Study on the viability of egg shell as a lost circulation material in synthetic based drilling fluid

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Abstract. Lost circulation is one of the most severe issues in drilling operation which can cause fracture formation or be induced during drilling activities. These scenarios make it imperative to design the drilling fluid in a minimal invasion of the fluid that occur in the formation along with assist in strengthening the wellbore condition. To solve this problem, Lost Circulation Materials (LCM) are required which is expected to bridge and seal the fractures. As the contemporary worldwide development towards environment friendly, technical ability and cost-effectiveness, hence the viability of Egg Shells as LCM are being investigated since the daily disposal waste is rich in Calcium Carbonate (CaCO3) compound. In addition, the effect of egg shell particle size distribution on the drilling fluid performance was also study. The performance of egg shells was compared with the industry standard-sized CaCO3 in term of its rheology properties, fluid loss, fluid invasion, and lubrication ability. The rheology properties result shows a stable reading while for High Pressure High Temperature (HPHT) filter press test, the drilling fluids performance showed the same mud cake thickness of 1/32 but slightly different in fluid loss. The drilling fluids also has a minimal invasion on Sand Bed Test (SBT) with lubrications coefficient of 0.0753. From this study, it is found that egg shells can function effectively as LCM additives, the same as the standard CaCO3 used in the industry.

1. Introduction

Nowadays, drilling fluids have become the heart in the drilling activities of oil and gas activities. Even though the drilling fluid may represent only 5-15% of the drilling cost but if it is not properly managed, it may cause 100% of drilling problems [1]. On account of that, the need to lower the risk and avoid unnecessary issues during drilling is always the priority.

Basically, drilling fluid are composed of several components such as viscosifier, emulsifier, fluid loss control, pH controller and weighting agent that play a different role in the mud system. Failure to manage these properties in drilling activity may cause severe problems. The most common problems are the mud losses or lost circulation where the drilling fluid flows into the geological formation instead of returning to the mud pit. This phenomenon is due to the drilling activities on fractured formation either naturally occur or induced during drilling activities [2]. This phenomenon can lead to other issues such as stuck pipe, wasted the casing string, failure to reach target depth and even the worst case is a blowout and environmental incident.

The best preventive measure of this problem is the use of effectively lost circulation material (LCM) in the drilling fluid stream for plugging the fractures [3]. There are two common approaches to
preventing lost circulation in the field which is a pre-treatment method and stress caging, where both of the methods apply the usage of LCM in the mud stream [2]. The materials that are widely used in the industry can be categorized into granular, flake, fibrous and blend of all the materials. Physical properties such as shape, sized and resiliency are the main concern in the selection of the materials which all are be subject to the width of the fracture and the severity of the losses [4].

At the present time, there are intensive researches done to look into low-cost materials in an effort to transform into a commercialized LCM. Egg shells are the new and valuable prospect to be studied as LCM since it can be easily found due to abundant of it sources. The major constituents of egg shell are 94% of CaCO₃, while calcium phosphate and magnesium carbonate at 1% each and other organic matter is 4% [5]. A previous study conducted which utilizes the calcium carbonate from oyster-sea shells as the bridging agent shows a minimal invasion of the drilling fluid occurs in the formation when compared to conventional LCM such as ground walnut shell [6].

The used of CaCO₃ as the bridging agent are common in order to combat seepage and severe losses during drilling due to its mechanical and chemical properties which are resistant to pressure differentials and swap & surge impact in the wellbore [7]. Granular materials are the most effective type of LCM as determined by the maximum size of the slot or fracture which it can be sealed [8][9]. However, many researchers have remarked that the granular bridging material should have the proper particle size distribution (PSD) in relation to the pore openings for optimum sealing characteristics [10]. The rule provided by Abrams states that the median particle size of a bridging agent must be equal or slightly greater than 1/3 of the mean pore opening [11].

Nowadays, egg shell has been used enormously as an activated absorbent regarding pollution problems. However, there is no research conducted yet to test its feasibility and performance as a lost circulation material in the drilling fluid system. On account of that, this study will investigate the viability of egg shell as LCM in drilling fluids as well as to study the effect of particle size distribution on the LCM performance.

2. Methodology

2.1. Egg shell Preparation

Three categories of egg shells particle size are examined which are fine, medium and course by follow the standard CaCO₃ size used in the industry as stated in Table 1. The egg shells are washed several times with distilled water to remove impurities and be dried overnight at 40°C. The dry egg shells will undergo further drying process in an oven at 105°C to remove the moisture content. The egg shells sample weights are recorded every one hour and the drying process ends when the reading is constant. The dries egg shells were crushed and grounded by using mortar and pestle before being sieved before it’s been measured further using Particle Size Analyzer (PSA) for the sizing accuracy.

| Category | Standard range of LCM | Average size of egg shell particle |
|----------|-----------------------|-----------------------------------|
| Fine     | 15-25 µm              | 18.631 µm                         |
| Medium   | 36-65 µm              | 59.249 µm                         |
| Course   | 36-65 µm              | 169.960 µm                        |

