Mix-Water as a Chemical Additive for Oil Well Cement Compressive Strength Development

[1,] S. IGBANI, [2,]K. KOTINGO, [3,] B.J. IGOLIMA, [4,] V.W. OSAKWE

[1, 3, 4,] Department of Petroleum Engineering, Faculty of Engineering, Niger Delta University, Bayelsa State, Nigeria.

[2,] Department of Mechanical Engineering, Faculty of Engineering, Niger Delta University, Bayelsa State, Nigeria.

ABSTRACT: Vividly, in primary oil well cementing, cement hydration is termed as the chemical reaction between powdered Portland oil well cement and mix-water, which is always in a particular water-to-cement ratio (w/c), to form a mixture. This mixture is known as cement slurry. The cement slurry is usually pumped downwards through the inner diameter of the runed casing string. Then, allowed to enroute upwards in the annular space between the outer diameter of the runed casing string and the drilled formation wall, to a desired depth within an optimal pumpable, flowable, or thickening time. At this point, the cement slurry is allowed in days passé, to set and hardened into a rigid body known as cement sheath. The cement sheath with the recommended minimum American Petroleum Institute (API) compressive strength (CS) of 1,500psi functions in the annular space as a primary safety barrier, to provide well integrity and complete well isolation in the wellbore. Additionally, previous studies have shown that the relationship between w/c and the CS of a given cement sheath system, is inversely proportional. Consequently, this study employed this premise surrounding this relationship between w/c and CS development of cement sheath system, to classify mix-water in terms of quantity, as a chemical additive. Consequently, this study disclosed that low quantity of mix-water in cement mixture acted as an accelerating cement strength developing chemical additives, while high quantity of mix-water in cement mixture aceds as a retarding cement strength developing chemical additive. As a result, the study shows that, high quantity of mix-water in cement mixture (0.5 to 0.8) acted as a retarding cement strength developing chemical additive, while low quantity of mix-water in cement mixture (0.2 to 0.45) acted as an accelerating cement strength developing chemical additive. Also, the study disclosed that higher quantity of w/c could be classified as water-extender.

KEYWORDS:Compressive strength; Cement sheath; Water-to-cement ratio; Chemical additives; Accelerators; Retarders

I. INTRODUCTION

Powdered Portland oil well cements are hydrophilic and are not hydrophobic in nature (Lag *et al.*, 2008). Therefore, water gives life and sustains the probable desired properties of cement CS during hydration, setting and hardening time. In wellbore cementing technology, hydration is termed as the chemical reaction, which occurs between powdered Portland oil well cement and mix-water, and probably in the presence of admixtures or additives (Ley-Hernandez *et al.*, 2018; Talal, 2013). This chemical reaction immediately produced a non-Newtonian viscous mixture. This mixture is called plain or neat cement slurry, if the reaction is between Portland oil well cement and mix-water only (Ley-Hernandez *et al.*, 2018). Practically, immediately cement hydration occurs, the mechanism of phase boundary nucleation and growth (pBNG) is initiated on the cement solid powdered particles, including any available solid surface, such as the runed casing string's surface and drilled formation wall in the wellbore annular space or annulus. The pBNG makes the cement slurry to loss its flowability, which enables the slurry to get set and hardened with-respect-to (wrt) time (Ley-Hernandez *et al.*, 2018). Also, at the prevailing wellbore conditions, the hardened cement body without aggregates is known as cement sheath.On the other hand, the hardened cement body with aggregates is known as concrete (Azar and Samuel, 2007).Nevertheless, these processes can either be prolonged on one hand using retarding additives, or on the other hand be shortened using accelerating additives (Broni-Bediako*et al.*, 2016). These retarding and accelerating conditions of cementing processes are applicable, eitherin atmospheric or high-pressure and high-temperature (HPHT) environments, with the aid of chemical additives (Broni-Bediako*et al.*, 2016). Also, the process of cement hydration, setting, and hardening can either be prolonged or accelerated, based on the dosage of the chemical additive (Li *et al.*, 2018).Explicitly, cement hydration involves the dissolution of the anhydrous phase concomitant of the cement slurry into a prime precipitating hydrate termed calcium silicate hydrate or C-S-H. Calcium silicate hydrate is the glue in cement sheath structures, which determines the compressive or structural strength development of cement sheath system (Ley-Hernandez *et al.*, 2018; Torabian*et al.*, 2017).

Furthermore, cement sheath is the cement rigid body formed in the annular space between the casing string and the formation wall, to provide well integrity and complete zonal isolation with a fortified CS. Hence, the CS of cement sheath resists the formation cyclic and static forces from compressing the cement sheath (Li *et al.*,2018). Notably, the cyclic forces are pore pressure, temperature, overburden pressure; while the static forces are identified as the linear expansivity of casing string and formation wall (Li *et al.*,2018).Consequently, the CS discloses the ability of the rigid cement bond at the annulus, to withstand compressing loads (Igbani *et al.*, 2020). Also, CS in this context can be defined as the capacity of cement sheath to withstand cyclic and static loads at subsurface prevailing well conditions (Azar and Samuel, 2007). Furthermore, CS is described as that feature of cement sheath, which stabilises and sustains oil and gas well integrity (Wojtanowicz, 2008). Concisely, in simple terms, the CS of cement sheath can be explained as the ability of rigid cementitious materials, to withstand deformation when exposed to load (Ridha*et al.*, 2014).

Therefore, CS is the ability of the wellbore safety barrier such as cement sheath, to withstand compressing load, in preventing the collapse of a drilled wellbore. A task that accomplishes well integrity and complete well zonal isolation in the annular space between the outer diameter of the casing string and the formation wall. This point outs the major functions of cement sheath system, as complete well zonal isolation and well integrity (Labibzadeh*et al.*, 2010; Heinold*et al.*, 2002). However, several factors militate against the cement sheath system's CS from performing its dominant functions. One of the major factors that influences CS, is the quantity of mix-water used in the formulation of cement slurry (Abd and Abd, 2017; Apebo *et al.*, 2013; Alawodeand Idowu, 2011; Felekoğlu*et al.*, 2007), and quality of mix-water used in the preparation of cement slurry (Igbani *et al.*, 2020). Other factors are temperature (Kim *et al.*, 2002; Vodák*et al.*, 2004; Joel &Ademiluyi, 2011; Xu *et al.*, 2021; Ahmad *et al.*, 2021); pressure (Muhaimin *et al.*, 2021; Fu *et al.*, 2021); corrosive gases (Pather*et al.*, 2021).

