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# A comprehensive investigation on the performance of durian rind as a lost circulation material in water based drilling mud

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ABSTRACT

Oil and gas operators worldwide are expecting service companies to deliver integrated techniques to minimize, if not prevent, drilling problems. Drilling fluids perform vital functions to ensure the success of drilling operations. The technical challenges often associated with water-based drilling fluids are loss of critical properties, such as fluid loss control and rheology, under demanding conditions, such as in drilling deeper, high-temperature and high-pressure wells. Fluid loss during drilling operations has a very significant effect in both reservoir formation damage and monetary terms. The use of durian rind (DR) as a new additive in controlling lost circulation would provide another opportunity to reduce waste and avoid pollution. Therefore, DR was used to improve the rheological properties of water-based mud, and it was prepared for use as a fluid loss additive. For a better understanding of the influence of pectin on drilling mud properties, the rheological evaluation of untreated DR was compared to that of mud samples containing treated DR. The pectin in DR was extracted using four different solvents, namely, ethanol, methanol, sodium hydroxide and hydrogen peroxide, and the most effective solvent to remove the pectin was then determined. The Fourier transform infrared spectroscopy (FTIR) results showed that NaOH was the best solvent for removing pectin from DR. Thermogravimetric analysis (TGA) was used to determine the thermal stability of DR before and after treatments. The TGA results demonstrated that the treated DR had improved thermal stability compared to untreated DR. The sizes of DR used were coarse, medium, and fine. The untreated DR presented better rheological properties than the treated DR. The experimental investigation showed that a concentration of 20 lb/bbl of intermediate-sized DR was the best concentration among the tested samples.

## 1. Introduction

Drilling fluid properties are very important for the success of any drilling operation. The functions of drilling fluids are to move the drill cuttings to the surface, to cool and clean the drill bit, to reduce friction, to maintain wellbore stability and to prevent pore fluids from prematurely flowing into the wellbore ([1–9]). Moreover, drilling fluids are designed to build a filter cake([10–15]), which is basically intended to decrease filtrate loss to formation, to be thin and to hold the drilling fluid in the wellbore. One of the vital functions of drilling fluids is to minimize the amount of drilling fluid filtrate entering the hydrocarbon-bearing formation, which can cause formation damage because of rock wettability changes, fines migration, and drilling fluid solids plugging. During drilling operations, the permeation of fluids into porous media can lead to irreparable damage and reduced well productivity ([13], [16]). Therefore, fluid loss additives are supposed to plug all pores, provide the core for filter cake formation and minimize the amount of mud loss.

Lost circulation is one of the serious problems that occur when drilling oil wells. Lost circulation occurs when the total pressure at any

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depth exerted against the formation exceeds the breakdown pressure of the formation ([1] [5], [17–24]). Lost circulation leads to the loss of materials, rig time, and so forth, and this has greatly affected financial resources by more than one billion dollars annually; [1,5].

Fidan et al. (2004) [20] determined that lost circulation occurs during drilling in approximately 20%–25% of wells drilled worldwide and that lost circulation can lead to a blow out. This problem occurs when the drilling mud's hydrostatic pressure is higher than the formation pressure. To overcome this problem, there are many materials that can be used as lost circulation materials (LCMs), such as organic and synthetic materials.

The choice of muds and their additives has become a complex issue because conserving the environment has become the primary concern before hydrocarbon exploration; [25–27]. At present, many plant-based organic particles have been commercially used as fluid loss materials because plants and fruits are abundant, inexpensive, and can be accessed easily in the market. Durian rind (DR), an organic waste, is another material that can be sourced easily during its peak season in tropical countries (Amid and Mirhosseini (2012) [28]).

Durian (Durio zibethinus) is a tropical fruit, and it is one of the most highly valued and desired fruits in tropical countries due to its distinct flavor and unique taste (Maran (2015) [29]). In tropical countries, the rind constitutes 45% of each fruit on average, and thus, DR waste generated approximately 133,688 to 171,303.9 metric tons from 2006 to 2013, respectively (Masrol et al. (2016) [30]). To avoid the pollution created by disposing of DRs [31], it is a notable effort to consider DR as an LCM, which can mitigate the environmental problems and reduce the cost of drilling mud.

Generally, DR consists of a chemical compound known as pectin or polysaccharides, in addition to cellulose, hemicelluloses and a lignin matrix, and pectin is widely used as a gelling and stabilizing agent (Penjumras et al. (2014) [32]).

Ismail et al. (2015) [33] and Majid et al. (2016) [34] investigated the potential of using DR as a bridging material to overcome fluid loss and lost circulation problems during drilling operations. Their results showed that DR has the potential to be used as a fluid loss additive and LCM in water-based mud; however, the pectin in DR significantly increased the gel strength and yield strength beyond the recommended ranges. From these studies, the following questions arose: Does the removal of pectin make DR a better LCM? To what extent does the removal of pectin from DR alter the rheological properties of water-based mud? These questions form the basis of this study to investigate the effectiveness of DR as an LCM in water-based mud.

## 2. Methodology

### 2.1. Durian rind preparation

The method to prepare DR was based on the technical paper by Mohammed et al. (2012) [35]. The steps and procedures to prepare DR are listed below:

(1) The DR was washed with water and finally with deionized water to remove clay, sand, dirt and other particulate material from its surface.
(2) After washing, the DR was dried in an oven at 50°-60°C for two days to ensure that there was no moisture in the sample.
(3) The dried DR was cut into small pieces and ground using a grinder.
(4) Then, the pieces of DR were sieved for size ranges of (44–74 μm), (74–250 μm), (250–2000 μm) and greater than 2000 μm, which were then categorized as fine, medium, intermediate and coarse sizes, respectively.
(5) The DR particles were packed in a sealable plastic bag.

#### 2.1.1. Determination of the durian rind size

The size of the DR is an important factor to take into consideration, and according to the API-RP-13C (2010) [36] procedure, the distribution of particle size to be taken into consideration is as follows: (See Table 1).

