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EDITORIAL

Investigation of different environmental-friendly waste materials as lost circulation additive in drilling fluids

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Abstract

Drilling fluid is a very important component to ensure smooth drilling process. Drilling fluid is developed and produced with many additives to fulfill its functions. One of the additives is lost circulation materials (LCMs) that will help to minimize or prevent fluid loss into the formation. This study aims to develop new LCM from agro-waste materials which are orange peel and sunflower seed. The LCMs were prepared in three different sizes: fine, medium and coarse and also with different concentrations: 0.8%, 1.3%, 2.2%, 2.7% and 4%. The performance of the drilling fluid with newly developed LCM was tested in terms of rheological and filtration properties. The results were compared with the commercial LCM that has been used in the industry which is nut plug. The results showed that drilling fluid with finest size and high concentration yielded good filtration control. From these preliminaries result, two best sizes were chosen, combined, mixed and tested. The chosen sizes were fine and medium. This new combination of LCM gave even better results compared to the fine-sized and high-concentration LCM. It can be concluded that to ensure good filtration control, the LCM could be combined together since the combination of different sizes minimized the pores created in the mud cake hence helping to reduce the potential of loss circulation problem.

Introduction

Drilling fluid or also known as mud is one of the important elements during drilling process, and a slight error in preparing the drilling fluid can cause a lot of problems. Designing a proper drilling fluid for the drilling process is vital and requires proper testing before it can be implemented to the field (Ademiluyi et al. 2011). Some problems that can occur from drilling fluids are such as formation damage, pipe sticking and lost circulation (Alsabagh et al. 2014; Bennion 2002; Kang et al. 2012; Annis and Monaghan 1962). These problems especially lost circulation can contribute to larger problems such as increment of cost, wasted rig time, affecting non-productive time, and it can go to the extent of losing the well (Alsabagh et al. 2014; Calçada et al. 2015; Kumar and Savari 2011; Nasiri et al. 2017).

There are generally three types of drilling fluids, namely water-based, oil-based and synthetic-based drilling fluids. The type of drilling fluid to be used on the field is to be decided based on a few criteria such as type of formation and conditions of drilling operations (country's regulations, etc.) (Dias et al. 2015; Evans 2003). The composition of these fluids might vary from one another but the functions of the fluids remain the same. Among the functions of drilling fluids include: controlling the pressure, transporting cuttings to the surface, lubricating and cooling down the drilling bit and borehole wall stabilizer (Alsabagh et al. 2014; Meng et al. 2012; Caenn and Chillingar 1996; Luckham and Rossi 1999).

During drilling operation, due to the high pressure and temperature, the drilling fluids will undergo certain changes. There will be solid matter formed at the borehole wall known as mud cake, and also there will be liquid components produced from the drilling fluids known as mud filtrate. When drilling through a permeable or highly permeable formation, the liquid components of the drilling fluids have the tendency to flow into these pores. According to Kumar (2010), the initial filtration is known as spurt loss while the fluid loss after mud cake is formed is known as continuous fluid loss.

These lost circulation problems may occur at any depth and not really confined to any specific area. This problem happens normally when the total pressure exerted against

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the formation exceeds the formation breakdown pressure, and also there is a path that allows the drilling mud to flow into the formation. Generally, it has been agreed that most of the lost circulation problems happened due to the drilling-induced or natural fractures that allow the fluids to enter the formation (Feng and Gray 2017).

Loss circulation problem can be defined as the loss of drilling fluids or cement slurries into the formation either partially or completely (Messenger 1981; Fidan et al. 2004; Nayberg 1987). Nayberg (1987) categorized losses into three types, namely seepage loss, partial loss and complete loss. The seepage loss happens when the losses are in the range of 1 until 10 barrel per hour (bbl/h). The partial losses happen when the amount of fluid loss is around 10–500 bbl/h while complete loss happens when the severity of the loss is more than 500 bbl/h. According to the classification and explanation, seepage losses can happen at any zones and normally the solid in the mud does not able to seal the borehole wall due to less fine-sized solids. On the other hand, the partial losses can happen at formation where there are small natural fractures, normally horizontal fractures. The last type of loss is complete loss, and this happens in the long, open sections of gravel, large natural horizontal fractures, caverns, interconnected vugs and widely opened, induced fractures (Nayberg 1987).

Generally, there are two ways or mechanisms that contribute to the fluid losses and it is either naturally occurred or induced (Wang et al. 2005). However, according to Howard and Scott (1951), there are four types of formation that can contribute to the loss circulation which are natural or intrinsic fracture, induced or created fracture, cavernous formation and unconsolidated or highly permeable formation. Therefore, careful evaluation and understanding of the formation must be done at early stage, so that appropriate drilling fluids can be designed.

