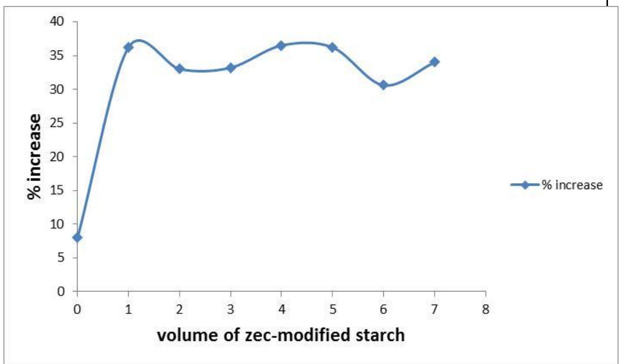

Figure 3.9 **WB3** percentage increase of free swelling volume of clay beneficiated with Zec-modified starch at 72hrs

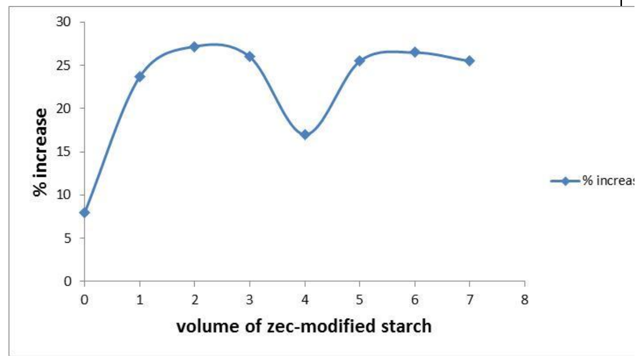

Figure 3.10 **WB4** percentage increase of free swelling volume of clay beneficiated with Zec-modified starch at 24hrs

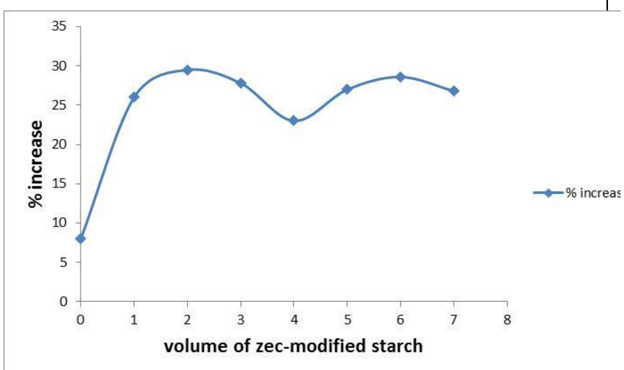

Figure 3.11 **WB4** percentage increase of free swelling volume of clay beneficiated with Zec-modified starch at 48hrs

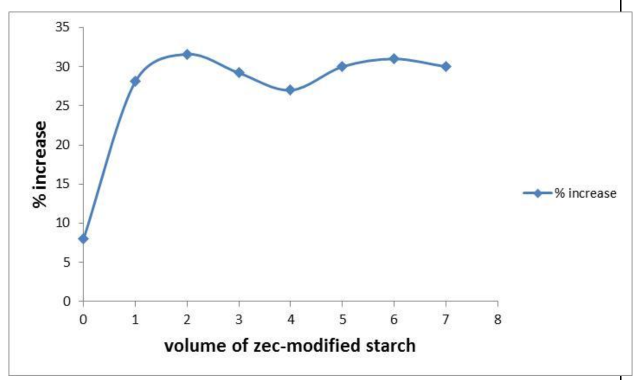

Figure 3.12 **WB4** percentage increase of free swelling volume of clay beneficiated with Zec-modified starch at 72hrs

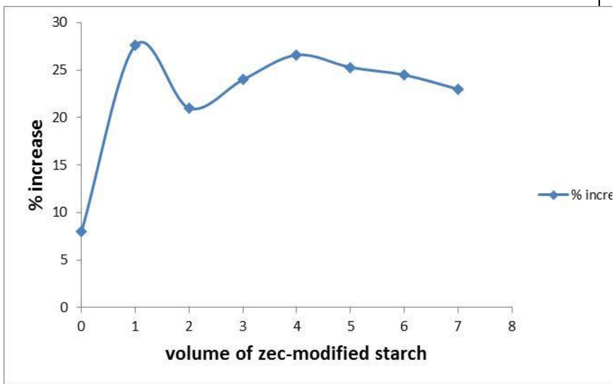

Figure 3.13 **WB5** percentage increase of free swelling volume of clay beneficiated with Zec-modified starch at 24hrs

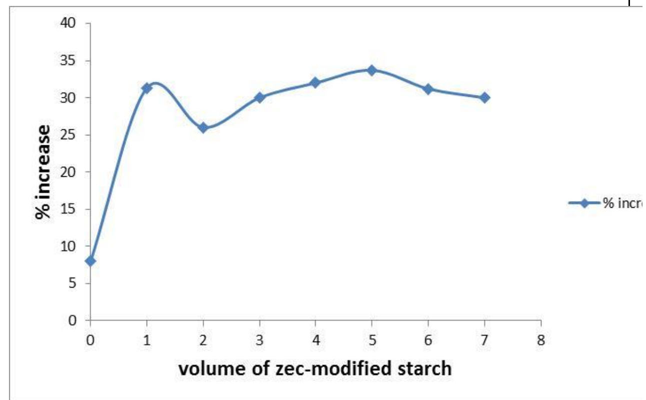

Figure 3.14 **WB5** percentage increase of free swelling volume of clay beneficiated with Zec-modified starch at 48hrs

