Rheological and Filtration Performances of *Rhizophora mucronata* Tannin Water-Based Drilling Fluid

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**Abstract**

Rheological and filtration performances of water-based drilling fluid (WBDF) with tannin as deflocculant and fluid loss additive were conducted at high pressure and high temperature (HPHT). Different masses of tannin (0, 2, 4, 6 and 8 g) were added into WBDF and the prepared samples were tested at 3 different temperatures namely 250, 300 and 350 °F. Rheological properties including plastic viscosity (PV), yield point (YP), and gel strength (GS) were evaluated for pre and post aging processes. Filtration properties were measured based on the filtrate volume and mud cake thickness using low pressure low temperature (LPLT) and HPHT filter press. The rheological properties for post-aging process seem to be lower than the pre-aging except for 8 g tannin. The viscosity decreased by compensating attractive charges among the clay particles to flocculate. At higher temperature, tannin tends to absorb the extra heat and prevents water molecules from forming hydrogen. The filtration properties were also improved with low filtrate volume and thin mud cake. The optimum mass was achieved at 6 g of tannin. The rheological and filtration properties values of tannin were compared with commercial deflocculant (CD) and the differences were in range of 5-14%.

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**Keywords:** Drilling fluid; Tannin; Deflocculant; Fluid loss; Rheological performance; Filtration performance

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1. Introduction

The increment of world population increased the demand on oil and gas which consequently increased the rate of depletion of near surface reservoirs. This led the industry to explore for the new hydrocarbon sources in deeper and more challenging reservoirs such as drilling in high pressure high temperature (HPHT) conditions. In the drilling operation, drilling fluids are used to transport drilling cuttings out of the hole before being recycled back [1]. Drilling fluid has numerous functions i.e. cleaning the borehole by carrying out drill cuttings from subsurface to the surface, withstanding subsurface formation pressure by providing sufficient hydrostatic pressure which prevents the formation fluids from entering the borehole, lubricating and cooling the drill string and bits during drilling processes [2].

Drilling fluids are classified according to the types of base fluids used and usually divided into three major groups water-based drilling fluid (WBDF), oil-based drilling fluid (OBDF) and synthetic-based drilling fluid (SBDF) [3,4]. WBDF commonly contains at least 50% of the continuous phase fluid and may also contain oil but in small amounts that does not exceed the amount of water. WBDF typically comprises of viscosifiers, pH control agents, weighting agents, lubricants, emulsifiers, corrosion inhibitors, salts and fluid loss control agents [5]. These additives are added to maintain or strengthen the rheological and filtration properties such as density, pH, plastic viscosity (PV), yield point (YP), gel strength (GS), filtrate volume and mud cake thickness [6,7]. Composition and selection of mud system are purposely determined by the properties of the reservoir formation, different formation requires different mud system to attain optimum drilling results. However, WBDF is more vulnerable to thermal degradation than OBDF and SBDF [8].

HPHT activities have increased in historical HPHT basins such as northern Malaysia, Indonesia and Thailand [9]. Under HPHT drilling condition, WBDF performances are based on its ability to maintain stable rheological and filtration properties [10]. WBDF loses its stability when flocculation starts to occur at high temperature and pH conditions. Moreover, cationic contaminants such as gypsum, anhydrite, salts or cement also affect WBDF stability while continuously in contact with the WBDF during drilling operation [11]. Both conditions post similar negative impact on drilling fluids’ stability and performances which result in fluctuation of viscosity and fluid loss volume due to aggregation and flocculation of clay structure [12-15].

Hence, to minimize the flocculation issue, deflocculant or thinner is introduced into WBDF to reduce the PV, YP and GS whenever it is necessary and applicable [16]. These additives provide an alkaline environment causing the clay particles to repulse each other, preventing it from associating together [17]. Thus, neutralizing positively charged edges of clay particles which electronically compensating attractive charges among particles [18]. Some examples of deflocculants include polyphosphates, lignosulfonates and modified tannins. Modified tannins usually contained hexavalent chromium which are toxic to the environment [19].