Similarly, factor such as the linear expansivity of the casing string and the formation wall; vibration from pipe tripping and continuous drilling after waiting on cement (WOC) influence the cement sheath system's CS development. The 'cause-and-effect' of these influencing factors on the cement sheath systems CS development are always mitigated using additives, to prevent cement *flash-set* or *pseudo-set*. A commonly used additive to prevent *flash-set* is gypsum. As a result, gypsum functions in the cement slurry, including cement solid matrix, to prevent the hydration of tricalcium aluminate (C_3A) clinker. The C_3A is the major clinker that produced ettringites that, enhanced *pseudo-set* (Black *et al.*, 2006; Azar and Samuel, 2007).Nevertheless, this study focused on the effect of the quantity of mix-water used in the formulation of cement slurry, w/c on the cement sheath CS. Also, this study suggested the classification of w/c as an additive, which influences strength development of cement sheath systems either at *in-situ* wellbore prevailing conditions or atmospheric conditions or at simulated well conditions.Additionally, this study critically pursues the issues surrounding the poor identification of chemical additives, wrong classification, and poor application of these additives, which culminate into the cement sheath losing its structural integrity and complete zonal isolation features.

Consequently, this study focused on the role of mixing water or mix-water in oil and gas well cementing, to enable the classification of mix-water as a chemical additive, which is the main problem of this study. Therefore, this study aim is, to classify mix-water as a chemical additive, based on the following objectives: to formulate various cement sheath systems of known w/c, to test the CS of theformulated cement sheath systems, and to classify river nun mix-water as an additive per its participation in the w/c. Significantly, this study attempted to include river nun mix-water as member of oilwell chemical additives. Also, the study emphasised the appropriate use of mix-water quantity, to reduce the frequently reported cases of incidents and accidents associated with structural cementing failures. This implies that the study's outcomes would save cost, investment and rescinds the cost and time for secondary or remedial cementing. In addition, this study would help to protect against environmental damage, prevent stakeholders' accident, including the protection of the international oil companies' public confidence and reputation.

II. LITERATURE REVIEW

Mix-Water to Cement Ratio (w/c) and Its Role in Oil well Cement Sheath Compressive Strength Development: Generally, the CS of cement sheath is the ability of the cement bond between the annular space of the casing string and formation wall at oil well prevailing conditions, to withstand loads or compressing forces, which tend to reduce its size. In other words, CS repels compression (being pushed together). Further on, CS is a prime feature of cement sheath strength development, while cement sheath is the final product of oil well cement slurry hydration. Additionally, CS of a cement sheath is very important, sinceCS usually represents the total qualities of cement sheath's mechanical performance responses, and the cement slurry's flowability, setting, and hardening time responses (Wan, 2011).

Accordingly, Mehta and Monteiro (2005) previously explained that the production of cement slurry required mix-water and cement powder, and that the rate of consumption of mix-water is approximately directly proportional with the size of the powdered cement ground particles, in some given ratio of w/c. This explains that the finer the ground of the cement powder, the more quantity of mix-water well be required for the cement mixture formulation (Azar and Samuel, 2007). Though, the use of improper w/c impacts negatively on the cement sheath'sCS development (Anifowose*et al*., 2021; Ley-Hernandez *et al.*, 2018; Apebo *et al*., 2013). Consequently, the CS development success or failure occured based on the quantity of mix-water used, in the preparation of the cement slurry (Bett, 2017; Apebo *et al*., 2013; Pattinasarany and Irawan, 2012; Taha *et al*., 2010; Al-Jabri *et al*., 2010; AI-Manaseer *et al*., 1998). Although, the designed cement slurry was obtained by an acceptable specified ratio of mix-water and powdered cement (w/c), subjected to an approved API mixing specification (Azar and Samuel, 2007; API Specification 10A, 2002). Thus, Azar and Samuel (2007) inferred that a reasonable w/c of about 2.8 gal/sack should be applied for Class G Portland cement to obtain a compromised cement slurry, while API Specification 10A (2002) specified between 4.5 and 5.0. In the same vein Azar and Samuel (2007) further explained that such cement slurry cannot be pumped to the targeted well depth, since its viscosity was too high, and its pumpability would be very poor. However, Azar and Samuel (2007) said that, to remedy this poor pumpability, much mix-water should be added into the cement slurry. In the contrary, Azar and Samuel (2007) acknowledged that at static conditions, if excess quantity of mix-water is used, to prepare the cement slurry. There might be the existence of free water, as supernatant at the near top of the wellbore column, leaving the cement slurry at the bottom as residue. This also includes a decrease in cement sedimentation stability (Minaev*et al.,* 2014). In retrospect, Haach*et al.* (2011) explicitly concluded that when the mix-water used to prepare a cement slurry is greater than the required quantity, the slurry's pumpability increases while the CS is reduced detrimentally. These studies' results wereretrospectively confirmed by Crooks's (2006), that free water in cement slurry should be prohibited in oil and gas wellbore cementing.Based on theseprinciples, excess mix-water not used by calcium silicate hydrate during cement slurry preparation, is known as free water, and it is very detrimental to the CS development of oil well cement sheath development. Similarly, the excess water, which residence in the pore system of the cement-water paste turned to be a source of water, for further curing during the residual hardening period. This excess water or free water can be diffused through or under conditions of high temperature or dryness. Although, when the w/c is higher, and when water-retaining agents are not added into the cement slurry, there would be high cement segregation and an increase in the cement filtration (Minaev*et al.*, 2014). In the aftermath, the free water in turned created some channels and some pocket of pores in the hardened cement or cement sheath. In consonant with the term free water, Bourgoyne*et al*. (1986) previously explained that excess quantity of mix-water not used by tobermorite (Calcium Silicate Hydrate, or C-S-H, or $3CaO.2SiO_2.3H_2O$), during hydration reduces the cement CS and creates more channels. These make the sheath more porous and permeable. Hence, this sheath characterised with these porous and permeable features will not only enablea kick, or subsurface fluids communication between the formation zones, but to the surface. When this happens, the cement sheath ceases to give its prime functions of complete zonal isolation and structural support, to the subsurface casing string and surface equipment. Consequently, this deprived appearance of pores and channels in the cement sheath allow for poor CS, good permeability of formation fluids through the channels, and poor durability of the sheath at subsurface conditions, which possibly a kick may occur that may graduate into a blowout.

