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Eco-Friendly Bridging Material: Experimental Characterization of Eggshells as an Affordable Natural Waste Non-Damaging Lost Circulation Material to Reduce Drilling Fluid Cost in Reservoir Drill-In-Fluid System

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Abstract

Lost circulation nowadays became one of the major problems in many drilling operations worldwide. This problem is complicated for it can significantly cause non-productive time during drilling operations. This research aims to study an eggshells as a LCM and to provide further insight about the reliability and cost analysis of eggshells as a potential drilling fluid additive. Moreover, the research successfully identified the usage of an abundant natural waste, i.e. eggshells, as an environmentally friendly fluid additive. This research also investigated the technical feasibility of the eggshells and also its economics impact on drilling operations. In addition, it is found that the eggshells can also act as a non-damaging LCM for production zone that is more affordable as compared to other natural waste loss circulation material and current commercially chemical. Series of laboratory tests were conducted such as mud balance for the density test, rheological test using viscometer Fann Vg, filtration loss test with filter press, and also alkalinity (pH) test. An excellent result from filtration loss test i.e. decreased fluid losses and showed great improvement almost same as commercially CaCO3 result in the filter cake thickness. The research proves great potential of the utilization of eggshells as a multi-purpose additive in a drilling fluid. Economic analysis also suggests that it can possibly be implemented and to be further developed for a large-scale field operations. Finally, it is found that using eggshells as LCM can reduce the cost up to 72.2 % cheaper than commercial CaCO3. It is also safe for drilling in the production zone (pay-zone) because of its solubility on acid that it can disappear during the acidizing job. If this paper can be implemented on a wide-range scale it will be very beneficial to reduce other commercial additives usage without losing its reliability.

INTRODUCTION

Lost circulation nowadays has become one of the major complicated problems in drilling operations in some drilling operations worldwide in the oil, gas, also geothermal industries. As a result of this, the oil and gas industry suffered a loss very high cost and millions of dollars are spent every year to stop this problem (Aadnoy et al., 2007). One of them is due to the loss circulation material additive. Loss circulation is one of the drilling biggest problem and expenses in terms of rig and safety. If loss circulation became uncontrolled, it can result in a very dangerous pressure control situation and loss the well (Baker Hughes, 1999). An LCM is one of the chemical additives in drilling mud to prevent and to stop loss circulation problems during the drilling operation. There are four types of loss circulation material (LCM) which are fibrous, slurry, granular,

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Journal of Earth Energy Engineering
Vol. 11 No. 2, July 2022, pp 88-101

and combination. For eggshells itself as our main research itself was categorized as granular-type loss circulation material. The reason using it is because the availability of this material worldwide.

Generally, there are four types of mud losses depending on the rate. These are seepage losses (< 10 bbl/hr), partial losses (up to 10-50 bbl/hr), severe loss (up to 50-200 bbl/hr), and complete loss / total losses (no return) that already known as an incurable loss (Halliburton, 1998). If the drilling fluid design contains LCM, it will enter and cover the lost zone. Figure 1 illustrates the condition of LCM sealing the fracture during the drilling operation.

Common properties that frequently tested were density test using mud balance, rheological test using viscometer Fann Vg, and filtration loss test using filter press. Rheological data from the test can be determined with the following equation below:

- Plastic Viscosity, cp: $PV = [R\ 600\ rpm] - [R300\ rpm]$
- Yield Point, lb/100 ft: $YP = [R\ 300\ rpm] - PV$
- Apparent Viscosity, cp: $\eta = [R\ 600\ rpm]\ /\ 2$
- Low Shear Rate Yield Point, lb/100ft $\eta = [2\ R\ 3\ rpm] - [R\ 6\ rpm\ ]$

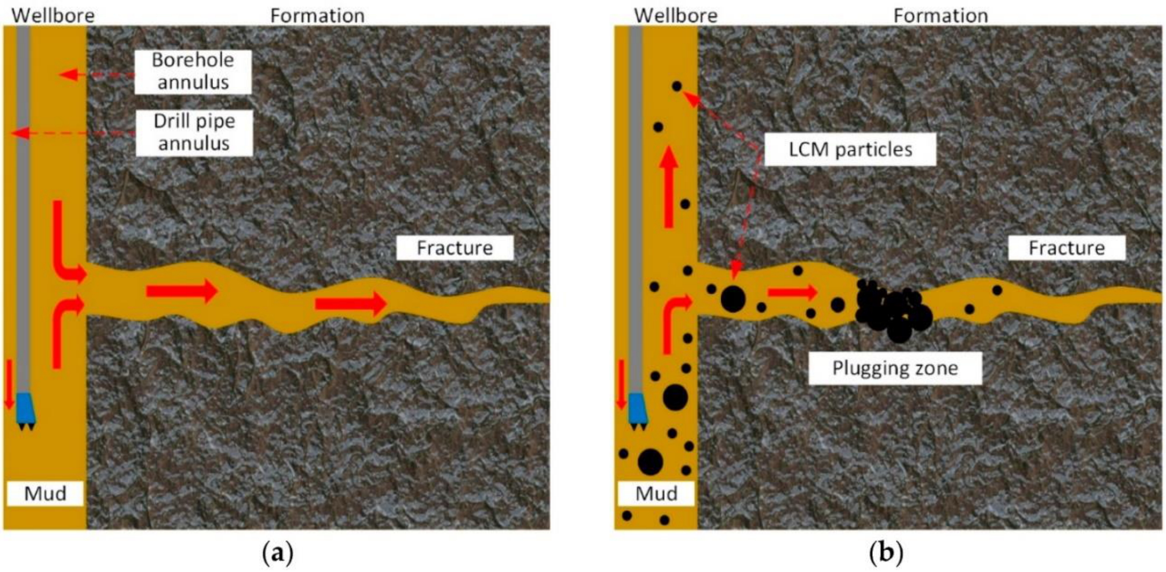

Figure 1. Schematic diagram of a loss circulation system and LCM Sealing the Fracture (Feng Y. 2018).

