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(Research Article)

Critical evaluation of effects of polymer concentrations on the set time and compressive strength of cement slurries

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Abstract

Thickening time and compressive strength of cement slurry are very critical parameters in well cementing. Thickening or pump time and compressive strength of cement slurries are greatly affected by the slurry weight and temperature. Conventional Lead slurries usually require extenders such as bentonite and some polymers to stabilize the slurry and minimize excessive free fluid. The low slurry weight of lead slurries usually give rise to long pumping or set time and low compressive strength. Some of the polymers also retard the setting of the cement slurry. Therefore, this study focuses on the investigation of the performance of sodium silicate in comparison with gypsum and polyanionic cellulose (PAC-R) as extenders for cement slurries. The concentration of the light weight additives tested were 0%, 1.5% and 3.0% by weight of cement (bwoc) for 12.5ppg slurry using sea water. The slurry stability, compressive strength and quick set time were determined at room temperature. The higher the concentration of the lightweight additives, the more stable is the slurry, best stability was observed for recipe with sodium silicate while the slurry with PAC-R could not mix at 3% bwoc. At the lower concentrations, for sodium silicate, compressive increases and decreases for gypsum. The mixture with PAC-R had zero compressive strength. The gypsum has retarding effect on the slurry while the sodium silicate has accelerating effect. Conclusively, sodium silicate and gypsum powder performed very well as cement extender at optimum concentration, with the former showing the best performance and impacting accelerating properties that will be useful fort low temperature cementing.

Keywords: Set time; Compressive strength; Gypsum; Extender; Pack-R and sodium silicate

1. Introduction

In the cement slurry design, parameters such as well depth, temperature gradient, bottomhole static temperature BHST), bottom hole circulating temperature (BHC) mix water quality, formation permeability, fracture gradient, pore pressure, drilling fluid hydrostatic pressure, gas migration potential and others need to be considered. Some of the general categories of additives used to change or improve the properties of cement slurries for use in oilfield well cementing applications are retarders, accelerators, extenders, weighting agents, dispersants, fluid-loss control agents, lost-circulation agents, strength-retrogression prevention agents, free-water/free-fluid control, expansion agents, and special additives. The demand for innovative additives with distinctive properties and enhanced functionality is rising. These specifications include the following: resistance to cement fluctuation, application density range, temperature stability, economics, viscosity range, single function, multifunction, solubility rate, and co-additives' synergism.

During ~~a~~ drilling operation, cementing is a crucial step. In a cementing procedure, cement slurry is pumped though the casing and displayed into the annulus between the casing and the nearby rock formation. The slurry in the annulus is then left to set, usually over the course of a few hours or days, and harden strongly to fuse the casing to the formation. According to Labibzade [10], this compound can be created using a variety of components, each with a distinct weight proportion in relation to the cement weight in the grout mixture. Compressive strength, or a material's capacity to bear

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deformation under load, is one of the characteristics used to evaluate the dependability of cementing. The kind of raw materials, including any additives used, the proportions of the combination, the structure of the concrete, the curing process and duration, and the exposure circumstances all affect the compressive strength of cement concrete [7]

Hard and corrosive forms, lost circulation zones, intrusion of poisonous gases such as carbon (IV) oxide, and excessively high temperatures should all be handled by cement with a good compressive strength [4] Poor cementing has given rise to numerous studies in this area employing various methodologies. The study conducted by Sauki and Irawan [13] examined the impact of pressure and temperature on the degradation of well cement caused by super-critical CO_2. The researchers found that the formation of alpha-calcium silicate at elevated temperatures and pressure, as well as the formation of carbonation in CO_2 environments—which provides temporary strength to the cement—led to a greater loss of compressive strength.

In their 2010 study, Labibzadeh et al. [10] examined how modern pressure and temperature variations affected the oil well class G cement's early compressive strength. They came to the conclusion that a faster early age compressive strength might result in a shorter transition phase time. They also noted that adding crystalline silica to the cement slurry could help prevent strength retrogression in the cement at high temperature [4].

After conducting several experiments, Zhou and Jia [16] created a cement slurry with a low density and strong compressive strength using the particle grading theory. The created cement slurry performs better in terms of compressive strength than the previous one. Class G cement is typically one of the varieties used to close off formations because to its excellent resistance to sulfate, temperature, and pressure. Notwithstanding these characteristics, additives are needed to enhance the cement's properties [15]. In their study, Bayu et al. [5] found that adding 0.2% lignosulfonate to a cement slurry boosted its compressive strength. Compressive strength was found to have decreased over this amount. The proper ratio of each ingredient determines how well other additives perform to improve cement operations and maximize compressive strength during cement operation. It is recommended to do a series of expensive, time-consuming, and laborious experiments with these additions [8].