Tannin is a water-soluble phenolic metabolite and chemically made up of complex phenolic compounds of high molecular weights ranging from 500-20000 Da [20-22]. Bacelo, et al. [23] stated that tannin is easily deprotonated due to the existence of phenolic groups. Deprotonated tannin becomes negatively charged and increases the alkalinity of WBDF. Tannin consists of a set of elements taking place in several upper plant species and frequently is obtained from mangrove species. Malaysia’s mangrove forest has extraordinary species richness and structure compared to mangrove forests in other parts of the world [24]. Typical mangrove species in Malaysia on the seaward sediment is the *Rhizophora* forest [25]. *Rhizophora mucronata* is one of the major species in Malaysia that offers a great possibility as a source of tannin [26,27].

The purpose of this study was to investigate the effect of using tannin powder extracted from *Rhizophora mucronata* as deflocculant in drilling fluid formulation for rheological and filtration properties of mud at different temperatures. The presence of tannin will reduce the rheological and filtration properties of WBDF. Furthermore, the performance of tannin was compared with commercial deflocculant (CD). To complete the objective of this study, several experiments were conducted using different masses of tannin. Rheological and fluid loss measurements were taken at three different temperatures namely 250, 300 and 350 °F.
2. Materials and Methodology

2.1. Preparation of tannin sample

Dried *Rhizophora mucronata* barks sample was milled and put in a cloth pouch. The pouch was tied and placed in a beaker filled with 3000 ml distilled water. The water was heated at a temperature ranging from 80 to 90 °C and stirred for six hours. After boiling, the cloth pouch was removed and extractant was evaporated using spray dryer with the inlet temperature set at 130 °C. The pump rate was set at 3 revolutions per minute (rpm). The tannin powder was collected in the cyclone collector and manual sweeping at the spray dryer’s wall. The powder was stored in airtight container.

2.2. Formulation of WBDF

Mixing of WBDF is a process of mixing the base fluid (water) with the chemical additives such as fluid loss agents, corrosion inhibitors, viscosity control and weighting material to boost its performance. Additives such as fluid loss agent, viscosifier, pH controller, high temperature polymer, cutting stimulant and weighting materials were obtained from SCOMI Global Research & Technology Center (GRTC). In this experiment, the WBDFs were mixed using a Hamilton mixer at 6000 rpm for 45 minutes. WBDFs were prepared in five different tannin concentrations (0, 2, 4, 6, and 8 g) and the formulation is shown in Table 1. The mud weight, pH reading, rheological properties and filtration properties of WBDFs were investigated before and after the samples were placed in a hot roller oven for 16 hours at 250, 300 and 350 °F under constant heating.

<table>
<thead>
<tr>
<th>Mix order</th>
<th>Additives</th>
<th>Mass (g)</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Water</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Soda Ash</td>
<td>0.25</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Caustic Soda</td>
<td>0.1</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Potassium Chloride</td>
<td>26</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Modified starch</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>High-performance xanthan gum</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>7</td>
<td>Ethanolamine</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>Oxygen scavenger</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>Cutting stimulant</td>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>Barite</td>
<td>345</td>
<td>5</td>
</tr>
<tr>
<td>11</td>
<td>Tannin</td>
<td>0, 2, 4, 6 &amp; 8</td>
<td>5</td>
</tr>
<tr>
<td>12</td>
<td>Commercial deflocculant (CD)</td>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>

2.3. Density and pH measurement

Mud balance was used to measure the density and effectively the weight of the WBDF. The lid of the mud balance was removed from cup and WBDF was poured into the cup. The lid was replaced and rotated until firmly seated and some fluid was expelled through the hole of the lid. The expelled fluid was wiped and the lid was cleaned. The beam was placed on the base support and balanced by moving the rider along the graduated scale. The reading was recorded when the scale bubble was under the centerline. The reading of the density was recorded in pounds per gallon (ppg) and the measurement was repeated three times.
Caustic soda was added after mixing of WBDF to control the formulation pH. The pH sensor was dipped in the WBDF in the small glass flask and gently swirled. When the reading on the screen was constant, the reading of pH was recorded and repeated three times.