One of the ways to combat the mentioned problems (loss circulation) is by adding lost circulation materials (LCMs) into the drilling fluids. There are many aspects of LCM that should be considered when designing the drilling fluids with LCM, and one of the important parameters is the particle size distribution (PSD) of the LCM itself. There are a few set of rules that had been studied and developed by previous authors. The first rule was pioneered by Abrams (1977). He came up with one-third rule or sometimes referred as Abrams' rule. His rules stated that the median particle size of the bridging additive should be equal to or slightly greater than one-third media pore size of the formation. The rule also stated that the concentration of the bridging size solids must be at least five (5) percent by volume of the solids in the final mud mix. These rules have been the fundamentals in the following researches related to LCM.

Another set of rules that had been developed is the ideal packing theory by Dick et al. (2000) which the concept is used in paint industry and now is applied to drilling operation. In that method, for a specific sample, there is a linear graph used to optimize the particles seeding distribution. Last but not least is the Vickers criteria in 2006. Vickers' work used Abram's work as guidelines, and Vickers suggested some standards for the PSD of the LCM additives (Vickers et al. 2006):

1. D_{90} = largest pore throat
2. $D_{75} < 2/3$ pore throat
3. $D_{50} = 1/3$ of the mean pore throat
4. $D_{25} = 1/7$ of the mean pore throat
5. D_{10} > smallest pore throat

Many authors have studied previously the effects of PSD to the sealing capabilities. The recent work was studied by Alsaba et al. (2017) and Razavi et al. (2016). Their work was focusing on the fracture plugging during the wellbore strengthening phenomenon. The types of LCM used were graphite- and gilsonite-based LCMs. Their main finding was that the optimum PSD should have a bimodal structure rather than unimodal structure. Their result suggested that combination of fine and coarse particles with appropriate size will lead to a success fracture sealing since the coarse particles will form a bridge along the fracture width while fine particles will accumulate behind the coarser particles and form a low-permeability zone which reduces the pressure on the formed bridge.

There are many types of LCM available in the market currently. There are sold in different sizes and types. Generally, there are four main types of LCM: flake, fiber, granular and blended materials. These LCMs have been tested and also have been developed from many sources. The flake-type materials are designed, so that it can bridge and form a mat on the formation to prevent any fluid loss into the formation. The materials used from this type can plug off many formations (especially porous) to prevent the mud from entering these formations. It was said that this flaky type can establish an effective seal to permeable and porous formations (Nayberg 1987). The examples of flake-type materials are such as corncobs, cellophane and mica. Ezeakacha and Salehi (2018) studied on the parameters affecting dynamic drilling fluids invasion. The LCMs used in the experiment were calcium carbonate and mica. While there are a lot of other parameters studied in that paper but the results showed that by using the right sizes of mica and calcium carbonate, the fluid loss amount can be controlled. Also, some type of LCMs might be effective at different types of reservoir.

Another type of LCM is the fiber-type. This type of LCM is generally as a part of drilling fluid system to reduce the fluid loss into the large fractures or vugular formations. The fibrous LCMs are normally made up from plant fibers, and sometimes they are also formed from mineral or synthetic fibers. Most of the current development and researches of LCM are based on fiber-type of LCM. Okon et al. (2014) studied on the rice husk to control fluid loss. In that study, it was reported that rice husk materials managed to yield good results in terms of controlling fluid loss while compared to conventional materials such as carboxymethyl cellulose (CMC) and polyanionic cellulose (PAC). The result showed that when 20-g rice husk per 350 mL used in the mud, there was around 64.89% reduction of fluid loss while compared to only 59.57% and 62.77% by using PAC and CMC, respectively. Another study of rice husk was done by Anawe Paul et al., but the study was compared with the usage of sawdust (Anawe et al. 2004). The study found out that rice husk increased the density, plastic viscosity and apparent viscosity of the mud. On the other hand, sawdust yielded much lower values of mud density and viscosities while compared to the rice husk. The study also suggested that rice husk has the potential to be an effective filtration loss additive, but it needs some modification to produce good quality of mud cake.

Other than that, a lot of researches had been done with regard to cellulose-type of LCM. For instance, Samavati and Abdullah (2016) studied on the ubi kayu starch for controlling the fluid loss in water-based mud. Ubi kayu starch is one of the examples of starch/cellulose derivatives. The samples work fine in terms of filtration loss before and after hot rolling at 250 °F and 275 °F. However, the mud with ubi kayu additives failed at higher temperature of 300 °F. Another example of research by using starch was done by Zoveidavianpoor and Samsuri (2016). In that research, they studied on the tapioca starch to control the filtration in water-based drilling fluids. The newly-developed starch was tested at different concentrations and sizes. The sizes selected were in nano- and micro-scales. They reported that nano-sized starch performed better in controlling the fluid loss by 64.2% at high concentration of 2.5%. In this research, two agro-waste materials which are orange peel and sunflower seed are chosen as a potential LCM additive. The materials were prepared and tested in the water-based mud system.