Factororial design (FD) is a technique that tracks how several variables interact to account for both main and interaction effects. Engineering problems have been successfully solved with FD, including uncertainty assessment [11], identification and estimation of important geological parameters White et al. [14], and analysis of rheological properties of treated Nigerian clay [1]. This research attempts to construct a mathematical model to forecast compressive strength using four distinct additives in order to improve compressive strength during cementing operation using factorial design. The model is based on the benefits of FD and the significance of additives in cement performance

Also, when cement is used in oil well cementing, the temperature of the cement slurry at total depth increases gradually from the moment it is mixed on the surface and pumped into the well until the cement cures and the formations next to the wellbore recover to their final static pressure. Both static and circulating temperatures have an impact on cement design. The temperature the slurry comes into contact with as it is pushed into the well is known as the circulating temperature. The formation heat that the slurry will be exposed to once circulation is stopped for a predetermined amount of time is known as the static temperature. In order to design and evaluate long-term stability or the rate at which the cement slurry's compressive strength develops, designers must be aware of the bottom hole static temperature (BHST). Since there can be a significant temperature difference between the top and bottom of the cement during deep hole cementing, BHST determination is particularly crucial. According to Abbaszadeh [3], cement sensitivity often rises as BHST increases. There are two distinct categories of cement compressive strength in the oil and gas sector. Early-age compressive strength refers to the cement's compressive strength immediately following the preparation and injection of cement grout into the wellbore, whereas long-term compressive strength is the cement's compressive strength following the well's exploitation and/or hydration process, and possibly even years into the well's production operation. One of the key tasks in the design of oil well cement is the development of strong early-age compressive strength [6]. Reaching an appropriate early-age compressive strength for oil well cement guarantees the casing's structural integrity as well as the mechanical and/or hydraulic isolation of borehole intervals [6]. Following the preparation and pumping of the cement grout into the wellbore, the cement slurry experiences hydrostatic pressure through shear strains, changing at the start of the gel formation from a true fluid into a semi-solid set material with detectable compressive strength. This is how the gel gets stronger bit by bit. The static gel strength that develops from a drop in volume is what lowers pressure. A longer transition phase provides a longer time for the volume to decrease. This makes the phase of transition extremely important since, in this condition, the cement column starts to support itself and does not transfer a substantial part of the hydrostatic pressure to the flow zone [9]. Gas migration is a phenomenon that causes more gas to flow through the cement column, which in turn causes inefficiencies in the cementing process. Reducing the duration of the transition phase, or in other words, expediting the development of cement compressive strength, can stop gas migration [9]. The Wait-On-Cement (WOC) time is another crucial point to observe in the early stages following cementing; it is the moment when the slurry's compressive strength starts to build immediately following the conclusion of the static gel-strength development. WOC time, then, is the amount of time it takes for cement to reach its minimum compressive strength, which, according to the API (American Petroleum Institute), is 3.45 MPa (500 Psi), which is sufficient to withstand shocks from later drilling operations. Due to the requirement to WOC, delays in strength development result in a substantial loss of time. As a result, drilling activities are halted, and the rig must remain inactive until the cement is judged sufficiently solid to permit further drilling [6]. In addition to the early-age compressive strength, the long-term compressive strength of cement is critical and required against the circumstances encountered within the well. The casing threads of the well must be able to be covered with hard cement and connected to the formation. Moreover, hard cement stabilizes the wellbore, guards against external pressures from earth floors that could potentially break pipes, and shields casing strings from electrolysis and corrosion from sour hydrocarbons, corrosive underground waters, and direct contact with strata. It also stops fluid migrations between formations and unintentional pollution of valuable hydrocarbons [2]. Operators can effectively cement a well that can produce hydrocarbons safely and profitably by following the three steps [12].

