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Enhancing the Performance of Local Cement as an Alternative for Oil and Gas Well Cementing Operation

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Abstract

The biggest identified problems with the use of locally manufactured construction grade cement in Ghana are; unpredictable thickening time, premature gelation of cement slurries and low strength development as compared to imported cementing samples. Locally manufactured cement hardly meet the physical properties exhibited by the imported cement sample, but with proper design of local cement, the important properties required for oil well cementing could be attained. This research focuses mainly on enhancing the physical properties of local cement using oil well cement additives. Laboratory investigations on both local and imported cement to determine physical properties such as thickening time, fluid loss, free fluid and rheology were conducted at bottom hole circulating temperature of 66°C (150°F). The cement slurries were tested in accordance with API Specification 10A and API Recommended Practice 10B. The results show that with the right selection of additives, local cement (CEM A) could be used as an alternative for imported class G cement for cementing operations in terms of the physical properties tested. By working in conjunction with local cement manufactures, oil companies can help ensure local cement maintains consistency.

Keywords*: Additives; Free Fluid; Fluid Loss; Rheology; Thickening Time.*

1. Introduction

Oil well cementing involves placing cement slurry from the surface to several thousands of feet below the surface of the earth [1-2]. The cement slurry which consists mainly of cement, water and performance-controlling additives [3] is pumped down the casing and up the annulus, where it is allowed to set and harden [4]. In oil well cementing, less error is tolerated as compared to conventional construction work. Oil well cement slurry must, therefore, be carefully designed to meet technical requirements such as optimum thickening time, low viscosity, low free fluid, adequate strength, fluid loss control, high sulphate resistance and overall high durability [5-6]. Oil well cement are formulated to provide the required physical properties at the downhole conditions of pressure and temperature. The high temperatures and pressures encountered downhole impose severe requirements on the setting behaviour of the oil well cement. The premature setting can have disastrous consequences; whereas too long setting times can cause financial losses due to excessive "wait-on-cement (WOC)" times [6]. Due to the important role of cement in oil and gas cementing operations, the oil industry purchases cements manufactured in accordance with American Petroleum Institute (API) specifications for cementing operations. This special class of cement is called Oil Well Cements (OWCs).

In spite of the usage of API specified cement, conventional construction (local) cement have been used for oil well cementing in many parts of the world for various reasons such cost, availability and logistics [7]. However, the situation is not the same in Ghana as all the produced cement goes into the building and the road sectors [8] of the economy. The biggest identified problems with the use of locally manufactured construction grade cement in Ghana are; unpredictable thickening time, premature gelation of cement slurries and low strength development as compared to imported cementing samples [5, 9]. Locally manufactured cement hardly meet the physical properties exhibited by the imported cement sample. However, with the right formulation of locally manufactured cement, the important properties required for oil well cementing would be attained. This research work, therefore, focuses mainly on designing cement slurry using locally manufactured cement and cement additives as alternative for oil and gas cementing operations in Ghana.

2. Universal cement system(UCS) additive

For several years, a service company has identified the value that could be created for its customers by the use of locally manufactured cement, particularly in areas remote from locations where oil well cement are manufactured. To overcome the problems associated with local cement, the service company developed and tested a product that allows non-API specification (local cement) to be used in oil well cementing designs and application and also manages problems associated with the local cement. This product is commonly referred to as Universal Cement System (UCS) additive. In the majority of cement tested worldwide, UCS additive has allowed the formulation of consistent slurry recipes with locally manufactured cement at concentrations that make it economically desirable. The physical properties that a UCS additive can provide include enhances compressive strength, controls fluid loss, controls rheology, imparts chemical resistance, controls premature gelation, and allows use in freshwater and seawater [10].

UCS additive can be added to cement that might not normally be usable in oil well cementing, such as those often produced in developing countries, those with high alkali sulphate and high free-lime content, and ASTM Type I/II construction-grade cement. UCS additive may be available in liquid or powder form (Fig. 1). The application of the powdery UCS is always preblended with the dry cement and not added directly to the mixing water for maximum results. The UCS additives can counteract the difference of the physical properties often seen between different batches of locally manufactured cement, reducing the high gelation effects, imparting chemical resistance, allowing their use at temperatures up to 250°F. The application of Gelation Control Additive (GCA) or UCS-additive of 1% by weight of cement (bwoc) has shown resistance to sulphate attack similar to that of a class G oil well cement. The sulphate resistance testing was based on ASTM C102. The untreated, non-resistant cement used in the study expanded and showed sulphate attack during a 90 day test period [10].

