# Evaluating the Efficiency of Nigerian Local Bentonite as an Extender in Oil Well Cementation

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## ABSTRACT

Nigerian local Bentonite has been in use as an extender in cementing operations since 2003 but has not been widely accepted because of some of its effects and challenges on most of the cement properties. This study is on the experimental and economic evaluation of the effect of Nigerian local bentonite obtained from Awkuzu in Anambra state and the imported bentonite on fresh and salt water cement slurry. The experimental test were basically on the thickening time and the ultrasonic compressive strength. Both local and foreign bentonites proved effective in fresh water cement slurries and can be used interchangeably except in cases where higher Plastic Viscosity (PV) and Yield Point (YP) are required .The foreign bentonite proved more effective under this high rheological properties for the same concentration with the local bentonite . In the salt water cement slurries both local and foreign bentonite were not fully effective, but the local bentonite responded better in the case study design in terms of rheology and free fluid tests. For the economic evaluation, a case study of a project involving the 13 3/8 inch casing cementing operation was simulated using fresh water cement slurry. The foreign bentonite contributed 21% to the overall cement slurry cost while local bentonite contributed 2%.leading to a total savings of $7,509.85. Therefore , local bentonite could be a more efficient and cost effective means of cement slurry extender if properly managed and evaluated.

## INTRODUCTION

Cementing plays a central role in well engineering. Although it occupies just a small portion of the drilling expenditure relative to other well operations, it plays a vital role in well integrity. A poor cementation is sure to significantly impact on the subsequent well performance and the return on investment (ROI). Well cementing is the process of introducing cement to the annular space between the wellbore and casing or to the annular space between two successive casing strings thus effectively sealing the annulus. It is especially important in the Niger Delta which consists of formations which are mostly unconsolidated (Aigbedion and Iyayi, 2007) and require support.

When oil and gas operations began in Nigeria in the early fifties, local additives and clays were used in the preparation of drilling fluids and cement slurries. The introduction of imported commercial bentonite as well as other foreign additives in the year 1960 drastically reduced the use of Nigerian local clay in the petroleum industry (Owolabi et al 1991). This also led to a significant reduction in research into local bentonite clay and other local additives that could have been used in oil and gas operations like drilling, cementing, stimulation and others.

The cement slurry used is a mixture of cement, water and additives. Cement slurries have a very delicate nature and exhibit property changes with slight change in cement composition, water composition or additives in use. The water used in the cementing operation could either be fresh water or salt water depending on the source and salinity. The choice of the type of water used is dependent on a number of factors such as availability, cost, and formation characteristics. Density is a very important parameter in oil well cementing because it translates into the hydrostatic pressure of the slurry. Many additives have been developed to control and meet density requirements. The heavy materials add weight to the slurry to attain higher densities. To lower the density, other additives known as extenders are used. Though extenders work with different mechanism, their general purpose is to reduce slurry density while maintaining slurry stability. With advancing technology, other significant properties which could affect the cement slurry design have been discovered such as rheology, slurry stability, thickening time, compressive strength and more recently, tensile strength. These properties are key to the achieving of the cementing objectives.

Extenders, otherwise known as light-weight additives are used to permit the use of longer columns of cement without formation breakdown and the resulting induced lost circulation, and to reduce the cost of cementing material even where low density is not a requirement (Allen and Roberts, 1982). Several types of materials are used as extenders and they use different mechanisms to achieve their purpose. Extenders used in cement slurry design include sodium silicate, clays, pozzolans (diatomaceous earth, fly ash), silica, commercial light weight cements among others. Clays are however the most commonly used extenders due to their superior swelling characteristics, their availability and lower costs.

Clays are natural, earthy, fine grained materials which exhibit colloidal properties (remain in suspension in fresh water for a long period of time) and varying degrees of plasticity when wet (Bates, 1969**)**. However, clay particles flocculate (clump) and settle quickly in saline water. They are formed from the chemical weathering of igneous and metamorphic rocks. There are three main groups of clay minerals: kaolinite, illite and smectite. Clays majorly used in the industry include bentonite, attapulgite and organophilic clays. Bentonite is the most commonly used clay.

According to Nelson (1990), bentonite use in the petroleum industry can be dated back to 1929. Bentonite also known as gel, is composed primarily of smectite (API 10A, 2010). It contains not less than 85% of the clay mineral montmorillonite. The montmorillonite content of bentonite is the controlling factor in its effectiveness as an extender. Bentonite is classified as sodium bentonite or calcium bentonite, depending on the dominant exchangeable cation. In fresh water, sodium bentonite is more reactive than calcium bentonite. In terms of performance bentonite is classified as “high yield” (Sodium bentonite) or “low yield” (Calcium Bentonite) (Rabia, 2001).

Bentonite works using the water extending mechanism where excess water is added to the cement. When placed in water, it absorbs the water and expands several times its original volume fold by swelling forming a thixotropic, gelatinous substance. This makes it very effective as a viscosifier in drilling muds and as an extender in cement slurries. Bentonite has primary, secondary and synergistic effects on the cement slurry. It affects slurry yield, density, rheology, thickening time, compressive strength and stability. Its synergistic effects are mostly seen in the presence of salt where it flocculates and becomes ineffective. It is majorly used in lead slurries where the cement to water ratio is low. It could be used in tail slurries when low density is required due to low fracture gradient of formation but is generally not preferred due to its effect on compressive strength.