2. Material and Method

2.1. Preparation of Cement Slurry

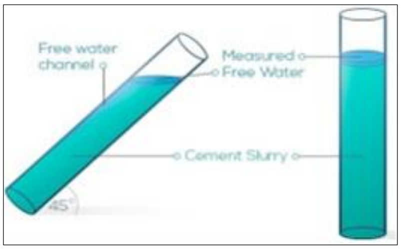
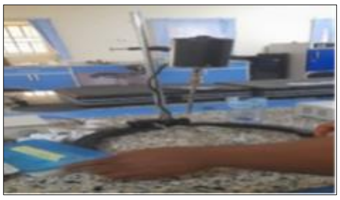
For the experiments, three extenders such as powder sodium silicate, gypsum, and Polyanionic Cellulose R were employed. As indicated in Table 1 cement slurry densities (12.5 ppg) were mixed with a sample concentration of 0%, 1.5%, and 3.0% by weight of cement (bwoc). The weights of the samples are shown in Tables 1. After weighing components using an electronic balance, they were evenly combined and transferred to the mixing fluids. A 1.2 L capacity standard CTC constant electric stirrer (see Table 2) was utilised to create a uniform mixture. In accordance with API RP10-2B procedure (API Edition, 2009), the mixer motor was turned on and maintained at (4000±200 rpm). Before adding cement, water and fluid additives were thoroughly dispersed by stirring them at a speed faster than rotation. In less than 15 seconds, the cement and solid additives were combined and added consistently. Following the incorporation of all dry ingredients into the mixture, the mixing speed was elevated to 12,000±500 rpm for a duration of 35 seconds. The temperature of the water and the dry ingredients (cement and solid additives) were maintained at 23±1.1°C prior to mixing. The extenders were the polyanionic cellulose R, gypsum, and sodium silicate, and the slurry design employed Class G cement, as shown in Tables 1. As shown in Table 1 antifoam (FP-30 L) was added to the cement slurry in order to reduce interfacial tension and prevent air entrainment. Rheological experiments, including free fluid, compressive strength, and rapid gelation or quick set time tests, were performed on the cement slurries.

Table 1 Design of Cement Slurry Recipe with Sodium silicate/ Polyanionic Cellulose R/Gypsum

Additives	**Laboratory Quantities for 600ml API @ % Bwoc**					
	Volume (ml)			**Weight (g)**		
Sodium silicate/ Polyanionic Cellulose R/Gypsum	0%	1.5%	3.0%	0%	1.5%	3.0%
	-			-	6.25	12.35
Cement				422.21	416.89	411.70
Seawater	463.94	463.05	462.18			
Antifoam	1.85	1.85	1.83			

Table 2 List of Equipment

Item	**Equipment/Apparatus**	**Type/Model**	**Function**
1	API Filter Press	Ofite 	Used to measure fluid loss

2	Mud balance	ofite 	The instrument used to determine the drilling fluid and cement slurry densities.
3	Viscometer	Chandler model 3530 	used to gauge drilling fluid and cement slurry viscosity and gel strength.
4	Free Fluid Set-up		Used to determine free fluid in cement slurry
5	Atmospheric Consistometer	Chandler model 1200 	Used for conditioning of slurry
6	Electric Stirrer		Constant Speed Mixer provides variable speed mixing from 100 to 21,000 no-load RPM with two preset constant speeds of 4,000 and 12,000 no-load RPM

2.2. Determination of Compressive Strength

Compressive strength test apparatus: -Compressive strength is the highest compressive stress that a specific solid material can withstand without breaking when subjected to a gradually applied load. The method in this study is the crush method. The calculation of compressive strength is based on dividing the greatest load by the initial cross-sectional area of a specimen.

2.2.1. Procedure

Cement, seawater, and antifoam were mixed with sodium silicate, gypsum, and polyanionic Cellulose R respectively as seen in Table 1. After that, the cement slurries were poured into containers and stored for at least 48 hours in order to assess its compressive strength. It was then crushed with the carver press. The cross sectional area of the container was determined.

2.3. Determination of Quick Gelation or Set Time

The Quick Set time test was meant to have an idea of the time the cement slurry will become hardened or unpumpable at ambient temperature. This is not an API standard thickening time test. After mixing, the slurry was poured into a 150cc plastic container with lid and left static at ambient temperature. The container was tilted periodically to determine when the slurry will become like a pasted and unpumpable.

3. Results

3.1. Quick Time Test of Cement Slurries Formulated with Different Concentrations of Sodium Silicate, Gypsum, and Polyanionic cellulose HV (PAC R)

Table 3 Quick Gelation Time of Sodium Silicate, Gypsum, and Polyanionic Cellulose R

Percentage of various Extenders (% bwoc)	Quick Gelation Time Test (min)			
	Neat	Sodium Silicate	Gypsum	Polyanionic Cellulose R
0 %	60	-	-	-
1.5 %	-	20	90	90
3.0 %	-	15	120	-

3.2. Compressive Strength of Cement Slurries Formulated with Different Concentrations of Sodium Silicate, Gypsum, and Polyanionic cellulose HV (PAC R)