With regards to averting the occurrences of kicks, Atahan*et al.* (2009) studied the effects of w/c and curing time on the critical pore-width of hardened cement slurry; the study used five mixes of Portland cement slurry with the w/c of 0.26, 0.30, 0.34, 0.38, and 0.42. Subsequently, all the specimens were cured in water saturated with lime for 7, 14, 28, and 365 days; and the specimens with w/c of 0.26, 0.34, and 0.42 were cured for 7, 28, and 365 days, respectively, and were exposed to a mercury intrusion porosimetry tests. These tests findings indicated that, the critical pore-width of the cement sheath appeared to be dependent of the w/c. The critical pore-width of the cement sheath systems were of the order of approximately 25nm; and was considered as the critical pore-width of the Portland cement gel. This also negatively affected the CS of cement sheath.In another developmental study, Zhang *et al.* (2003) deduced that as the w/c decreases, the total shrinkage of sheath increases. Also, when Yasar *et al.* (2004) studied the effect of w/c and coarse-limestone aggregate-type on the CS of the sheath at atmospheric condition, it was observed that the CS of the sheath was inversely a function of w/c and aggregate size of the limestone. In addition, Singh *et al.* (2014) worked on the responsibility of w/c on the strength development of the cement bond. The disclosed results showed that CS of the cement hardened rigid body decreased with an increase in the w/c, which the illustration byFelekoğlu*et al.* (2007) in Figure 1, confirmed the studies of Singh *et al.* (2014); Yasar *et al.* (2004); Zhang *et al.* (2003).In conclusion, the reviewed studies were based on the impacts of w/c on the properties of CS of cement sheath and concrete systems. The studies on concretes were to ascertain the precursor of this study. In addition, these impacts were observed at atmospheric, and at oil and gas well prevailing conditions. Hence, the consulted studies disclosed that, higher w/c strongly and inversely affected the CS of the cement sheath and concrete systems (Figures 1 and 2). However, chemical additives were always used in the upstream petroleum industry, to beneficiate the CSdevelopment of oilwell cement sheaths.

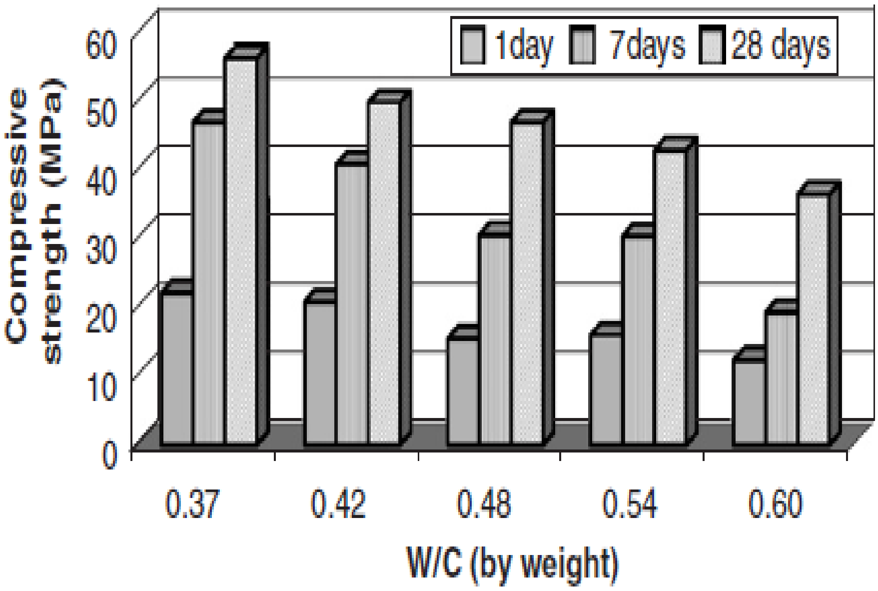

Fig 1.Effect of w/c on the fresh and hardened properties of self-compacting concrete (Felekoğlu*et al.*, 2007)

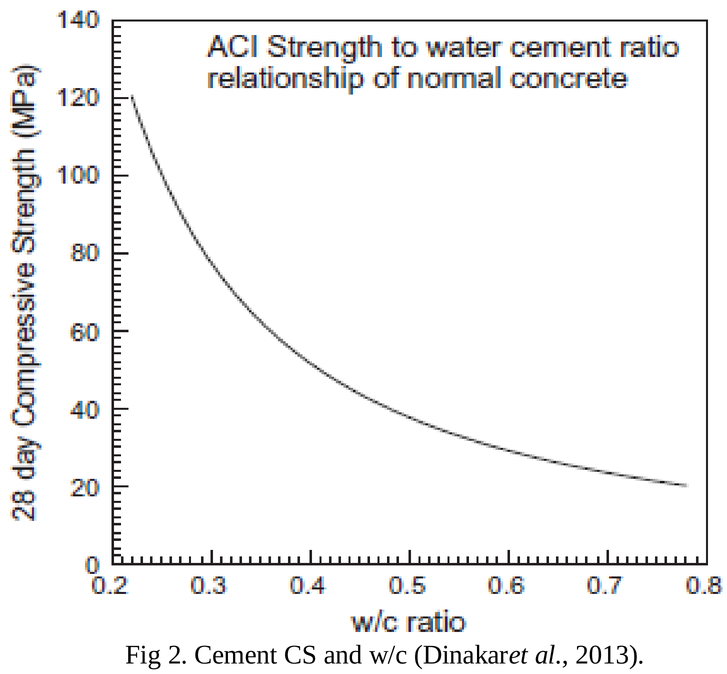

Fig 2. Cement CS and w/c (Dinakar*et al.*, 2013).

Cement Sheath Compressive Strength Additives: In the upstream petroleum industry, primary oil well cementing involves the design of cement slurry, placement of the designed cement slurry within a specific period into the desired annular-space or annulus and depth, allowing the slurry to set and hardened. During the process of cement slurry placement, setting and hardening, including the usage of the wellbore, both the cement slurry and cement sheath encounter hash subsurface conditions (Igbani *et al.*, 2020; Zeng *et al.*, 2019; Bello, 2014).These harsh conditions include the permafrost temperature in the Artic zone, which is below freezing 32^0F (0^0C); deep oil wells of temperature up to 500^0F; steam wellbore of temperatures between 450^0 and 500^0F; fireflood or geothermal wellbores of temperatures between 1500^0 and 2000^0F; pressures of between atmospheric and 30,000psi; anthropogenic effects of thermal enhanced oil recovery, just to mention a few (Broni-Bediako*et* *al.*, 2016).These hash subsurface conditions tending to alter the desired cement sheath CS development were contained using additives or admixtures (Broni-Bediako*et al.*, 2016; Ogbonna, 2009). Therefore, any substance or material blended with powdered Portland oil well cement during manufacturing, to formulate cement slurry, or any substance or material dispersed into cement slurry, to improve the desired oil well CS can be described as cement sheath strength developing chemical additive. Accordingly, Broni-Bediako*et al.* (2016) reviewed some previous studies on oil well cement additives. In this study, Broni-Bediako*et al.* (2016) identified mix-water as the universal solvent used, to dissolve and hydrate powdered Portland cement into cement sheath. With regards to this premise, Rike (1973) previously opined thatan additive should be firstly added into the mix-water and properly mixed before the design of the slurry.This singular action should be performed, to avoid accidental lump-sided or excess fraction of the additive, causing *flash-set* of the cement sheath. These oilwell cement additives can either increase or regulate the CS of cement sheath up to 20,000psi or at a given value, respectively (Broni-Bediako*et al.*, 2016).

