Evaluation of the Performance of Local Cements with Imported Class 'G' Cement for Oil Well Cementing Operations in Ghana*

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Abstract

Portland cement is the most commonly used cement in the oil and gas industry and it accounts for about 99% of all primary cementing operations throughout the world. For Portland cement to qualify as oil well cement, the chemical and physical properties must meet the required standards of the American Petroleum Institute (API). This research evaluates the performance of three locally manufactured cement samples and imported class G cement sample for oil and gas well cementing operations in Ghana. The paper details results of API specification tests and the physical properties of the local cements with the imported class G cement. The results indicated that locally manufactured cements have the potential to be used for cementing oil and gas wells. However, further tests should be conducted to ascertain their stability under High Pressure, High Temperature (HPHT) conditions.

Keywords: Compressive strength, Free fluid, Portland cement, Rheology, Thickening time

1 Introduction

Portland cement is a hydraulic product made by burning and grinding a mixture of calcareous and argillaceous materials, such as limestone and clay, limestone and shale, limestone and marl, chalk and clay or limestone and iron blast furnace slag (Morgan, 1987). Portland cement is made up of the four major clinker minerals, namely: tricalcium silicate (C_3S); dicalcium silicate (C_2S); tricalcium aluminate (C_3A); and tetracalcium aluminoferrite (C_4AF) to which 3-5% gypsum ($CaSO_4.2H_2O$) is added (Sasaki *et al.*, 1986; Lea, 1970; Lu *et al*., 1993; Saasen *et al*., 1994, Hibbeler *et al*., 2000). Chemically, CaO, SiO_2, Al_2O_3 and Fe_2O_3 constitute about 80% of Portland cement. The other significant minor oxides are MgO, SO_3, K_2O, and Na_2O (Lea, 1970; Atiemo, 2012). Although Portland cement is primarily a construction material (Morgan, 1987) it is the most commonly used cement in the oil industry (Bett, 2010). It accounts for about 99% of all primary cementing operations (Joel, 2013) throughout the world (DiLullo *et al.,* 1994; Thiercelin *et al.,* 1997; Magarini *et al*., 1999). In oil well cementing, Portland cement is used primarily as an impermeable seal material. It is used as a seal to secure and structurally support casing string inside the well (Heinold *et al.*, 2002; Zhang *et al*., 2010) and prevent fluid communication between the various underground fluid-containing layers or the production of unwanted fluids into the well which can lead to casing corrosion (Heinold *et al.*, 2002; Sauki and Irawan, 2010).

For Portland cement to qualify as oil well cement, the chemical and physical properties must meet the standards set by the American Petroleum Institute (API). In Ghana, imported class G cement is used for the oil and gas wells cementing operations. Cementing of oil/gas well is a capital-intensive project, and the cost of getting the imported cement is quite enormous. Therefore efforts have been made to study the potential of three locally manufactured cements for oil and gas well cementing operations. The purpose of this research is to evaluate the possibility of utilising locally manufactured cement for oil/gas well cementing operations in Ghana. This investigation is an effort to compare the physical properties of locally manufactured cement in Ghana with the class G cement.

2 Materials and Methods

2.1 Materials

Three brands of cement available on the Ghanaian market and commonly used by Ghanaians for construction purposes were purchased from retail outlets in Aflao in the Volta Region, Buipe in Northern Region and Tarkwa in the Western Region. The imported sample (class G cement) was obtained from Schlumberger Oil Services Company in Ghana. Distilled water was used for the cement slurry formation.

2.2 Experimental Design

Laboratory experiments were performed on local cement slurry to determine the potential of locally manufactured cement. The cement slurry and specimen preparation were carried out by closely following API Specification 10A. The physical

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properties were determined by closely following API Specification 10A and API Recommended Practice 10B (Anon, 1997; 2013). The physical properties tests conducted included thickening time, compressive strength, free fluid, and rheology of the cement slurry. Three brands of locally manufactured cement (CEM A, CEM B and CEM C) and imported class G cement (CEM G) were investigated at the testing conditions specified in API Specification 10A (Table 1).