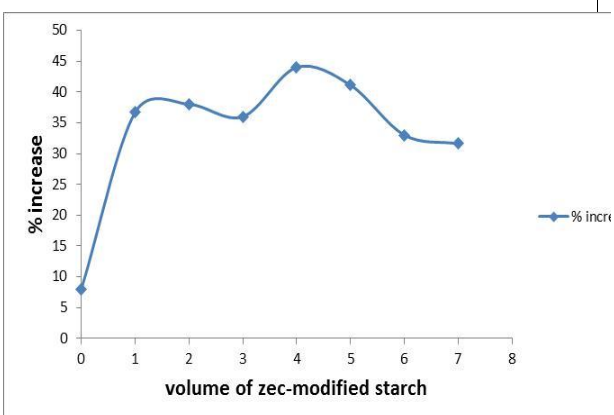

Figure 3.15 **WB5** percentage increase of free swelling volume of clay beneficiated with Zec-modified starch at 72hrs

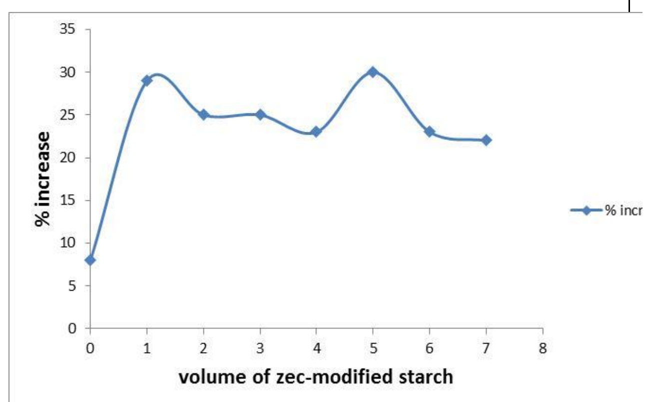

Figure 3.16 **WB6** percentage increase of free swelling volume of clay beneficiated with Zec-modified starch at 24hrs

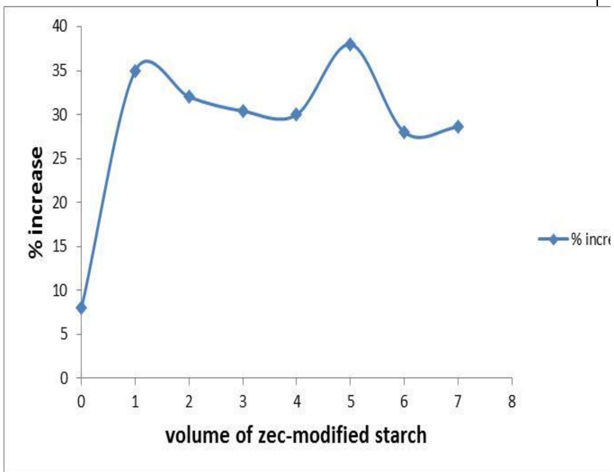

Figure 3.17 **WB6** percentage increase of free swelling volume of clay beneficiated with Zec-modified starch at 48hrs

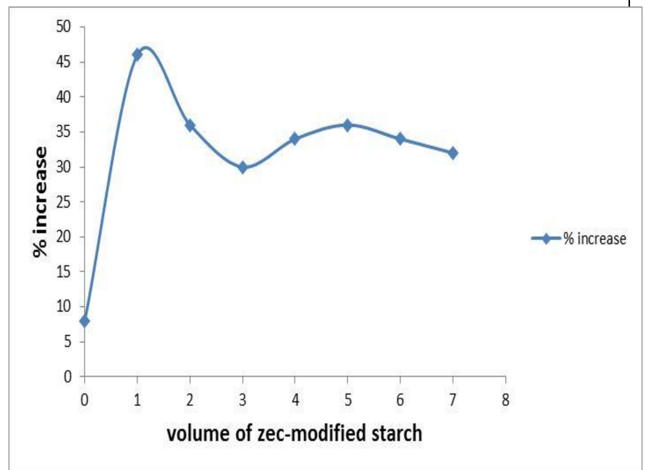

Figure 3.18 **WB6** percentage increase of free swelling volume of clay beneficiated with Zec-modified starch at 72hrs

2.2 Discussion

Figure 3.1 - 3.18 is a graphical representation of the free swelling volume of clay beneficiated with zec-modified starch. Swelling volume of clay samples depends largely on the dominant cation present in the sample. From this experiment, it was observed that the clay samples read no significant swell increase, this can be related to the fact that the clay falls in the kaolinite family of clay. Kaolin is a fine particle size, inert and non-toxic clay that has a high proportion of alumino-silicate like the bentonite clay, although unlike the bentonite clay, it does not have a good swelling ability. However, the clay samples beneficiated with Zec-Modified starch read a high swell increase at all percentages. The increase in volume of the clay samples beneficiated with Zec-Modified starch can be attributed to the fact that starch constituents enhances swelling. Starch is an important constituent in the formulation of drilling fluid as it used to adjust the viscosity of the drilling fluid, which is further used to lubricate the drill head and suspend cuttings during petroleum extraction.

4.0 Conclusion

This research on the experimental study of the swelling volume of local clay has dealt with the meaning of swelling volume and the mechanism by which clay swell. From the experimental results obtained, it could be deduced that:

- The clay samples beneficiated with Zec-modified starch increased significantly at every percentage added.
- The clay samples investigated falls in the kaolinite family. Thus it is suitable for drilling the conductor and surface intervals operations.

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