Experimental procedure

Materials

There were two types of agro-waste lost circulation materials used in this experiment. The first one is sunflower seed samples and another one is orange peel waste samples. The experiments were also used some conventional lost circulation materials as comparison or base mud which is nut plug. The lost circulation materials were prepared for three different sizes: fine, medium and coarse. The materials were cut, dried and grinded to yield desirable sizes. The samples were grinded by using blender or mortar grinder, and further a sieve shaker was used to classify the samples according to its sizes. The preparation of the samples' sizes was based on Table 1 (API Recommended Practice 13 2014).

Preparation of the drilling fluid samples

The water-based drilling fluids were prepared with two (2) different types of newly-developed lost circulation materials. Each LCM was prepared with five (5) different concentrations: 0.8%, 1.3%, 2.2%, 2.7% and 4%. The fluid samples were prepared, so that the density of all samples remained constant which was around 10–11 lb/gal. The fluid samples were also designed based on low-solids mud design. The density of the samples was measured by using pressurized mud balance. Generally, the additives used to prepare the samples were: water (base fluid), barite (weighting agent), soda ash, bentonite, caustic soda and the LCMs. The samples' properties were tested for rheology and filtration before and after dynamic aging. The dynamic aging was done by inserting the mud samples into the aging cell, and let it roll for 24 h in the rolling oven at 250 °F. The base muds were also prepared by using commercially used LCM which is nut plug with different sizes. The concentration was fixed, only 4% of nut plug used for all the sizes. The base mud was prepared as a comparison to the mud prepared with orange peel and sunflower seed. One of the purposes of this study is to see the effects when two different sizes of LCM were combined together. The screening criteria were done and based on the results, two best sizes were chosen and they were fine and medium sizes of LCM.

Rheological testing

The samples were tested for rheological properties by using Fann 35 viscometer. The rheological properties measured include gel strength, plastic viscosity (PV) and yield point (YP). The samples were placed into the rheometer thermo-cup until the mud's surface level is equal height to the scribed line on the rotor surface. Six different measurements from different speeds were taken (600 rpm, 300 rpm, 200 rpm, 100 rpm, 6 rpm and 3 rpm). The gel strength

Table 1 Particle sizes classification

Particle size (microns)	Particle classification
> 200	Coarse
200–250	Intermediate
74–250	Medium
44–74	Fine
2–44	Ultrafine
0–2	Colloidal

readings were taken twice: once at 10 s and second time at 10 min. The PV and YP can be determined from the formula below:

Plastic viscosity—the indication of solid contents (sand or silt) in the drilling fluids.

$$\text{Plastic viscosity, PV} = \theta_{600} - \theta_{300}$$

Yield point—the indication of the capacity of drilling fluids to carry cuttings during dynamic process.

$$\text{Yield point, YP} = \theta_{300} - \text{PV}$$

Filtration properties measurement

Filtration properties (amount of mud filtrate and mud cake thickness) of the mud samples were tested by using API filter press. The testing was following the API specifications. Filtrate is an indication of the amount of water lost from the mud to the formation, and the filtration testing simulates how much the fluid loss can take place inside the wellbore. Filter cake forms from the solids in the mud will help to prevent excessive fluid loss. The filter cake should have the following characteristics: thin, flexible with low permeability, and have correct solids distribution. If the filter cake is thick, it will reduce the effective hole diameter and can increase the chance of differential sticking. Generally, good fluid loss control is achieved when there are low mud filtrate amount and thin mud cake. The testing of filtration properties started by placing some amount of mud samples into a stainless steel chamber/cell. The cell will then place inside the API filter press frame, and the mud will be exposed to 100-psi pressure. The fluid loss volume will be recorded after 7.5 and 30 min.

Results and discussion

The samples were prepared and tested for density, pH, rheological and filtration tests. There were 45 samples (including base mud) altogether prepared and were tested for its properties.

The effects of different concentrations and sizes of LCM on the rheology

The rheology of the drilling fluids is studied in terms of four properties which are apparent viscosity (AV), plastic viscosity (PV), yield point (YP) and gel strengths. Table 2 shows the results of apparent viscosity of orange peel and sunflower seed samples, respectively. The drilling fluids were prepared and tested with different concentrations of orange peel and sunflower seed at 0.8%, 1.3%, 2.2%, 2.7% and 4%. The samples were also prepared with three different kinds of sizes; fine, medium and coarse. The sizes determination was following the API recommendation (API Recommended Practice 13 2014). The mud samples were also prepared with the combination of two different sizes which were fine and medium sizes, and the mud properties were tested too.