Bentonite is majorly used with fresh water slurries as its effectiveness reduces in the presence of salts; this is because salt inhibits its hydration thus reducing slurry yield. This greatly limits the use of bentonite extended cement slurries in offshore operations especially where salt domes are encountered. There are two standard procedures for preparing extended salt water slurries. The first is the use of attapulgite clay while the other is by firstly pre-hydrating bentonite with fresh water before using it with salt water. Research has shown that aside from these two standard procedures, a method of directly hydrating bentonite with readily available salt water and still attaining maximum yield exists (Pabley, 1985). The salt water bentonite invention is comprised of bentonite clay, a caustic agent (preferably caustic soda, NaOH) and a filtration control agent such as starch or carboxymethyl cellulose, CMC.

Since the discovery of the beneficial properties of bentonite in the oil industry, the use of Wyoming bentonite has become the “standard”. In recent times though, commercial quantities of bentonite clay deposits have been discovered in several towns in Nigeria. Modest estimate of the bentonite clay reserves in Nigeria by Aigbedion and Iyayi (2007) place the reserve at 166.9 million metric tons. For just this reason and due to the vast resources employed in the importation of foreign bentonite, the Federal Government placed an embargo on the importation of foreign bentonite in 2003 and mandated that locally sourced bentonite be used.

As a result, there has been increased research into the possibility of using Nigerian local bentonite as a substitute for the imported clays in oil well operations while still maintaining the standards of the oil industry. Clays obtained from deposits around the country have been tested in an attempt to find a clay that meets API specification.

Most of the local clays tested generally have proven to be Calcium based and did not meet with API rheological values; some possessed standard properties of their own before beneficiation while others did not. However, they can be beneficiated using additives to improve performance. The industry is however yet to gain full confidence in the local bentonite and most companies are still clamoring for the ban to be waived, while some companies go as far as smuggling in the foreign products into the country. If local bentonite can be proven to be more effective than imported ones or treated to attain a similar effect, the over dependence on imported bentonite by the oil industry will be reduced. This will go a long way in reducing the large sum of money spent on importation of foreign reserves thereby boosting the country's economy.

## MATERIALS AND METHODS

The local bentonite used for this study was a non treated bentonite sourced from a company that deals in its supply. It was originally sourced from a location in Awkuzu town in Oyi local government area of Anambra State, Nigeria. The town is located on 6.234 longitude and 6.943 latitude. The foreign bentonite used was gotten from a multinational company in Rivers State. Whether it was chemically treated during processing prior to importation into the country or not remains unknown. On physical examination both bentonite clays were found to be smooth to touch and formed a smooth paste when they came in contact with water. Differences were however observed in their colour; the locally sourced bentonite was light brown while the foreign bentonite was closer to tan. The sea water used in the study was sourced from an offshore location 120km southwest of the Niger Delta. The salinity of the water in that area is generally accepted to be between 34,000-35,000ppm (UNEP, 1984).

Four cement slurry samples were designed and labeled using the following notation: **BCSFW-F:** Bentonite Cement Slurry in Fresh Water- Foreign, **BCSFW-L:** Bentonite Cement Slurry in Fresh Water- Local, **BCSSW-F:** Bentonite Cement Slurry in Sea Water- Foreign, **BCSSW-L:** Bentonite Cement Slurry in Sea Water- Local.

BCSFW-F and BCSFW-L had exactly the same design with respect to temperature, pressure and additive concentration used with the only variable being the type of bentonite. The same applied to BCSSW-F and BCSSW-L.

In fresh water design (BCSFW), 4.94grams of bentonite was mixed with 473.76grams of water. The mixture was left to stand for 30mins in accordance with API specification to allow for hydration of bentonite After pre-hydration, 1.11grams of defoamer was added to the mixture after which 373.58grams of cement was added to the slurry. Samples obtained were observed to have sufficiently yielded and were seen to be uniform with no irregularities.

Additives were measured using an electronic weighing balance and mixed using a Constant Speed Mixer in conformity with API specifications as stated in API 10B.

As a control, bentonite was used with sea water using the formulation for the fresh water design. The bentonite particles immediately flocculated and totally separated from the water as expected leading to no yield. In salt water design (BCSSW), the same procedure of pre-hydrating bentonite and subsequent addition and mixing of other additives was applied. However a novel design invented by Pabley (1985) was used. Hence there was a slight variation in its preparation. 15.84grams of bentonite was mixed with mix water containing 0.99grams of NaOH, 5.28grams of CMC and 488.34grams of sea water and then allowed to hydrate for 30mins. The mixing order used was addition of NaOH pellets to the sea water, followed by CMC and then bentonite. After pre-hydration, 1.05grams of defoamer and 351.93grams of cement were added to the mixture and mixed in conformance to API standards. Samples obtained were very viscous and had to be mixed for more than 35secs to obtain a uniform slurry. BCSSW-L was observed to be more viscous than BCSSW-F.

The test conditions for all four samples were Bottom Hole Circulating Temperature (BHCT) of $150^0$F, Bottom Hole Static Temperature (BHST) of $180^0$F, test pressure of 2500psi and True Vertical Depth (TVD) of 4400ft.

The properties analyzed in this study were slurry yield, density, rheology, free fluid, thickening time and compressive strength

The slurry yield of samples was calculated using the equations below as given in Norton (2002).