Eggshells As a Non-Damaging Loss Circulation Material

Waste materials nowadays are causing some issues which can affect the earth and society. In order to minimize them, one option is to reuse again those materials. Besides our research, there are so many examples of utilizing waste materials in oil and gas industries and already commercialized by several companies like nutshells as the loss circulation material (LCM), Grass Powder (GP) to examine filtration properties and mud rheological properties (Hossain & Wajheeuddin, 2016), Potato Peels Powder (PPP) as a rheological modifier and fluid loss reducer (Hameedi et al., 2019), Mandarin Peels Powder (MPP) as LCM and rheological modifier (Hameedi et al., 2019) and other biodegradable waste like Palm Tree Leave Powder (PLTP) that can decrease alkalinity and filtration (Hameedi et al., 2019). Natural waste made from trees can also be utilized as drilling fluids additives for a lost circulation material to improve the seepage losses (Ramasamy &Amanullah, 2018). Several waste materials can be implemented for numerous applications in the oil and gas industry.

Eggshells are one of the waste materials commonly considered useless that nowadays frequently to be disposed but can be useful for other applications. Eggshells can be found in any area of Indonesia with 5,155,998 tons of eggshells produced in 2021 (BPS, 2021) as shown in Figure 2. Most of the community only utilizes the egg only without the use of shells.

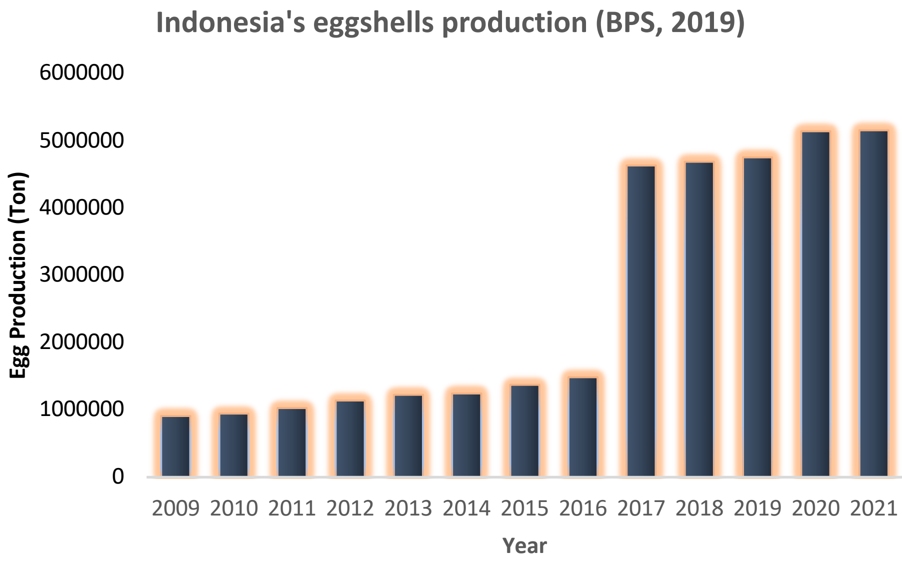

Figure 2. Indonesia's eggshells production (modified from BPS, 2021).

Eggshells are made of calcium carbonate that can dissolve in acid and release carbon dioxide. Eggshells are waste materials from hatcheries, homes, and fastfood industries and contains 95.1% minerals and 3.3% protein. The most common minerals are 98.43% $CaCO_3$, 0.84% $MgCO_3$, and 0.75% $CaPO_4$ (Insani, 2017).

As the global advances towards becoming more environmentally friendly, technically efficient, and cost-effective, hence use of eggshells as LCM can reduce the cost of drilling because $CaCO_3$ is quite expensive. Therefore, it is easy and convenient to find eggshells to use as an additive. Besides that, utilizing this material will help to reduce the waste of eggshells that were not used before. The process itself creates no waste as well.

As additional data, Figure 3 shows research on drilling fluid average cost compared with total drilling cost from the South Rumaila Field, Iraq (Al-Hameedi et al., 2019). $CaCO_3$ is one of bridging materials that quite expensive. By utilizing eggshells, drilling fluid cost essentially can be minimized.

The main purpose of this research is to see if the use of eggshells can be an applicable alternative for drilling fluid additives, and how it can be transformed into a lost circulation material/ bridging agent on NDDF/ RDIF system, weighting up the mud, reduce filtration loss, with little effect on rheological properties. For addition, providing an eggshells alternative that is environmentally friendly, biodegradable, safe for drilling operation with still reliable performance but with the lowering drilling fluid cost significantly.