### 2.2. Extraction of pectin

In this research, pectin was extracted using two types of solvents, which are ethanol and methanol. The pectin was extracted using ethanol and methanol in a water bath with constant stirring. The time taken for the extraction process was 1 h at a temperature of 95°C. The size of DR used for the extraction was the medium size. After extraction, the DR was allowed to cool to room temperature in a water bath. Then, the DR was filtered and washed using distilled water and dried in an oven for 4 h at 60°C. By using NaOH, it was possible to remove lignin and other organic compounds such as DR. This treatment is known as an alkaline treatment. The procedures to remove the pectin or other compounds by using coarse, intermediate, medium, and fine DR involved heating in a 10% wt NaOH solution at 60°C for 4 h. Preheated DR cellulose fiber was filtered and washed using distilled water. The residue was then dried in a vacuum oven for 4 h at 55°C. After the drying process, the DR was ground.

The other solvent was hydrogen peroxide. Extraction using hydrogen peroxide is also known as a bleaching process. The procedures for the bleaching involved heating durian cellulose fiber in a 10% by volume hydrogen peroxide solution for 3 h. The solution was allowed to cool and filtered using excess distilled water. The residue was then dried again in a vacuum oven at 55°C for 4 h.

### 2.3. Water-based mud formulation

Water-based mud was prepared using the guideline based on API-RP-13B-1 (2009) [3]. For this purpose, 350 ml of water was used, and 15 g of bentonite was added. The basic water-based mud was used for comparison with the water-based mud with lost circulation additives for the rheological test.

#### 2.3.1. Water-based mud formulation

The constituents of the base mud preparation are shown in Table 2, and the procedure is described below:

(1) 350 ml of water was measured in a graduated cylinder and placed in the mixing cup.
(2) 0.25 g of soda ash was dissolved in water and stirred in the multi-mixer for 2 min.
(3) 15 g of bentonite was added and stirred for 5 min.
(4) 1.0 g of starch was added and stirred for 5 min.
(5) 0.25 g of caustic soda was added to the mixture and stirred for 5 min.
(6) The mixture was stirred for 30 min before the mud was tested.

#### 2.3.2. Water-based mud formulation with lost circulation material

In this research, the LCM used was DR with and without pectin. For the water-based mud with LCM, the procedure was as follows:

(1) Steps (1) to (4) were the same as the base mud formulation in section 2.3.1.

**Table 1**
Definition of particle sizes; API-RP-13C (2010) [36].

| Particle Size(microns) | Particle Size(mm) | Particle Classification(size) |
|---|---|---|
| > 2000 | > 2.0 | Coarse |
| 250–2000 | 0.25–2.0 | Intermediate |
| 74–250 | 0.074–0.25 | Medium |
| 44–74 | 0.044–0.074 | Fine |

**Table 2**
Basic mud formulation.

| Additive | Quantity (lb/bbl) |
|---|---|
| Bentonite | 15 |
| Soda ash | 0.25 |
| Caustic soda | 0.25 |
| Starch | 1 |

(2) The desired amount of LCM was added to the mixture and stirred for 15 min.
(3) 0.25 g of caustic soda was added to the mixture and stirred for 5 min.
(4) The mixture was stirred for 30 min before the mud was tested.

Table 3 shows the composition of the mud with different LCM concentrations.

### 2.4. Testing chemical and physical properties using Fourier transform infrared spectroscopy (FTIR) and thermogravimetric analysis (TGA)

#### 2.4.1. FTIR

FTIR spectra of raw DR and extracted DR were obtained by using an IRTracer-100. The fibers were crushed into small particles and pressed into ultrathin pellets. The scans were recorded in absorbance mode in the range 400–4000 $cm^{-1}$ with a resolution of 2 $cm^{-1}$ for each sample.

#### 2.4.2. TGA

TGA was performed from 50 to 900° C at a heating rate of 10° C/min using a TGA-Q500. Approximately 10–20 mg of each sample was heated under a nitrogen atmosphere with a gas flow of 20 ml/min to prevent any thermoxidative degradation.

### 2.5. Rheological properties

In this research work, the rheological properties of water-based mud with untreated and treated DR were determined. The water-based mud formulation was obtained from Scomi Energy [37]. The rheological properties measured were the following:

(1) Plastic viscosity (PV)
(2) Yield point (YP)
(3) Gel strength
(4) Fluid loss and mud cake thickness

The basic mud formulation is shown in Table 2. The concentrations tested were 5, 10, 15, 20, 25, and 30 lb/bbl.

**Table 3**
Composition of mud system with different LCM concentrations.

| Sample | Mud system |
|---|---|
| 1 | Base mud at 75°F |
| 2 | Base mud +5 ppb DRs at 75°F |
| 3 | Base mud +10 ppb DRs at 75°F |
| 4 | Base mud +15 ppb DRs at 75°F |
| 5 | Base mud +20 ppb DRs at 75°F |
| 6 | Base mud +25 ppb DRs at 75°F |
| 7 | Base mud +30 ppb DRs at 75°F |
| 8 | Base mud +5 ppb extract DRs at 75°F |
| 9 | Base mud +10 ppb extract DRs at 75°F |
| 10 | Base mud +15 ppb extract DRs at 75°F |
| 11 | Base mud +20 ppb extract DRs at 75°F |
| 12 | Base mud +25 ppb extract DRs at 75°F |
| 13 | Base mud +30 ppb extract DRs at 75°F |