*Slurry yield, cuft =* *slurry volume, [gal/sk]/ 7.48 [gal/ft3] ………………… (1)*

*Slurry volume, gal/sk =* *94lb/ (S.G* $_{cement}$ ** 8.33lb/gal)*

*+ Weight of additive, lb/ (S.G* $_{additive}$ ** 8.33lb/gal)*

*+ water volume, gal. ……………….……………….……… (2)*

*Weight of additive (lb/sk) =* *quantity, gal/sk / absolute volume, gal/lb ……………… (3)*

*Weight of additive (lb/sk) = quantity, %bwoc * 94 ……………….………………… ……(4)*

*Where S.G = Specific Gravity;* $S.G_{cement} = 3.14$

Slurry density was then calculated using the following formula:

*Slurry Density* = (94 + weight of additive(s) + (8.33 * volume of water))/volume of slurry, gal/sk ………………………………………………………………………………*(5)* The density of all four samples was also determined using an API pressurized mud balance as per recommendations in API 10A, 2010.

The rheology test was done to characterize the rheological behaviour of the cement samples. A 12-speed Rotational Viscometer was used according to API specifications (API 10A, 2010) and the test was done at both ambient and test temperatures. This is because temperature largely affects the rheology of cement slurry either by thinning it or stabilizing it. In preparing samples for rheology tests, samples were pre-hydrated for 2 hours before mixing as opposed to the previously mentioned method. This was in conformance with API recommendations. The test was then run at ambient temperature after which the samples were conditioned to BHCT using an API atmospheric consistometer and the test was repeated again. According to API, a ratio of ramp-up and ramp-down reading at each speed of value higher than 1 indicates settling of slurry, lower than 1 indicates gelling of slurry and a value close to 1 indicates a non-settling time-independent slurry. Values of Plastic Viscosity and Yield point were computed at both ambient and test temperatures using the following formulas:

*Plastic Viscosity, PV (cp)* = (300rpm-100rpm) * 1.5 ………… ………..…. (6)

*Yield Point, YP (lbs/100ft2)* = PV- 100rpm ………………..………………. (7)

*The 600 rpm reading was not taken because at such high shear rate (above 511s$^{-1}$), cement slurries have been reported to generate inconsistent results (API, 2010)*

The free fluid test was performed in a 250ml glass measuring cylinder at BHST. Freshly prepared BCSFW-F was conditioned to test temperature using an API atmospheric consistometer. It was then poured into the cylinder and sealed with an elastic band to prevent evaporation. The test was allowed to stand for 2 hours after which the free fluid was measured using a syringe. The value obtained was read and recorded. It was then expressed as a percent of the volume of slurry used. The amount of free fluid is a measure of the slurry stability. Slurry stability is of prime importance in preventing annular flow. Generally the acceptable industry free fluid value is less than 1% (Baker Hughes Incorporated [BHI], 2010) while that of API is less than 5.9%. The same procedure was repeated for the remaining samples- BCSFW-L, BCSSW-F and BCSSW-L.

The thickening time test was performed using a HPHT Consistometer at BHCT and test pressure. Wellbore conditions were simulated using API recommended Hydrocarbon oil. The test was set up as per API recommendations and was closely monitored for the pump time, thickening time and setting time; 40Bc, 70Bc and 100Bc. Thickening time provides the length of time that the cement will remain pumpable under conditions of temperature and pressure.

The compressive strength of the samples was measured using an Ultrasonic Cement Analyzer (UCA) which employs the non destructive method of testing. The test was run at BHST and 3000psi. Placement conditions were simulated using water. Freshly prepared samples were poured into the slurry cup and the test was set as per API recommendations. The test was run for 24hours with values of compressive strength at 8, 12 and 24 hours recorded. Acceptable compressive strength value required to support the casing ranges from 5-200 psi (API, 2010).

Once it was ascertained by laboratory testing that the project was physically feasible, the economic feasibility was then determined. The economic analysis involved a cost analysis of a single project using two alternatives; alternative 1 being local bentonite use while alternative 2 was foreign bentonite use. The project involved cementing a 13 3/8 casing of a simulated Well XYZ North-1 using lead and tail slurries. The lead slurry was the object of concern in the analysis. A Microsoft Excel model was designed to calculate the volume (cubic feet) of cement slurry required to seal off the annulus. The cost of lead slurry for both cases was calculated and the effect of local or foreign bentonite on the overall project cost was analyzed.

## RESULTS

The results obtained for each sample were presented in tables and interpreted graphically. The analyses of results from the experimental tests carried out were based on comparative interpretations and graphical correlations on the behavior of the samples at both ambient and test temperatures. The effectiveness of bentonite on the slurry properties of samples was evaluated on the basis of API specifications and industry accepted standards.

The slurry yield of samples was calculated using Eq. (1) to (4). The slurry yield gotten for BCSFW-F and BCSFW-L was identical as they had exactly the same formulation and the specific gravity of both bentonites used was the same. The slurry yield obtained for fresh water slurries was 2.419cuft/sk.

Slurry yield for BCSSW-F and BCSSW-L were the same also due to identical S.G of local and foreign bentonite. The slurry yield obtained for salt water slurries was 2.567cuft/sk.

Density of the samples was calculated using (5).

Density = (94 + weight of additive(s) + (8.33* volume of water/sk))/volume of slurry, gal/sk.

For fresh water slurries, BCSFW-F/ BCSFW-L:

Weight of additives = 3.76 + 0.28 (lb/sk)
= 4.04 lb/sk

Volume of water = 14.29 gal/sk.