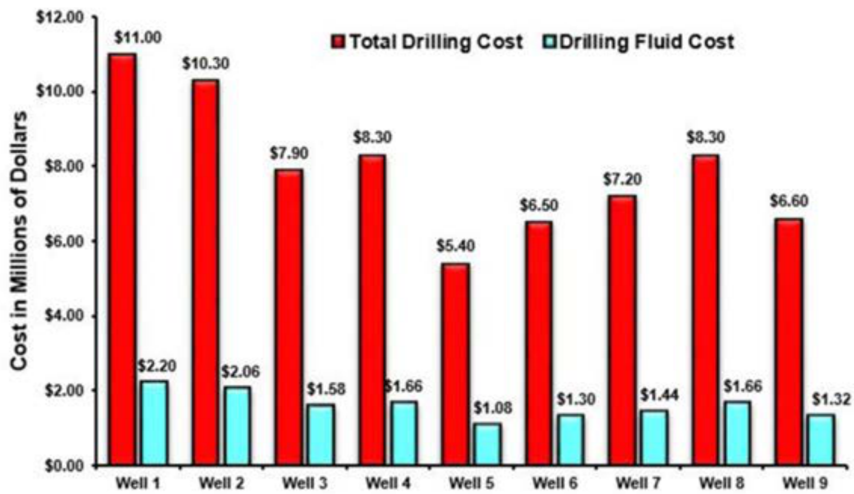

Figure 3. Cost of the drilling fluid from total cost of the drilling operations (Al-Hameedi et al., 2019).

Journal of Earth Energy Engineering
Vol. 11 No. 2, July 2022, pp 88-101

MATERIALS AND METHOD

In this paper, our research makes non-damaging drilling fluid (NDDF) / Reservoir Drill-in fluid (RDIF) water base mud system as the reference mud / base mud. Then, the result reference mud compares using eggshells as the combination of Calcium Carbonate (CaCO3) that acts as Loss Circulation Material and do the experiment with field data case study.

Therefore our research defined the experiment steps with identity and grounding the eggshells into a powder. There is no waste from this process. For other uses, it can be grounded into three grades which are fine, medium, and coarse. The detailed size is shown in Table 1.

Table 1. Eggshells particle size

Category	Range of LCM (micron)
Fine	15-30
Medium	135 – 165
Course	550 - 650

Series of laboratory tests are conducted including mud density test, rheological test with viscometer Fann Vg, filtration test with filter press, also alkalinity test (pH). After that, The result was analyzed with mud that mixed only with commercial additives and mud that combine with eggshells and compare them both technical advantages and environmental advantages. Figure 4 shows a detailed flowchart of this research.

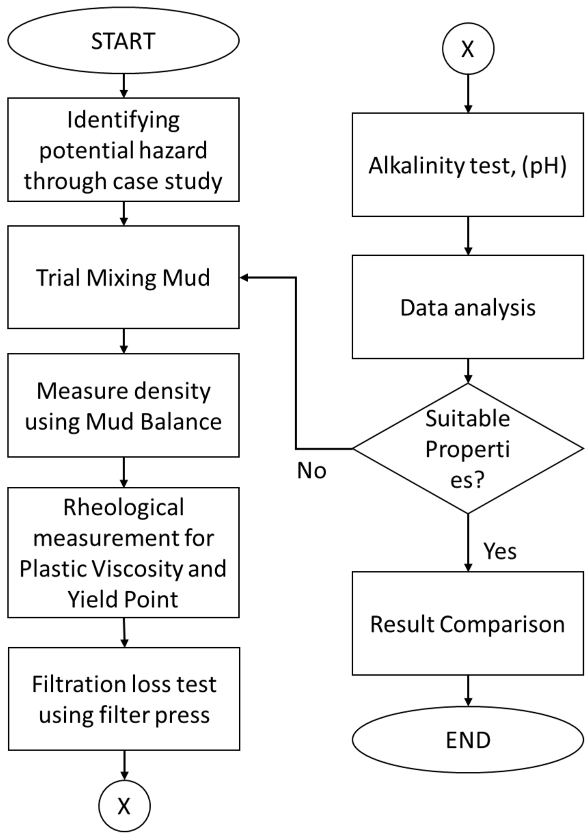

Figure 4. Flowchart of eggshells experimental procedures and laboratory measurements.

Eggshells Preparation

In the preparation and collection of the eggshell's material as LCM, the main objective of this section is to elucidate the steps of how to make eggshells waste as loss circulation material. First, Eggshell wastes were collected from several places such as food industries and households as illustrated in Figure 5.

Figure 5. Illustration of eggshells.

Next, eggshells were put in a dry sunny space for 3 days to mitigate if there are bacterial effects on the waste. Thirdly, eggshells can be ground into three grades, which are fine, medium, and coarse. There is no waste from this process. Using these size ranges, it is possible to prepare wellbore strengthening blends for sealing fractures up to about 1500 microns opening width.

The materials can be blended with smaller marble particles and/or graphitic solids to produce a continuous range of size required for wellbore strengthening. Figure 6 shows the result of the ground, while Figure 7 shows the outline steps on how to prepare eggshells as loss circulation material.

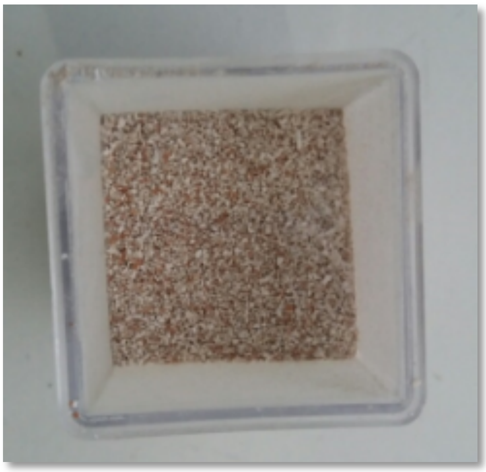

Figure 6. Result of eggshells as drilling fluid additive.