Fig. 1 UCS Additive in Powder and Liquid Form [10]

3. Materials and methods

3.1. Materials

A brand of cement available on the Ghanaian market and commonly used by Ghanaians for construction purposes was purchased from retail outlets for the cement slurry formulation. Fresh water from a company's laboratory was used for the cement slurry formation. Additives such as defoamer, fluid loss additive, retarder and Universal Cement System (UCS) were obtained from a service company in Port Harcourt, Nigeria. The additives used in the cement composition were selected based on the test pressure and temperature conditions. UCS was employed to reduce the premature gelation or to improve upon the rheological properties of the local cement slurry at elevated temperature. Retarder and fluid loss additive were used to increase the setting time and control fluid loss of the cement slurry at high pressures and temperatures respectively. Defoamer was also used to remove slurry foam during cement slurry formulation.

3.2. Experimental design

Laboratory experiments were performed on local CEM A to formulate a cement slurry recipe for oil and gas well cementing operations. The locally manufactured CEM A was blended with different percentages of additives to deal with the premature gelation associated with locally manufactured cement at high temperature. The cement slurry was tested at BHCT of 150°F. The cement slurry and specimen preparation were carried out by closely following API Specification 10A. The physical properties were determined by closely following API Specification 10A, and API Recommended Practice 10B [2, 11]. The physical properties tests conducted included thickening time, free fluid, fluid loss and rheology of the cement slurry (Table 1). Two modified cement slurries for CEM A were also tested for physical properties using the test conditions and slurry composition presented in Table 1.

Table 1 Experimental conditions and slurry composition

Test Condition	Units	CEM G	CEM A	Modified CEM A1	Modified CEM A2
BHST	°F	190	190	190	190
BHCT	°F	150	150	150	150
BHP	psi	7900	7900	7900	7900
Heat Up Time	min	53	53	53	53
Water					
Water Type	-	Fresh Water	Fresh Water	Fresh Water	Fresh Water
Water Requirement	gal/sk	5.03	5.03	5.03	5.03
Chloride Content	ppm	400	400	400	400
Cement					
Cement Weight	% bwoc	100	100	100	100
Slurry Weight	ppg	15.8	15.8	15.8	15.8
Mixing Fluid	gal/sk	5.11	5.11	5.11	5.11
Yield	cu.ft/sk	1.16	1.16	1.16	1.16
Additives					
UCS	% bwoc	-	-	1	1
Defoamer	gal/sk	0.02	0.02	0.02	0.02
Fluid Loss Agent	% bwoc	0.5	0.5	0.5	0.5
Retarder	% bwoc	0.18	0.18	0.3	0.18

3.3. Thickening time testing

The results of the laboratory thickening time tests provide an indication of the length of time that cement slurry remains pumpable [12]. That is, the time after initial mixing when the cement can no longer be pumped [13]. The consistency of cement slurry is expressed in Bearden units of consistency (Bc) [12]. The Thickening Time (TT) test was performed in a High-Pressure High-Temperature (HPHT) Consistometer that is usually rated at pressure up to 30 000 psi and temperatures up to 400°F. The cement slurry was mixed according to API procedures and then placed in a slurry cup into the consistometer for testing. The testing pressure and temperature were controlled to simulate the conditions the slurry will encounter in the well. The test concluded when the slurry reached a consistency considered unpumpable in the well. The maximum consistency during 15 minutes to 30 minutes after the initiation of the test and the time for the cement slurry to reach the consistency of 100 Bc were recorded [2, 11].

3.4. Free fluid testing

The purpose of a free fluid test is to measure the excess fluid in the cement slurry not required to fully mix the dry cement blend [14]. The cement slurries were preconditioned in a Model 165AT Atmospheric Consistometer for thirty minutes. The preconditioned slurry was remixed within 10 seconds and poured into a 500 ml graduated flask according to API Specification 10A [2]. The mouth of the flask was sealed and then placed on a vibration free surface for 2 hours. The slurry was then examined for any free fluid on the top of the cement column. This free fluid was decanted and measured with a syringe to determine the percent of free water (φ) based on the weight and the specific gravity of the cement using Equation (1).

$$\varphi = (V_{FF}) \; x \, S_g \; x \frac{100}{m_S} \tag{1}$$

where V_{FF} is the volume of free fluid collected (supernatant fluid), expressed in millilitres; S_g is the specific gravity, and m_s is the initially recorded mass of the slurry in grams.