## 3. Results and discussions

### 3.1. FTIR

FTIR is an appropriate technique for identifying the compositions of untreated DR and of DRs treated with the four different solvents. The solvents used to extract pectin from the DR were ethanol, methanol, sodium hydroxide, and hydrogen peroxide. As indicated by the results, the spectra of untreated and treated DRs were compared against a commercial pectin standard provided by Sigma-Aldrich [38]. Fig. 1 shows the FTIR spectra of untreated DR, commercial pectin, DR treated with ethanol, DR treated with methanol, DR treated with hydrogen peroxide, and DR treated with sodium hydroxide. A peak near 3400-3200 $cm^{-1}$ was observed in all spectra, which corresponds to the O-H stretching vibration of OH groups in cellulose and pectin molecules. The existence of O-H groups was due to the moisture content, and hydroxyl groups are present in cellulose, hemicellulose, and lignin (Fatah et al. (2014) [39]). The low-intensity spectrum of O-H groups for the DR treated with sodium hydroxide was caused by the removal of cellulose. The DR treated with hydrogen peroxide showed a high intensity or narrower spectrum of O-H stretching vibration, which indicates that it contained more O-H groups. The increase in O-H groups was due to the removal of lignin. After lignin was removed, the exposure of hydroxyl groups in hemicellulose and cellulose increased. The untreated DR and the DRs treated with ethanol and methanol showed the same trend of O-H groups, which revealed that chemical treatments do not affect the cellulose.

Sato et al. (2011) [40] stated that the functional identity for confirming the presence of pectin are the peaks at 1747 $cm^{-1}$ (esterified carboxyl groups) and 1639.4 $cm^{-1}$ (free carboxyl group). As shown in Fig. 1, the spectrum of commercial pectin presented a narrower peak around 1640 $cm^{-1}$ to 1780 $cm^{-1}$, which represented the esterified carboxyl and free carboxyl groups. Hence, to determine an effective solvent to remove pectin, the resulting spectrum should have a low intensity around this peak. The experimental result of the DR treated with NaOH has a low intensity peak around 1640 $cm^{-1}$ to 1780 $cm^{-1}$ compared to the other samples. This result indicates that the peak that is supposed to show the carboxyl and free carboxyl groups had disappeared due to the removal of pectin. Moreover, according to Williamson (2013) [41], the peak at ~1730 $cm^{-1}$ is the carbonyl peak that corresponds to carboxylate (-COOH) groups or ester (COO) linkages in pectin. These results confirm that the pectin molecule was removed during the extraction using sodium hydroxide.

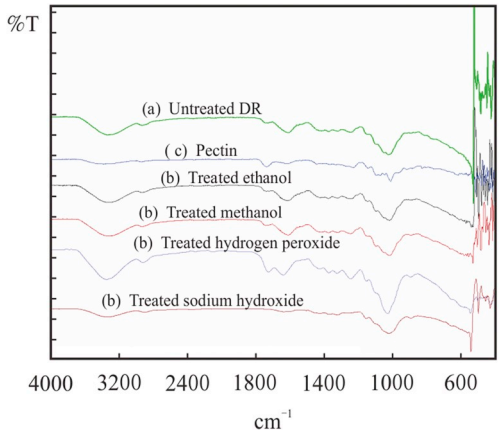


**Fig. 1.** FTIR spectra of untreated (a) and treated DRs (b) and pectin (c).

### 3.2. TGA

Natural fibers generally consist of cellulose, hemicellulose, and lignin. All these compounds exhibit different thermal stabilities. Therefore, TGAs of untreated and treated DRs were conducted. In general, different natural fibers may exhibit slightly different thermal stabilities because of different chemical constituents (Fan and Fu(2017) [42]). Fig. 2 illustrates the thermogravimetric curves of the untreated DR. TGA of the untreated DR was conducted under an air flow in the temperature range of 0°C–1000°C. The heating rate was 10°C $min^{-1}$. The pyrolysis of natural materials such as DR is due to several weight loss steps in a thermogravimetric curve, including moisture removal and decomposition of the major constituents of the biomass, such as cellulose, hemicellulose, and lignin (Manshor et al. (2014) [43]).

As shown in Figs. 2 and 3, there were three distinct decomposition peaks observed from the derivative of the thermogravimetric curve. The first decomposition peak for untreated DR occurred at 120°C, and this corresponded to a 13% weight loss due to the removal of moisture from the untreated DR. Moisture is mainly absorbed in the amorphous region of the fiber. Natural fiber is hygroscopic in behavior, which is extremely responsive to water.

Therefore, at a temperature of 120°C, the untreated DR can remove its water content or moisture. At a temperature of approximately 220°C, the mass loss was high (i.e., 65%) due to the decomposition of hemicellulose. Finally, there was an 87% mass loss of untreated durian when the temperature reached 380°C. This mass loss was attributed to the decomposition of organic compounds such as lignin and cellulose in the untreated DR. There was relatively no change in weight when the sample was heated above 560°C.

The effect of temperature on the treated DR is also illustrated in Figs. 2 and 4. Three degradation regions were observed. The first region was due to the thermal degradation of hemicellulose at approximately 250°C, while the peak at approximately 390°C might be due to the decomposition of cellulose and lignin. The last peak was observed at 780°C.

As presented in Figs. 2 and 4, the moisture content increased from 13% (untreated) to 20% (treated) due to washing of the treated DR during the chemical treatments, which reduced voids and increased the moisture content. From this observation, the untreated DR starts to degrade at approximately 220°C, while the treated DR degrades at a temperature of approximately 250°C. Based on Mohamad et al. (2014) [44], for high-temperature and high-pressure environments, the temperature reaches as high as 488°F (232.2°C) and the pressure as high as 13,900 psi for Malay Basin. The intensity of the TGA peaks observed at approximately 235°C is characteristic of pectin. The treated DR has

