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*Original Article*

# Rheological and fluid loss properties in water-based drilling fluid by using the sugarcane bagasse as additives

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**Abstract**

The research purpose is to study the performant of the rheology and the filtration loss of water-based drilling fluid with 1, 3 and 5% weight per volume (w/v) of sugarcane bagasse (SCB) at 30, 60, and 80 °C according to API RP13B-1. The drilling fluid with SCB showed pseudoplastic flow as the power-law model, increasing on SCB concentration but reducing on the temperature. The viscosity results in the increase of yield point and gel strength as rising of concentration and temperature. The filtration loss of drilling fluid with 3 and 5% SCB at 80 °C reduces as respectively 37.8 to 39.6% that is better than water-based drilling fluid. Therefore, the SCB is suitable to use as an additive for improving the rheology and filtration loss control in drilling fluid ascending order 5%>3%>1% of SCB, resulting from the roughness surfaces and small porous of cellulose, and tobermorite ($Ca_5Si_6O_{16}(OH)_2{\cdot}4H_2O$).

**Keywords:** sugarcane bagasse, carboxymethyl cellulose, viscosity, filtration loss

## 1. Introduction

The complex drilling fluid has several functions. They are intended to clean the well, hold the cuttings in suspension, prevent caving, ensure the tightness of the good wall and form an impermeable cake near the wellbore area (Khodja-Saber, Canselier, Cohaut, & Bergaya, 2010). Typically, the composition of drilling fluid is a bentonite and barite with the base (water or oil), and other additives (Caenn, 2011). In the process of drilling petroleum well, porous formations are encountered and these formations allow for either whole drilling fluid or filtrate from the drilling fluid to enter the formation. It causes to the thick layer of solids that deposited along the wellbore acting as a filter (Sampey, 2006). The utilization of these additives depends on the condition of borehole and function of drilling control. For example, viscosity control additives are basically categorized as viscosifier the and filtration loss control commonly used a financial chemical such as xanthan gum, guar gum, polyanionic cellulose (PAC), carboxymethyl cellulose (CMC), and other fibrous. These additives are popularly used for a performance of rheological and filtration control. Furthermore, most critical to use these additives are costly and usually imported from aboard, and also an environmental problem.

Sugarcane is one of the foremost and economic crops that grow all around Thailand, and its entire production is over 1,500 million tons. After the extraction of all economical sugar from sugarcane, about 40-45% of the fibrous residue is the bagasse that it is a large number of wastes. Many concerns have been raised regarding the treatment and disposal of waste materials causing environmental problems. Most technical applications of the SCB and sugarcane bagasse ash (SCBA) have been in the area of civil engineering, using this material as partial replacement of cement in concrete and drilling fluid (Abbasi & Zargar, 2013; Chusilp, Jaturapitakkul, & Kiattikomol, 2009; Saengdee & Terakulsatit, 2017; Srinivasan & Sathiya, 2010).

Generally, SCB is one of the lignocellulosic materials consist of 41.1% cellulose, 19.75% hemicellulose, and 22.91% lignin, respectively (Jiratpong & Songtanasak, 2011). This composition of SCB is one of the biopolymers like to starch, lignin, chitin, and various polysaccharides occurring from nature. The carboxymethyl cellulose is used as the commercial additive materials for the filtration loss control

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and viscosity performance in the drilling fluid is a kind of cellulose derivative, which is a water-soluble polymer that can be extracted from SCB (Reangsumran, Ratanawadeeviroj, & Khunton, 2018). Therefore, this research relates to an investigation for using the powder of SCB to control filtration and increase the viscosity properties in drilling fluids. The main objective to study the effects of temperature (30, 60 and 80 ºC with limited only in laboratory scale) and mixing ratio (1, 3 and 5% weight by volume (w/v)) of the SCB on the performant in the rheological and filtration loss properties of drilling fluid.

## 2. Materials and Methods

### 2.1 Preparation of drilling fluid samples

SCB was collected during the processing of milling to extract the sugarcane juice at a sugar factory in Nakhon Ratchasima, Thailand. These raw materials were air-dried and milled. After that, sieving size less than 75 micrometers (200 mesh) was divided material into two parts for chemical and physical properties test by mixing with water-based drilling fluid.

