Petroleum and Coal

Article Open Access

USE OF IRON GUM CLAY AS LOCAL ADDITIVE IN OIL WELL CEMENT

F. A. Afolabi, G. Chukwu, P. J. Wakawa, S. G. Udeagbara*

Department of Chemical and Petroleum Engineering, Afe Babalola University, Ado Ekiti, Nigeria

Received March 25, 2019; Accepted June 13, 2019

Abstract

A good cementing job helps in upholding well integrity, which is the main function of cement slurry design. Most additives used in preparing cement slurries in Nigeria are imported synthetic materials which are expensive and usually not environmental-friendly. This research work focused on testing a local material, Iron gum clay, which has the potential to substitute industrially used additives. Cement slurries prepared with the local clay and their resultant core samples were subjected to five major integrity checks, and their performances were compared to industry standard additives. From the results, the local earth material gave a good match to industry synthetic additives in terms of compressive strength and fluid loss control properties. Comparing the design to a field case, it is concluded that iron gum clay will be a suitable cement additive for deep and ultra-deep wells.

Keywords: *Iron gum clay; Cement; Additives; Slurry design; Well integrity.*

1. Introduction

Cementing in the oil and gas industry is the process of mixing a slurry of cement, cement additives and water, and pumping it down through casing to critical points in the annulus around the casing or in the open hole below the casing string, holding it in place and to prevent fluid migration from subsurface formations. Primary cementing is the operation performed immediately after the casing is run downhole providing zonal isolation, protection and support as soon as it sets. Remedial cementing correct problems associated with the primary cement job. The most successful and economical approach to remedial cementing is to avoid it by thoroughly planning, designing, and executing all drilling, primary cementing, and completion operations. Before any type of cementing job is undertaken, be it regular or squeeze, information must be obtained, and choices must be made as regards the types of well fluids to be used, the bottom hole static temperature which affects the setting time of the cement and the type of cement to be used. A cement job can be considered a failure if the cement does not fill the annulus to the required height, provide a good seal at the casing shoe and if it does not isolate undesirable zones. When any such failures occur, some remedial work must be carried out. Common methods assessing the effectiveness of cement jobs are Temperature surveys, radioactive surveys and Cement bond logs (CBL).

In the fluid laboratory, to ensure service quality issues are avoided, quality control and quality assurance measures are put in place. The preliminary ones are water analysis, specific gravity and pH check for cement, chemicals and additives. The main laboratory tests carried out on slurries are mixability of cement with various additives and water, density check, slurry stability, thickening time which is the length of time cement slurry will remain pumpable at bottomhole pressure and temperature, fluid loss - amount of filtrate lost by the fluid under bottomhole temperature, rheology which dictates solids settling and free water properties, and friction pressures, compressive strength - test that indicates whether the cement sheath will withstand the differential pressures in the well, gas migration which checks the ability of a cement slurry to resist fluid (gas or water) flow under static conditions, and Young's modulus. From these quality checks, it is always noted that cement sheaths that are ductile and more resilient than usual are needed to perform a successful job. Hence, additives are included in the design build up [1].

1.2. Cement design

Cement additives are chemicals and materials blended into base cement slurries to alter and enhance the performance of the cement to address the specific and unique conditions of each well. Variations in additive concentration may cause significant changes in thickening time, compressive strength, and a viscosity [2].

There are different types of cement additives that have been developed to allow the use of Portland cement in numerous oil and gas application. Accelerators speed up the normal rate of reaction between cement and water, reducing the thickening and setting times of the slurry to avoid unnecessary time spent waiting on cement. They are important in shallow wells where temperatures are low and "waiting-on-cement time" needs to be shortened. Accelerators do not increase the ultimate compressive strength of cement but promote rapid strength development.

In deeper wells, the higher temperature really promotes the setting process, making accelerators unnecessary. Instead, retarders are required to delay the reaction process to allow for adequate setting and sufficient time for slurry placement in deep and hot conditions [1]. They are chemicals used to decrease the speed of cement hydration because cement commonly used in well applications do not have a long thickening time for use at the bottom hole circulating temperatures (BHCT) above 100^0F. Hence, an extension of the thickening time is essential.