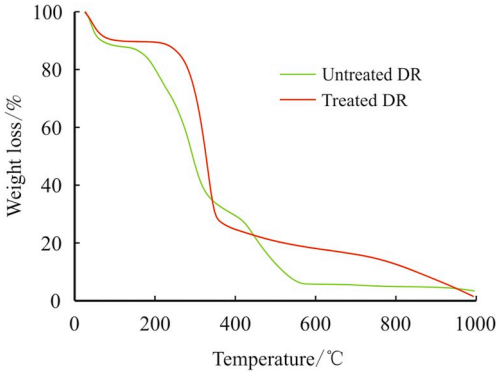


**Fig. 2.** TGA curves for untreated and treated DRs.

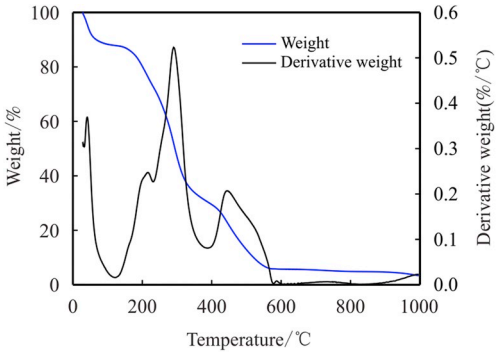


**Fig. 3.** TGA and DTGA curves of untreated DR.

high thermal stability at 235°C due to the absence of pectin. Previous studies stated that at a temperature of approximately 220°C-260°C, pectin disappears after alkaline treatment. These results are consistent with the literature, which stated that pectin degrades at a low temperature (Rachini et al. (2009) [45,46]). The degradation peak of the treated DR occurred at higher temperatures, which indicates that the treated DR exhibits higher thermal stability at higher temperatures. This result confirms the improvement in the thermal properties of DR due to alkaline treatment. Therefore, the treated DR can be used as an LCM at high temperature.

### 3.3. Scanning electron microscopy (SEM) analysis

SEM was used to observe the surface morphologies of the untreated and treated DRs. The chemical treatments conducted on DR were expected to induce morphology changes.

Fig. 5 shows a micrograph of the untreated DR, where amounts of noncellulosic components such as pectin, lignin, and hemicellulose scattered over the surface can be observed. As shown, after the DR was treated, the surface roughness worsened due to the deterioration of lignin and hemicellulose, the components that essentially bind individual fibrils into bundles to form fibers, as in Fig. 6. Moreover, surface roughness occurs due to the removal of hydrogen bonding in the structure of the fiber network of the DR during alkaline treatment. Furthermore, during the alkaline treatment, it is likely that the NaOH reacted with hydroxyl groups on the surface of cellulose fibers, disrupting their hydrogen bonds and increasing surface roughness.

In general, alkaline treatment improves surface roughness and hence increases the amount of cellulose on the surface of fibers (Akhtar et al.(2016) [47]). Therefore, the DR treated with NaOH alkaline

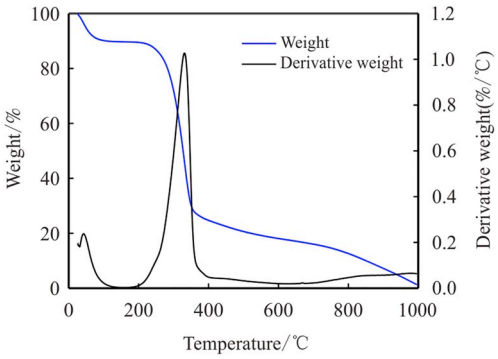


**Fig. 4.** TGA and DTGA curves of treated DR.

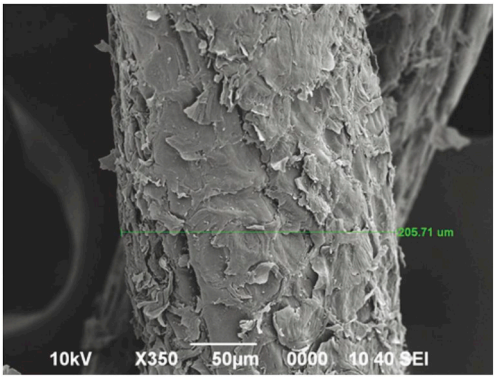


**Fig. 5.** Scanning electron micrograph of untreated DR.

solution has improved physical and mechanical properties. When the treated DR is used as an LCM, mechanical interlocking occurs to a greater extent when the fiber surface roughness increases the interfacial shear strength.

### 3.4. Rheological properties

#### 3.4.1. Plastic viscosity of water-based mud with untreated durian rind

PV is defined as the resistance of drilling fluid to flow caused by mechanical friction. PV greatly depends on the bulk volume of solids in the mud and on the viscosity of the suspending liquid. Moreover, PV is also related to the physical properties of the material, such as size and concentration.

Fig. 7 shows the PV for a drilling fluid with untreated DR. The PV for basic mud was 9 cp. Generally, as the concentration increases, the PV increases. The PVs for drilling muds with fine, medium and intermediate particles increased as the concentration of untreated DR increased. However, for the coarse size, the PV increased from concentrations of 5–15%, decreased again from concentrations of 20–25% and then increased at a concentration of 30%. The decrease in PV for the untreated DR concentration of 20–25% was due to the irregular shape of DR in the coarse size particles. When an untreated DR concentration of 30% was added, the PV increased because of the high friction between the DR particles with high concentration.

According to the recommendation of Mi-Swaco (2016) [48], the PV should be in the range from 10 to 15 cp. The untreated fine DR