**Density** **= (94 + 4.04 + (8.33*14.29))/ 18.094**
**= 11.997ppg**

For salt water slurries, BCSSW-F/ BCSSW-L:

Weight of additives = 4.23 + 0.28 +1.41 +0.263 (lb/sk)
= 6.183 lb/sk

Volume of water = 15.25 gal/sk.

**Density** **= (94 + 6.183 + (8.33*15.25))/ 19.203**
**= 11.832ppg**

Results obtained from pressurized mud balance for the samples were in the range of 11.8ppg-12.2ppg which was within acceptable range of calculated density.

Data obtained from the experiment showed that the samples BCSFW-F, BCSFW-L, BCSSW-F and BCSSW-L exhibited some degree of variance in their rheological properties. Based on API recommendations for interpretation of rheology measurements, it was seen that the ratio of ramp-up reading to ramp-down reading for both BCSFW-F and BCSFW-L were close to 1. This indicates that they are both non-settling, time independent slurries. It can also been seen from Table 1a that BCSFW-F stabilized more at increased temperatures.

It was also observed that BCSFW-F had higher values of PV and YP than BCSFW-L. Therefore in cases where high plastic viscosity and yield points are required, BCSFW-F may be a better option. The two slurries also had good gel strength with the 10mins gel strength being greater than the 10secs gel strength.

**Table 1: Rheology and Gel Strength values for samples**
**(a) BCSFW-F and BCSFW-L**

| | | RHEOLOGY | | | | | | | | | | | | | | GEL STRENGTH | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Dial reading@80$^{0}$F | | | | | Dial reading@150$^{0}$F | | | | | PV@80F | YP@80F | PV@150F | YP@150F | 10s Gel, 80F | 10mins Gel, 80F | 10s Gel, 150F | 10min Gel,150F |
| | | 300 | 200 | 100 | 6 | 3 | 300 | 200 | 100 | 6 | 3 | | | | | | | | |
| **BCSFW-F** | RAMP-UP | 44 | 41 | 36 | 20 | 9 | 91 | 85 | 72 | 15 | 14 | | | | | | | | |
| | RAMP-DOWN | 45 | 42 | 37 | 17 | 10 | 89 | 85 | 79 | 20 | 13 | | | | | | | | |
| | **RATIO** | **0.98** | **0.98** | **0.97** | **1.18** | **0.90** | **1.02** | **1.00** | **0.91** | **0.75** | **1.08** | | | | | | | | |
| | AVG | 44.5 | 41.5 | 36.5 | 18.5 | 9.5 | 90.0 | 85.0 | 75.5 | 17.5 | 13.5 | 12.0 | 32.5 | 21.8 | 68.3 | 8.0 | 10.0 | 11.0 | 14.0 |
| **BCSFW-L** | RAMP-UP | 46 | 43 | 39 | 9 | 6 | 52 | 50 | 45 | 8 | 8 | | | | | | | | |
| | RAMP-DOWN | 46 | 43 | 40 | 13 | 7 | 52 | 49 | 45 | 8 | 7 | | | | | | | | |
| | **RATIO** | **1.00** | **1.00** | **0.98** | **0.69** | **0.86** | **1.00** | **1.02** | **1.00** | **1.00** | **1.14** | | | | | | | | |
| | AVG | 46.0 | 43.0 | 39.5 | 11.0 | 6.5 | 52.0 | 49.5 | 45.0 | 8.0 | 7.5 | 9.8 | 36.3 | 10.5 | 41.5 | 7.0 | 9.0 | 6.0 | 10.0 |

**(b) BCSSW-F and BCSSW-L**

| | | RHEOLOGY | | | | | | | | | | | | | | GEL STRENGTH | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Dial reading@80$^0$F | | | | | Dial reading@150$^0$F | | | | | PV@80F | YP@80F | PV@150F | YP@150F | 10s Gel, 80F | 10mins Gel, 80F | 10s Gel, 150F | 10min Gel,150F |
| | | 300 | 200 | 100 | 6 | 3 | 300 | 200 | 100 | 6 | 3 | | | | | | | | |
| **BCSSW-F** | RAMP-UP | 54 | 41 | 26 | 7 | 4 | 20 | 13 | 6 | 2 | 1 | | | | | | | | |
| | RAMP-DOWN | 51 | 36 | 21 | 4 | 3 | 14 | 11 | 7 | 1 | 1 | | | | | | | | |
| | **RATIO** | **1.06** | **1.14** | **1.24** | **1.75** | **1.33** | **1.43** | **1.18** | **0.86** | **2.00** | **1.00** | | | | | | | | |
| | AVG | 52.5 | 38.5 | 23.5 | 5.5 | 3.5 | 17.0 | 12.0 | 6.5 | 1.5 | 1.0 | 43.5 | 9.0 | 15.8 | 1.3 | 3.0 | 8.0 | 2.0 | 5.0 |
| **BCSSW-L** | RAMP-UP | 111 | 86 | 55 | 10 | 9 | 53 | 43 | 30 | 6 | 5 | | | | | | | | |
| | RAMP-DOWN | 110 | 84 | 52 | 10 | 7 | 51 | 40 | 24 | 5 | 4 | | | | | | | | |
| | **RATIO** | **1.01** | **1.02** | **1.06** | **1.00** | **1.29** | **1.04** | **1.08** | **1.25** | **1.20** | **1.25** | | | | | | | | |
| | AVG | 110.5 | 85.0 | 53.5 | 10.0 | 8.0 | 52.0 | 41.5 | 27.0 | 5.5 | 4.5 | 85.5 | 25.0 | 37.5 | 14.5 | 9.0 | 29.0 | 4.0 | 11.0 |

BCSSW-F proved to be a slurry prone to high settling as indicated by ramp-up and ramp-down ratios that were higher than 1 while BCSSW-L was observed to have ramp-up and ramp-down ratios that were close to 1 at ambient but at test temperature there was a slight variation in the ratios. This indicates that it is a stable slurry with a slight tendency to settle. Also dial readings for BCSSW-F and BCSSW-L at test temperature were significantly lower than those at ambient, indicating that the slurry thinned with increase in temperature. This is clearly illustrated in Table 1b.