2.4. Rheological properties

The rheological properties of the WBDFs were measured using FANN 35A viscometer and the dial reading for 600, 300, 200, 100, 6 and 3 rpm were taken at 120 °F. PV and YP were calculated using Equations (1) and (2) respectively [28]:

\[
P V = \text{dial reading at 600 rpm} - \text{dial reading at 300 rpm} \tag{1}
\]

\[
YP = \frac{\text{dial reading at 300 rpm} - PV}{PV} \tag{2}
\]

GS at 10 seconds and 10 minutes were also recorded. Each dial reading was repeated and recorded three times.

2.5. Aging process of WBDF

Aging process was conducted to determine the effects of WBDF after being exposed to heat in the oven for 16 hours to imitate the real wellbore conditions [29]. For this study, WBDF was poured into the aging cell and pressurized with 100 psi for mud system at 250 and 300 °F. For the temperature of drilling fluids at 350 °F, the aging cell was pressurized at 160 psi. After 16 hours, the rheological performance of aged WBDF was measured according to the same procedure in Section 2.4.

2.6. Filtration properties

Static filtration properties of WBDF for both API and High Pressure High Temperature (HPHT) filtration tests were performed according to API 13B procedure [28].

3. Results and Discussions

The density of the WBDF was kept constant at 15 ppg. Under HPHT conditions, high mud density is required to exert hydrostatic pressure and prevent the formation fluid to flow into the wellbore to minimize the risk of well-control [30]. The pH of the drilling fluid was also kept constant at 9.5 since it is desirable to have mild-alkaline pH value of 9.5 and above to ensure the maximum performance of the deflocculant [19,30,31].

3.1. Effects of tannin additive towards rheological properties of WBDF

Fig. 1 shows the values of PV for pre and post-aging of the mud at 250, 300 and 350 °F. Tannins acted properly as a deflocculant agent because of the reduction in PV values in post-aging process [1]. However, significant reduction in PV values of WBDFs without tannin at all temperatures tested indicated the destabilization of drilling fluids. This can be justified based on the post-aging observation of barite sagged in drilling fluids. This observation is supported by Galindo, et al. [12] which resulted in viscosity reduction and loss in suspension due to thermal degradation of respective additives occurred. Shah, et al. [32] also stated in HPHT conditions, drilling fluid shows a tendency to display sagging behaviour. The study conducted by Yunita, et al. [33] on the effect of temperature on rheology using surfactant showed that additives had higher thermal stability as the reduction of PV and YP were 25.71 and 37.5 % respectively. This suggests that tannin formulated WBDF may be able to withstand high temperature condition than WBDF without tannin.

As tannins were introduced to the mud samples, they started to stabilize the WBDFs based on the observation and the PV values. Addition of tannin between 2 to 6 g reduced the PV value with the highest at 350 °F followed by 300
and 250 °F. For all sets of temperature run, similar trend of PV values was obtained with 6 g of tannin had the lowest PV value. Stable mud post-aging observations were depicted with 15.4, 20.5 and 28.2% of percentage reduction at 250, 300 and 350 °F respectively. As mentioned by Bacelo, et al. [23], the anionic condition provided by hydroxyl ions in the tannin neutralized the positively charged edges of clay particles by compensating attractive charges among the clay particles to form gel structure i.e. flocculation would increase the viscosity of the WBDF [1]. However, addition of 8 g of tannin increased the PV value to a value higher than the pre-aging value. According to Skalle [14] and Mahto and Sharma [34], an increase in PV signifies the occurrence of flocculation. Thus at this condition, the addition of tannin of more than 6 g was not effective due to the "full deflocculation" as viscosity has reached its minimum value and subsequent additions of deflocculants would have an adverse effect [17]. Ibrahim, et al. [35] also reported similar observation, the formulated thinner showed an unsatisfactory quality of thinning agent due to the excessive presence of hydroxide ions that destabilized the electrochemical charges in WBDF and led to flocculation. CD formulated WBDF with a mass of 6 g recorded the PV values of 31, 29 and 26 cP at 250, 300 and 350 °F respectively but the differences in the percentage reduction between the 6 g tannin formulated WBDFs were insignificant with only 6.5, 6.9 and 7.7 % respectively.