Fluid-loss additives improve primary cement jobs by helping to prevent cement dehydration in the annulus and prevent gas migration. They have viscosity and gelation properties that improve bonding within the cement system. They are normally polymers with cellulose derivatives most common [3]. They reduce dehydration opposite porous zones and consequently flash setting of the cement. Most fluid loss additives tend to viscosify the slurry, and consequently, dispersants are often added at the same time to control this effect.

High-density slurries are used to cement high-pressure wells where the increased hydrostatic head is required to hold down gas or fluids. Example additives are hematite and barite [2]. By so doing the mechanical compressive strength is enhanced to withstand the heightened external and internal stress anticipated downhole [4].

1.3. Morale behind study

Most industry-standard cement additives in Nigeria are synthetically manufactured and imported. This factor has an adverse controlling effect on the cost and availability of additives, which contribute to the increase in total capital and operational expenditure of oil well drilling and completion projects [5]. Besides, they are chemical compounds making them potential threats to the environment. They contribute to the toxicity of drilling wastes making their disposition into the immediate ecological environment a serious challenge, especially offshore.

Lately, there is a desire to shift focus from synthetic-based mud and cement additives to more environmentally friendly and less-toxic materials that can be easily decomposed by the natural ecological system contributing to its preservation, and acceptability of oil and gas project activities in immediate communities. Environmental wastes (agricultural) and Local earth materials like clay and the likes seem to fit this goal. For instance, a lot of local clays that require minimal processing have been observed to stand as potential substitutes to bentonite for rheological modifications in oil field chemicals for well drilling and completion [6].

The main aim of this research work is to test a local material called 'iron gum' clay as a potential substitute for imported additives for cementing purposes. Here, properties like compressive strength, fluid loss control capability and others are investigated in order to ascertain its suitability as a general-purpose cement additive. 'Iron gum' clay, more commonly known as 'dibo-dibo', is a local clay material originating from the south-west region of Nigeria. Its use is rampant domestically for patching metallic and alloy materials when mixed with suitable binders or adhesives. It has good rheological properties, and when its slurry sets, it is very stable under extreme temperature and pressure conditions.

2. Methodology

2.1. Local Earth material

The sample used for this study, the 'Iron gum' clay locally referred to as 'dibo-dibo', is a white clay whose slurry have been observed to have interesting rheological properties and the resultant cake when dry is tough with high resistant to elevated temperate conditions. It has a specific gravity of 2.30. Initial characterization of the local sample using gas chromatography mass spectrometry Analysis revealed that it contains ethyl alpha-d-glucopyranoside compound. This is a saccharide compound, an alkaline earth metal salt of oxa-polyacids that has pharmaceutical benefits (Patent: US5075336) [11]. AAS analysis gave silica (SiO^2) content of 42.45% and aluminium oxide (Al_2O_3) content of 36.14%.

2.2. Test design

The experimental study was designed with the objective of testing to verify the possible combination of functions of iron-gum clay as an additive in a cement system by preparing samples of cement slurry and replacing regular additives with the local clay and comparing the performances to a standard cement design optimized for a particular field job. The cement itself is a Dyckerhoff class G Portland cement. The complete recipe design and the well information are given in table 1 below.

Table 1a. Well details

Job type	Production Casing	Heating time	28mins
Pipe size	9.625in	MD	1455m/4809ft
Hole size	12.25in	TVD	808m/ 2651ft
BHCT	55^0C/133^0F	Pressure	130bar/1600psi
BHST	41^0C /106^0F	Yield	171.28

Table 1b. Materials for the standard slurry system

Material	Concentration	S.G	Test amount
Dyckerhoff class G	100%BWOC	3.18	350.3g
Bentonite	4%BWOC	2.65	14.01g
Cellulose	0.1GPS	1.04	3.23g
Liquid latex	0.5GPS	1.025	15.94g
Defoamer	0.02GPS	0.52	9.57g
Drill water	132.82L/100kg	1	464.34g

Standard quality control and analysis test of slurry and set mortar carried on our sample are thickening time, rheology, compressive strength, fluid loss and free fluid, permeability and porosity. These tests were carried out using the following equipment: high pressure high temperature consistometer; atmospheric consistometer; ultrasonic cement analyser; viscometer; gas and liquid permeameter; compressive strength machine.