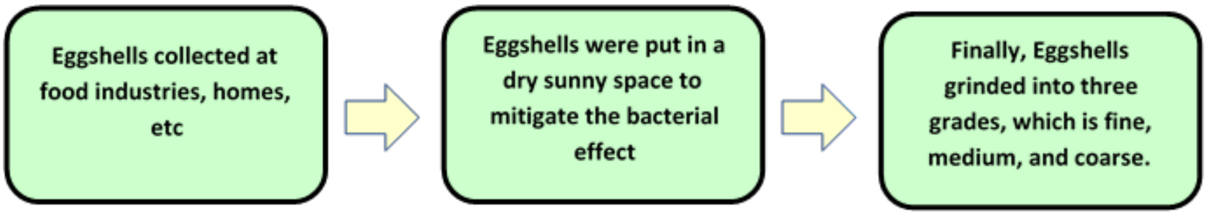

Figure 7. The outline steps of how to prepare eggshells as loss circulation material.

Experimental Procedures

The results of the conducted experiments for this research are discussed in detail. According to MI-Drilling fluids manual, pilot testing/lab testing of drilling fluids is required in small-scale samples to minimizes the risk before sending a fluid downhole that may be incompatible with the formations or ineffective under downhole conditions (MI-Drilling fluids, 2000). In general, pilot testing/lab testing usually concentrated on

Journal of Earth Energy Engineering
Vol. 11 No. 2, July 2022, pp 88-101

rheological properties and fluid loss, also fluid density with additional data of chemical properties evaluation. Laboratory test design needs to calculate the amounts of material, however, in lab tests, a gram is equivalent to a pound and 350 cm3 is equivalent to one 42-gal oilfield barrel.

On the laboratory testing, several samples of the chemical were tested in order to compare eggshells addition properties. Our research compared to several common additives from the same primary function and secondary function. For the primary function as loss circulation material, eggshells compare the cost with other LCM such as $CaCO_3$ as our main concern, and with other commercial LCM for the cost. On the other hand, eggshells compared with $CaCO_3$ for weighting agent, PAC-L, CMC and Starch for the fluid loss control agent.

Standard API drilling fluid experimentation tests were implemented such as rheological properties test, pH meter for alkalinity, mud balance for density, also filtration loss test with a filter press. All measurement results were tested under static circumstances and ambient laboratory conditions.

Case Study

V-02 well is one of the oil wells at X-field. Based on the good design plan, this well will be drilled to KOP 7545.93 ft (2300 m). The well will be directionally drilled with a maximum deviation of this well is 55° in the 17 ½" interval. As shown in Table 2, the are some potential drilling hazards that may occur during the drilling operation.

Table 2. Potential drilling hazard and casing design for V-02 Well, X-Field.

Hole Size	Casing Size	Depth (MD/ TVD)	Fluid Density (ppg)	Potential Drilling Hazard
42"	36"	4183.07 ft MD / 4183.07 ft TVD	9.0 – 9.2	Unconsolidated Zone, Gumbo, Bit Balling
26"	20"	6397.64 ft MD / 6397.64 ft TVD	12.4 – 12.6	Shallow Gas (H_2S), Reactive Clay
17 ½"	13 3/8"	9842.52 ft MD/ 8858.29 ft TVD	11.0 – 11.2	Loss Circulation, Pipe Sticking, Abrassive Formation, Hole Stability Problem
12 ¼"	9 5/8"	14412.73 ft MD / 11482.94 ft TVD	11.4 – 11.6	Loss Circulation, Kick, Formation Damage (Pay Zone)

From the subsurface data, pore pressure fracture gradient is shown in Figure 8. This well has a primary target depth on 8858.29 ft – 11482.94 ft on sandstone formation with hole size 12 ¼" in the production section with estimated mud weight in the target zone (pay zone) is around 11.4 – 12.0 ppg. A detailed borehole and typical wellbore construction are shown in Figure 9.

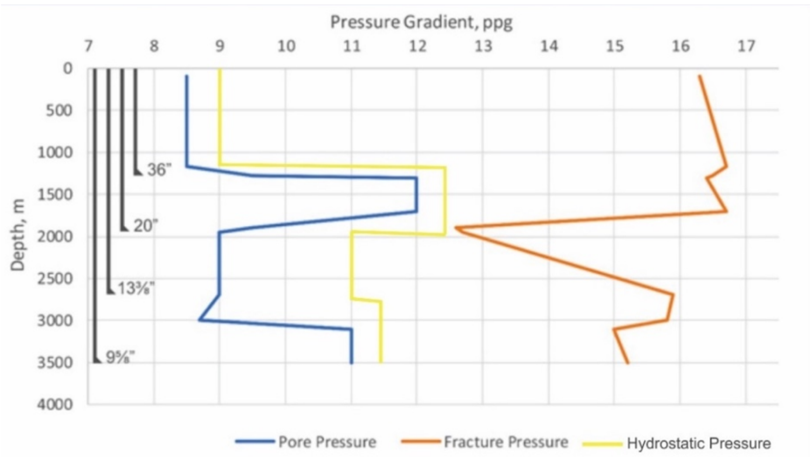

Figure 8. Pore pressure fracture gradient (PPFG) of V-02 Well, X-Field.