Fig. 1. PV for different mass of tannin at different post-aging temperature

Fig. 2 shows the YP of the tannin formulated WBDFs at different temperatures. YP values decreased after the addition of tannin. The results show that YP followed the similar trend as PV which 6 g recorded the lowest value. Post-aging YP values for 8 g tannin increased from 250 to 300 °F, then decreased at 350 °F probably due to thermal degradation of the additives. This occurred because of the molecules expansion of the additive particles which decreased the fluid flow resistance as the temperature is increased [36]. Makinde, et al. [37] found out the YP decreased steadily as the temperature was increased caused by the flocculation of bentonite clay but with suitable treatment using lignosulphate, it reduced the effect of flocculation at high temperature. From this research, tannin has similar properties as lignosulphate which tends to absorb the extra heat and prevents water molecules from forming hydrogen ions promoting high tendency of flocculation. Annis and Smith [30] stated that the increment of YP revealed the flocculation and based on the post-aging observation for 8 g of tannin, the mud samples showed a clear evidence of flocculation with the increment of 12 % YP. CD formulated WBDF with mass of 6 g recorded the readings of 29, 26 and 22 lbf/100ft² at 250, 300 and 350 °F respectively with percentage reduction of 6.9, 11.5 and 9.1 % as compared with 6 g tannin formulated WBDF.
The effects of tannin formulated WBDF towards GS at 10 sec and 10 min are shown in Fig. 3 (a) and (b) respectively. Based on the results, tannin formulated WBDF showed good progressive gel properties with 10 sec to 10 min ratio in the range between 1-2 [38]. The results show that GS seems to decrease with an increase of temperature. This is true for both the 10 sec and 10 min samples and they seem to follow the same pattern as PV and YP. Addition of 6 g tannin concentration seems to have the highest percentage of reduction whereby 10 sec GS decrease by 9.1, 30.8 and 33.3 %, and 10 min GS decrease by 9.5, 18.2 and 27.3 % at 250, 300 and 350 °F respectively. These results are supported by Neshat and Shadizadeh [39], they used Black Myrobalan as a source of deflocculant whereby it reduced the 10 sec GS by 70 % and 10 min GS by 44 % in flocculated bentonite mud. CD formulated WBDF performance for all temperatures tested, recorded readings of 10, 8 and 7 lbf/100 ft² (0, 12.5 and 14.3 % reduction) for 10 sec GS, and 18, 17 and 15 lbf/100 ft² (5.6, 5.9 and 6.7 % reduction) for 10 min GS respectively.

### 3.2. Effects of tannin on filtration properties of WBDF

The results for API and HPHT filtration volume are plotted in Fig. 4. The volume of filtration seems to decrease as tannins were introduced into the mud formulation. Hence tannins have the possibility to function as a fluid loss additive. The performance of filter cake also improved by having low filtrate volume (less than 4 ml for API filtration test and less than 5 ml for HPHT filtration test) with the production of thin filter cake (less than 2/32 inch for API and less than 3/32 inch for HPHT in order to meet the API standard). This observation is parallel with the filtration volume was reduced from 5.4 ml to 5 ml (7.4 % reduction) as 2 g of tannin was added. As the amount of tannin was increased to 4 g, the filtration volume seems to decrease significantly, to 4.0 ml (25.9 % reduction). Drilling fluid with 6 g of tannin recorded the lowest filtration volume of 3.6 ml (33.3 % reduction). However, the filtration volume for the 8 g addition of tannin seems to increase to 4.2 ml with 22.2 % reduction. This is slightly higher than the volume of 4 g of tannin added. The results of a study conducted by Al-Malki, et al. [40] on the effect of filtration control additive using starch was found to decrease the fluid loss by 36% of bentonite-based mud. The reduction of filtration volume reveals that 6 g of tannin is the optimum mass. Kania, et al. [41] stated the modern use of deflocculant including for filtration and filter cake thickness reduction. As the solid in the fluid is uniformly dispersed, the packing density increases and the filtrate volume is reduced.
On the other hand, after aging process and the outcomes from HPHT filter press show that the filtration volume of drilling fluids without the addition of tannin seems to increase from 9.4 ml to 13 ml, as the temperature was increased from 250 °F up to 350 °F. This indicates that the mud formulation may be unstable at high temperature and high fluid loss leads to formation damage and bore hole instability [42]. Filtration volume for HPHT follows the same trend as the API filtration with the addition of 6 g of tannin filters the lowest volume at 250, 300 and 350 °F which are 4.7, 4.7 and 4.0 ml (50, 57.3 and 69.2 % reduction) respectively. This is due to the good dispersing properties and bridging effect by the additive as the filter cake builds up [43]. Beyond 6 g of tannin, the filtration performance seems to decrease with fluid loss volume. The results showed tannin formulated WBDF obtained lower filtrate volume compared to WBDF without tannin. Thus, tannin can be used as a fluid loss additive.
Fig. 4. Filtration volume for different mass of tannin at different post-aging temperature