A water-based drilling fluid suspension is prepared using 60 grams of bentonite per liter of water, 100 grams of barite per liter of water and various concentrations of SCB in 1, 3 and 5% w/v are respectively added to mixing for 15 minutes by using the high-speed mixture. During mixing the SCB was added slowly to the agitated base fluid to avoid a lump occurring within the drilling fluid system. The composition of the various mud samples was shown in Table 1. The experiment of physical property was done on a laboratory scale with 1, 3 and 5% weight per volume of sugarcane bagasse (SCB) at 30, 60 and 80 °C according to API RP13B-1. Because of the property of SCB has a high viscosity and gel strength at high temperature resulting in the drilling fluid adding with SCB cannot be mixed since 90 °C.

### 2.2 Chemical property analysis

X-ray fluorescence spectrometer (ED-XRF, Horiba XGT-5200) was used to determine the samples chemical composition. The mineralogical analysis was performed via X-ray diffraction (XRD) using a Bruker-D2 Phaser.

### 2.3 Rheological property tests

Rheological properties of drilling fluids used in oil or gas well drilling include apparent viscosity, plastic viscosity, and yield point. Rheology is the study of flow and deformation of all form of matter but its greatest development has been in the study of the flow behavior of fluids through conduits and pipes. In general, two models as Bingham plastic and Power-law described the rheology of drilling fluid. The equation of each model as shown in Table 2.

### 2.3.1 Bingham plastic model

Theoretically, Bingham plastics fluids are distinguished from Newtonian fluids, as they require finite stress to initiate flow. These fluids do not flow until the applied shear stress, exceeds a certain minimum value known as the yield point. Once the yield point has been exceeded, changes in shear stress are proportional to changes in shear rate and the constant of proportionality is called plastic viscosity (Clark, 1995). According to Figure 1A, a graphical representation of this fluid usually presents a linear correlation. The plastic viscosity is the slope of the Bingham plastic line, which this viscosity decreased when the shear rate increasing due to a phenomenon called "shear thinning". Base on Equation (1) and (2) were used to plot the relationship of shear stress and shear rate to analyze flow model.

Table 1. Composition of various drilling fluids.

| Composition of mud | Base drilling fluid (g) | Base +1% SCB (g) | Base +3% SCB (g) | Base +5% SCB (g) |
|---|---|---|---|---|
| Water | 1000 | 1000 | 1000 | 1000 |
| Barite | 100 | 100 | 100 | 100 |
| Bentonite | 60 | 60 | 60 | 60 |
| Sugarcanes bagasse (SCB) | - | 11.6 | 34.8 | 58.0 |

Table 2. Rheological models applied to the drilling fluid.

| Rheological models | Equations | |
|---|---|---|
| Bingham plastic model | $\tau = \tau_0 + \mu_p\gamma$ | (1) |
| Power law model | $\tau = k\gamma^n$ | (2) |
| | $n = 3.322 \log (\text{ø}_{600} / \text{ø}_{300})$ | (3) |
| | where n=1, for Newtonian fluid | |
| | n>1, for shear thickening | |
| | n<1, for shear thinning | |
| | $k = 510\ \text{ø}_{300}/511^n$ | (4) |
| | $\mu_a = \text{ø}_{600} / 2$ | (5) |
| | $\mu_p = \text{ø}_{600} - \text{ø}_{300}$ | (6) |
| | $\gamma_p = \text{ø}_{300} - \mu_p$ | (7) |

Variation definition:
$\tau$ = shear stress (lb/ft$^2$), $\tau 0$ = yield point or minimum volume (lb/100 ft$^2$), $\mu p$ = plastic viscosity (cP), $\gamma$ = shear rate (s$^{-1}$), k = fluid consistency index, n = flow behavior index, ø600 = viscometer dial reading at 600 rpm, ø300 = viscometer dial reading at 300 rpm, and $\gamma_p$ = yield point (lb/100 ft$^2$).