The first evaluation of the rheology is the apparent viscosity, AV. The apparent viscosity is an indication of the viscosity or the shear stress on a given equipment (viscometer). If the fluid is a Newtonian fluid, the apparent viscosity is numerically equal to the plastic viscosity, and if it is a non-Newtonian fluid, specifically Bingham fluid model, apparent viscosity is a function of plastic viscosity and yield point. Generally, by looking at the apparent viscosity results in Table 2, as the concentration of orange peel is increasing, the apparent viscosity is also increasing. This apparent viscosity increasing trend as the concentration increases can be seen from all three sizes of orange peel including the mixture of sizes (fine and medium). The same trend can also be seen from the sunflower seed samples, whereby as the concentration is increased, the apparent viscosity also increased. For example, when 0.8% of fine-sized sunflower seed used in the mud, the value of AV is 19 cP. However, when the amount of fine-sized sunflower seed is increased to 4%, the value of AV is also increased to 27.5 cP.

The other effect studied in this test is the effect of LCM sizes. The results in Table 2 show that as the sizes of the LCM is increased, the values of AV are reducing for all concentrations, when the mud weight is remained constant. It can be seen when the concentration of orange peel LCM used is 2.2%, the AV values for fine-sized LCM is 27.5

Table 2 Apparent viscosity results for orange peel and sunflower seed samples

Concentration (%)	AV for orange peel samples (cP)				AV for sunflower seed samples (cP)			
	Fine size	Medium size	Fine and medium sizes	Coarse size	Fine size	Medium size	Fine and medium sizes	Coarse size
0.80	24	22.5	25.5	20	19	17	19	15
1.30	25	23.5	26.5	22	20.5	18	21	16.5
2.20	27.5	24.5	29	22.5	23.5	19.5	23.5	17.5
2.70	29.5	25	30.5	23	26	21.5	25.5	19.5
4.00	33.5	28	32	24	27.5	23	27	21

cP and it keeps reducing to 24.5 cP for medium-sized and 22.5 cP for coarse-sized orange peel LCMs. The mixture of fine and medium sizes for both orange peel and sunflower seed samples did not differ much from the other samples. By looking at the result, it seems like the AV for both samples is quite similar with the AV of the fine-sized samples.

The next evaluation is the plastic velocity. Plastic velocity is the measurement of the fluid resistance to flow that is caused by mechanical friction between the solid phase and liquid phase of the mud (Davoodi et al. 2018). PV values can be affected when there are more solid particles in the fluid (Zoveidavianpoor and Samsuri 2016). Therefore, as more solids are added (when the concentration is increased), PV values will also increase. This is because when there are more solids in the fluids, there will be more mechanical friction between the solid and liquid phase as mentioned earlier. Hence, the fluid resistance to flow will be higher and subsequently will increase the value of PV. This scenario can be seen from all samples of mud, regardless of their type (orange peel and sunflower seed). The PV results for orange peel and sunflower seed samples are shown in Figs. 1 and 2, respectively. There is an increment trend of PV values from low concentration to high concentration because there are more solid particles in the higher concentration muds. However, it can be noticed that there is a slightly different trend of PV values if the sizes of LCM samples were compared. The fine-sized samples show higher PV values as compared to medium and coarse sizes of the LCM samples. This is true and can be expected because when the sizes of the samples are reduced, there will be more solid particles inside the finer LCM samples when the mud weight is maintained (Davoodi et al. 2018). By following the theory of PV, when there are more solids, the mechanical friction will be higher hence increasing the PV values. The highest PV value of orange peel samples is when 4% of fine-sized orange peel used which yielded the value of 18 cP. The same scenario can also be seen from the sunflower seed results, which is the 4% of fine-sized sunflower seed gave highest PV value which is 19 cP (Figs. 1, 2).

Another important evaluation of mud property is the yield point. In Bingham plastic model, yield point is actually a critical value in which the fluids will start to flow until the shear stress exceeds this critical value. In another word, YP is the minimum shear stress that must be applied in order for a fluid to start flowing. Yield point also sometimes is referred to the measurement or evaluation of the attractive forces that exist in the drilling fluid under flowing conditions. It is also a parameter that gives an indicator of the pseudo-plastic parameters of the fluid and its capacity to carry solids in suspension (Caenn et al. 2011). From the results in Figs. 3 and 4, it can be seen that for both orange peel and sunflower seed samples, as the concentration of the samples increased, the YP values are also increased, for each particular sample size. For instance, YP value for fine-sized samples of orange peel at low concentration of 0.8% is 22 lb/100 ft^2 and the YP value at high concentration of 4%