Table 1 Experimental Conditions and Slurry Composition (API Specification)

Test Conditions	
Bottom Hole Static Temperature (BHST), ^oF (^oC)	140 (60)
Bottom Hole Circulating Temperature (BHCT), ^oF (^oC)	125 (52)
Bottom Hole Pressure, psi (MPa)	5160 (35.6)
Heat Up Time, min	28
Slurry Composition	
Water Type	Distilled
Water Requirement, gal/sk (m^3/t)	4.98 (0.442)
Cement Weight ,%bwoc	100
Slurry Weight, ppg (kg/m^3)	15.9 (1905)
Mixing Fluid, gal/sk (m^3/t)	4.98 (0.442)
Yield, cu.ft/sk (m^3/t)	1.14 (0.76)

2.3 Thickening Time Testing

The results of the laboratory thickening time tests provide an indication of the length of time that cement slurry would remain pumpable (Alp and Akin, 2013). That is, the time after initial mixing when the cement can no longer be pumped (Salam *et al*., 2013). Consistency of cement slurry is expressed in Bearden units of consistency (Bc) (Alp and Akin, 2013). 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 (206.8 MPa) and temperatures up to 400 ^oF (204 ^oC). 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 un-pumpable 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 consistency of 100 Bc were recorded (Anon, 1997; 2013) as shown in Fig. 1.

2.4 Free Fluid Testing

The intention of a free fluid test is to help determine the quantity of free fluid that will gather on the top of cement slurry between the time it is placed and the time it gels and sets up (Joel, 2009). 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 (Anon, 2013). The mouth of the flask was sealed and then placed on a vibration free surface for 2 hours. The slurry was 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).

$$\varphi = (V_{FF}) \text{ x } S_g \text{ x} \frac{100}{m_S} \quad (1)$$

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.

2.5 Moisture Content Testing

The moisture content of the cement sample were determined in accordance with API Specification for Drilling Fluid Materials (Anon, 2004). About 10 g of the cement was placed in a covered container (petri-dish) of known weight (m_1) and weighed (m_2). The container containing the cement was uncovered and together with the cover was placed in an electric oven and dried at 221 ^oF (105 °C) for 30 minutes. The container with the cement was taken out, covered and placed in a desiccator for about 15 minutes to cool, after which it was reweighed (m_3). The Moisture Content (MC) of the sample was calculated as in Equation (2).

$$MC = \frac{m_2 - m_3}{m_3 - m_1} \text{x}100 \quad (2)$$

2.6 Compressive Strength Testing

Compressive strength is one of the properties used to test the reliability of cementing and is the ability of a material to withstand deformation when load is applied (Falode *et al.*, 2013). Higher compressive strength generally means lower porosity and increased durability (Alp and Akin, 2013). Insufficient compressive strength means casing failures are more likely and the life span of the well can be dramatically reduced (Huwel *et al.*, 2014). There are two common methods for determining the compressive strength of a cement slurry; non-destructive and destructive. Destructive method was employed in this research. The destructive test indicates how the cement sheath will withstand the differential pressures in the well. The main advantage with this type of method is that an exact value of compressive strength can be determined

(Huwel *et al*., 2014).

The prepared samples were poured into a four square inch moulds and puddled for 27 times per specimen with a puddling rod and then cured at 140 ^{o}F (60 ^{o}C) using Thermo Scientific Precision 180 Series Water Bath. The samples were cured for 8 hours before they were cooled and then crushed with Carver Model 3851 Manual Press. The resultant pressures were read from the pressure gauge and the compressive strengths were calculated using Equation (3).

$$\text{Compressive Strength (psi)} = \frac{\text{Force (pounds)}}{\text{Area (square inch)}} \quad (3)$$

2.7 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, and to predict the effect of wellbore temperature on slurry placement (Boškovic *et al.*, 2013). According to Shahriar (2011), 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 (Bannister, 1980). The Rheology of fluids also has a major effect on solids setting and free fluid properties and also on the friction pressures (Joel, 2009). Because rheological testing is typically conducted at atmospheric pressure, the maximum temperature is limited to about 190 ^{o}F (88 ^{o}C) (Anon, 1997). The shear stress and shear rate behaviour of 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 (4) and (5) respectively (Darley and Gray, 1983; Anon, 1997).

$$\mu_p \text{ (cp)} = 1.5(\theta_{300} - \theta_{100}) \quad (4)$$

$$\tau_o \text{ (lb/100ft}^2) = \theta_{300} - \mu_p \quad (5)$$

Where θ_{300} is 300 rpm dial reading and θ_{100} is 100 rpm dial reading.

3 Results and Discussion

3.1 Thickening Time Analysis

Thickening time is an essential parameter for designing a successful cement job. If the cement slurry remains liquid over an extended period of time and functions as a solid when it stops flowing, in a reasonable time, it will be suitable for more jobs (Roshan and Asef, 2010). Fig. 1 shows the results of the thickening time of the four cement samples using the well conditions stated in API Specification 10A (Table 1).