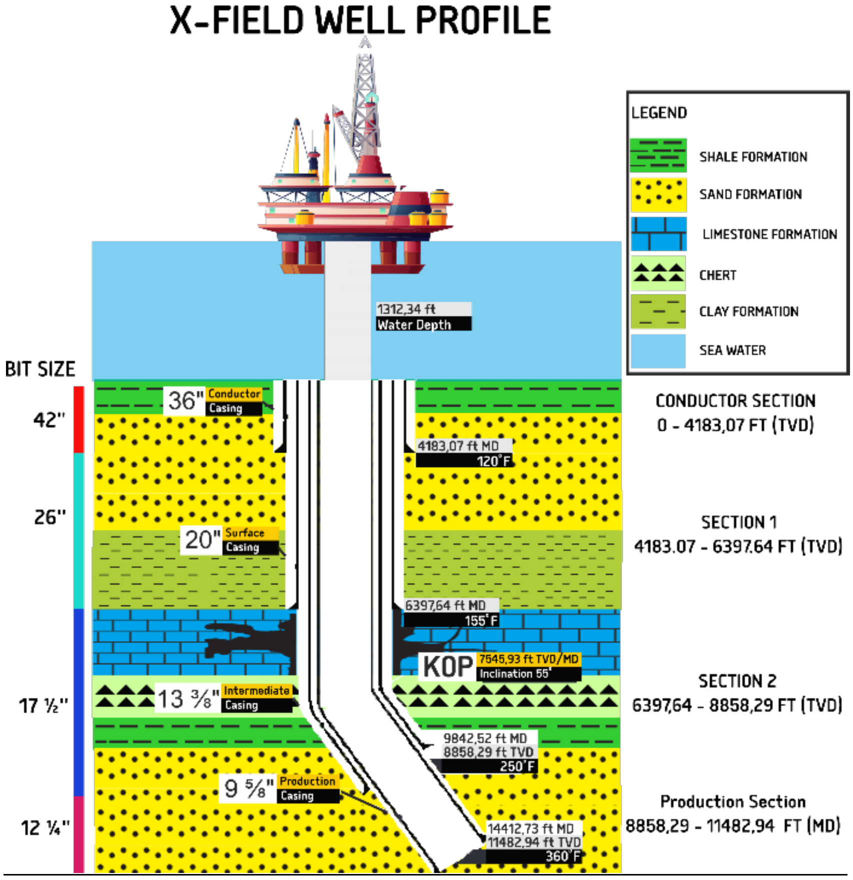

Figure 9. V-02 Typical well design schematic profile, X-Field

The main study of this paper is on the production section over the depth interval around 9842.52 to 14412.73 ft MD (8858.29-11482.94 ft TVD) with 12-¼ inch hole size. This section has a potential drilling hazard such as loss circulation (seepage losses), kick, and formation damage. This data already summarized in Table 3. This section will be drilled with Non-Damaging Drilling Fluid System (NDDF) is commonly called by Reservoir Drill-in-fluid system that aimed to minimize formation damage.

NDDF/ RDIF mud refers to the type of drilling fluid that eco-friendly to pay zone because it is essentially solids-free and can be soluble to acid that has the objective to reduce formation damage caused by the drilling fluid itself. Other Interval goal of this section is to provide borehole stability, overcome loss circulation, minimize the loss of water to the formation to decrease the formation destabilization with control API fluid loss.

Table 3. V-02 well production section data.

Criteria	Data
Primary Target	Sandstone Formation – 12 1/4" section
Primary Target Depth	8858.29 ft – 11482.94 ft
Estimated Mud Weight for Target	11.4-12.5 ppg
Depth (ft)	8858.29 - 11482.94
Mud Type	Non-Damaging Drilling Fluids / RDIF System
Exp. Mud Weight (ppg)	11.0 – 11.2
Potential Drilling Hazard	Loss Circulation, Kick, Formation Damage (Pay Zone)

Journal of Earth Energy Engineering
Vol. 11 No. 2, July 2022, pp 88-101

This breakthrough in this research which is eggshells as loss circulation material is very recommended for the production section because eggshells can become part of the Non-Damaging Drilling Fluid (NDDF) mud system. Eggshells itself has a secondary function as non-Damaging weighting agent that is preferable than barite because it can reduce CaCO3 usage and improve other filtration loss control agents to reduce the loss of water to the formation. Reducing common additive usage and adding Eggshells can significantly reduce the drilling fluid cost especially for CaCO3 that is more expensive than other additives. Eggshells have the same effect as common CaCO3, and it can become an alternative to reduce this cost.

RESULTS AND DISCUSSION

The results of the conducted experiments for this research are discussed in detail. In this section, several data that have been obtained during experimental work were presented. For the detailed composition of reference, mud is summarized in Table 4. This section aims to show the effect of Eggshells on the properties of drilling fluid. The results include mud density (MW), filtration loss test and filter cake thickness, plastic viscosity (PV), yield point (YP), gel strength (GS), and other additional drilling fluid properties. For comprehensive discussion for each property by comparing Eggshells and other commercial additives and other natural wastes chemical.

Table 4. Reference NDDF / RDIF Mud Composition

Additives	Role	Laboratory						
		Mass (gr)	Volume (mL)	Mass (lb)	Volume (bbl)	Volume (gal)	% Volume	% Weight
Water	Base Fluid	271.015	263.122	271.015	0.7518	31.5746	75.18	63.84%
Soda Ash	Ca++ Controller	1.500	0.593	1.500	0.0017	0.0711	0.17	0.31%
KOH	Alkalinity Control	0.500	0.245	0.500	0.0007	0.0294	0.07	0.10%
XCD	Viscosifier	1.000	0.667	1.000	0.0019	0.0800	0.19	0.21%
CaCl2	Weighting Agent (Salt)	120.000	53.571	120.000	0.1531	6.4286	15.31	19.87%
CaCO3 (Fine)	LCM, Weighting Agent	90.000	31.802	90.000	0.0909	3.8163	9.09	15.68%
Total		484.015	350	484.015	1.0000	42	100	100.00%
Density					gr/cc	1.38		
					lb/gal	11.52		

Mud Weight Effect

The density test result suggests that adding Eggshells increases the density of the mud. This is because up to 95% of Eggshells components are made of CaCO3 that has a secondary function as weighting agent on drilling fluid chemical type and it is preferable to Barite because Eggshells is acid-soluble and can be dissolved with hydrochloric acid to clean up production zones with limitation weighting up to 12 lbm/gal (PPG). For comparison of other commercial non-damaging weighting agent is shown in Figure 10.