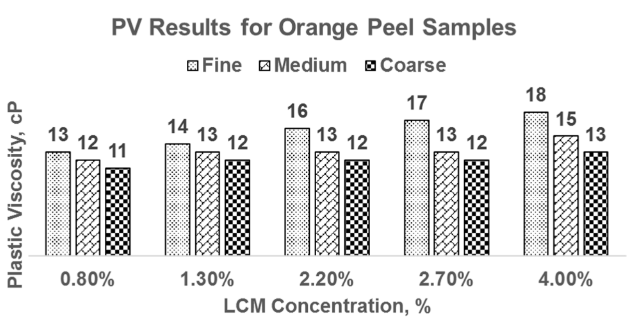

Fig. 1 Plastic viscosity results for orange peel samples

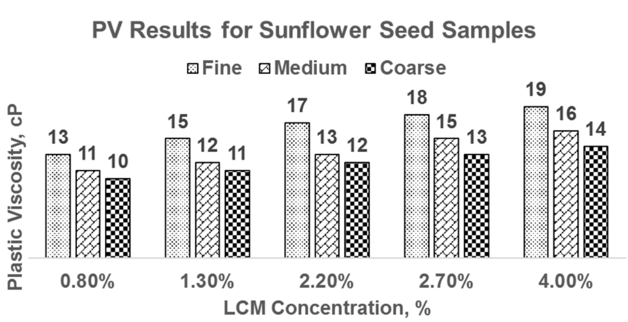

Fig. 2 Plastic viscosity results for sunflower seed samples

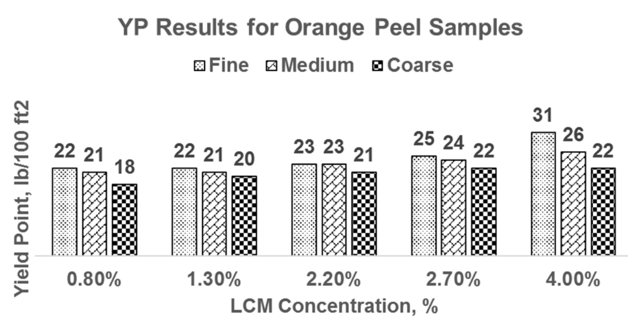

Fig. 3 Yield point results for orange peel samples

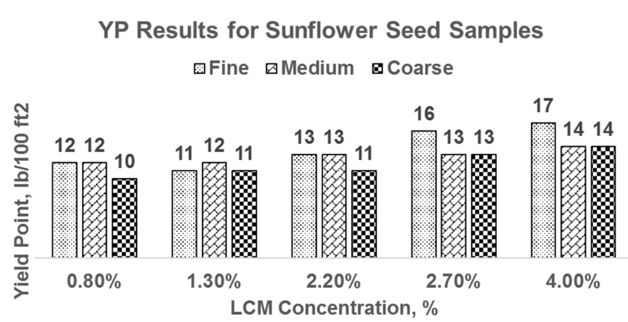

Fig. 4 Plastic viscosity results for sunflower seed samples

concentration is 31 lb/100 ft^2. Another example is the coarse sample of the sunflower seed. The YP reading at low concentration of 0.8% is 10 lb/100 ft^2 while the reading at higher concentration of 4% is 14 lb/100 ft^2. This shows that as the concentration increases, more solids content are added into the mud which created more attractive forces that will result in increasing YP. The comparison of orange peel and sunflower seed samples shows that orange peel exhibits higher YP values which suggest that orange peel samples based on this result have more attractive forces among the particles.

One of the purposes of this study is to investigate the effects when two different sizes of LCM were combined together. As mentioned in previous section, fine- and medium-sized of both LCM additives which are orange peel and sunflower seed were combined separately and tested. Hence, there were five mud combinations of fine and medium sizes of orange peel samples with different concentrations and five mud combinations of fine- and medium-sized sunflower seed samples with different concentrations. The results for PV and YP for these samples are shown in Fig. 5 for orange peel samples and Fig. 6 for sunflower seed samples. From the result, it can be seen that for orange peel samples, the YP is higher than PV values. Both PV and YP values increased when the concentration of the orange peel increased. This trend is similar to the previous samples that were not combined.

On the other hand, the sunflower seed samples show YP results lower than the PV values. However, the same trend shows by the sunflower seed samples as orange peel samples, whereby when the concentration is increased, the PV and YP values are also increased.