2.3. Experiments

2.2.1. Slurry tests

The fluid loss apparatus together with a 250mL cylinder was used to test for the fluid loss of the slurries by allowing them age with water in the atmospheric consistometer then transfers them into a preheated static fluid loss cell. The API fluid loss was calculated using this formula: $Calculated\ API\ Fluid\ Loss = Vol\ filtrate\ (ml) \times 2\sqrt{\frac{30}{t(min)}}$

Thickening time tests were carried out to determine the length of time which cement slurries remain in a pumpable state under simulated wellbore conditions of temperature and pressure. The tests were programmed to run for 24hours and stop automatically. Result charts were generated thereof. Rheological tests were run on the slurries at the surface and simulated downhole conditions to know the fluid properties (plastic and yield point) using a Fann viscometer. The compressive strength of the slurry was conducted using the sonic method with the help of the ultrasonic cement analyser at temperature and bottom hole static pressure of 160°F and 1600psia, respectively. The tests ran for 48 hours, and corresponding graphs were plotted.

2.3.2. Cement mould tests

In this segment, Portland cement, bentonite, NaCl, $CaCO_3$, ash, cellulose, iron gum clay and brine were used in preparing six samples of slurry which were poured into cylindrical and square moulds to form cores and subjected to compressive and permeability tests. Two samples were designated to test the impact of iron gum clay on compressive strength, and fluid loss and migration properties of cements. Here, emulsions of binders were added to mixtures of pulverized local clay and cement, and then other additives were finally added to make up into a slurry. Bentonite quantities were varied (1% and 1.5%) in all samples to carry out sensitivity investigations. Standard lab samples for compressive strength included limestone and ash while the ones for fluid-loss control included cellulose.

3. Discussions

3.1. Slurry tests

The thickening time tests are designed to stand maximum a whole day (24hrs) however with the results of the experiment for local clay-augmented cement, it stood for more than a whole day and never got to set indicating that the clay sample is not an accelerator for down hole operations. Upon addition of sodium carbonate to the slurry, iron gum clay exhibited characteristics of a retarder as the thickening time was slowed down considerably. It also behaved like an extender by increasing the yield better than the first slurry as the thickening time also increased to a way better consistency. These extender and retarder properties improved with sodium carbonate concentration. The standard laboratory cement slurry with bentonite had a consistency measurement of 33BC after 19 hours, which was better than the recipe where bentonite was replaced with local clay (13 BC at 19hrs). However, the addition of sodium carbonate improved the thickening time to 55BC, although this does not meet up with the upgraded final sample for the field operation which measured 95BC.

The temperature and pressure condition of the compressive strength test was at 133°F and 1600psi, respectively. The test checked the cement samples capacity to withstand high pressure before fracturing. Here, the test was performed using a sonic method (an ultrasonic cement analyser cell), which makes use of sound waves while the readings are used to generate result charts. From the results, it is seen that the cement system augmented with iron gum clay and sodium carbonate combination withstood comfortably very high pressures typical of downhole conditions without fracturing. The compressive strength reading was way better than the actual design for the completed well. Hence, the local material together with the sodium carbonate, will be very good for cement operation in deep wells. The lab cement sample with regular bentonite and other synthetic additives gave a compressive strength reading of 180 psi at 133°F after 48 hours while cement sample with 'dibo-dibo' and sodium carbonate gave a reading of 260 psi at the same condition for the same duration which was even better than the final recipe optimized for the well operation, 235 psi.

The fluid loss test investigates the ability of a cement system to control the loss of fluid as a function of additives in the cement slurry, and this is depicted in the amount of filtrate left therein. The performances of samples containing iron gum clay alone and with sodium carbonate were better than the standard lab sample, indicating that iron gum clay may be a perfect fluid loss additive. After standing for 30 minutes, according to API standards, a sample with iron gum clay alone had lost 32mls of entire 81mls, while with sodium carbonate 34mls. The standard lab sample with bentonite gave a result of 62mls. These show that the iron gum clay, without any other supporting additive, will be a good candidate for fluid loss control in formations were damage will be a critical issue. Also, as earlier mentioned, moderate retaining of cement fluid is good for the setting and hardening process, which is a reaction that takes place over a certain appreciable period of in the presence of water.