Fig. 5 shows the thickness of mud cake for different masses of tannin used. The mud cake thickness did not show a significant change in API filter press. However, the thickness was still acceptable for all of mud samples. As the temperature is applied, mud samples without tannin started to exhibit the properties of unstable mud as the cake thickness increased. Nevertheless, the addition 6 g of tannin produced the thinnest mud cake among the other masses of tannin at all temperatures tested with 33.33, 37.5 and 50 % reduction at 250, 300 and 350 °F respectively (2.5/32 inches for all the temperatures tested). The enhanced performance of the mud cake was attributed to the bridging between the tannin molecules and negatively charged faces of the clay particles [35]. The thickness of mud cake should not be very thick to prevent drilling problems such as differential pressure sticking and lost circulation. It needs to be as thin as possible and less permeable to reduce the amount of fluid loss that could be reactive to the rock formation and causes bore hole instability [44]. Addition of tannins to the drilling fluids is for the purpose of enhancing deflocculation and solid distribution to produce high quality mud cake [3] since the most ideal mud state is a well dispersed mud [14]. Rafati, et al. [45] also mentioned that more compact mud cake provides better chances of maximum sealing pressure.

CD formulated WBDF reduced filtrate volume by 4.4, 4.4 and 8.1 % at 250, 300 and 350 °F respectively compared to tannin formulated WBDF. Despite these differences, the readings were insignificant and tannin was able to perform almost on par with CD. Mud cake thickness between CD formulated and tannin formulated WBDFs were the same. Mahmoud, et al. [46] used the same deflocculant as CD at the same temperature and pressure of 350
°F and 500 psi. It generated filtrate volume and filter cake of 6.9 ml and 4.8/32 inch (0.151 inch). Compared to the findings in this study, both values, 4.0 ml and 2.5/32 inch (0.078 inch), are lower than theirs. This confirmed that at harsh condition of high temperature, tannin formulated WBDFs produced stable and good rheological and filtration performances due to the addition of deflocculant.

Based on the results obtained, regardless of having minor differences, tannin seems to work perfectly fine in reservoir temperature ranging from 250 to 350 °F. This shows that tannin might be able to be used as a deflocculant in terms of reducing the rheological and filtration properties.

4. Conclusion

WBDF with addition of tannin as a deflocculant has successfully been formulated. The rheological and filtration properties were affected by the amount of tannin and the optimum mass of tannin was 6 g. It was also found that the tannin formulated WBDF could withstand temperatures up to 350 °F which is suitable for HPHT application in drilling operation. The formulated mud rheological properties such as PV, YP, 10 sec GS and 10 min GS seem to reduce significantly up to 28.2 %, 33.3 %, 33.3 % and 27.3 % respectively at the highest post-aging temperature of 350°F. In term of filtration performances, HPHT filtration volume and mud cake thickness decreased drastically at the highest post-aging temperature of 350 °F up to 69.2 % and 27.3 % respectively. The performance of tannin formulated WBDF was compared with a CD formulated WBDF and resulted with 5-14 % deviation of performance in the rheological and filtration properties. Tannin is naturally available that can be extracted from Rhizophora mucronata and mangrove-based plants has high potential to be used as additives or deflocculant in the formulation of WBDF.

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