Nevertheless, API has recommended 1,500psi as the minimum CS for cements and materials for oilwell cementing (API Specification 10A, 2002). This specification is different from that of drilling further; after the casing have been cemented, which recommends a CS in the range of 102 to 725 psi; since further hydration and structural changes occur through the exploitative life cycle of the cemented wellbore, and even after plugging and abandonment of the wellbore (Omosebi*et al*., 2016).

Specifically, some studies have recommended 500psi as the minimum CS for cementitious materials, and the minimum CS required for bonding and supporting casing string in the annulus (Laili, *et al.*, 2015; API Specification 10A, 2002; McConnell Jr *et al.*, 1996). Practically, cement accelerators are additives used to shorten the thickening time and setting time of basic oilwell (mostly class G or H) cement slurry, in shallow wellbore with temperature below 100^0F, at atmospheric pressure, to bring about early cement strength development of about 500psi within 4hrs. The commonly used cement accelerators are calcium chloride ($CaCl_2$), sodium chloride (NaCl), gypsum ($CaSO_4 \cdot 2H_2O$ or CSH_2), sodium silicate (Na_2SiO_2), just to mention a few (Broni-Bediako*et al.*, 2016).The cement accelerator $CaCl_2$ is a flaked or powdered hygroscopic material. About 2 to 4% of $CaCl_2$ by weight of cement (BWOC) requires higher quantity of mix-water to cement ratio, to accelerate the thickening time and setting time of cement slurry and bring about early setting and hardening of cement. As presented in Table 1, NaCl is also identified as chemical additive (AbalakaandBabalaga, 2011).

Table 1: Basic Portland oilwell cement sheath development chemical additives

Term	Classification	Examples	By Weight of Cement (BWOC) %	Temperature (^{0}F)	References
Oil well Cement Sheath Compressive Development Chemical Additives	Retarder: Retarding Early Strength Development Additives	High concentration of Sodium Chloride (NaCl).	Above 8%	Above 160^0F	(Lake & Mitchell, 2006; Michaux *et al.*, 1990; Rike, 1973; Ludwig, 1951).
		High concentration of Calcium Chloride ($CaCl_2$).	Above 6%	Above 120^0F	(Magarini *et al.* 1999)
		Lignosulfonate	0.1 - 0.2%	Less than 200^0F	(Bett, 2017)
	Accelerator: Accelerating Early Strength Development Additives	Low concentration of $CaCl_2$.	2 - 4%	40 - 120^0F	(Magarini *et al.*, 1999)
		Low concentration of NaCl.	2 - 2.5%	Less than 160^0F	(Winnefeld *et al.*, 2017; Bett, 2017; Lake & Mitchell, 2006; Magarini *et al.*, 1999; Michaux *et al.*, 1990; Rike, 1973).
Oil well Cement Sheath Compressive Development Chemical/Mechanical Additives	Extenders: Based on concentration or quantity of the extenders; the extenders reduce the weight and compressive strength of cement.	Low concentration of bentonite, sodium silicate, foamed cement, and microsphere act as accelerator; while the reverse act as retarder. The chemical additives are bentonite, sodium silicate, and foamed cement; while microsphere is a mechanical additive.	0.1-4.9% (accelerator) 5 - 15% (retarder)	At 100^0F	(Bett, 2017; Samsuri *et al.*, 2001).

Basic Characteristics for Oil well Cement Sheath Development Chemical Additives

- Chemical additives are applicable in oil and gas wells of permafrost temperature below freezing point (Magarini *et al.*, 1999).

- Chemical additives are suitable in thermal and geothermal oil and gas wells of temperatures above 600^0F (Magarini *et al.*, 1999).
- Chemical additives are appropriate in cementing oil and gas wells of ambient to 30,000psi pressures (Magarini *et al.*, 1999).
- Chemical additives are only active during cement hydration (Ogbonna, 2009).
- Chemical additives enhanced the mechanical properties of cement during cement hydration (Ogbonna, 2009).
- low concentration of chemical additives shortens the time for early cement sheath strength development (Broni-Bediako*et al.*, 2016; Rike, 1973).
- High concentration of chemical additives acts as retarders (Bett, 2017).
- Retarding chemical additives prolong the time for early cement sheath strength development (Satiyawira*et al.*, 2010).
- Chemical additives as extender in high quantity lightens the weight and reduces the strength of cement sheath and reduces the viscosity of cement slurry (Broni-Bediako*et al.,* 2016; Azar and Samuel, 2007).

Acknowledgment of the Study's Gap: Concisely, the reviewed studies have disclosed that, the cement sheath's CS is always affected by the w/c of between 0.2 to 0.8. Additionally, the reviewed studies summarised that the pocket pores and channels created by excess mix-water were due to the improper application of w/c. Explicitly, the studies also disclosed that, the higher the w/c, the lower the CS of cement sheath; while the lower the w/c, the higher the CS of cement sheath, but the slurry's acceptable design with the required w/c,should be based on the instance of the required pumpability of the cement slurry.On the contrary, these studies were unable to classify the w/c range into either accelerating, retarding, or light weight additives, as it affects the CS of cement sheath. Though, Bentz *et al.* (1994) mentioned that mix-water is the cheapest material used in designing cement slurry, which exist as dilution. Therefore, w/c has not been neither identified nor classified as chemical additive, despite previous results showing that w/c affects the CS development of cement sheath systems (Broni-Bediako*et al.*, 2016; Azar and Samuel, 2007; Bentz *et al.*, 1994). Consequently, in an attempt to classify w/c as a chemical additive, this study employed the methodology of API specification for cements and materials for well cementing (API Specification 10A, 2002).

III. METHODOLOGY

In this study, both samples of powdered Class G oilwell cement and the river nun mix-water were collected and prepared according to the API (API Specification 10A, 2002) and the Nigeria Standard Drinking Water Quality and WHO standards,respectively(NSDWQ, 2007; WHO, 2011). Subsequently, these prepared samples of powdered Class G oilwell cement and the river nun mix-water were used in the formulation of neat cement slurries, at different w/c. As a result, these neat cement slurries were cured into cubes of cement sheath systems. Finally, each of the cement sheath systems were subjected toCS tests. Figure 3 described this study's methodology employed.