Free fluid test, designed to know the amount of fluid that settles on top or segregates out from the main slurry in a column after a static period (generally two hours), was determined at ambient and heated conditions. The practical implication is that when free water separates out of the slurry while undergoing setting in the annulus, this could lead to a poor cementing job with a whole lot of water pockets being created in the set cement which can herald in other problems later in the life of the well. For all the sample slurries, after ageing with water for two hours, there was no case of settling out, but homogeneity was observed indicating zero free water.

Samples were subjected to rheological studies to investigate fluid flow, viscous and plastic properties, and at two different temperatures (80°F and 106°F) to investigate these properties' sensitivity to temperature. The standard cement slurry with bentonite as the viscosifier had the best performance and it exhibited a Bingham pseudoplastic behaviour under normal down-hole and slightly elevated temperature conditions where the plastic viscosity dropped from 57cP to 54 cP. The cement slurry with iron gum clay alone performed better than that stimulated with sodium carbonate. In fact, its plasticity increased with temperature as the plastic viscosity increased from 39cp at 80°F to 42cp at 106°F. However, the yield point dropped under elevated temperature from 19Ib/100ft^2 to 10Ib/100ft^2. Cement slurries with local clay material exhibited a rheological behavioural model somewhere between Herschel-Bulkley fluids and pseudoplastics. They were not too thin or too viscous, and we can say that they can be used with other viscosity modifiers in cementing operations.

3.2. Cement core tests

Cement mixed-in with local clay (iron gum clay) gave the highest compressive strength, therefore can be said to be a good additive for control of external stresses in holes. This has already been proven by the compressive strength test carried out on the slurry using the ultrasonic analyser, although it was augmented with sodium carbonate here. Iron gum clay will substitute comfortably for conventional weighting materials and other additives used for improving cement hardness and toughness in the annulus during setting if carefully managed. Sample B, without any weighting material, as expected, had the poorest performance, thus highlighting the importance. The quality of set cement improves with bentonite concentration, implying there is a synergistic effect from the combination of synthetic and local clay.

Table 2. Compressive strength test results

Property	Sample A1	Sample A2	Sample B1	Sample B2	Sample C1	Sample C2
Ultimate load (kN)	26	39.2	2.6	7.9	33.5	43.8
Compressive strength (N/mm^2)	10.4	15.68	1.04	3.16	13.40	17.52

Sample A- Cement core with CaCO3 and Ash as compressive strength additives + 1% Bentonite
Sample A2- Cement core with CaCO3 and Ash as compressive strength additives + 1.5% Bentonite
Sample B1- Cement core with cellulose for fluid loss control + 1% Bentonite
Sample B2- Cement core with cellulose for fluid loss control + 1.5% Bentonite
Sample C1- Cement + local clay + 1% Bentonite
Sample C2- Cement + local clay + 1.5% Bentonite

A porous mortar is a result of poor cement system design where incompatible additives react adversely creating large void spaces in the core/mould. For this study, local clay was able to reduce the porosity considerably (12.34%) which was further reduced with increase in bentonite content (11.10%). Ash performed better than cellulose as a void reducing additive. In the permeability measurements (Table 3), it was noticed that iron gum clay reduced tendency for fluid migration, and subsequently fluid loss. This ascertains it as a fluid loss control additive as previously suspected from fluid loss tests on slurry. However, bentonite reacted anti-synergistically with the local clay and ash in the effort to reduce permeability. Here, also, cellulose exhibited a better performance in fluid loss control as compared to ash, but in all iron gum clay had the best performance. It was noticed that combining cellulose with bentonite is good for fluid loss control.