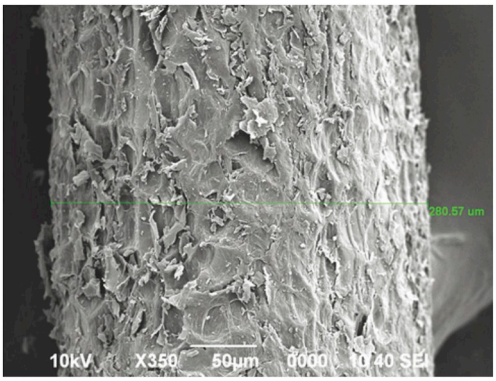


**Fig. 6.** Scanning electron micrograph of the DR treated with sodium hydroxide (NaOH).

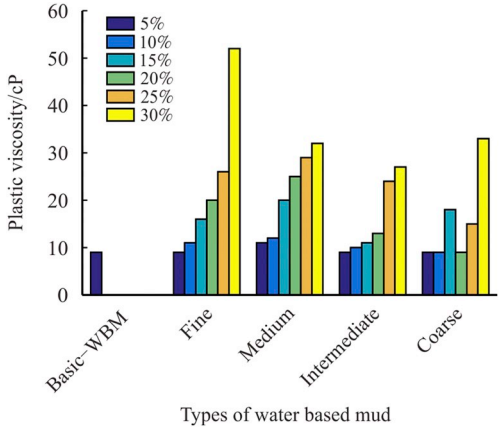


**Fig. 7.** PV for water-based mud and water-based mud with untreated DR.

concentration of 10% was in the range 10–15 cp. For the medium size, the concentrations of 5 and 10% were acceptable since the values were in the recommended range. For the intermediate size, the concentrations with acceptable values of PV were 10, 15, and 20%. The coarse size acceptable concentration was 25%. Since the shape of coarse untreated DR is spherical, the viscosity is not constant, particularly in the concentrations of 20–30% compared to the previous concentration of coarse DR. The high viscosities for other concentrations were not acceptable since it is caused by a viscous base due to the increasing solid content in the drilling fluid, such as barite and fluid loss materials. The higher PV will affect the lifting of the cuttings performance, which increases resistance in the mud (Piroozian et al. (2012) [49]).

#### 3.4.2. Plastic viscosity of water-based mud with treated durian rind

Fig. 8 shows the PVs of drilling fluid with the treated DRs. For the fine size, the PV increased with concentration. The PV for water-based mud with 10 and 15% treated DR was in the recommended range given by Mi-Swaco (2016) [48], 10–15 cp. The value of PV increased after treatment because the pectin was extracted or removed from the DR. This causes an absence of gel from the pectin and eventually frees the DR particles, which results in high friction when rotating in the viscometer. The PV for fine-size treated DR increased with concentration. For fine DR, the concentrations that were acceptable were 5 and 10%. The PV for water-based mud with the medium-sized DR also increased with concentration.

The concentration of medium-sized DR that was in the recommended viscosity range was 5–15%. For the intermediate size, the PV again increased with the concentration of DR. The acceptable concentration of PV for the intermediate size was 10–20%. The high PV was due to the absence of the gel, which increases the friction when rotating in the viscometer. For the coarse size, the acceptable value of PV occurred at concentrations of 15 and 25%.

#### 3.4.3. Yield point for drilling with untreated DR

YP is used to determine the ability of a drilling fluid to lift cuttings out of the annulus. Fig. 9 shows the YPs of basic water-based mud and water-based mud with untreated DR. There was no significant change in the value of YP when DR was added to the mud, except for the concentration of 30% DR with fine and medium sizes. According to Mi-Swaco (2016) [48], the standard range is from 20 to 25 lb/100 $ft^2$.

For the fine-sized DR, the YP increased with concentration. It is

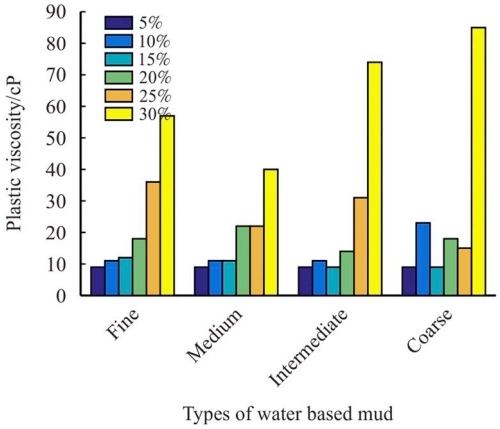


**Fig. 8.** PVs for water-based mud and water-based mud with treated DR.

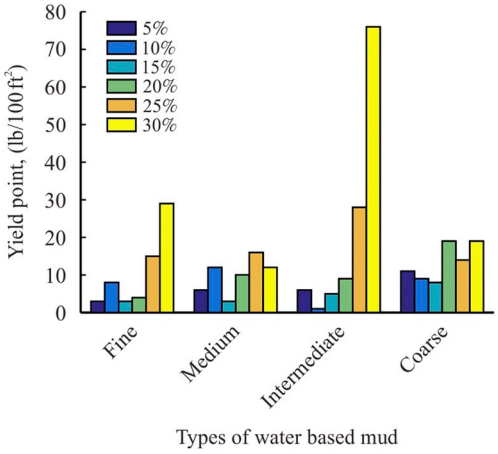


**Fig. 10.** YPs of basic water-based mud and water-based mud with treated DR.

known that a fluid with a high YP has more significance as it indicates a better cutting-carrying capacity. There was no size that could be acceptable since their YPs were not in the recommended ranges. For the medium size, the YP also increased with concentration. The concentration for the medium size that produced a YP in the recommended range was 25% only. For the intermediate size, the YP again increased with concentration. The concentrations of 20, 25, and 30% were acceptable compared to the others because they produced YPs that were within the recommended range. For the coarse-sized DR, the increase in DR concentration also increased the YP. However, there were no concentrations that fulfilled the range of the recommended YP.

### 3.4.4. Yield point for water-based mud with treated durian rind

Fig. 10 shows the YPs for water-based mud with treated DR. For basic mud, the YP was 6 lb/100 ft$^2$. According to the recommendation of Mi Swaco, the acceptable value of YP is 20–25 lb/100 ft$^2$. The YP for the fine size showed a decreasing trend compared to the untreated fine size of DR. This result is due to the loss of pectin after the treatment. The concentration of 30% was in the recommended YP range. Furthermore, for the medium size, the YP values also showed a decreasing trend for the water-based mud with treated DR. However, the concentration of 10% produced an acceptable YP compared to the other concentrations. For the intermediate size, only the concentration of 20% was in the recommended YP range. There was no acceptable value for the coarse size.