The acceptable industry standard for free water in lead slurries is 1% - 1.5% maximum. However, API specification allows for free water of 5.9% maximum (API 10A Clause 8.5, 2010). From Fig. 2, it was deduced that BCSFW-F was a very stable slurry, it had excellent free water and met with both API specification and Industry standards. It was observed that BCSFW-L did not meet with Industry standards for lead slurry but met with API specifications. The slurry was however noticed to be otherwise stable with little or no settling

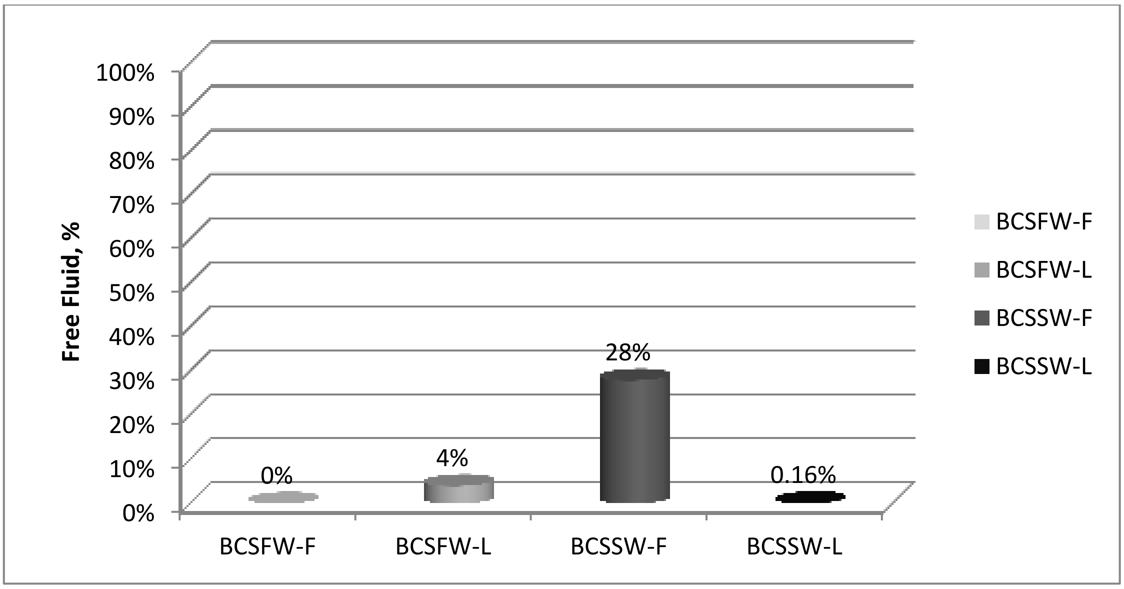


**Fig 2: %Free fluid of samples, BCSFW & BCSSSW**

BCSSW-F was found to be a very unstable slurry. On conditioning to BHST it appeared thinner. From Fig. 2, it can be seen that free water greatly exceeded both API specification and Industry standards.

BCSSW-L on the other hand met with both API specifications and Industry. It was also observed to be stable although it thinned slightly after conditioning.

From Fig. 3, it was observed that BCSFW-F had an accelerating effect on the thickening time while BCSFW-L had a retarding effect. Both samples were observed to form a good cement sheath at 100Bc. From this it can be deduced that the two samples are valid depending on the length of thickening time required. Retarders or accelerators could also be added to tailor the thickening time as required.

It has however been noticed that except in special cases, longer thickening times are required for lead slurries which is the type of slurry under investigation. It can thus be inferred that BCSFW-L might actually be preferred over BCSFW-F with respect to thickening times.