### 2.3.2 Power-law model

Power-law model represents parameter k and n are constants characteristic of a particular fluid that defined from Equations (2) as shown in Table 2. Both parameter n and k are obtained from the log-log plot of shear stress versus shear rate (Figure 1B). For n is equal 1 (n=1), k becomes the plastic viscosity and the equation reduces to Bingham plastic model that the fluid behaves as a Newtonian fluid and the Power Law equation is identical to the Newtonian fluid equation. For n greater than 1 (n>1) the fluid is classified as dilatant showing the shear rate dependent with their apparent viscosities increase as a shear rate increase. For n is less than 1 (n<1), then the fluid is referred to as pseudoplastic. The pseudoplastic fluid is also shear rate dependent with their apparent viscosities decreasing as shear rate decrease.

For this study, the rheological properties were measured the plastic viscosity, apparent viscosity, and yield

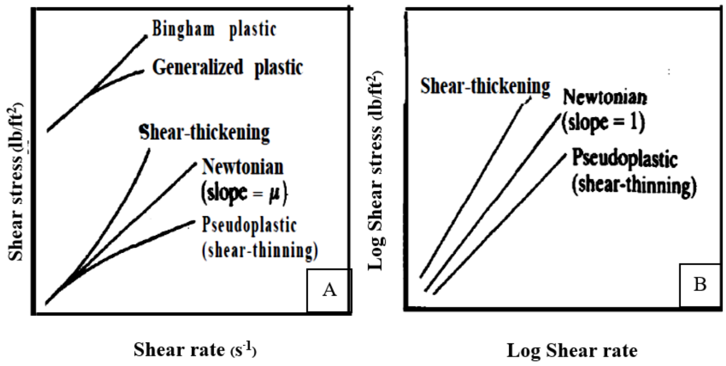


Figure 1. Basic Shear diagram depicting typical fluid behavior for real fluids (Brodkey & Hershey, 1988)

point by Fann 35SA viscometer. These properties are described by the following Equations (5), (6), and (7) as shown in Table 2. The gel strength of mud was a measure of shearing stress necessary to initiate a finite rate of shear. The gel strength was measured by the rotational speed of three rotational speeds (rpm) and it is usually reported in lb/100 $ft^2$.

## 2.4 Filtration tests

An important mud function is to wall the borehole with a relatively impermeable filter cake. This cake is a composed of mud solids which bridge over the minute pores in the rock, with additional solids being deposited as more mud filtrate is forced through. It is often desirable to have mud, which will quickly produce a high impermeable wall cake, thereby reducing the filtration loss and cake thickness. Baroid filter press is the tool used to measure the fluid loss and cake thickness of mud and the results present in the relationship of filtrate loss and the square root of time (API RP 13B-1, 1997).

## 2.5 Potential of hydrogen ion tests

The potential of hydrogen ion (pH) of fluid was conducted using a glass electrode pH meter, Metrohm 713. The fluid hydrogen ion or pH of drilling mud has to be controlled in the range of 9 to 12 in order to prevent the corrosion in the system (API RP 13B-1, 1997).

## 2.6 Microstructure analysis

The texture and particle shapes of the samples were observed by field emission scanning electron microscope (FE-SEM), using a model Carl Zeiss, AURIGA. These micro-structure properties of additives are determined both before and after mixed with drilling fluid.