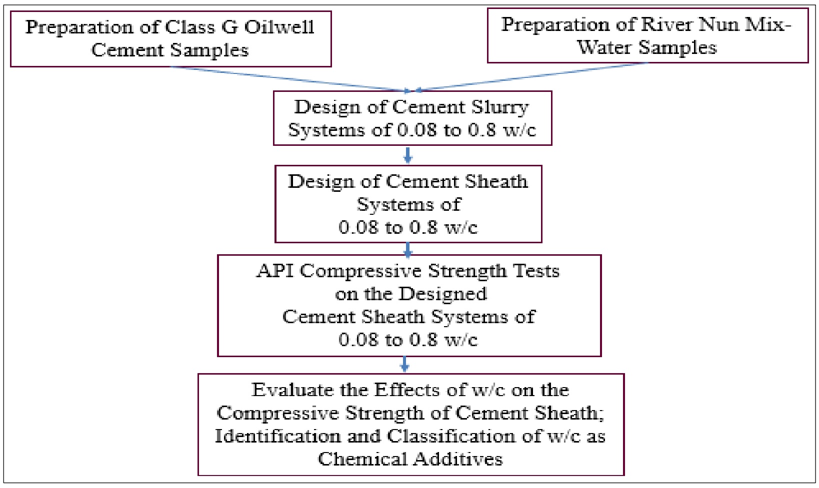

Fig 3: This study's methodology.

IV. MATERIALS AND METHOD :

Materials and Equipment: The basic materials used for this study were Portland oil well cement (Class G oilwell cement) and River nun mix-water. Also, the basic equipment and apparatus used in this study were

Cement mixer, Vibrator, Thermometer, Measuring cylinder (1000ml), Triple beam balance, Mini-plastic bucket, Trowel, Plastic cans, Wooden mold and Rebounce hammer.

Method

Collection and Preparation of River Nun Mix-Water: Firstly, all apparatus were washed, cleaned, and well calibrated before usage. The river nun mix-water was collected from the middle of the river within the vicinity of Amassoma waterfront. Forty-liter of mix-water was collected into jerry cans. This mix-water sample was subjected to water chemical tests using the Nigeria Standard Drinking Water Quality and the World Health Organisation standards ((NSDWQ, 2007; WHO, 2011), to ascertain its potability. The water chemical analyses results are presented in Table 2.

Table 2:Basic Physicochemical Characteristics River Nun Mix-Water at Amassoma Vicinity

S/No.	Parameter/Unit	Experimental Value	WHO (2011) Standard
1.	pH, unitless	6.920	6.5 - 8.5
2.	Salinity, mg/L	0.013	0.44
3.	River Temperature, ^0C	25.343	25
4.	Conductivity, µS/cm	45.667	1000
5.	Turbidity, NTU	29.435	5
6.	Total Dissolve Solid, mg/L	23.100	1000
7.	Nitrate, mg/L	0.278	50
8.	Chloride, mg/L	1.900	200
9.	Sulphate, mg/L	0.544	200
10.	Total Suspended Solid, mg/L	3.544	2.56
11.	Total Hardness, mg/L	1.667	100
12.	Ferrous Iron, mg/L	0.156	0.30

Preparation of Portland Class G Oil Well Cement Samples: Five (5) bags of 50kg of Portland Class G oilwell cement was acquired from an oilfield chemical dealer. The powdered Portland Class G oil well cement was sieved with a shaker screen size #20 API to mesh size of 840 micron, which removed lumps from the cement powders from each of the samples. Each of the samples contained 500g of the sieved powdered Portland Class G oil well cement. As a result, 76 samples were prepared. Additionaly, the manufacturer's properties specifications of the Portland Class G oil well cement used are presented in Tables 3 to 5.

Design of Portland Class G Oil Well Cement Slurries: Cement slurries were designed by the addition of 500g of the sieved powdered Portland Class G oil well cement into 19-container held 40; 60; 80; 100; 120; 140; 160; 180; 200; 220; 240; 260; 280; 300; 320, 340; 360; 380; 400g of river nun mix-water. The w/c are presented in Table 6 and labelled SP1-SP19. Practically, these slurries were formulated based on the principles of API (API specification 10A, 2002). Accordingly, each of the containers with mix-water as its content was subjected to mixing at the speed of 4,000 rpm for about 15 seconds; after all the measured Class G cement (500g) had been added into the mix-water (40, 60, ... 400g). This explained that, each of the cement slurries were formulated at different w/c (0.08 to 0.8).

Further on, the mixing of each of the content of containers was covered and placed for mixing at the speed of 12,000rpm for 35 seconds in the cement-mixer. After the samples of the slurries were formulated, each set of the 19-cement slurry were cured for 7, 14, 21, 28 days. Therefore, 76 cement slurries were formulated and cured into cement sheath systems for this study.

Table 3: Manufacture's analysis for surface area of Class G BOWC (wt.%).

CEMENT TYPE	COMPONENTS %					SURFACE AREA (m^2/g)
	C_3S	C_2S	C_3A	C_4AF	Gypsum	BET Method
Class G-HSR Cement	62.93	14.82	0.57	11.34	1.8	1.00±0.0075

Table 4: Chemical Properties of Class G

S/No.	Parameter/Unit	Value
1.	Loss on ignition, %	0.80
2.	Insoluble residue, %	0.42
3.	MgO, %	2.0
4.	C_3S, %	63
5.	C_2S, %	14.80
6.	C_3A, %	2.2
7.	$C_4AF + 2C_3A$, %	18
8.	Gypsum, %	< 1.8
9.	Alkali content expressed as Na_2O, %	0.66
10.	SO_3, %	1.65
11.	Al_2O_3 to Fe_2O_3	> 0.64

Table 5: Physical Properties of Class G

S/No.	Parameter/Unit	Value
1.	Specific Gravity, unitless	3.14
2.	Surface Area, m^2/g	1.00
3.	Bulk Weight, lbs./ft^3	3.14
4.	Water for standard consistency [(Water (g)/Cement (g)* %]	0.44
5.	Initial Setting Time at atmospheric condition, minutes	30
6.	Final Setting at atmospheric condition, minutes	600
7.	Minimum Thickening Time, minutes	90
8.	Maximum Thickening Time, minutes	120
9.	Thickening Time + Additives to enable placement in HT, ^0F	550
10.	Maximum Consistency Between 15 – 30 minutes, Bearden (B_c)	30
11.	Minimum CS at curing: time (8hrs), temperature (100^0F), and Atmos. pressure, psi	300
12.	Maximum CS at curing: time (8hrs), temperature (140^0F), and Atmos. pressure, psi	1,500
13.	Depth Usage as Neat Cement Slurry, ft.	≈ 8,000
14.	Depth Usage when mixed with Additives, ft.	> 8000
15.	Response to Retarders, unitless	Excellent
16.	Free water content, mL	4.3
17.	Soundness, %	0.08