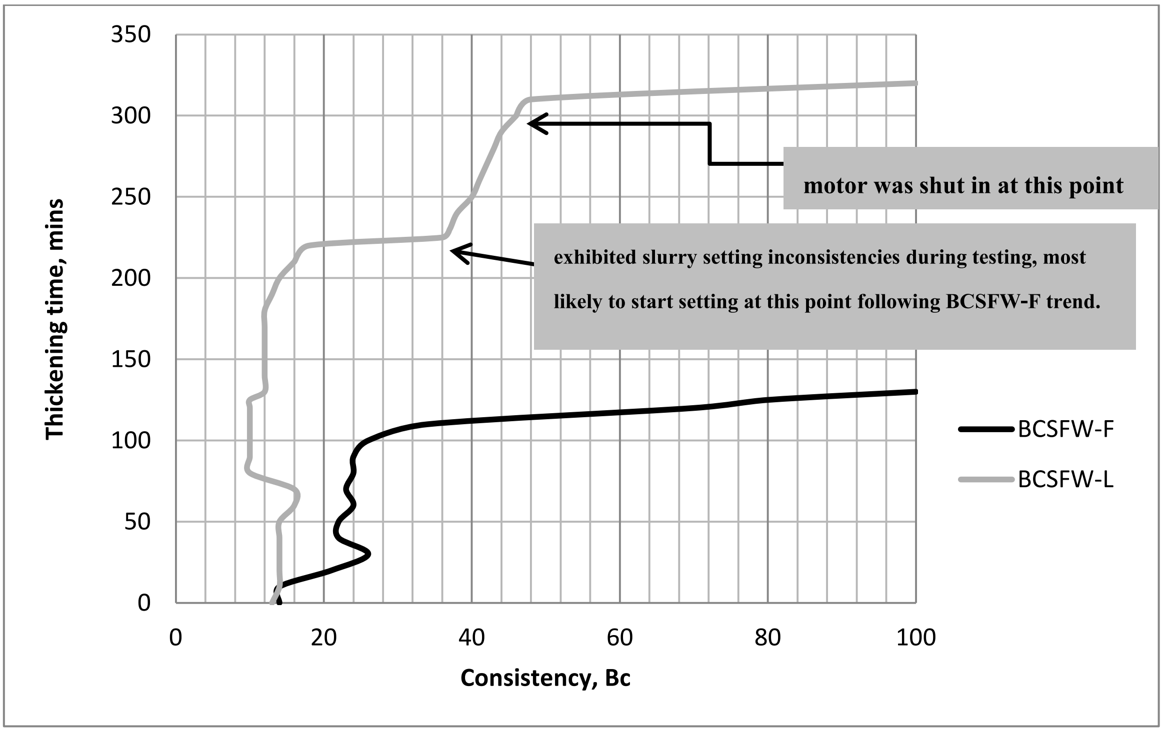


**Fig. 3: Thickening times of BCSFW-F and BCSFW-L**

A challenge encountered in the testing of BCSFW-L was that the slurry exhibited some inconsistencies during testing. It was observed that part of the cement set around the paddle while some part remained liquid in the consistometer cup leading to inaccurate results as illustrated in Fig. 3. On further research, it was discovered that this slurry inconsistency occurs only in testing and not in actual field jobs. It however might still prove to be problematic as accurate results cannot be predicted from lab tests.

Both BCSSW-F and BCSSW-L did not attain thickening time after extended time and had to be shut down. It was observed that the slurries were still very liquid exhibiting no signs of setting. None of the required parameters; 40Bc, 70Bc and 100Bc were attained. It was also observed from their compressive strength test that both samples did not set after 24hours. At surface temperatures, the two samples were observed to set hard; it however took a very long time. BCSSW-F set at about 39hours while BCSSW-L set at about 28hours. On setting it was observed that BCSSW-F had a lot of free water and worm holes in the cement sheath. This could prove problematic in field operations especially where special wellbore conditions like gas migration exist. This phenomenon was not observed in BCSSW-L.

It was suspected that the excessive retardation was caused by the presence of some additives which effect retardation; CMC is a known retarder and sea water is known to retard cement slurries at high concentrations. It was also observed that temperature significantly affected the thickening times of samples and this was attributed to the slurry thinning of slurries noticed at higher temperatures.

Whilst desirable results were not achieved as compared to fresh water slurries, it was observed that BCSSW-L reacted better to the design than BCSSW-F. It is possible then that with further research desirable results could be attained.

The acceptable compressive strength required to support a casing is 50-200psi. Except in special cases, the primary function of a lead slurry in a well is to support the casing. Results from compressive strength tests indicated that both BCSFW-F and BCSFW-L attained good compressive strength after 24 hours as expected from Bentonite extended cement slurries. It was however noticed that BCSFW-L had slightly better compressive strength than BCSFW-F.