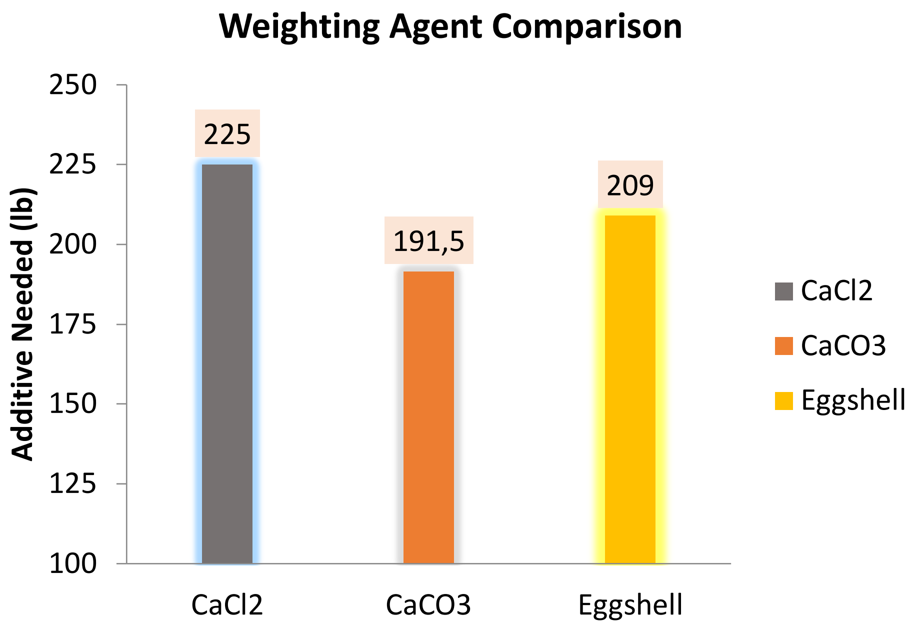

Figure 10. Weighting agent additive needed to achieve 11.5 ppg comparison.

Rheological Properties Effect

However, for the rheological properties test, adding eggshells show little to no effect on plastic viscosity (PV) and Yield point (YP), compared with commercial CaCO3 as shown in Figure 11.

Filtration Loss Effect

In filtration loss test, reference mud modified by adding 20.5 grams of each filtration loss control agent chemical, such as PAC-L, Starch, and CMC. From the result, a filtration chart is made to compare each FLCA additive as shown in Figure 12 and the detailed data is summarized in Table 5. From this chart, the mud filtration test using filter press the eggshells showed an excellent result, i.e., it can decrease fluid losses significantly and improve the filter cake thickness. This is possible because of the secondary function of the CaCO3 itself as fluid loss control agent (FLCA) instead of just as a loss circulation material (LCM).

Table 5. Filtration loss test result

Filtration loss test	API Loss (mL)			Mud Cake (mm)
	7.5'	15'	30'	
Base Mud	5.00	10.36	15.19	0.65
Pac L	0.75	1.55	3.65	0.45
CMC	1.00	2.07	4.86	0.52
Starch	1.00	2.07	4.86	0.675
Eggshell	1.25	2.59	6.08	0.6
$CaCO_3$	1.38	2.85	6.68	0.65

Journal of Earth Energy Engineering
Vol. 11 No. 2, July 2022, pp 88-101

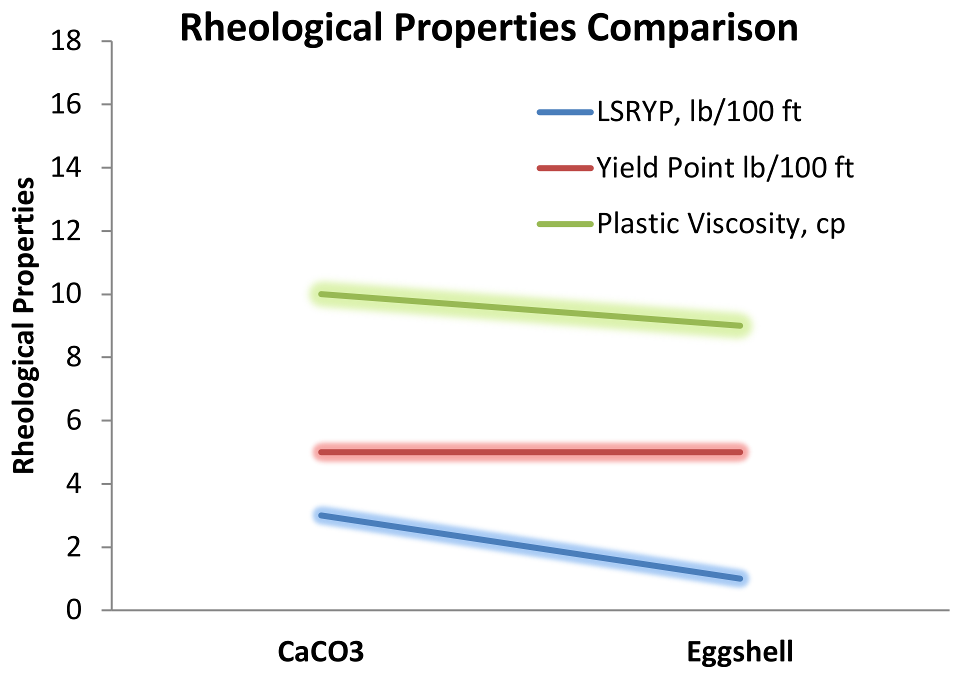

Figure 11. Rheological properties comparison.