Table 6: w/c used in this study

Sample	Weight of Mix-Water (w), g	Weight of Cement (c), g	Water-to-Cement Ratio (w/c)
SP_1	40	500	0.08
SP_2	60	500	0.12
SP_3	80	500	0.16
SP_4	100	500	0.2
SP_5	120	500	0.24
SP_6	140	500	0.28
SP_7	160	500	0.32
SP_8	180	500	0.36
SP_9	200	500	0.4
SP_{10}	220	500	0.44
SP_{11}	240	500	0.48
SP_{12}	260	500	0.52
SP_{13}	280	500	0.56
SP_{14}	300	500	0.6
SP_{15}	320	500	0.64
SP_{16}	340	500	0.68
SP_{17}	360	500	0.72
SP_{18}	380	500	0.76
SP_{19}	400	500	0.8

Design of cement sheath systems : The API specification for oil well cements and materials was used, to produce the cured cubes of cement sheath systems, at the average daily atmospheric of 32^0F (API Specification 10A, 2002). Accordingly, after the cement slurries prepared were vibrated for about 25 seconds, each of the prepared cement slurries were poured into a wooden mold made-up of 5 compartments, which each is 2 by 2 squared inch in measurement, which were filled, pounded, and stirred, to eject entrapped pockets of dissolved air in the designed cement slurry. Subsequently, these cured cubes were further cured in a water bath for about 48 hours. Then, these samples of cured oilwell sheath cubes were exposed to CS tests. All expirements were performed at atmospheric conditions.

Compressive Strength Tests for the Cement Sheath Systems : After the cement sheath cubes have been cured for 48hrs in a water-bath, two (2) cured cubes from each of sets were used for the CS tests. The re-bounce hammer was applied on it and the CS was measured in all the samples. The expermentalresults are presented next for discussion.

V. RESULTS AND DISCUSSION

Results: This study formulated neat oil well Portland cement slurries with mix-water from river nun at various w/c (0.08 to 0.8) ratios. These cement slurries were cured into 2 by 2 by 2 inches cubes (as displayed in Plate 1) for 7, 14, 21, and 28 days, at the average atmospheric temperature of 320F. When these cured cubes of cement sheath systems were subjected to CS tests. These results were collected, organised, and analysed then presented in a spreadsheet of Microsoft Excel then presented in line charts (see Figures 4 to 8).

Plate 1: Cement sheath system cured for 7 hours.

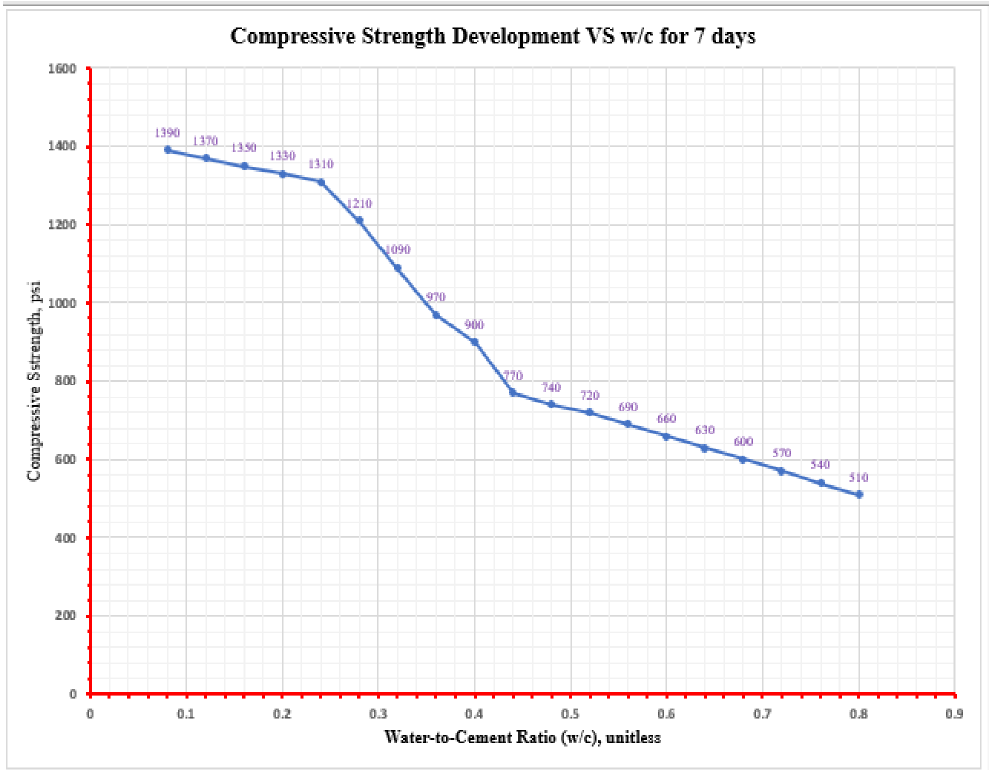

Fig 4: 7 days effects of w/c on CS development.