From Fig. 1, it could be seen that at a consistency of 100 Bc, the setting period for CEM B is shorter, followed by CEM A, CEM C and finally the imported class G. Generally, the entire locally manufactured cements appeared to have shorter setting time or pump shorter as compared to the imported class G cement. This implies that more additives would be required to bring up the thickening time results of locally manufactured cements to the level of the imported class G cement. For example, for high temperature wells, more concentrations of retarders would be needed to bring up the thickening time results.

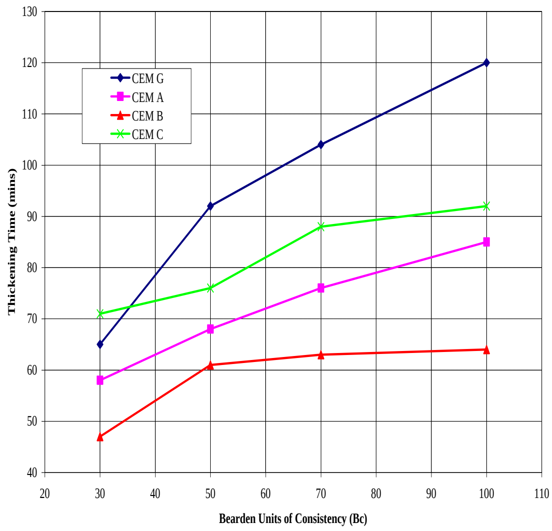

Fig. 1 Thickening Time vs. Consistency

Among the three local cements tested, CEM C appeared to pump longer than CEM A and CEM B. CEM C met the API requirement set for oil well cement, at a consistency of 100 Bc (Fig. 1). This implies that less retarder is required for CEM C than CEM A and CEM B if it is to meet the thickening time of the imported class G cement. According to Shahrudin *et al.* (1993), the higher the tricalcium aluminate content, the higher the rate of reaction during the hydration period of a cement. Therefore the difference in setting time could be due to the difference in tricalcium aluminate content of the cement. Chemically, locally manufactured cements will have the highest amount of tricalcium aluminate and, therefore, would have a high rate of reaction during their hydration period, causing the cement slurries to set at shorter times than imported class G (CEM G) cement containing lower tricalcium aluminate.

The characteristics of these local cements are not different from other local cements as confirmed in other earlier works done by Mfonnom *et al.* (2009) and Joel (2009a) on local cement in Nigeria. According to the API Specifications 10A (Anon, 2013), the maximum consistency during 15 minutes to 30 minutes period after the initiation of test should be 30 Bc. The imported class G cement had the highest consistency value during the 15 minutes to 30 minutes period after the initiation of the thickening time test compared to the local cements, but generally all the cement samples tested satisfied the API requirement (Table 2).

Table 2 Consistency during Fifteen to Thirty Minutes Period

Cement Type	**CEM G**	**CEM A**	**CEM B**	**CEM C**	**API**
Consistency (Bc)	23	9	19	14	Max 30

3.2 Free Fluid Analysis

Free fluid (water) is one of the most important factors that should be as low as possible in cementing operations especially after the cement sets. Test results indicated in Table 3 show that there is no big difference in the free fluid results for all the cements tested in terms of the API recommended standard as both the locally manufactured samples and imported sample were below API standard. However, imported class G had the highest free fluid content as compared to the locally manufactured cements (Table 3). The higher value of free fluid content of class G cement could be due to poor handling which could have resulted to exposure to a lot of moisture. These results were confirmed by the moisture content of each sample. The moisture content of imported sample (CEM G) was higher followed by the local cements; CEM A, CEM B, and CEM C in the same order as the free fluid (Table 4).

Table 3 Free Fluid at BHCT of 125 ^{o}F (52 ^{o}C)

Cement Type	**CEM G**	**CEM A**	**CEM B**	**CEM C**	**A PI**
Free Fluid (%)	3.96	1.05	0.65	0.2	5.9

Table 4 Moisture Content of Cement Samples

Readings (g)	**CEM G**	**CEM A**	**CEM B**	**CEM C**
Weight of Container (m_1)	30.85	30.85	30.85	30.85
Weight of Cement and Container (m_2)	40.85	40.85	40.85	40.85
Weight of Dry Cement and Container (m_3)	40.72	40.78	40.79	40.82
Moisture Content (%)	**1.32**	**0.70**	**0.60**	**0.30**

3.3 Compressive Strength

Compressive strength of the set cements is important as it commonly represents the overall quality of cements. Higher compressive strength generally means lower porosity and increased durability (Nelson, 1990). Fig. 2 shows the results of the compressive strength test cured at 140 ^{o}F (60 ^{o}C) for 8 hours for all the cement samples.