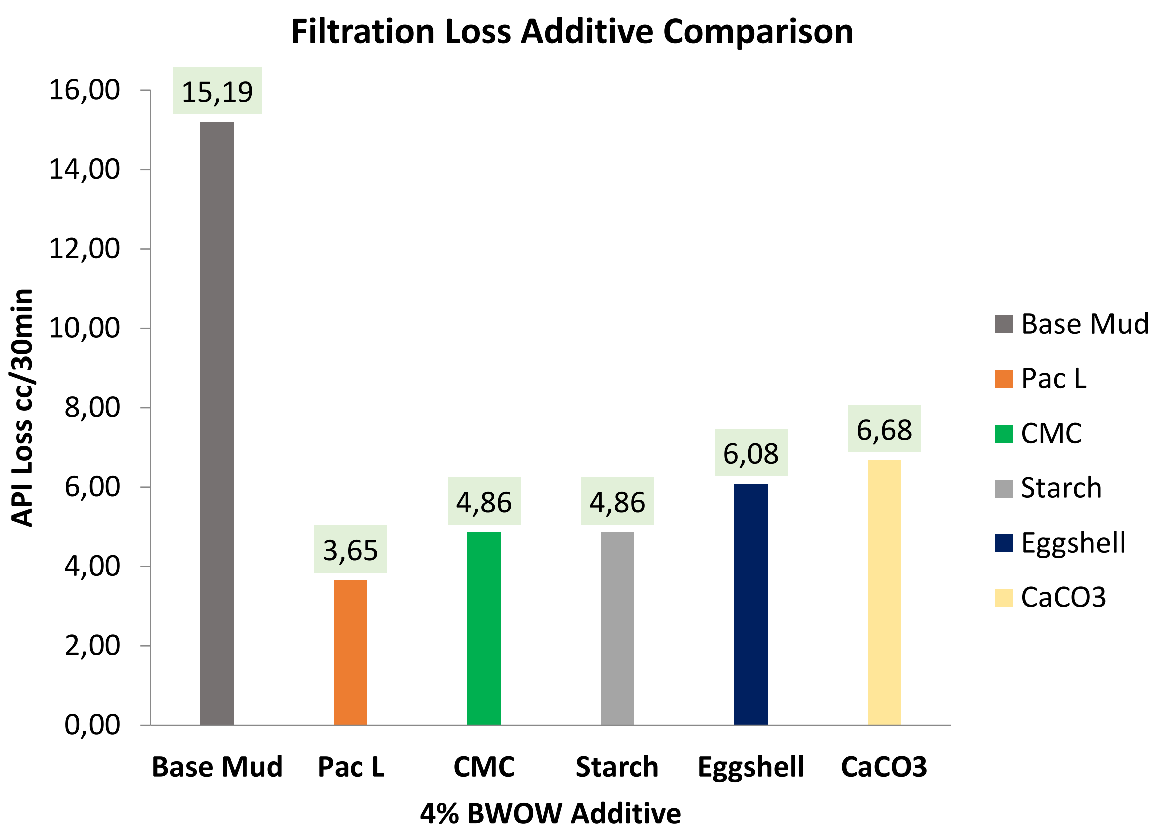

Figure 12. API fluid filtration loss additive comparison (cc/30min).

Alkalinity Effect

For additional data, the result of salinity data was slightly decreased on the pH. The detailed data is summarized in Table 6.

Table 6. Alkalinity test result

Mud System	pH
Base Mud	10.5
CaCO3	10
Eggshell	9.5

Economical Analysis and Discussion

The economical analysis is the most important thing in this discussion, this section presented the comparison of the cost for each chemical additive as shown in Figure 13. Based the comparison eggshells are 72.2% cheaper than CaCO3 without losing it's reliability.

The utilization of Eggshells to prevent losses and control drilling mud characteristics becomes an option to reduce costs of the drilling fluid itself. It can control/ regulate the seepage loss, the rheological properties, or other physical specifications yet eco-friendly and biodegradable demonstrate minimizing damage on pay-zone caused by drilling fluid.