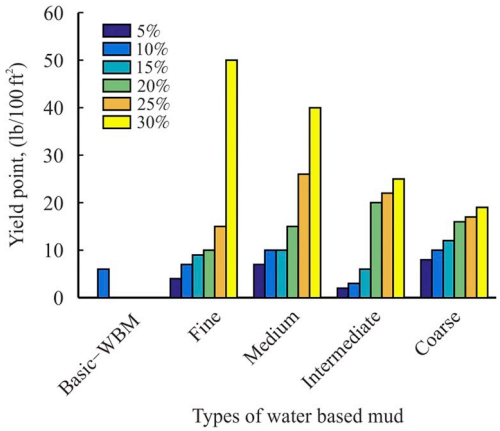


**Fig. 9.** YPs of basic water-based mud and water-based mud with untreated DR.

### 3.4.5. Gel strength for water-based mud with untreated durian rind

Gel strength is defined as the ability of a drilling fluid to hold drill cuttings and other components under static conditions. Figs. 11 and 12 show the gel strength of the water-based mud with untreated DR at 10 s and 10 min. Based on Figs. 11 and 12, the gel strength at 10 s and 10 min for the fine, medium and intermediate sizes increased with concentration. This result is due to the existence of pectin in DR, which acts as a gelling agent. The standard value for gel strength given by Mi-Swaco (2016) [48] is 8–16 lb/100 sq ft for gel strength (10 s) and 16–30 lb/100 sq ft for gel strength (10 m). The gel strengths (10 s) and (10 m) for basic water-based mud were 4 lb/100 sq ft and 11 lb/100 sq ft, respectively. Water-based mud with untreated DR experienced a significant change compared to basic mud. For the fine size, the concentrations for acceptable gel strength (10 s) were 20%, 25% and 30%, while for the gel strength (10 m), the concentration was 30%. For the medium size, the concentrations for acceptable gel strength (10 s) were 10–30%, while for gel strength (10 m), the concentrations were 15–30%. Furthermore, for the intermediate size, the concentrations for acceptable gel strengths 10 s and 10 m were 10–30%. For the coarse size, the gel strength did not increase accordingly due to the irregular shape of DR, as mentioned in the discussion of PV. The values for gel strength 10 s were acceptable for all of the concentrations, while for 10 m, only the gel strength at the concentration of 20% was not acceptable.

### 3.4.6. Gel strength for water-based mud with treated durian rind

In Fig. 13 and Fig. 14, the results show the gel strengths (10 s) and (10 m) for drilling fluid with treated DR. The gel strength (10 s) for fine DR was constant for concentrations of 10–20% but increased for concentrations of 25–30%. There was no concentration that produced acceptable gel strengths as they were out of the recommended ranges. A gel strength that is significantly high was avoided because it would require high pump pressures for recirculation in the case of pump shut down during fishing operation. The gel strengths (10 m) that were acceptable for the fine size were at concentrations of 5% and 30%. For the medium size, 10% and 15% were the acceptable concentrations for gel strength (10 s), while for gel strength (10 m), the concentrations were 10% and 15%. For the intermediate size, 20% was acceptable, while for the coarse size, 15% was acceptable for gel strength (10 s). The gel

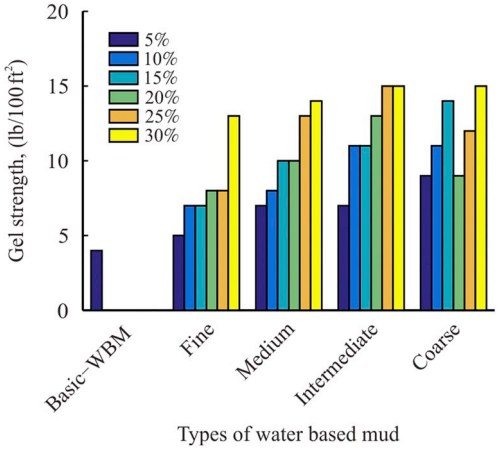


**Fig. 11.** Gel strength (10 s) for basic water-based mud and water-based mud with untreated DR.

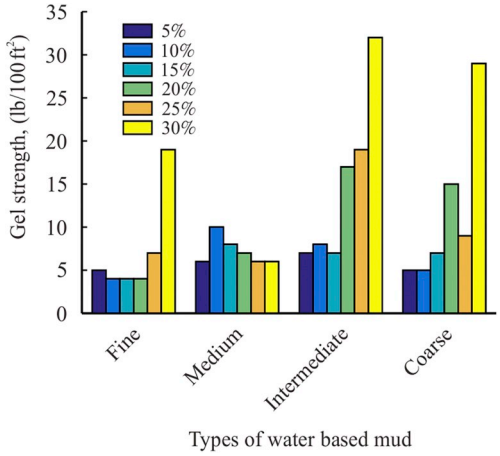


**Fig. 13.** Gel strength (10 s) for water-based mud with treated DR.

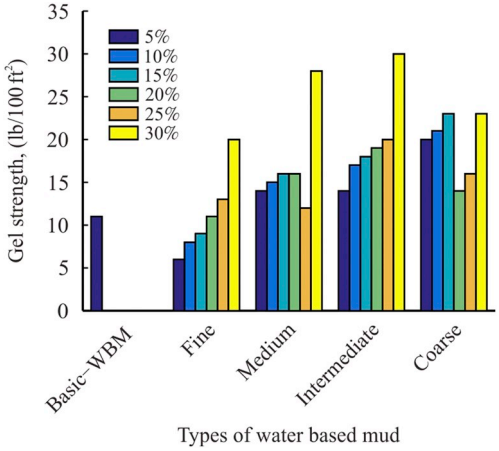


**Fig. 12.** Gel strength (10 m) for basic water-based mud and water-based mud with untreated DR.

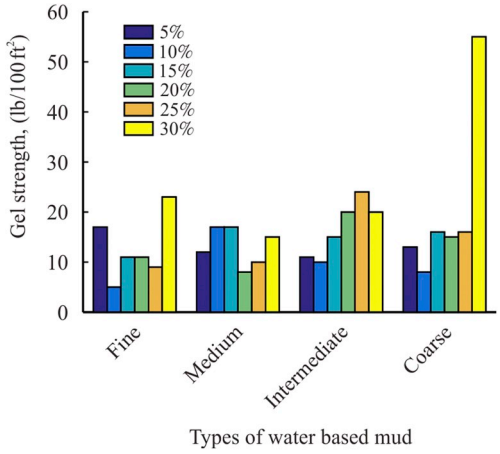


**Fig. 14.** Gel strength (10 m) for water-based mud with treated DR.

strength (10 m) that was acceptable for the intermediate size was at concentrations of 20–30%, while for the coarse size, only concentrations of 15% and 25% produced gel strengths that were in the recommended range.