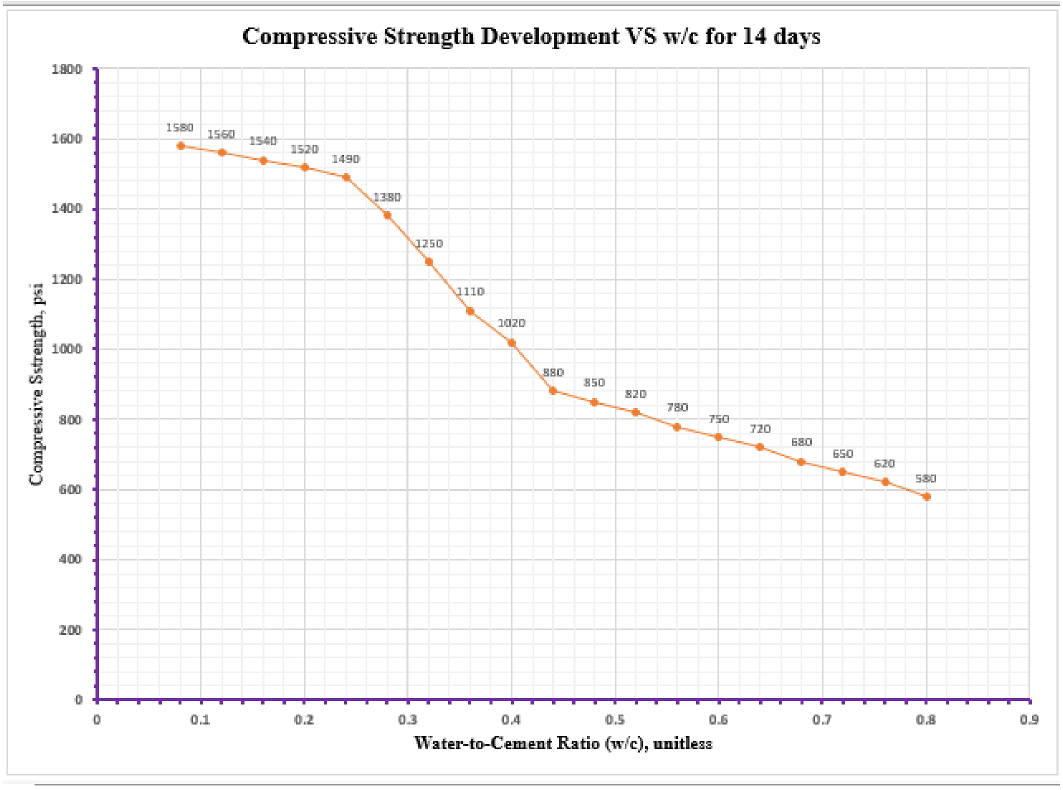

Fig 5: 14 days effects of w/c on CS development.

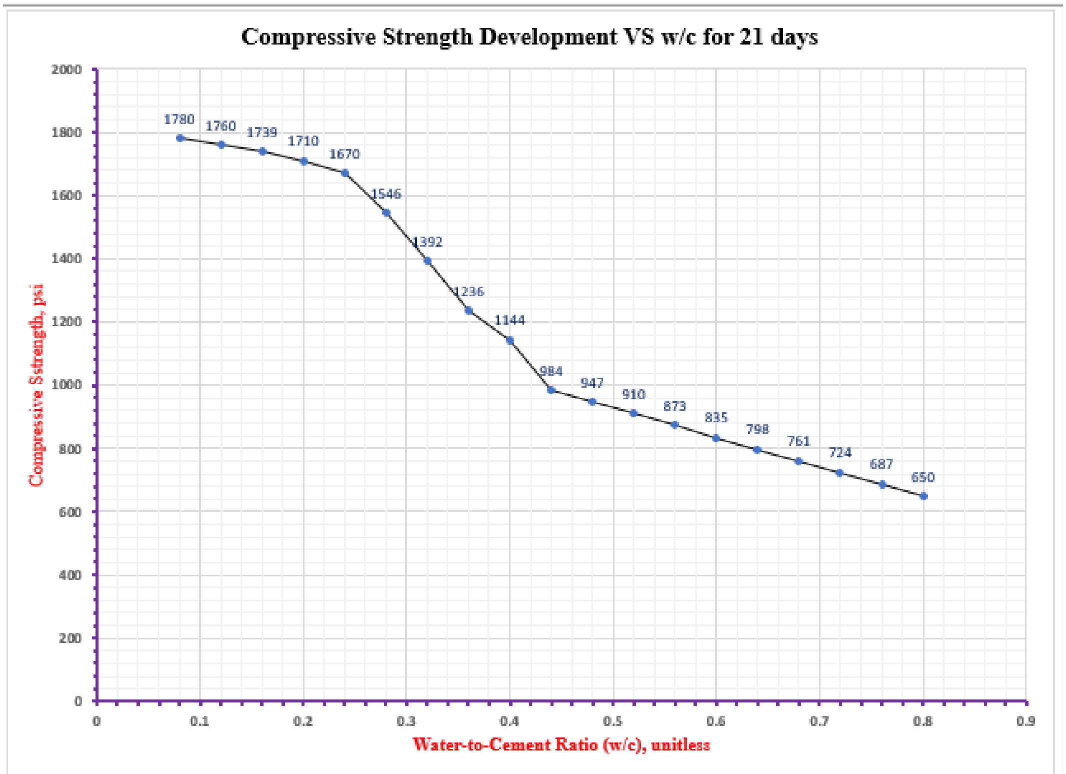

Fig 6: 21 days effects of w/c on CS development.

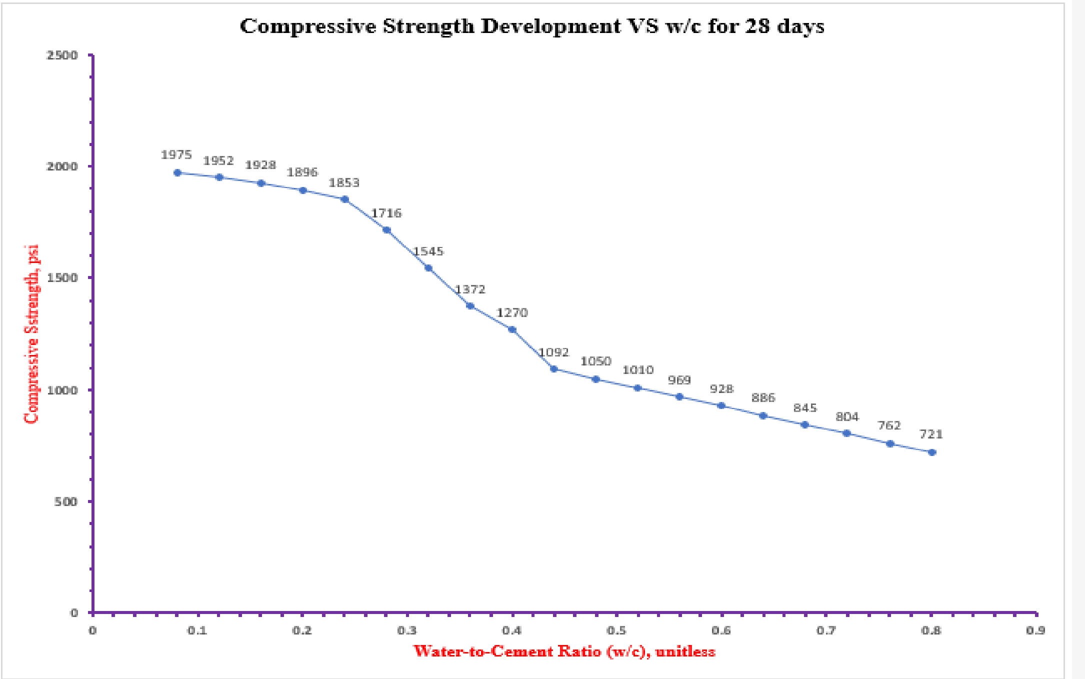

Fig 7: 28 days effects of w/c on CS development.