Gel strength is another rheological property to evaluate the emulsion's capacity to carry drill cuttings or solid particles during drilling operation and to ensure that those solids are kept in suspension in the fluid throughout the process. The standard practice of testing the gel strength of a sample is to let the fluid to settle in static condition

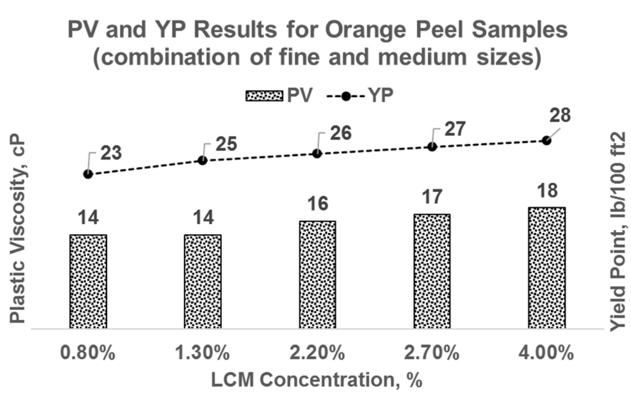

Fig. 5 PV and YP results for combination of fine and medium sizes orange peel samples

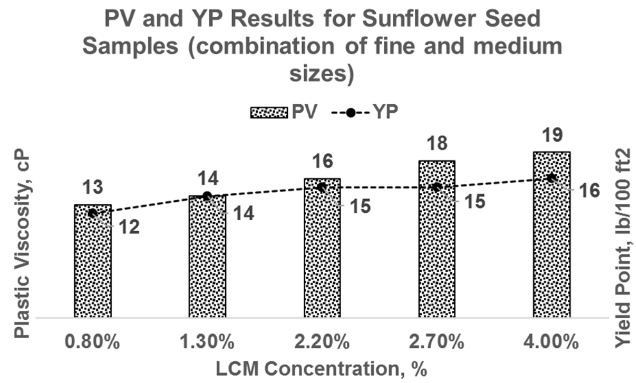

Fig. 6 PV and YP results for combination of fine and medium sizes sunflower seed samples

for short period of time such as 10 s and 10 min, and then readings are taken for both times. The reading is the shear stress reading at low shear rate. These measurements are actually the indication of the strength of attractive forces or sometimes called as gelation under static conditions. The aim is to obtain small difference in readings at 10 s and 10 min. The small difference gives indication that there will be small tendency of the mud to develop gelation. When there is a big difference between 10-s and 10-min reading, the mud is said to exhibit progressive gels characteristic and this is not desirable. The progressive gelation will reach high viscosities in short period of time, and this characteristic can induce pressure peaks when the circulation of the system is restored after an operational shutdown, posing risks to the operation (Dias et al. 2015; Fink 2003). The contribution to this phenomenon is normally because of high solid content that leads to flocculation. The results of gel strength at 10 s and 10 min for both orange peel and sunflower seed samples showed good results which means that the difference in both 10-s and 10-min readings is small. This can be seen in Tables 3 and 4. From the results of 10-s readings for orange peel samples of medium-sized particles, the increment after 10-min measurement is very small. At concentration of 2.2%, the reading for 10 s of medium-sized sample is 9 lb/100 ft^2 while the reading after 10 min is 15 lb/100 ft^2. For the combination of fine- and medium-sized samples of sunflower seed, the reading at 10 s for 2.2% concentration is 12 lb/100 ft^2 while the reading at 10 min is 17 lb/100 ft^2. In general, as the concentration of the samples increased, the gel strengths values also increased, and it can be seen from all samples either fine, medium or coarse sizes. The highest gel strength values are at highest concentration of 4%. However, the sunflower seed samples showed that the difference between 10-s and 10-min readings is higher compared to orange peel samples.

Table 3 Gel strength results for orange peel samples

Concentration (%)	Gel strength 10 s, lb/100 ft^2				Gel strength 10 min, lb/100 ft^2			
	Fine size	Medium size	Fine and medium sizes	Coarse size	Fine size	Medium size	Fine and medium sizes	Coarse size
0.80	9.5	8	9	9	12	12	13	13
1.30	11	8	10	9	13	14	13	14
2.20	10	9	12	10	15	15	15	17
2.70	10	11	13	12	16	17	17	18
4.00	12	13	14	14	17	18	19	19

Table 4 Gel strength results for sunflower seed samples

Concentration (%)	Gel strength 10 s, lb/100 ft^2				Gel strength 10 min, lb/100 ft^2			
	Fine size	Medium size	Fine and medium sizes	Coarse size	Fine size	Medium size	Fine and medium sizes	Coarse size
0.80	8	9	9	8	14	15	14	13
1.30	8	9	10	9	15	15	15	16
2.20	9	11	12	11	18	18	17	17
2.70	10	11	12	11	19	19	18	19
4.00	12	12	13	13	21	22	20	23

The effects of different LCMs on filtration properties

The main evaluation of LCM to determine whether it has good performance or not is through the filtration test. For the filtration test, there are two properties that will be obtained: mud cake thickness and fluid loss volume. During drilling operation, mud cake will be formed as the mud enters the wellbore and due to the differential pressure, some solid particles which are called as mud cake will be formed along the borehole wall. When the mud cake is formed, residue from the drilling mud will be produced as well and called as mud filtrate.