### *3.4.7. Fluid loss of water-based mud with untreated and treated durian rinds*

The filtration and wall building characteristics of a drilling mud are important for providing a comparative measure of the amount of mud filtrate invasion into a porous and permeable formation and the amount of filter cake that will be deposited on the wall of the wellbore whenever filtration occurs (Okon et al. (2014) [50]). Therefore, the crux of this paper centered on drilling mud filtration control using DR. According to Mi-Swaco (2016) [48], the total fluid loss should be less than 15 ml.

Fig. 15 shows the total fluid loss of drilling fluid with untreated DR. DR was added to drilling mud to prevent uncontrolled water loss while it is pumped into the formation. The result shows that basic mud has fluid loss up to 16 ml. The basic mud failed to obtain the recommended value of fluid loss because of the weak flocculating nature of bentonite or the attractive force among the bentonite's particles are not strong enough to form a crosslink that minimizes mud filtrate. For the fine, medium and intermediate sizes of untreated DR, the fluid loss decreased as the concentration of DR increased. With an increase in the concentration of untreated DR particles, bridging occurs faster and helps in loss declines.

As presented, the results depict that there was a reduction in the fluid loss volume at untreated DR of 5 g–30 g of drilling mud sample. This result is attributed to the crosslinkage between mud particles as the untreated DR particles reduced the permeable state of the bentonite particles by strengthening the force between the particles. This result confirmed that untreated DR was successful in preventing fluid loss. However, 5 g of all sizes of untreated DR failed to obtain the recommended value of fluid loss. From the results, the fine size of untreated DR showed a smaller amount of fluid loss compared to the other sizes. This result is due to the fine-sized DR that provides better filling properties. A bridge may be initiated when several particles of DR lodge against each other in the pore throat. The smaller particles may then bridge the openings between the previously bridged particles.

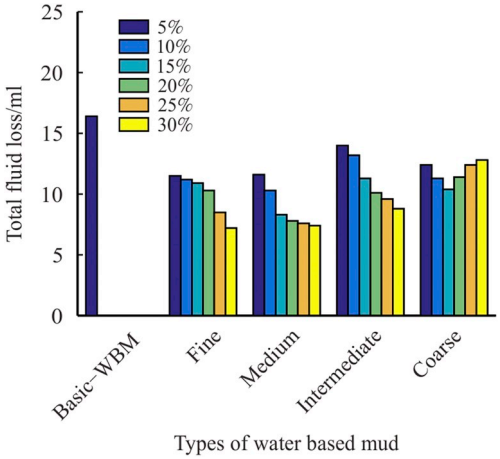


**Fig. 15.** Total fluid losses of basic water-based mud and water-based mud with untreated DR.

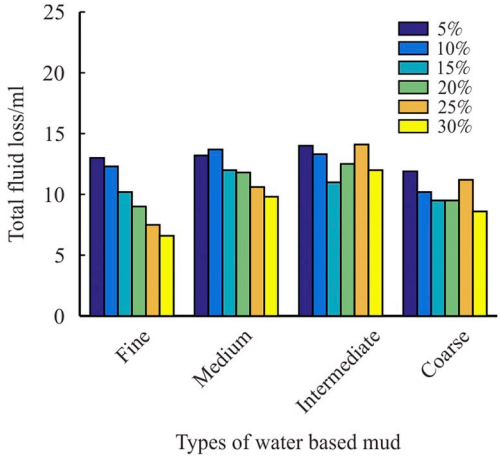


**Fig. 16.** Total fluid losses of basic water-based mud and water-based mud with treated DR.

Furthermore, the fine-sized materials have more surface area; thus, they possess more resistance to pressure, and they can plug pore throats.

For the coarse size of untreated DR, as the concentration increases, the volume of mud loss decreases from concentrations of 5–15 g. However, after 20–30 g of untreated DR was added, the volume of mud loss increased. This result confirms that for coarse-sized DR, the optimal concentration to minimize fluid loss was 15 g.

Fig. 16 shows the total fluid loss of basic water-based mud with treated DR. For fine DR, the fluid loss decreased as the concentrations of DR increased. The water-based mud with pectin-less DR experienced higher fluid loss than those with pectin. Although the fluid loss of the medium size was in the range of recommended values, the fluid loss decreased as the DR concentration increased. For the intermediate size, all sizes were in the range, and the same holds for the coarse size. The results showed that the higher the concentration of DR in water-based mud, the faster the bridging process would occur; hence, it would reduce the fluid loss. The increase in fluid loss was due to the removal of pectin due to its is hydrophilic characteristics. Removing pectin might affect the fluid loss volume due to the treated DR being unable to swell, that is, it cannot bind large volumes of water.

### 3.4.8. Mud cake thickness for water-based mud with untreated durian rind

Mud cake is important when invasion of filtrate and particles occurs, causing irreversible formation damage and decreased permeability; therefore, a mud cake needs to be formed as fast as possible to prevent damage due to solid particles and cuttings. The mud cake thickness was measured to determine its ability to reduce filtrate loss, to be thin, and to hold the drilling fluid in the wellbore.