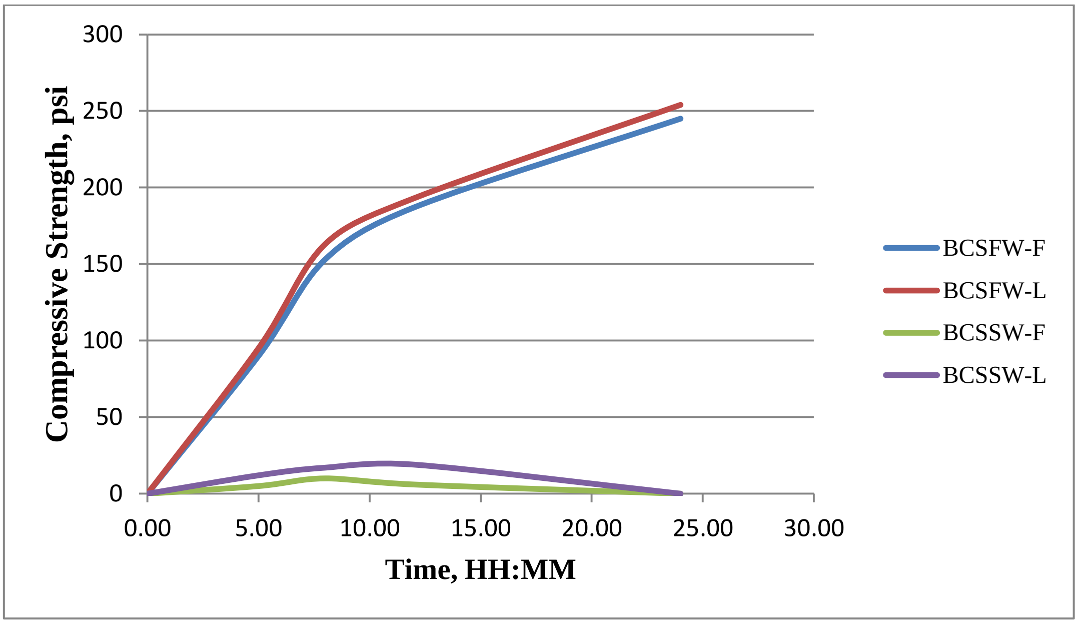


**Fig. 4: Compressive Strength of BCSFW-F, BCSFW-L BCSSW-F & BCSSW-L**

Results obtained for BCSSW-F and BCSSW-L were less than desirable. In the early phase of testing both samples built slight compressive strengths but as the tests proceeded, they lost strength and attained 0psi after 24hours. This was not surprising as it was observed during thickening time tests that the sample did not set after 24hours. Significant compressive strength starts to build from thickening time after slurry has set hence the poor results.

An economic analysis was done only for fresh water slurries as bentonite use in sea water was deemed physically infeasible within the scope of this work. It involved determining the cost of two different alternatives in executing a single project and comparing them to ascertain the most cost-effective option. Project XYZ was taken as a case study.

**Project XYZ: Cementation of 13 3/8 casing for Well XYZ North-1 using lead and tail slurries.**

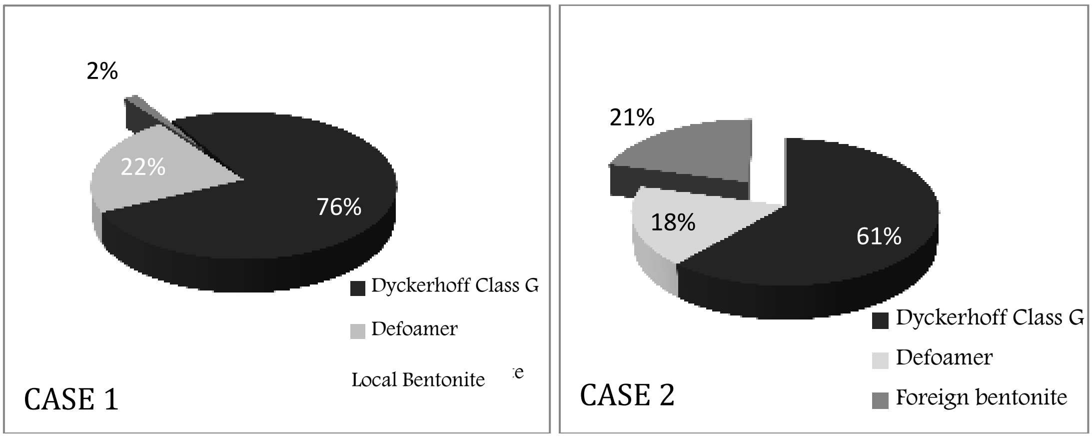
**Case 1** involved the use of local bentonite in preparation of the lead cement slurry for Project XYZ while **Case 2** involved the use of foreign bentonite. A simple cost analysis was carried out; results obtained are presented below.

| Ref | Products | Quantity/Well | Unit Price | Total Cost | Total Wells |
|---|---|---|---|---|---|
| sxs | Dyckerhoff Class G | 1240.56 | $ 19.20 | $ 23,818.75 | $ 23,818.75 |
| gal | Defoamer | 49.62 | $ 139.80 | $ 6,936.88 | $ 6,936.88 |
| lbs | Local Bentonite | 4664.5 | $ 0.11 | $ 513.10 | $ 513.10 |
| lbs | Foeign Bentonite | 4664.5 | $ 1.72 | $ 8,022.94 | $ 8,022.94 |
| | | | **Total Project Cost for Case 1:** | **$ 31,268.72** | **$ 31,268.72** |
| | | | **Total Project Cost for Case 2:** | **$ 38,778.57** | **$ 38,778.57** |

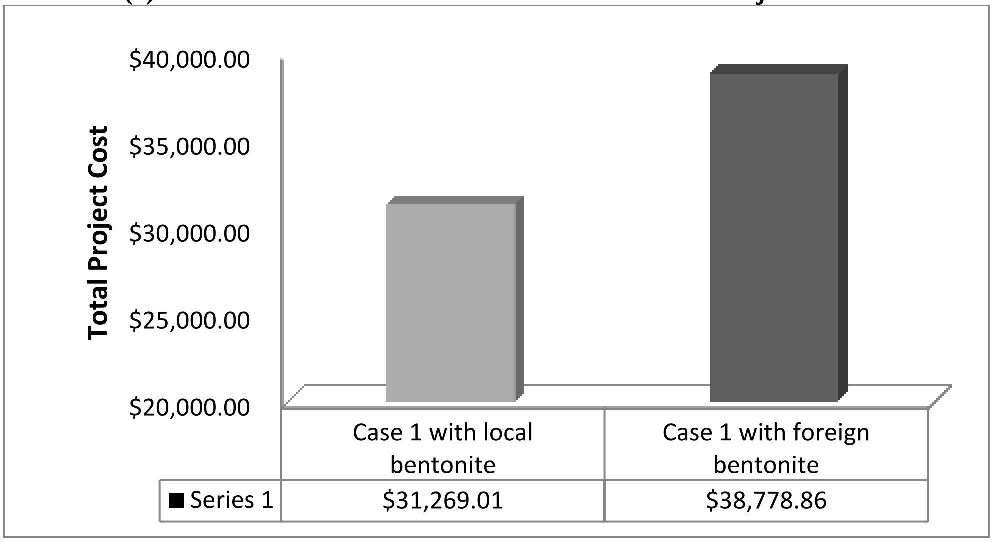
**Table 2: Cost of Case 1 and Case 2 for Project XYZ**