For the purpose of the filtration test, before the mud was tested by using filter press equipment, the mud samples were inserted into a rolling oven at 100 psi and 250 °F. This is because during real drilling process, mud filtrate will be produced once the mud is exposed to high pressure and temperature. Therefore, the mud samples were inserted into the rolling oven with higher pressure and temperature to simulate the downhole condition, whereby normally the pressure and temperature downhole will be high. Also, by using the rolling oven, the mud samples were allowed to undergo dynamic changes. Figure 7 shows the comparison of fluid loss orange peel mud samples at different concentrations and sizes. Figure 8 shows the comparison of fluid loss sunflower seed mud samples at different concentrations and sizes.

Generally, the mud samples will produce lesser mud filtrates as the concentration of LCM used increased. For instance, in Fig. 7, for the fine-sized orange peel samples,

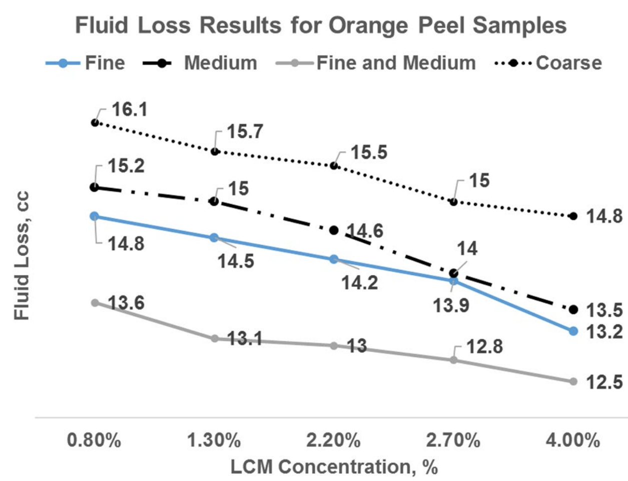

Fig. 7 Fluid loss results for orange peel samples

as the concentration increases, we can see that the amount of filtrates produced is reducing. When 0.8% of fine-sized LCM was used, the amount of filtrate produced was 14.8 mL. However, when the concentration is increased to 4%, the amount of filtrate produced was 13.2 mL. There is a reduction of about 10.8%. The same scenario can be seen for sunflower seed samples in Fig. 8. The mud sample of medium size with 2.7% concentration gave result of 12.6 mL mud filtrate collected. For the 4% concentration of the medium size, it shows 11.8 mL mud filtrate result. This is about 6.3% reduction. The increment of LCM concentration

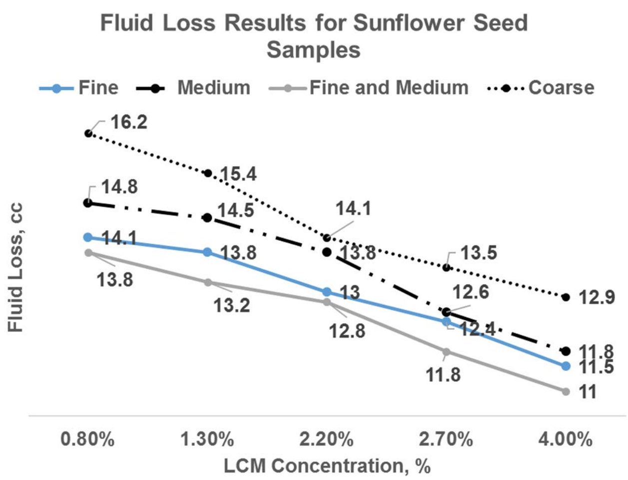

Fig. 8 Fluid loss results for sunflower seed samples

will create more effective fluid loss control. This is because more solid particles of LCM will be accumulated at the bottom of the filtration test equipment and eventually stop more fluids from flowing through the filter paper. The results of the mud cake thickness for all samples are shown in Table 5.

For this filtration test, the mud samples were tested after the mud samples were put in the rolling oven for 24 h. The results of this filtration test were compared with the base mud (mud with nut plug as LCM) in Table 6. Based on the results in Fig. 7, it can be seen that for fine and medium sizes of orange peel, the filtrates collected were better while compared to the base mud with nut plug in Table 6. However, the value of filtrate collected for coarse size with 0.8% concentration orange peel gave higher filtrate compared to base mud. The rest of the concentration of orange peel gave better values of filtrate collected compared to the base mud. The same thing can also be observed from sunflower seed results in Fig. 8. All samples for fine, medium and coarse sizes of sunflower seed gave lower filtrates collected compared to the base mud except the sample of coarse size sunflower seed with 0.8% concentration. Based on this result, it shows that the new LCM from orange peel and sunflower seed could give same or even better performance compared to the one that has been widely used in the industry.

