

RESEARCH ARTICLE

The Laboratory Investigation of the Effect of Calcium Chloride (CaCl₂) from Duck Eggshells on the Thickening Time and Strength of Drilling Cement

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Abstract

The thickening time and mechanical strength are vital in the performance of the drilling cement and are usually tested by API standards. The paper determines the role of duck eggshells' calcium chloride (CaCl₂) as a natural accelerator on the cement slurry properties. CaCl₂ was prepared by a regulating reaction between eggshell powder and 1M HCl and then was mixed with the Class G cement at the 1%, 2%, 3%, and 4% weight proportions. The experimental findings show that the most preferred performance is observed when the CaCl₂ is 4%, which reduces thickening time to 128 minutes and increases compressive strength to 4,464.62 psi and shear bond strength to 370.28 psi. These results imply that using waste materials as the source of CaCl₂ bio-based accelerators would be a viable source that would be environmentally viable in the optimization of drilling cements

Keywords: Compressive Strength, Shear Bond Strength, Calcium Chloride, Thickening Time, Drilling Cement

1. Introduction

Cementing process is a critical part of oil and gas well construction. Cementing is an essential drilling exercise. The quality of the cement used affects the well's lifespan and productivity; therefore, selecting the right cement is essential in the oil and gas industry (Ershadi et al., 2011). The cementing process plays a vital role in extending the service life of an oil well thus alleviating the necessity of future interventions such as workovers. (Mursyidah et al., 2017). A well-cementing operation is meant to ensure a mechanical and chemical bond between casing and formation, thus protecting the casing against mechanical disturbances like vibration and preventing direct contact of corrosive fluids.

More so, this process isolates the strata that are behind the casing (Bourgoyne et al., 1986). The function of the cement is to strengthen the casing and create an isolated barrier between the formation and the casing (Radonjic et al., 2014). Cement is used to withstand pressure from both vertical and horizontal directions (Choolaei et al., 2012). As tested, the sample's shear-bond strength (SBS) and compressive strength (CS) fit within the required industry standard (Rubiandini et al., 2005). In the oil and gas industry, these values must comply with the standards set by the American Petroleum Institute (API, 2011). CS represents the resistance of cement to horizontal loads, i.e., formation or casing pressure, and SBS represents the ability of cement to resist vertical loads caused by the weight of the casing string.

Compressive strength is one of the most important properties of drilling cement, as it is closely related to both

the tensile strength and elastic properties of the cement (Roshan and Asef, 2010). Shear bond strength is the force exerted to shear or split the casing and cement. This is an important measure, especially within the oil and gas industry, where casing interfaces and cement must be subjected to severe stresses under huge variations in operating environments. (Salehi et al., 2017). Shear bond strength denotes the bond strength between the cement and the casing and between the cement and the formation. That will provide cement with the strength to support the casing weight, firmly attach it to the formation, and eliminate collapse. (Rubiandini, 2000) Compressive strength (CS) and shear bond strength (SBS) can be good quality parameters of binding cement. CS is defined as the capacity of the cement to resist a geological force during the formation. In contrast, SBS is the capacity of cement that can support a vertical force due to casing string weight.

Along with cement strength, thickening time must also be considered to ensure successful drilling. The thickening time should also be considered to allow successful drilling. Thickening time is the time within which the cement slurry is to reach a certain consistency (Ahmed et al., 2018). Setting the thickening time in drilling operations is very important, as it is related to temperature and borehole conditions. The deeper the borehole, the longer it takes to pump the fluid. If the thickening time is less than the pumping time, the cement suspension may set before the desired depth is reached (Novrianti and Umar, 2017).

Accelerators come in handy by speeding up the cement hardening process and strengthening cement. It is beneficial because it engages the waiting on cement (WOC) time and delays during the cement hardening process, occasioned by other additives. Different experiments have