*N/B: (i) The cost of locally sourced non-treated bentonite was determined directly from a Bentonite company in Rivers state to be #2000 per 50kg. An average dollar-naira exchange rate of $1=#162.5 was used. (ii) The cost of foreign bentonite was determined directly from a Multinational servicing company in Rivers state.*

As can be observed from Table 2, all conditions were the same for both cases with bentonite cost being the only variable.



**(a) Contribution of Bentonite cost to Overall cost of Project XYZ.**



**(b) Total Cost of Project XYZ for Case 1 and Case 2**

**Fig. 5: Cost Analysis of Case 1 and 2 of Project XYZ**

It is observed from Fig. 5a that while local bentonite contributed just 2% to the overall cost of Project XYZ, foreign bentonite contributed 21%. If case 2 is executed then, it is likely to require a larger investment. This largely defeats the goal of oil and gas operations which is “to maximize profit by effectively and economically producing oil and gas”.

Fig. 5b also indicates that Case 1 will be more economical than case 2 with a total savings of $7,509.85. This points to the fact that local bentonite will minimize the cost of executing Project XYZ. However certain factors still need to be put into consideration. Results obtained in experimental and economical analysis were then correlated to make a decision.

Both BCSFW-F and BCSFW-L proved effective in cementation, a slight variation was observed in their effects on cement slurries. While slurry yield, density, compressive strength and free fluid were almost identical there was a difference in their effect on rheology, gel strengths and thickening time with the latter being the most significant. Foreign bentonite was observed to accelerate the thickening time while local bentonite was shown to retard it. This indicates that if a cement slurry with long thickening time is required local bentonite is a more cost-effective option. This happens to be the case more often than not. Also the difference in the overall project cost was $7,509.85; this is sufficient to cover for the accelerator cost which might be incurred if shorter thickening times are required.

If a more stable slurry is required, foreign bentonite might be a better option; but again the excess cost of $7,509.85 is most likely sufficient to cover the cost of stabilizing the slurry; either by increasing the concentration of local bentonite used or adding some other additives. After considering all these factors, it is safe to say that Case 1 is a more cost effective option for executing Project XYZ and local bentonite is a better option for extending fresh water lead cement slurries. Generally, BCSSW-F and BCSSW-L did not give desirable results. BCSSW-F did not respond favourably to the new design. However, BCSSW-L was shown to respond better; free fluid values and rheological values were in the acceptable range.

For salt water slurries, while they both exhibited limitations in properties like thickening time and compressive strength, it was observed that local bentonite responded better to the design than foreign bentonite. This was clearly seen in free fluid tests and rheology tests. It was also observed that the salt water slurries were sensitive to temperature as indicated by their thinning at higher temperatures. It can be deduced then that local bentonite use in salt water slurries is possible but further research must be done to perfect the design.

## DISCUSSION

Bentonite is one of the most widely used additives in cementing operations. It serves a number of important functions such as density reduction, slurry yield increase among others, its most important function however seems to be its reduction of the overall cementing operation cost. While Nigerian local bentonite is now in use in the oil and gas industry, its effect on cement properties have not been properly studied and modeled leading to a low level of confidence in it as opposed to imported ones. This research work is an attempt to evaluate both local and foreign bentonite so as to better characterize their effects on necessary cement properties. This study shows that while both local and foreign bentonite can be effectively used in fresh water cementing operations as both samples complied with either API specifications or Industry standards or both, the use of local bentonite is preferable as it is more cost effective in most cases. In few cases however; cases of higher PV and YP requirement and shorter thickening time requirement, foreign bentonite seems to be a better option. This is consistent with previous research on the subject matter. Nonetheless, these properties can still be tailored to operational requirement at a more economical rate by varying the local bentonite concentration or redesigning the slurry. It is therefore recommended that for a more economic primary cementing job, local bentonite should be used for extending fresh water cement slurries in place of the more traditional approach of foreign bentonite use.

The study also indicated that bentonite could be used directly in preparing salt water cement slurries; a phenomenon that has been deemed impossible for many years now. While the results obtained from salt water cement slurries were not fully desirable, there was significant improvement in some properties like rheology and free fluid especially in the local bentonite design. This strongly indicates that it is quite possible to use Nigerian local bentonite in salt water slurries and with further research, the technology could be perfected. Its use is however deemed infeasible within this scope of this work because of the excessive thickening time, slurry instability, slurry thinning at high temperatures and poor compressive strength development observed. It is recommended that the thinning effect of temperature should be further studied and properly modeled.

It must also be put into consideration that imported bentonite which is so much depended on has been in existence for a very long time and perfected over countless number of research. It therefore means that if the current trend of research into local content is kept up, in a short time, local Nigerian bentonite could become the champion of the Oil and Gas Industry. This would prove to be a profitable venture for both the oil and gas industry and the Nigerian populace. A win-win situation for all parties involved.

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