# 3. Results and Discussion

## 3.1 Chemical properties analysis

Elemental composition of SCB consists of $SiO_2$, $CaO$, $K_2O$, $SO_3$, $Al_2O_3$, $Fe_2O_3$, $P_2O_5$, $MgO$, $Rh_2O_3$, and $MnO_2$. After drilling mud mixed with 5%, w/v of SCB, the com-position of element respectively included $SiO_2$, $SO_3$, $Al_2O_3$, $Fe_2O_3$, $BaO$, $CaO$, $Rh_2O_3$, and $SrO$ (Table 3). Dominant minerals in the drilling fluid after mixing with a concentration of 5% SCB consisted of barite, kaolinite, quartz, calcite, gypsum, hematite, magnesite, and tobermorite ($Ca_5Si_6O_{16}(OH)_2 \cdot 4H_2O$) as shown in Table 3 and Figure 2. Especially, the content of $MgO$, $SiO_2$, $Al_2O_3$, $CaO$, and tobermorite in SCB affected to the rheological properties due to it is a calcium silicate hydrate mineral that leads to a denser and more stable structure causing to viscosity and gel strength performance of the drilling fluid (Kolias, Kasselouri-Rigopoulou, & Karahalios, 2005). The gypsum, pyrolusite, and hematite affected to pH value of drilling fluid mixed with SCB ranges as 8.47 to 9.98 resulting pH was lower than standard as 9 to 12. According to Figure 3, the increase in temperature causes the pH to decrease. These conditions could cause corrosion to occur as the temperature rising along with depth and adding more SCB concentration.

## 3.2 Rheological property

Rheological behavior was determined by the rela-tionship of shear stresses and shear rates. The graphical results of water-based drilling fluid under temperatures of 30, 60 and 80°C tended to behave as a Bingham plastic fluid (Figure 4). The rheological behavior of the water-based drilling fluid with the SCB demonstrated the flow behavior in between the Bingham plastic and the power-law model, which slightly increased the concentration of additive (Figure 5). This indi-cated a significant increase in the apparent viscosity as addi-tive concentration increased, due to a greater colloidal fraction of bentonite and increasing flow resistance.

From Equation (3) and (4) of the power-law model, the index (n) indicated that all drilling fluid samples exhibited pseudoplastic flow ($n<1$). As mentioned above, the flow behavior of typical drilling mud usually follows the parameters of Bingham plastic and power-law models as a pseudoplastic fluid. The consistency factor of the drilling fluid samples tended to increase with the increasing quantities of added materials. The constant was similar to the apparent viscosity of the fluid that described the thickness of the fluid. The power-law model did not exactly describe the behavior of drilling fluid but the constants n and k normally describe hydro-mechanical utilization used in hydraulic calculations (API RP 13B-1, 1997). The higher k value represented more viscous fluid and n is a measure of the degree of the non-Newtonian behavior of the fluid.

Table 3. Elemental and mineral compositions of bentonite drilling mud and additives before mixing, and drilling mud mixed with 5% weight by volume of SCB at 30 °C.

| XRF Analysis | | | | XRD Analysis | | |
|---|---|---|---|---|---|---|
| Elements | Bentonite based drilling fluid (%) | SCB (%) | Base +5% SCB (%) | Minerals | Bentonite based drilling fluid (%) | Base +5% SCB (%) |
| MgO | 3.915 | 1.829 | - | Quartz | 23.537 | 7.345 |
| $Al_2O_3$ | 11.394 | 5.389 | 14.913 | Kaolinite (Bish) | 9.700 | 32.402 |
| $SiO_2$ | 50.527 | 60.119 | 55.231 | Hematite | 1.021 | 0.770 |
| $P_2O_5$ | - | 3.599 | - | Calcite | 6.000 | 7.494 |
| $SO_3$ | 23.073 | 5.913 | 18.122 | Barite | 46.526 | 42.747 |
| $K_2O$ | 0.561 | 6.444 | - | Magnesite | 0.499 | - |
| CaO | 2.752 | 8.589 | 2.564 | Pyrolusite | 0.360 | 0.475 |
| $Fe_2O_3$ | 4.769 | 5.021 | 5.747 | Gypsum | 4.076 | 5.566 |
| SrO | 0.343 | - | 0.131 | Periclase | 4.390 | - |
| $Rh_2O_3$ | 0.267 | 0.686 | 0.329 | Tobermorite | 3.538 | 1.741 |
| BaO | 2.073 | - | 2.963 | Total | 100 | 100 |
| $MnO_2$ | - | 0.484 | - | | | |
| Others | 0.326 | 1.927 | - | | | |
| Total | 100 | 100 | 100 | | | |