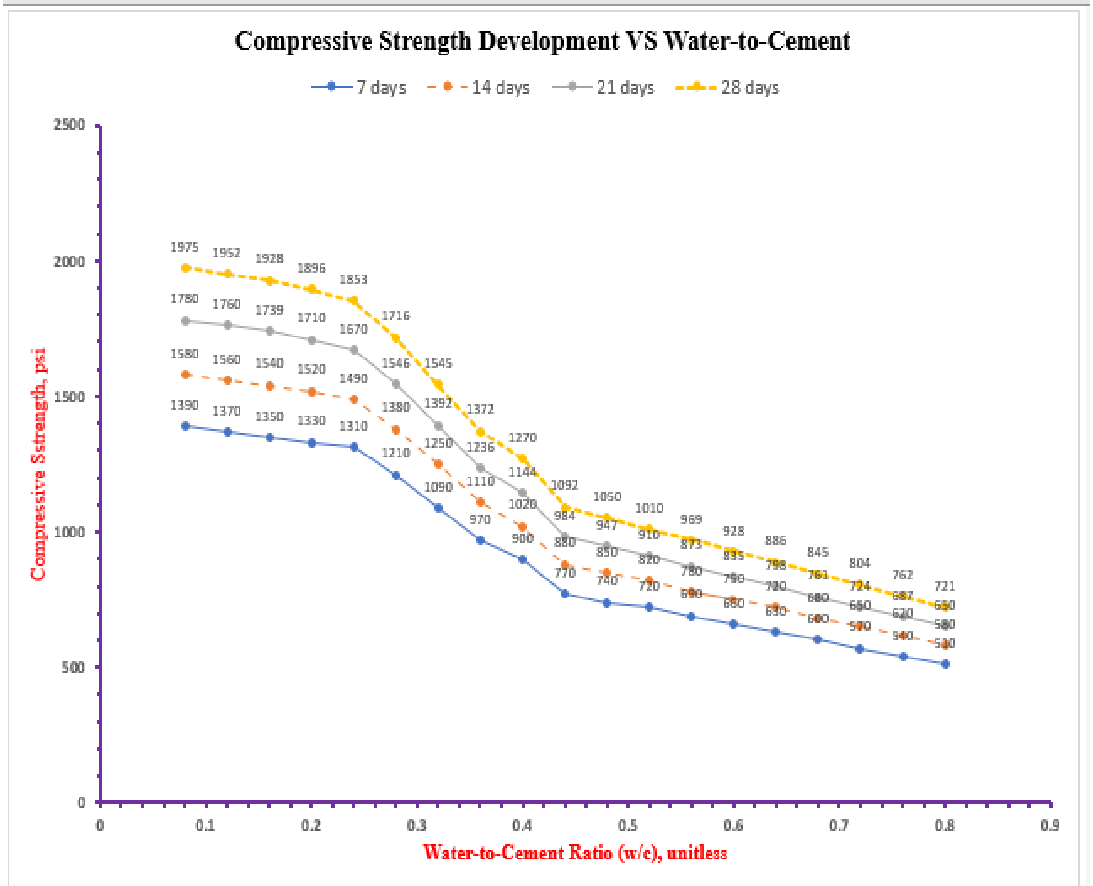

Fig 8: Relative Effects of w/c on the CS development

VI. DISCUSSION

Figures 4 to 8 show the results of the CS tests performed on the various formulated cement systems. These plots illustrate the relationship between CS (psi) and water-to-cement ratio, w/c (unitless). These results in Figures 4 to 8 show that the CS values at the w/c of 0.8 are all above 500psi. These have demonstrated that river nun mix-water can be used for oil and gas well cementing, at the 'waiting on cement' (WOC) for 7, 14, 21 and 28 days, to drill further (Laili, *et al*., 2015; API Specification 10A, 2002; McConnell Jr *et al*., 1996). On the other hand, the CS values at the w/c of 0.08 evidenced that these CS values are above the recommended minimum API standard of 1500psi, except that in Figure 4, which is 1390psi (API Specification 10A, 2002). Therefore, the results in Figures 4 to 8 disclosed that as the w/c increased, the CS value for each of the cement sheath systems decreased (Dinakar *et al*., 2013). The continues increased of w/c exhibited the characteristics of dilution and lightening of cement sheath. Consequently, the adding of river nun mix-water to the designed cement slurries at different quantities, increased its w/c and caused the reduction of the cement CS.Furthermore, the added mix-water did not only dramatically retard the CS development process, but weaken the developed CS of the cement sheath system and reduced the cement slurry's viscosity. Hence, the presence of other chemicals' concentrations in the cement slurry can be weakened or altered by the addition of mix-water. These characteristics are highly exhibited by extender chemical additives (Ahmad *et al*., 2021; Bett, 2017; Samsuri *et al*., 2001).In addition, the results in Figure 8 expressed comparatively the experimental outcomes. The results in Figure 8 also confirmed that the CS value at any given w/c increased with-respect-to the cured time or days passé, which agrees with Felekoğlu*et al.'s*,(2007) results.

VII. FINDINGS, CONCLUSION AND RECOMMENDATION

Findings

- Mix-water is used at different well conditions.
- Mix-water is a universial chemical compound.
- Mix-water initiates hydration.
- Mix-water exhibits the characteristics of cement strength developing chemical additives.
- High quantity of mix-water in cement mixture (0.5 to 0.8) acted as a retarding cement strength developing chemical additives.
- Low quantity of mix-water in cement mixture (0.2 to 0.45) acted as an accelerating cement strength developing chemical additives.

VIII. CONCLUSION

- w/c controls the rate of powdered cement hydration.
- Low quantity of mix-water in cement mixture acts as an accelerating cement strength developing chemical additives, while high quantity of mix-water in cement mixture acts as a retarding cement strength developing chemical additives.
- w/c could be applied to lighten the weight and reduces the strength of cement sheath and reduces the viscosity of cement slurry by dilution.
- w/c could be classified as water-extenders additives.
- Mix-water could be classified as a cement strength developing chemical additive.
- Mix-water could act as a co-chemical additive.

Recommendations from this Study

- Mix-water should be subjected to physicochemical water analysis, to determine its potability before usage.
- Class G oilwell cement should be used for formulating cement slurries and cement sheaths along the river nun area.
- Mix-water apart from its uses as mixing medium, mix-water should be classified as a cement strength developing chemical additive.

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