2.2. Drilling fluid formulation

Synthetic-based mud of 12 ppg weight is formulated by following the formulation in Table 2. The drilling fluids are prepared for four standard lab barrels, three for the different sizes LCM and one for the base which is the absence of the LCM.
Table 2. Drilling fluid formulation.

| Mixing Order | Chemicals                          | Quantity (g) | Mixing time (min) |
|--------------|-----------------------------------|--------------|------------------|
| 1            | Base fluid                        | 153.43       | 15               |
|              | Primary Emulsifier                | 5.00         |                  |
|              | Secondary Emulsifier              | 7.00         |                  |
| 2            | Viscosifier                       | 7.00         | 5                |
| 3            | Lime                              | 8.00         | 5                |
| 4            | Fresh water                       | 65.74        | 15               |
|              | Salt                              | 23.48        |                  |
| 5            | Weighting Agent                   | 215.55       | 10               |
| 6            | Lost Circulation Materials        | 15.00        | 10               |

2.3. Rheology test
Drilling fluid rheological characterization was carried out before and after the hot-rolling process by using a viscometer to determine its plastic viscosity (PV), yield point (YP), and gel strength (GS). The hot hot-rolled process is carried out in an oven at 250°F for 16 hours. On the other hand, the Electrical Stability (ES) test also conducted by using the ES meter. The rheological properties are calculated using the below formula:

Plastic Viscosity (PV) = reading at 600 rpm - reading at 300 rpm \hspace{1cm} (1)

Yield point (YP) = reading at 300 rpm – PV \hspace{1cm} (2)

2.4. HTHP filtration test
The drilling fluid formulation prepared earlier was poured into the cell with a filter paper at the bottom of the cell. The temperature of 120°F and the pressure of 100 psi are applied for this test. The filtrate volumes were recorded for 30 minutes and the mud cake thickness was measured using vernier caliper.

2.5. Sand bed test (SBT)
The SBT consist of a transparent fluid loss type cell packed with a 5 cm height of 20-40 mesh quartz sand. Drilling fluid then placed at 2.5 cm above the sand bed before be pressurized at 100 psi. Once the pressure applied, the distance traveled by the fluid in 30 minutes is measured.

Figure 1. Sand bed testing kit.
2.6. Lubricity test
The test started by calibrated the equipment using deionized water to achieve the co-efficient of friction at 34 with tolerance of 2. Drilling fluid sample was tested at 60 rpm rotating motor speed and 150 applied torque. Reading at every 3 minutes was taken and the average torques was calculated. The equation in calculating the lubricity co-efficient are as follows:

\[
\text{Correction factor} = \frac{\text{Standard meter reading for deionized water (34)}}{\text{Meter reading obtained in deionized water calibration}}
\]

\[
\text{Lubricity co-efficient} = \frac{\text{Meter reading} \times \text{Correction Factor}}{100}
\]

3. Result and discussion

3.1. The effects of egg shell as an additive in drilling fluid rheology.

From the Figure 2, there is not much different in PV value between both drilling fluids. In addition, it also has the same increasing pattern after hot-rolling process. Normally, the PV is affected by the solid content in the mud system and the high PV values will increase the surge and swab pressure, decrease the rate of penetration (ROP) and increase the risk of differential sticking. Based on the result, the PV value of both drilling fluids ranging from 17 to 25 cP is considered as an acceptable value based on the average value for 12 ppg mud weight [12]. However, practically there are no specific optimize value of PV for each drilling activities since there are different dynamic environment in particular fields.

Figure 2. Plastic viscosity of drilling fluids before (a) and after hot-rolled (b).

Figure 3. Yield point of drilling fluids before (a) and after hot-rolled (b).
YP is a resistance of the initial flow of fluid or the stress required in order to move the fluid which implies the ability of drilling mud to lift cuttings out of the annulus. From Figure 3, there are no significant differences between the two drilling fluids and both are showing the same increasing trend after being hot-rolled. This is considered as an acceptable value since drilling fluid with high YP value will carries cuttings better than a fluid of similar density but have lower YP.

![Figure 3](image3.png)

**Figure 3.** YP trend of two drilling fluids before and after hot-rolled.

![Figure 4](image4.png)

**Figure 4.** Electrical stability of drilling fluids before (a) and after hot-rolled (b).

The Electrical Stability (ES) is one of the vital properties for oil based and synthetic based drilling fluid because it indicates the drilling fluids emulsion stability. For instance, the ES number represents the mud emulsion stability and the higher ES value shows higher emulsion stability. From Figure 4, the stability of egg shell is considered as good as standard CaCO3 performance. This is due to the fact that if ES is lower than a normal mud specification, the appearance of the drilling fluid is in bad shape such as dull, grainy and shows marked tendencies adhere to the spindle. By contrast with the results, the tested drilling fluid appearance is smooth, shiny and does not adhere to the stirring spindle of a mixer which indicates the high degree of emulsion stability characteristic [13].