3.5. Fluid Loss Testing

Fluid loss tests are conducted to establish API procedures to help determine the relative amount of fluid loss that will occur in a given cement slurry. The amount of filtrate lost by the fluid under bottomhole temperature and 1 000 psi differential pressure is measured in this test [11]. A differential pressure normally exists to prevent fluid flow from the formation into the wellbore, and most formations have pore throats that are too small to allow cement particles to invade the formation. However, if a differential pressure exists into the formation, the water in the cement slurry can leak into the formation. After conditioning the slurry at the Bottomhole Circulating Temperature (BHCT) for thirty (30) minutes, the slurry was placed in the fluid cell, and a differential pressure of 1 000 psi was applied across the 325 mesh screen for about thirty minutes. For tests that "blowout" before 30 minutes in API fluid loss was determined using Equation (2).

$$\text{Fluid Loss at } Q_{30\text{mins}} = \frac{2 \, x \, Q_t \; x \, 5.477}{\sqrt{T}} \tag{2}$$

where Q_t is the volume (mL) of filtrate collected at the Time T (mins) of the "blowout".

3.6. Rheology testing

Rheology of cement slurries is of great importance for the design, construction and quality of primary cementing. Knowledge of the rheological properties is necessary to assess the possibilities for mixing and pumping cement slurries, determine the relationship of pressure to depth during and after repression, return circulation to calculate the phase of "free fall", forecasts temperature profile during pumping a cement slurry, design and capacity required for optimal suppression of cement puree [15]. According to Shahriar [16], the fundamental knowledge of oil well cement slurry rheology is necessary to evaluate the ability to remove mud and optimise slurry placement. Incomplete mud removal can result in poor cement bonding, zone communication and ineffective stimulation treatment [17]. The Rheology of fluids also has a major effect on solids setting and free fluid properties and also on the friction pressures [14]. Because rheological testing is typically conducted at atmospheric pressure, the maximum temperature is limited to about 190°F [11]. The shear stress and shear rate behaviour of the slurry at different temperatures was measured in this test. The rheological properties of the fluid samples used in this study were measured using Fan Viscometer Model 35A. The properties of interest studied included Plastic Viscosity (μ_p) and Yield Point (τ_o). The plastic viscosity and the yield point value were obtained using Equations (3) and (4) respectively [20-21]

$$\mu_p = 1.5(\theta_{300} - \theta_{100}) \tag{3}$$

$$\tau_o = \theta_{300} - \mu_p \tag{4}$$

where θ_{300} is 300 rpm dial reading, and θ_{100} is 100 rpm dial reading.

4. Results and discussions

4.1. Thickening time analysis

According to Broni-Bediako *et al.* [5], locally manufactured cement in Ghana pump shorter as compared to imported class G cement and would require more additives to bring up the thickening time of the local cement. Fig. 1 showed the results of the thickening time of locally manufactured CEM A and imported class G cement mixed with various concentrations of retarder, defoamer, UCS and fluid loss additive and tested at 1 2250 ft, 7 900 psi and 150°F (Table 1). From Figure 1, it could be seen that the modified local cement appeared to have improved and better thickening time than imported class G. The thickening times of locally modified local cement showed longer setting with a slow increase in consistency of the cement slurry. This gives an idea that with the right concentration of additives, locally manufactured cement could be used at elevated temperatures without the cement slurry setting prematurely. The improvement in the value of the thickening time could be due to the right concentrations of UCS that were blended with the local cement. According to Hibbeler *et al.* [7], in choosing between available class G cement or considering the option of using a construction grade cement, the primary performance factors of concern are retarder response and early gelation of the cement slurry.