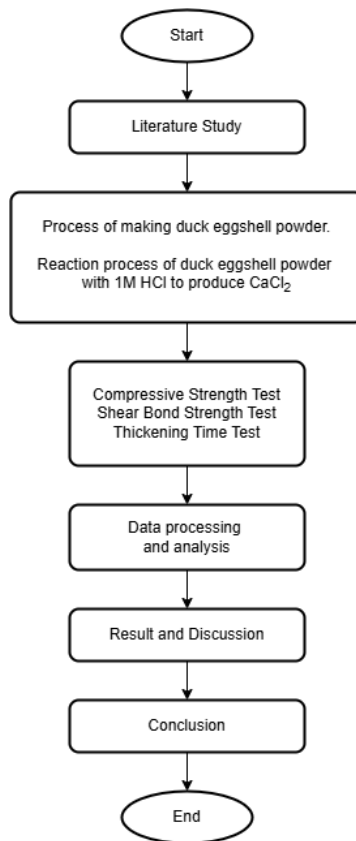


Fig 1. Research workflow

been done to advance the quality of cement fluff and accelerator by adding some chemical additives. Calcium carbonate is a material that can reinforce the strength of drilling cement and lengthen the thickening time (Cao et al., 2017). The primary source of calcium (Ca) is the precipitation of CaCO_3 or calcium carbonate by treatment of carbonate with hydrochloric acid (HCl). The product formed, calcium chloride (CaCl_2), improves the set of cement when used as a supplementary cementitious material of eggshell waste (Zulkifly et al., 2019). The addition of eggshell waste (calcium chloride, CaCl_2) causes positive changes in the strength and absorption qualities of the mortar on the compressive strength (Dorn et al., 2023). CaCl_2 , NaCl, and NaNO_3 accelerate the cement of the class B cement as an additive to the thickening time, compressive strength, and rheology of cement slurry with temperature variations.

Duck eggs are an easily digestible and highly nutritious source of animal protein, commonly consumed by the people of Riau province. Duck eggs are consumed because they are an inexpensive and readily available source of animal protein, found both in markets and from duck breeders. According to the Central Statistics Agency, duck egg production in Riau province is 1617.90 tons. The eggshell is the structural part of the egg that protects its contents. The chemical composition of duck eggshells includes about 94 % calcium carbonate, 1 % magnesium carbonate, 1 % calcium phosphate, and 4 % organic matter, mainly protein. The calcium content of duck eggshells is higher than that of other eggs. Duck eggshells have not been optimally utilized by the people of Riau, leading to them becoming waste which can potentially cause pollution due to microbial activity in the environment. This waste has

great potential to be utilized, considering that calcium carbonate has many applications in various industries. This study aims to innovate in the management of eggshell waste, reducing its negative environmental impact and creating useful products by extracting CaCl_2 from duck eggshells and analyzing its effect on the thickening time and strength of drilling cement.

2. Research Method

The current study was shaped into an experimental study at the Petroleum Engineering Laboratory of the Faculty of Engineering, Islamic University of Riau. Natural calcium was used from duck eggshells found in Pekanbaru. The shells were thoroughly cleaned, oven-dried, and ground into fine powder. This obtained powder was subsequently sieved through a 250-mesh screen to allow equal distribution of the particles in a size appropriate to chemical extraction.

One milliliter (1) hydrochloric acid (HCl) solution was made by adding a measured amount of concentrated (0.1M) HCl, 21 ml of concentrated HCl to 63ml of distilled water inside a 250ml volumetric flask. The mixture was lightly swirled and brought to a boil with distilled water. After cooling, it was put in a reagent bottle. Later, 30 grams of the powdered eggshells of the duck were dissolved in a beaker using 100 ml of the aforementioned 1M HCl solution. This reaction mixture was incubated at 80 °C with continuous stirring at 40 rpm for 2 hours. The solution was later filtered, neutralized to pH 7, dried at room temperature under light conditions over 24 hours, then weighed to measure the extracted CaCl_2 .

Cement slurry was prepared by weighing a mass of API Class G cement, weighing 350 grams. Dosages of Calcium

Table 1. Cement samples

| Samples | Concentration of CaCl ₂ |
|---------|------------------------------------|
| S1 | 1% |
| S2 | 2% |
| S3 | 3% |
| S4 | 4% |