### 3.2. The effects of egg shell particle size distribution (PSD) on filtration loss.

Based on Table 3, the filtrate volume shows a slightly different reading according to the size of LCM used meanwhile the mud cake thickness measured for all samples are the same. One of the major advantages of having a thin mud cake thickness is to reduce the risk of differential stuck pipe occurrence since thick mud cake will increase the area of contact between the pipe and formation. The results indicate that the selected size of LCM has a significant effect on the permeability of the mud cake but not give much effect on the mud cake thickness.

|        | Fine | Medium | Course |
|--------|------|--------|--------|
| Filtrate (mL) | 4.0  | 3.6    | 3.6    |
| Mud Cake Thickness (in.) | 1/32 | 1/32   | 1/32   |

**Table 3.** Mud filtrate volume and mud cake thickness.

In this experiment, the medium size of LCM shows the lowest fluid loss due to its better particle size distribution in sealing the formation pores thus forming a better impermeable mud cake. As
mentioned earlier, the usage of LCM sizes with D50 cut mean that there are variance particle sizes in
the particular categories at a specific range, not necessarily 100% of the particles have exactly the
same size within the same categories. On the other hand, this condition may be explained by the
process of mud cake generation. When the drilling overbalance pressure forced the fluid and particles
to invade near wellbore zone, deposition of solid particle occur over the formation face. The larger
particles will form the base first and the high drag force will drive the smaller particles to deposit on
the cake surface thus reduce its permeability as well as the fluid loss [14].

There are several theories in term of particle size distribution to evaluate the bridging or plugging
capability of LCM. One of the popular theory is Abram’s rule which states that in order to plug and
form a stable bridge at the pore openings, the average diameter of drilling fluid particles should be
around 1/3 of the largest pore opening. In this experiment, the HTHP test was conducted with the used
of filter paper with a pore opening of 2.7 micron, tested with three different sizes ranging from 18.631
to 169.960 micron. Even though the filtration and mud cake thickness shows good results, since the
size of LCM are very large than the pore size, thus the significant effect of PSD cannot be clearly
monitored.

3.3. The effects of egg shell particle size distribution (PSD) on fluid invasion.

Based on Figure 5, the depth of a fluid invasion decrease with increasing of LCM size and the best
result obtained by course size egg shell with the invasion of 1.2 cm. The result also shows that the
larger size of egg shell has a better plugging capability and can withstand the rigor pressure even in the
very high permeability of the sand bed. This result proved the performance of egg shell in reducing the
fluid invasion since the previous researcher suggest that the depth of invasion should be less than 2.5
cm [15].

![Figure 5. Fluid invasion of different sizes of egg shell.](image)

In this experiment, 20-40 mesh (420-841 micron) quart sand is used and tested with three
categories of egg shell sizes. Once again, the particle size distribution factor plays a significant role in
preventing the drilling fluid invasion. In order to plug and form a stable bridge at the pore openings,
the diameter of the LCM should be around 1/3 of the largest pore opening, following the Abram’s rule
[11]. In this case, the pore throat opening is undefined due to the unavailability of the equipment thus
the optimum LCM size cannot be determined. However, based on the result, the fluid invasion
dropped drastically when the course size egg shells are used due to the fact that the finer particles were
relatively small and not enough to form a seal within the sand bed.
3.4. The effects of egg shell as an additive on drilling fluid lubricity

| Time (min) | 3   | 6   | 9   | Average (Torque) | Lubricity Coefficient |
|------------|-----|-----|-----|------------------|-----------------------|
| Base       | 7.7 | 6.7 | 6.5 | 6.97             | 0.0697                |
| Course     | 7.8 | 7.4 | 7.4 | 7.53             | 0.0753                |

In this experiment, the lubricity test was carried out on drilling fluid without the presence of LCM (base) and with the addition of course egg shells size. The selection of the course size is due to the fact that drilling fluid lubricity is affected by solid content, particle size, viscosity and the presence of a lubricating agent. Table 4 shows the lubricity coefficient for base drilling fluid and course size egg shell is 0.0697 and 0.0753 respectively. The result shows that there is not much difference and both of them still in acceptable range since a good lubricity coefficient in fresh water mud and saltwater mud is should less than 0.15 and 0.20 respectively [16]. In addition, this result shows that the application of egg shell in drilling fluid has low friction induced thus reduce the risk of the casing and other equipment’s wear.

4. Conclusion

The course size of egg shells can be concluded as the best performance in this experiment since it shows the lowest fluid invasion and an acceptable value of fluid loss and mud cake thickness. In terms of drilling fluid rheological properties, the presence of egg shells does not change much on the PV, YP and the emulsion stability. On the other hand, this also supports by the result of lubricity testing on course size egg shells with lubricity coefficient of 0.0753, a necessary value in reducing the torque and friction during drilling. In conclusion, the results obtained indicate that the application of egg shell as an additive in drilling fluid shows a good plugging capability thus proved its feasibility as a LCM.

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