Fig. 17 shows the mud cake thickness of water-based mud with untreated DR. The recommended mud cake thickness from Mi-Swaco (2016) [48] was 0.0625 inches. For fine- and medium-sized DRs, all concentrations were accepted since it was in the acceptable standard range. This result confirms that the size range of untreated DR particles was successful in creating a solid framework for the filter cake. Moreover, DR was also able to create deformable particles to fill small gaps and improve the seal. From the figures, the small size of untreated DR provides a better value of mud cake thickness because small particles become packed firmly compared to large-sized particles. However, for intermediate- and coarse-sized DRs, only the 5% concentration was not acceptable since the values were beyond the recommended range. A high thickness of mud cake was avoided to avert any anticipated pipe sticking.

Fig. 18 shows the mud cake thickness of water-based mud with treated DR. For the fine size, the accepted concentrations were 15% and 20%, while for the medium size, the accepted concentration was 15%. For the intermediate size, only the concentration of 20% was in the recommended range, while for the coarse size, the concentration of 10% was in the range.

### 3.4.9. Rheological model

The rheological model was determined using a Brookfield viscometer. Fig. 19 shows some rheological models for real fluid behavior. Fig. 20 shows that all three basic water-based mud, water-based mud with untreated DR, and water-based mud with treated DR slightly follow the Bingham plastic model. The model is more to low shear rate viscosity (Growcock and Harvey (2005) [51]). A Bingham plastic fluid flows when the shear stress ($\tau$) exceeds the $\tau_y$, known as the YP. Hence, the change in shear stress is proportional to the change in shear rate with a constant YP ($\mu_p$).

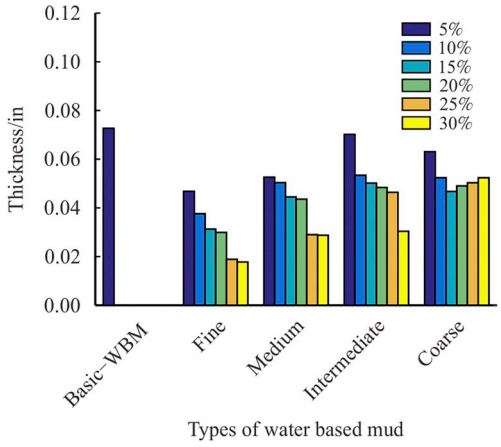


**Fig. 17.** Total fluid losses of basic water-based mud and water-based mud with untreated DR.

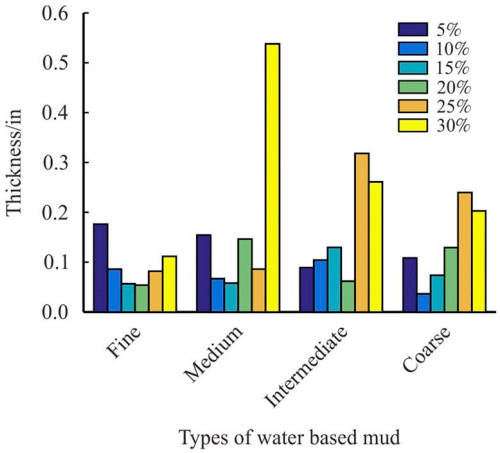


**Fig. 18.** Total fluid losses of basic water-based mud and water-based mud with treated DR.

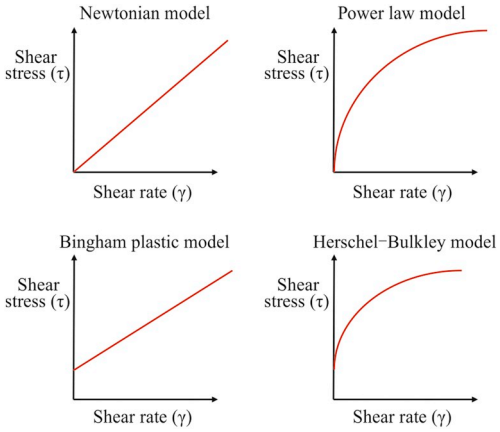


**Fig. 19.** Rheological model for real fluid behavior.

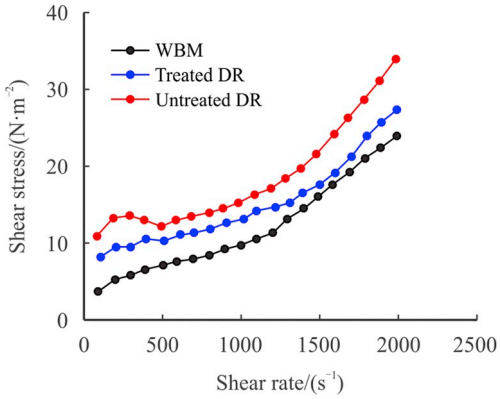


**Fig. 20.** Shear stress vs shear rate of WBM, untreated DR, and treated DR.

## 4. Conclusions

(1) Based on the obtained FTIR results, NaOH was the most effective solvent for removing pectin in DR.
(2) Based on the TGA results, alkaline treatment with NaOH improved the thermal stability of DR.
(3) The rheological properties of the treated DR were not improved after extraction.
(4) The rheological properties of the untreated DR provided the best result in terms of the rheological properties. It was found that the concentration of 20 lb/bbl of intermediate size was the best concentration compared to the other sizes. This result was due to the existence of pectin in DR that helped the performance of water-based mud.
(5) The rheological model of basic water-based mud, water-based mud with untreated DR and water-based mud with treated DR slightly followed the Bingham plastic model.

## Nomenclature

| | |
|---|---|
| DR | Durain Rind |
| YP | Yield Point |
| GS | Gel Sterngth |
| PV | Platsic Viscosity |
| NaOH | Sodium Hydroxide |
| WBM | Water Based Mud |
| LCM | Lost Circulation Material |
| TGA | Thermogravimetric Analysis |
| API | American Petroleum Institute |
| FTIR | Fourier Transform Infrared Spectroscopy |
| DTGA | Derivative of the Thermogravimetric Analysis |

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