Experimental results of compressive strength of neat, sodium silicate, gypsum, and polyanionic cellulose HV (PAC R) cement slurries were presented in Figure 1

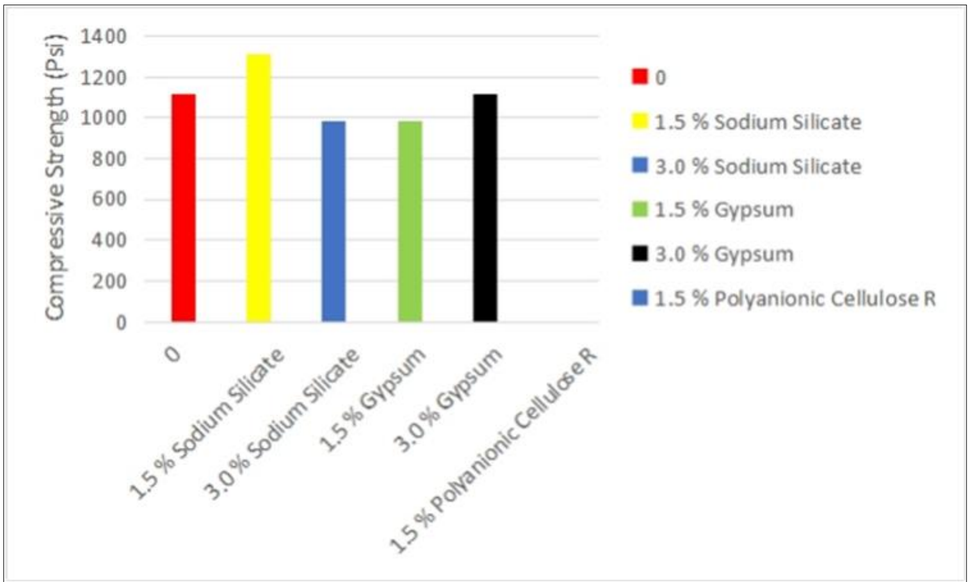


Figure 1 Compressive Strength of different concentrations of three Extenders cement slurries of 12.5ppg

4. Discussion

4.1. Quick Time Test of Cement Slurries Formulated with Different Concentrations of Sodium Silicate, Gypsum, and Polyanionic cellulose (PAC R)

The set time for neat cement slurry was 60min. The gelation time for 1.5% sodium silicate cement was 20 min while 3% sodium silicate cement slurry was found to be 15 min. There was an observable decrease in the gelation time of the cement slurry as the dosage of the extender (sodium silicate) increased. However, the gelation time of 1.5% gypsum cement was 90 min and increased to 120 min when the dosage increased to 3%. The gelation time for 1.5% Pack R cement slurry was 90 min (Table 4.2). The above result showed that dosage of the admixture affected the gelation time. 1.5% of the sodium silicate gave rise to the lowest (quickest) set time,

4.2. Compressive Strength of Cement Slurries Formulated with Different Concentrations of Sodium Silicate, Gypsum, and Polyanionic cellulose (PAC R)

Compressive strength is a vital property of cement slurries. The integrity of cement sheath is at stake if there is a compromise in the compressive strength. From the result obtained from the study (Figure 1) indicated that 1.5% sodium silicate cement had the highest compressive strength followed by 3% gypsum cement slurries while 3.0% sodium silicate cement and 1.5% gypsum cement had the same value for the compressive strength. The neat cement slurry showed high compressive strength while Pack R cement slurry had zero compressive strength. Therefore, 1.5% sodium silicate and 3% gypsum cement slurries showed good results in terms of compressive, they would withstand stand high formation pressure prevent corrosion caused by channeling of formation fluid. Good compressive strength cement should be resistant to high temperatures, lost circulation zones, infiltration of harmful gases such as carbon (IV) oxide, as well as hard, corrosive forms [4]. The anionic particle presence in the Pack R could have been the reason for the zero value of compressive strength. The dosage of concentration of the additive played a very important role in the alteration of the compressive strength of the slurries and this assertion is in tandem with the finding of Salahaldein [17] that the proper ratio of each ingredient determines how well other additives perform to improve cement operations and maximize compressive strength during cement operation.

5. Conclusion

Gypsum and sodium silicate showed acceptable performance as extenders in cement slurries. Both performed well, however, how well they can stop the generation of free fluid depends on the concentration.

Sodium silicate showed accelerating effect while gypsum showed retarding effect on cement slurry set time. The highest compressive strength was found at 1.5% of sodium silicate cement, followed by 3% gypsum cement slurries,

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest.

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