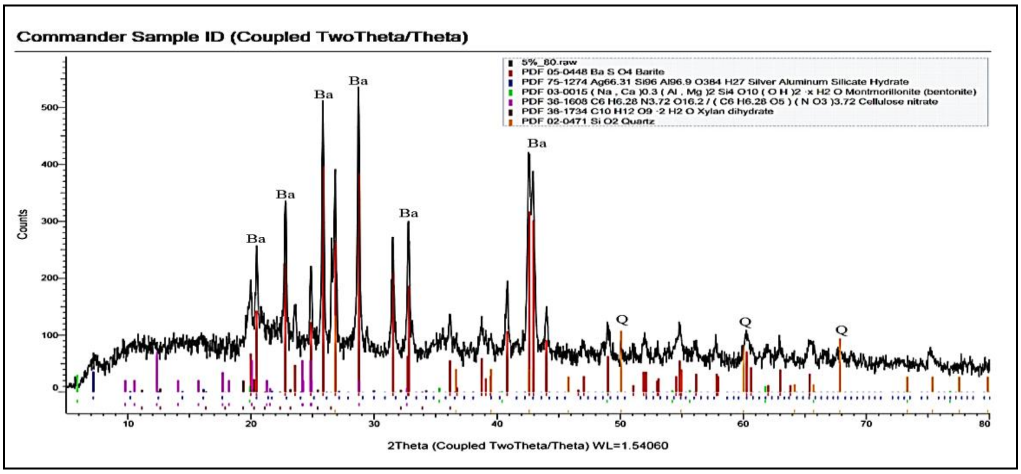


Figure 2. XRD of drilling fluid mixed with 5% of SCB at 80 °C.

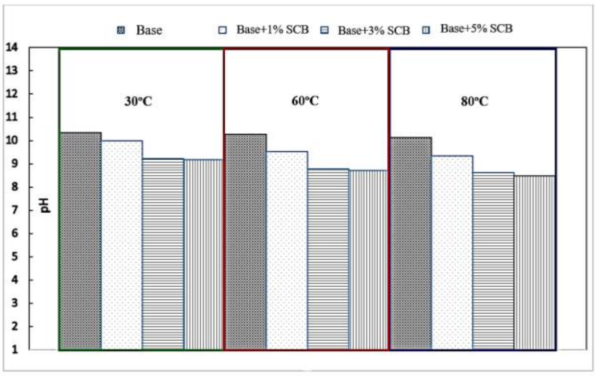


Figure 3. pH of drilling fluid mixed with 1, 3, and 5% of SCB at 30, 60, and 80 °C.

Apparent and plastic viscosities showed an increasing trend of yield point and gel strength (Figure 6). The apparent viscosity reflects the flowability to drill fluid and related to the rate of penetration, and the plastic viscosity caused by the friction between the suspended particles and influenced by the viscosity (Falode, Ehinola, & Nebeife, 2007). These properties increased the efficiency of cuttings removal during the drilling mudflow from the borehole bottom up to the surface. Moreover, if the viscosity is relatively high it is resulting in a slower pump flow rate, higher energy losses, and delays in circulation.

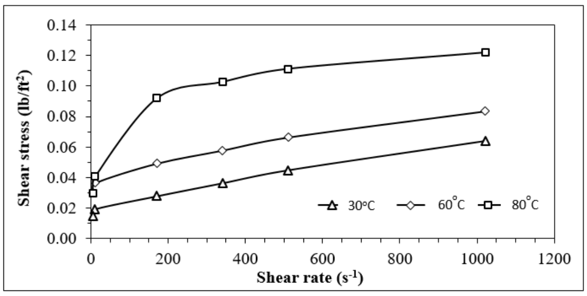


Figure 4. Consistency plot of water-based drilling fluid at 30, 60, and 80 °C.