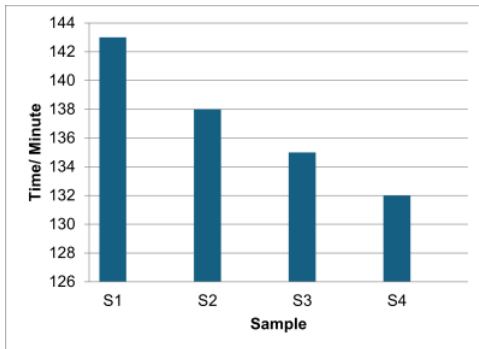


Fig 2. Thickening time results

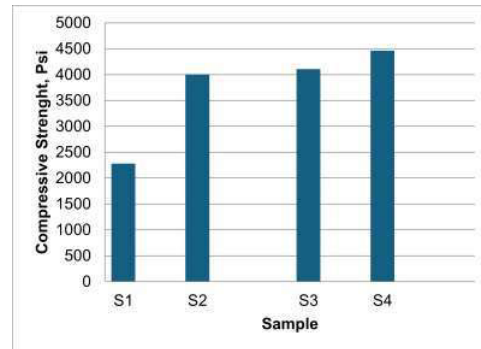


Fig 3. Compressive strength results

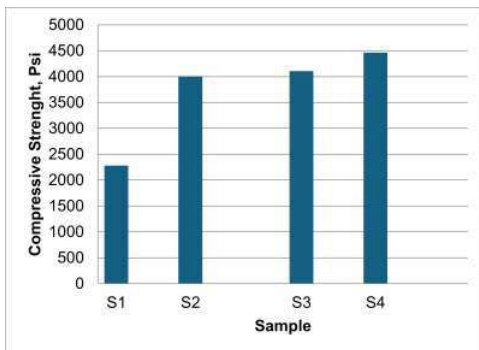


Fig 4. Shear bond strength results

chloride obtained in the eggshells of concentric ratios 1%, 2%, 3%, and 4% of the weight of cement were 3.5 g, 7 g, 10.5 g, and 14 g, respectively. Since there was a steady water-to-cement ratio (WCR), 161 ml of distilled water was added to dry-mixed cement and CaCl₂. Homogeneity of the slurry was obtained after high-speed mixing at 1200 rpm for 35 seconds, followed by 400 rpm mixing for 15 seconds.

Casted slurries of cement were put into lubricated cavities in the form of cubes, covered with aluminum foil, and labeled accordingly. The prepared slurries were allowed to harden under controlled conditions by placing them in a water bath. The hydraulic press was used to characterize the mechanical strength to determine compressive strength (CS) and shear bond strength (SBS) under biaxial loading conditions. The thickening time was measured using an atmospheric consistometer per the API prerequisites. **Table 1** gives a complete list of sample compositions. The research workflow is shown in **Figure 1**.

3. Findings and Discussion

Based on the research, it was found that the extraction of CaCl₂ from duck eggshells affects thickening time and drilling cement strength. **Figure 2** shows the effect of CaCl₂ extracted from duck eggshells on thickening time, while **Figures 3** and **Figure 4** present the compressive strength and shear bond strength values obtained by adding CaCl₂ extracted from duck eggshells to the drilling cement.

The outcomes of thickening time analysis presented in the graph indicate an apparent negative correlation

between the concentration of calcium chloride (CaCl₂) available from duck eggshells and the cement slurry setting time. Sample S1, which presumably contains no CaCl₂ or the lowest concentration (1%), has the longest thickening time, about 143 minutes. As the dosage of CaCl₂ is increased between Samples S2 to S4, the thickening time continuously decreases, albeit to the shortest, i.e., about 128 minutes in Sample S4, which is linked to the largest additive composition (4%). This experimental trend is consistent with the well-documented behavior of CaCl₂ as a cement system accelerator. The presence of the Ca²⁺ cations in the CaCl₂ augments the hydration rate of tricalcium silicate (C₃S), which further minimizes the time cement takes to attain gel-like consistency. The lower thickening period demonstrated in this study proves that CaCl₂ obtained within the duck eggshells is an effective thickener, just like the commercial one.

In oil well cementing, shorter thickening times may be beneficial to minimize the waiting-on-cement (WOC) time, especially in high-pressure, high-temperature (HPHT) wells where fast-strength development is important. Nevertheless, a quick reduction in thickening time should be suitably controlled so there is enough pumping ability and time for cementing activities. Here, 128 minutes in Sample S4 is still considered to be within reasonable limits of operation, thereby offering a suitable compromise between acceleration and workability.