Table 3. Permeability measurements for cement core samples

Sample A (1% BWOC)	Sample A (1.5% BWOC)	Sample B (1% BWOC)	Sample B (1.5% BWOC)	Sample C (1% BWOC)	Sample C (1.5% BWOC)
0.056 mD	0.057 mD	0.057 mD	0.047 mD	0.030 mD	0.068 mD

4. Conclusion

From the compressive strength tests on both the slurry and core, we can say that the local iron gum clay had a good performance that will withstand very high pressure and temperature typical of very deep wells. Considering the retarding properties as well, iron gum clay can serve as a smart multifunctional additive on the oilfield which will save cost in well drilling and cementing operations, if well managed and evaluated at design stage. Its tolerance to harsh temperature is proven by the increase in internal shear forces, surprisingly, without sodium carbonate. Iron gum clay's fluid loss control capability is also noteworthy, for both cases of core sample and slurry. This means that apart from saving cost, the local material can aid in formation damage prevention and control which result from excess fluid loss to the region around the wellbore. It is interesting to know that presence of bentonite in cements containing the local clay will improve their toughness, but this won't favour fluid loss control, and by inference, lost circulation. In all cases, it can be argued that iron gum clay is a viable substitute for synthetic additives, however with little augmentation in some cases i.e. sodium carbonate stimulation. Hence, iron gum clay as a general purpose additive for cement slurry is recommended for oilwell cement jobs in order to reduce cost of procurement of synthetic additives, and for reducing environmental risks associated with oilfield operations.

References

[1] Halliburton Energy Institute: Cementing 1: Student Workbook. Halliburton Company Publication. USA. 2003.

[2] Broni-Bediako E, Joel OF, Ofori-Sarpong G. Oil well Cement Additives: A Review of The Common Types. Oil and Gas Research, 2016; 2, 112, DOI: 10.4172/2472-0518.1000112. 2016.

[3] Al-Yami AS, Ramasamy J, Wagle V. Chemical Additives For Oil Well Cementing. Research & Reviews: Journal of Chemistry, 2017; 6(4): 1-14.

[4] Weatherford Cementing Program. Weatherford International. 1986.

[5] Ogbonna JF, Iseghohi PT. Utilization of Local Additive in The Cementation of HPHT Wells in Nigeria. SPE International Technical Conference and Exhibition Abuja. 2009 SPE 128608.

[6] Imuentinyan I, Adewole ES. SPE-172475: Feasibility Study of the use of Local Clay as Mud Material in Oil Well Drilling in Nigeria. SPE NAICE, Lagos Nigeria, August 5 – 7, 2014.

[7] Atiemo E. Studies on the Effect of Selected Local Admixtures on the Essential Properties of Cement for Housing Construction. Doctoral Thesis, Faculty of Civil and Geomatic Engineering, Kwame Nkrumah University of Science and Technology. 2012.

[8] Bermudez M. - Effect of Sugar on the Thickening Time of Cement Slurries. SPE 113024, SPE Annual Technical Conference and Exhibition. Anaheim California USA. 2007.

[9] Mehta PK. Natural pozzolans: Supplementary cementing materials in concrete. CANMET Special Publication. 86: 1–33. 1987.

[10] Mesboua N, Benyounes K, Benmounah A. Study of The Impact of Bentonite On The Physico-Mechanical and Flow Properties of Cement Grout. Cogent Engineering, 2018; 5(1): 1446252.

[11] National Center for Biotechnology Information. PubChem Database;Patent = US5075336, http://pubchem.ncbi.nlm.nih.gov/patent/us5075336 (accessed July 27, 2018).

[12] Ogbonna JF. The Secondary Effects of Lignosulfonate Cement Retarder on Cement Slurry Properties. Journal of Engineering and Applied Sciences, 2009; 4: 1-7.

[13] Oriji AB, Lawal FS, Bala Z. Evaluating The Efficiency of Nigerian Local Bentonite As An Extender in Oil Well Cementation. Chemical and Process Engineering Research, 2014; 28:78-88.

[14] Salam KK, Arinkoola AO, Ajagbe B, Sanni O. Evaluation of Thickening Time of Oil Field Class G Cement Slurry at High Temperature and Pressure using Experimental Design International. Journal of Engineering Sciences, 2013; 2: 361-367.

[15] Shahriar A. Investigation On Rheology of Oil Well Cement Slurries, Doctoral Thesis, School of Graduate and Postdoctoral Studies University of Western Ontario. 2011

To whom correspondence should be addressed: Dr. A. Afolabi, Department of Chemical and Petroleum Engineering, Afe Babalola University, Ado Ekiti, Nigeria, E-mail gastonsilas@yahoo.com