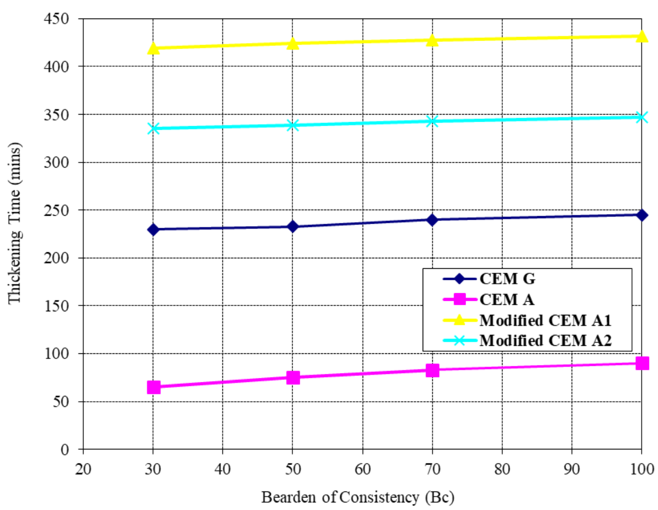

Fig. 1. Thickening time vs. consistency at 150°F

From the result presented in Fig. 1, local cement responded very well to retarder concentrations. Furthermore, the locally manufactured cement was compatible with a fluid loss agent, defoamer and universal cement system used for the cement slurry design. The modified CEM A1 with a retarder of 0.3 by weight of cement (%bwoc), a fluid loss additive of 0.5 %bwoc, defoamer of 0.02 %bwoc and UCS of 1% bwoc (Table 1), the local cement appeared to pump longer and better than the imported class G cement (Fig. 1). The end of thickening time test was considered to be 70 Bc. At the consistency of 70 Bc, the modified CEM A1 pumped about 188 minutes (3 hrs: 8 mins)longer than the imported class G. The results of the thickening time showed that the modified cement slurry had been overdesigned when compared with the imported class G cement. However, the results revealed that the modified locally manufactured cement CEM A1 could be used for cementing oil wells which require operating time of 7 hours or less.

From Fig. 1, the modified CEM A2 appeared to have a better slurry design than the modified CEM A1 when both are compared with the imported class G cement. The modified CEM A2 with a retarder of 0.18 %bwoc, a fluid loss additive of 0.5 %bwoc, defoamer of 0.02 %bwoc and UCS of 1 %bwoc (Table 1), proved to pumped shorter than modified CEM A1. All the concentrations of additives used in the modified CEM A1 were maintained for modified CEM 2 except the retarder's concentration. The addition of UCS of 1 %bwoc and a retarder of 0.18 %bwoc gave a better thickening time results which compared favourably with the imported class G cement. At the consistency of 70 Bc, the modified CEM A2 pumped about 343 minutes (5 hrs: 43 mins) but 85 minutes (1 hr: 25 mins) shorter than the modified CEM A1 (Fig. 1). Comparing the modified CEM A2 and imported cement, the modified CEM A2 pumped 104 minutes (1 hr: 43 mins) longer than imported cement. The increase in the thickening time values was due to the addition of the right concentration of UCS as the UCS played an imperative role by acting as a retarder in addition to its primary function. Normally, a contingency time of 1 hour is added to the pumping time to allow for possible equipment failure [23]. Therefore, modified CEM A2, would be suitable for 283 minutes (4 hrs: 43 mins) cementing job.

4.2. Free fluid and fluid loss analysis

When cement is setting, free fluid separates from the slurry, settling at the top of the cement column or in small water pockets if the well deviates. This water can create channels while moving at the top of cement, resulting in a poor cement bond or casing failure if the water pockets are between the casing to the casing annulus [14]. The results of free fluid between the locally manufactured cement and imported class G at 150°F and 7 900 psi (Table 1) is presented in Table 2. The modified CEM A1 and A2 proved to have no free fluid when mixed with a fluid loss additive at 0.5 %bwoc. In terms of fluid loss, both the imported class G and modified cement samples compared favourably (Table 2). According to Anon [24], under standard laboratory conditions (1 000 psi filter pressure, with a 325 mesh filter) a slurry for a squeeze job and primary cement job should give a fluid loss of 50-200 cc and 250-400 cc within thirty (30) minutes respectively. The results showed at both modified CEM A1 and CEM A2 could be used for squeeze cementing and primary cementing operation per the recommended value by Anon [24].

Again, the results compared favourably with the recommendation by Boškovic *et al.* in 2013. According to Boškovic *et al.* [15], fluid loss for class G cement is not precisely defined by API Specification, but they recommended that within thirty (30) minutes test period up to 1000 cc, 500 cc, less or equal to 100 cc and 30-50 cc respectively is vital for cementing technical casing string, production casing string, liner casing and gas wells. From the results, the modified CEM A1 and CEM A2 could be used for cementing technical and production casing string.