In terms of sizes, for all the samples, it can be seen that regardless of concentration and type of LCM, the amount of filtrates collected was the least when the smallest size of LCM used in the mud. For instance, the 0.8% concentration of orange peel gave value of 14.8 mL for fine size, 15.2 mL for medium size and 16.1 mL for coarse size. This shows that as the size of LCM is increased, the amount of filtrate produced will also increase. The fine-sized LCM samples will be pressed and accumulated on the filter paper. Due to their small sizes, they will be pressed and packed closely together and subsequently the other particles will fill up the small opening pores, hence reducing the permeability of the mud cake. When this occurs, the amount of fluid that can pass through the mud cake will be limited and as a result, the filtrates collected will be less. This is also the reason why the mud cake thickness is thin when the fine-sized LCM used. The larger LCM particles generally will produce loose, thick, poorly packed particles in the mud cakes, hence creating larger pore spaces that will allow mud filtrate to pass through (Zoveidavianpoor and Samsuri 2016). Hence, it can be said that fine-sized LCM generally gives better filtration results. The advantage of the small sizes of LCM is that it could possibly avoid thicker accumulation during filtrate invasion. This characteristic is favorable because the well

Table 5 Mud cake thickness results for orange peel and sunflower seed samples

Concentration (%)	Results for orange peel samples (mud cake thickness, mm)				Results for sunflower seed (mud cake thickness, mm)			
	Fine size	Medium size	Fine and medium sizes	Coarse size	Fine size	Medium size	Fine and medium sizes	Coarse size
0.80	1.1	1.18	1.2	1.3	0.9	1.1	1.2	1.2
1.30	1.12	1.29	1.25	1.4	1.2	1.25	1.31	1.36
2.20	1.24	1.34	1.32	1.55	1.4	1.31	1.33	1.56
2.70	1.36	1.45	1.4	1.65	1.43	1.45	1.45	1.7
4.00	1.45	1.55	1.5	1.72	1.5	1.7	1.6	1.9

Table 6 Fluid loss and mud cake thickness results for base mud samples (nut plug)

Parameter	Concentration	Samples' sizes			
		Fine	Medium	Fine and medium	Coarse
Fluid loss (cc)	4%	15	15.5	13.4	15.9
Mud cake thickness (mm)		2.00	2.40	2.15	2.62

dispersed and thin mud cake will reduce the potential of differential sticking problems especially at the formations that have high tendency to cause sticking problems (Zoveidavianpoor and Samsuri 2016; Davoodi et al. 2018).

In this study also, as mentioned in the previous section, one of the evaluations is to see the effect if different sizes of LCM are used together in one mud. The combination of fine and medium sizes of LCM is also illustrated in Fig. 7 for orange peel samples and Fig. 8 for sunflower seed samples. From the result of the filtration test, it can be seen that for both LCM types: orange peel and sunflower seed, both gave better result in terms of filtrate collected and also mud cake thickness. For instance, in the combination of both sizes with 0.8% concentration of orange peel, the amount of filtrate collected was 12.5 mL while compared to fine size and base mud which yielded the value of 13.2 mL and 13.4 mL, respectively. The same scenario can be seen in the case of sunflower seed, whereby when the combination of both sizes were used for 4% concentration, the amount of filtrate collected was 11 mL while the fine-sized sunflower seed with 4% concentration gave the value of 11.5 mL and the base mud gave 13.4 mL value. This shows that the combination of different sizes actually has the potential of giving good filtration control. The medium sizes of LCM particles will be accumulated first on the filter paper, and the remaining pores created by these medium sizes particles will be filled up by the small sizes of LCM particles, hence giving good filtration control with reasonable mud cake thickness.

Conclusion

From the results, there are a few important remarks that can be observed:

1. Agro-waste materials such as orange peel and sunflower seed can be used as a potential alternative LCM in drilling fluids. The use of these materials is environmental friendly.
2. The concentration of the LCM plays a role in controlling the rheological and also filtration properties of the mud samples. In order to have better filtration, more amount of LCM should be used; however, the rheological properties such as PV and YP must be monitored closely, so that it will not give very high values.
3. Sizes of LCM definitely will affect the performance of the mud in terms of filtration controls. The fine sizes of LCM give better filtration control and thinnest mud cake produced. Hence, it will be good to use fine-sized LCM since it has good performance.
4. However, the performance of the LCM can be improved by combining different sizes of LCM. In this paper, it is proven that combination of fine- and medium-sized LCM yields better filtration control (Nasiri et al. 2017; Xu et al. 2017).
5. For recommendation, the testing could be repeated with the combination of different types of LCM to produce better result in terms of PV, YP and filtration properties (Nasiri et al. 2017; Xu et al. 2017).
6. There are many types of conventional LCM used in the industry such as corncob and walnut shells. For future investigation, the results of this project also could be compared with the conventional LCM used in the industry, so that the materials used in this paper could be accepted by the industry.

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