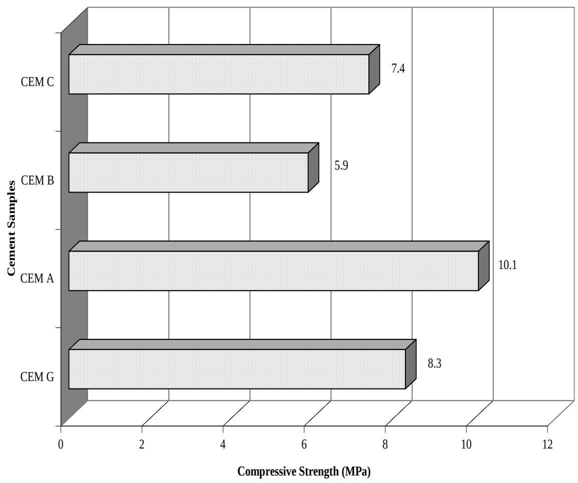

Fig. 2 Compressive Strength of Cement Cured at 140 ^{o}F (60 ^{o}C) for 8 Hours

Early stage compressive strength was more pronounced in locally manufactured CEM A than the imported class G cement and the rest of the locally manufactured cements. CEM A had a better compressive strength than the imported class G. This could be attributed to tricalcium aluminate (C_3A). Because C_3A has a faster rate of reaction during hydration and a faster setting time (Fig. 1), its early stage compressive strength is expected to be higher. Surprisingly, locally manufactured cements CEM B and CEM C proved otherwise, as their compressive strengths were lower than imported class G though they have shorter setting period. Generally, none of the cement samples met API minimum requirement which is a minimum of 1500 psi (10.3 MPa) at 140 ^{o}F (60 ^{o}C) for 8 hours.

3.4 Rheological Properties

Table 4.5 presents the results of rheology test conducted at BHCT of 125 ^oF (52 ^oC). The basic reason for determination of rheological properties was to predict plastic viscosity and yield point values. The rheological values obtained from the local cement samples compared favourably with that of the imported cement. No gelation was observed at Bottom Hole Circulating Temperature (BHCT) of 125 ^oF (52 ^oC) for all the cement samples. In almost all the tests conducted, the values of the Plastic Viscosity (PV) were below 100 cp (100 mPa.s), which according to Abbas *et al.* (2014) is desirable to keep cement slurry pumpable. The values of the Yield Point (YP) calculated also showed that all the slurries were pumpable at 125 ^oF (52 ^oC).

Table 5 Rheological Properties of Local and Imported Cement Samples

Rheology @ BHCT of 125 ^oF(52 ^oC)	CEM G	CEM A	CEM B	CEM C
300 rpm	74	121	174	95
200 rpm	67	107	155	82
100 rpm	58	87	135	65
6 rpm	20	28	28	20
3 rpm	15	18	25	18
Plastic Viscosity, cp (mPa.s)	**24 (24)**	**51 (51)**	**58.5 (58.5)**	**45 (45)**
Yield Point, lb/100 ft^2 (Pa)	**50 (24)**	**70 (34)**	**115.5 (55.3)**	**50 (24)**

4 Conclusions and Recommendations

From the research it could be concluded that:

(i) Locally manufactured cement CEM A proved to have faster early compressive strength development and lower free fluid content than imported class G cement. However, CEM A pumps shorter than imported class G.

(ii) Locally manufactured cement CEM B proved to have suitable free fluid properties for oil well cementing than imported class G Cement. Both cements met API specification for free fluid. In terms of compressive strength and thickening time, class G cement proved to be better than CEM B, though both cements could not meet API specifications.

(iii) Locally manufactured cement CEM C proved to have better free fluid properties than imported class G. In terms of compressive strength and thickening time, class G cement proved to be better than CEM C. However, CEM C met API minimum value for thickening time, but pumped shorter when compared to class G.

(iv) Rheological values obtained from the locally manufactured cements compared favourably with that of the imported cement. No abnormal gelation was experienced for both the local cements and the imported class G cement.

For the investigated properties, and at the stated conditions of temperature and pressure, CEM A compares favourably with class G in respect of API specifications, followed by CEM C and CEM B in terms of their potential for oil and gas well cementing.

It is recommended that further tests be conducted on locally manufactured cements on the chemical properties and also confirm stability for High Pressure and High Temperature (HPHT) operations.

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