Table 2. Fluid Loss and Free Fluid at 150°F

Cement Type	CEM G	CEM A	Modified CEM A1	Modified CEM A2
Fluid Loss (cc/30 minutes)	90	70	190	136
Free Fluid @ 90 deg incl. (%)	0	0	0	0

4.3. Rheology analysis

The rheological properties of oil well cement (OWC) slurries are important in assuring that such slurries can be mixed at the surface and pumped into the well with minimum pressure drop, thereby achieving effective well cementing operation [22, 23]. The basic reason for determination of rheological properties was to predict plastic viscosity and yield point values. In general, the problem of pumping cement slurry through wellbore occurs when plastic viscosity becomes high [25]. The introduction of 1% bwoc UCS additive to the local cement produced slurries that were pumpable with viscosities that compared favourably with that of the imported class G cement at 150°F. The result of rheological properties of modified local cement and imported class G cement at 150°F is presented in Table 3.

Table 3. Rheological properties of modified local and imported cement samples at 150°F

Rheology @ BHCT of 150 °F	CEM G	CEM A	Modified CEM A1	Modified CEM A2
		Dial Reading		
300 rpm	158	298	100	73
200 rpm	125	240	72	52
100 rpm	90	172	42	31
6 rpm	35	86	5	4
3 rpm	27	71	3	3
Plastic viscosity (cp)	**102**	**189**	**87**	**63**
Yield point (lb/100 ft^2)	**56**	**109**	**13**	**10**

At a BHCT of 150°F, the problem of premature gelation associated with the local cement slurry was dealt with. This could be attributed to the introduction of the right concentration of UCS. The plastic viscosity for all the cement samples was below 100 cp, which according to Abbas *et al.* [25] is desirable to keep cement slurry pumpable. The values of the Yield Point calculated also showed that all the slurries were pumpable at 150°F (Table 3) though a little below 15 lb/100 ft^2 recommended by Salehi and Paiaman [26]. Comparing the imported class G cement sample and the modified CEM A1 and CEM A2, the modified cement appeared to have rheological stability than the imported cement sample. Notwithstanding, both modified cement and imported cement are pumpable. The rheological results for all the local cement after the introduction of 1 %bwoc of UCS additive showed lower rheological values than the imported class G cement at a temperature of 150°F.

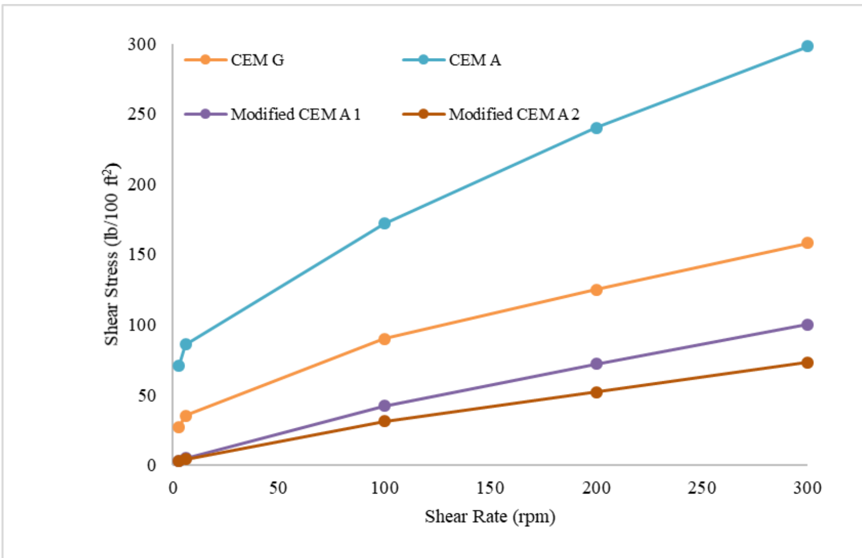

Figure 2 Shear stress vs. shear rate at 150°F

5. Conclusions

From the research, it could be concluded that:

i. Locally manufactured modified CEM A, proved to have better properties suitable for application in oilwell cementing operations, in terms of fluid loss, thickening time, and free water when tested at 150°F.
ii. Locally manufactured CEM A is compatible with Universal Cement System. The addition 1 %bwoc of Universal Cement System additive reduced the premature gelation associated with local cement thereby improving the bulk-flow characteristics at 150°F.
iii. Locally manufactured CEM A responded very well with the retarder used and can be used to achieve the require thickening time for oil and gas well cementing operations.

6. Recommendation

It is recommended that further tests be conducted to ascertain the stability of locally manufactured cement under High Pressure, High Temperature (HPHT) conditions.

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