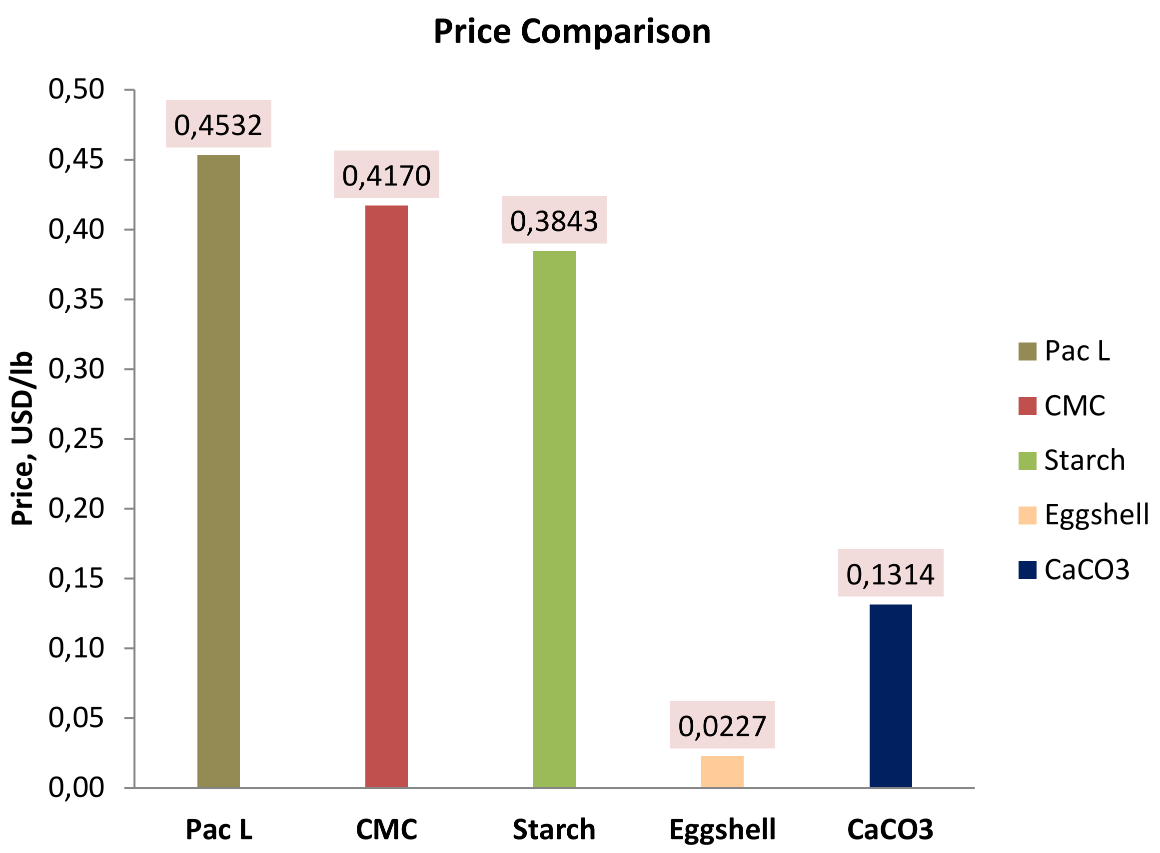

Figure 13. API fluid loss control agent cost comparison.

Based on this research, the eggshell is proved to be a great potential as a multipurpose additive for drilling fluid. Moreover after economic evaluation, it can potentially be implemented on large-scale and reasonable choice to move ahead later on. It shows potential to uses not only on drilling but also on completions and workover operations.

 Journal of Earth Energy Engineering
Vol. 11 No. 2, July 2022, pp 88-101

CONCLUSION

From the discussion above this research provides further insights about the probability, cost analysis, and comparison to provide eggshells as potential non-damaging loss circulation material as the main function, also eco-friendly weighting agent, and as filtration loss reducer. Due to the intercorrelation between drilling fluid properties, several experiment measurement has already done to get properties data from eggshells. Based on this research, the following conclusions were made:

- Eggshells can be soluble to acid and is a good choice to reduce $CaCO3$ usage as Non-Damaging Drilling Fluid Chemical that environmentally friendly in the production section (pay-zone) because eggshells are soluble to acid that affect in cost reduction. In light of our research outcomes conducted by normal API standard tests for drilling fluid.
- The result demonstrates an increase in mud weight, little effect to rheological properties, a significant increase in filtration loss control and improve the mud cake thickness, also slightly decrease in pH.
- The results showed that the eggshells act as Loss-Circulation Materials is the cheapest material, eco-friendly, and biodegradable compared to other commercial materials and the higher advantage rather than published natural waste loss circulation material. It is easy to find on a large scale as well.
- In short, using eggshells for LCM can reduce costs more than 72.2% cheaper than $CaCO3$. And it is safe for drilling in the production section because it is soluble to acid that means it can disappear during acidizing job.

On completion of this research work, it is recommended that:

- Briefly, the results provided in this research can be utilized widely in the oil and gas industry to make the drilling fluid cost more economically due to utilizing the common chemical additives and also help reducing waste of Eggshell the whole world. Eggshells prove a great potential to be a multipurpose additive for drilling fluid. Moreover, after economic evaluation, it can possibly be implemented on a large-scale and reasonable choice to move ahead later on. It shows the potential to uses not only drilling but also on completions and workover operation.
- Eggshells proposed as a non-damaging lost circulation material / bridging agent, if this paper can be implemented on a wide-range scale it will be very beneficial to reduce other commercial additives usage, so the cost for drilling fluid can be cheaper than before without losing its reliability. This research is very satisfying and economically and technically feasible to be developed.

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Appendix A. Nomenclature.

CaCl2	: Calcium Chloride
CaCO3	: Calcium Carbonate
CMC	: Carboxymethyl Cellulose
FLCA	: Filtration Loss Control Agent
LCM	: Loss Circulation Material
LSRYP	: Low Shear Rate Yield Point
PAC	: Polyanionic Cellulosic
MD	: Measured Depth
MW	: Mud Weight (ppg)
NDDF	: Non-Damaging Drilling Fluid
PV	: Plastic Viscosity (cp)
RDIF	: Reservoir Drill-In-Fluid
TVD	: True Vertical Depth
WBM	: Water Based Mud
YP	: Yield Point (lb/100 ft)

Appendix B. Tables

Table 7. Mud Volume for Drilling in Production Section

PRODUCTION SECTION		
Pit Volume	2000	bbl
Hole Volume	2105	s
Riser Volume	2943	bbl
Total Mud Volume Needed	7048	bbl

Table 8. Chemical Needed for Drilling in Production Section

Material	Total Used
	lb
Soda Ash	8457.6
KOH	3524
XCD	7048
CaCl2	845760
CaCO3	493360
Eggshells	144484