The findings in the compressive strength graph support a distinct positive relationship between the strength of the

concentration of calcium chloride, CaCl₂, obtained in duck eggshells and that of the performance of oil well cement. Sample S1, the one with the least compression energy, estimated at 2500 psi, is probably the control sample or sample with the minimal amount of CaCl₂ concentration, which is 1360 (18H). By contrast, Samples S2 and S3 achieved significant results in their compressive strength, which was about 4000psi and 4100psi, respectively, showing that the addition of CaCl₂ in the ratio of 2-3% also improves early strength of concrete because of the accelerating performance of this chemical component of cement hydration. Sample S4 presented the highest compressive strength, that is, around 4465 psi; therefore, the concentration of CaCl₂ that attains the best mechanism strengthening in the considered experiment is 4% CaCl₂.

Technically, the increase in compressive strength could be because of the use of CaCl₂ as a chemical accelerator that has promoted the fast process of producing calcium-silicate-hydrate (C-S-H) in the hydration of the silicate phases of Portland cement. More Ca²⁺ ions accelerate the reaction process, making the microstructure denser and stronger in early ages. Remarkably, the performance property of bio-derived CaCl₂ from duck eggshells offered similarities with the commercially available accelerators and hence could be considered a sustainable alternative material. Although the results are encouraging, prudence in actually applying increased dosages of CaCl₂ in the fields should be exercised because with concentrations above 4%, as has not been yet tested in the study, the returns might become smaller or cause the reverse effects including higher setting temperature, lower long-term performance, or steel casing corrosion. These possible problems require more research.

Industrially, producing CaCl₂ using duck eggshell waste as a raw material is an inexpensive and eco-friendly approach. The strategy promotes sustainability in the drilling activity by reprocessing agricultural waste into high-quality cement additives. The research shows that 4% CaCl₂ produced with duck eggshells plays a significant positive role in increasing compressive strength without affecting sample stability, which would be useful in preventing illegal applications. However, other factors must be further analyzed in the future, such as thickening time, expansion, and long-term durability, to meet the operational requirements under real-world conditions.

According to the shear bond strength test conducted, the results, as illustrated in the figure, reveal that adding calcium chloride (CaCl₂) at varied levels in the duck eggshells exhibited a gradual improvement in the interfacial bonding capacity of the cement. The weakest bond strength was that of sample S1, which could either be the control or the least CaCl₂ concentration (1%). In contrast, the shear bond strength of samples S2 and S3, i.e., additions of 2% CaCl₂ and 3% CaCl₂, respectively, indicated a sharp rise, signifying that CaCl₂ exposure enhances the ability of cement to bond with a casing or a formation surface remarkably. Upon examination of shear bond strength, the maximal value was registered in sample S4, which includes the highest concentration of addition (4%), implying a supposedly perfect balance between the cement and the casing interface robustness amidst the conditions of the tests conducted.

The shear bond strength enhancement could be attributed to the enhancement of hydration kinetics by Ca²⁺ ions, which leads to the earlier and more dense development of hydration products, notably calcium-silicate-hydrate (CSH). This denser microstructure results

in a loss of porosity at the cement-casing interface, creating more mechanical interlocking and chemical adhesion. Greater shear bond strength is important regarding well integrity because it directly relates to how well cement, in terms of its ability to resist annular gas migration, displays long-term zonal isolation, particularly in more demanding downhole conditions.

Moreover, the addition of CaCl₂ derived through the use of duck eggshells presents a green alternative to standard chemical accelerators. This bio-based approach is a source of technical performance and fits the greater importance of environmental responsibility and using circular materials in industry. However, people have to be cautious in generalizing these findings to the field conditions because more parameters need to be tested, including thermal stability, compatibility with other additives, and cyclic long-term mechanical performance.

4. Conclusion

Based on the results of the data analysis and calculations performed, the conclusions are This paper verifies that calcium chloride (CaCl₂) extracted from duck eggshells can be used as a source of a bio-derived accelerator within an oil- healthy cement system. A constant decrease in thickening time was observed as the concentration of CaCl₂, which was at 1%, increased to 4%, and the mechanical properties of cement became remarkably better. When the dosage was increased to 4% CaCl₂, the greatest compressive strength (4,464.62 psi) and shear bond strength (370.28 psi) were achieved, which proves the importance of the compound to fulfill the fastening and condensing of the cement matrix. Such findings affirm the technical realization of the eggshell-derived CaCl₂ to support long-term strength construction and resilience through the factory and fiber bond.

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