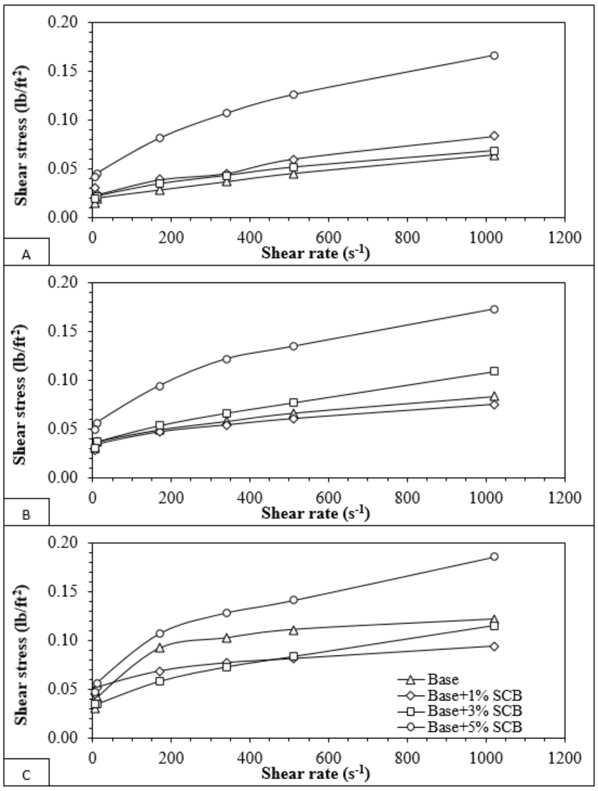


Figure 5. Consistency plot of drilling fluid with SCB at (A) 30 °C, (B) 60 °C, and (C) 80 °C.

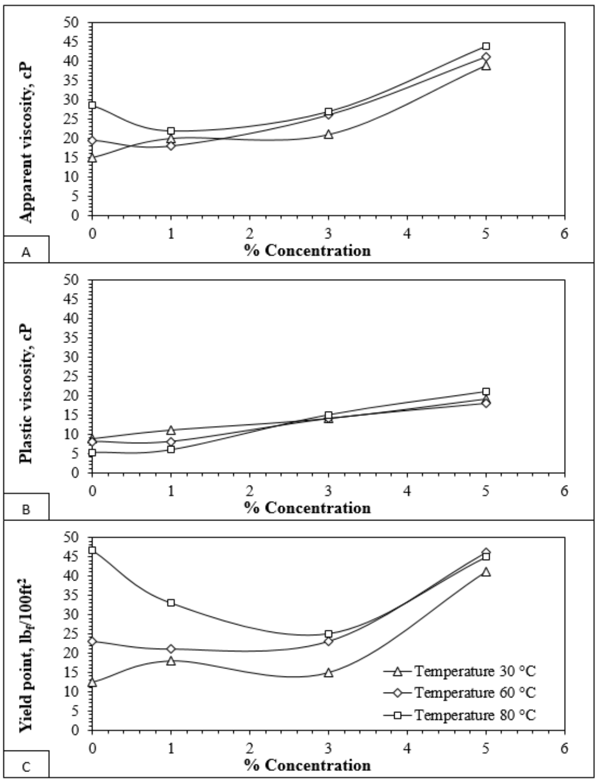


Figure 6. Viscosity of drilling fluid with SCB (A) apparent viscosity, (B) plastic viscosity, and (C) yield point.

Influences of temperature on the apparent viscosity, plastic viscosity and yield stress as represented in Figure 6. Elevated temperature from 30 to 80 °C resulted in the slightly decreased plastic viscosity. The trend of the line indicates that the drilling fluid behaved as non-Newtonian, with shear-thinning as temperatures increased (up to 80 °C) displaying lower plastic viscosity and higher yield stress. However, the plastic viscosity was lower at the higher temperatures, as the water evaporated leaving greater amounts of hard solid.

The aim of filtration is to create a low-permeability mud filter cake as a seal between the wellbore and the formation. The control of fluid loss restricts invasion of the formation by filtrate and minimizes the thickness of the mud filter cake. The drilling fluid mixed with 1, 3, and 5% of SCB at 30, 60, and 80 °C (Figure 7). This histogram showed the time-dependent filtration behavior of drilling mud indicating that fluid loss increased exponentially with time and temperature. The lowest filtration loss at 60 °C and drilling fluid with 3 and 5% SCB showed the low filtration loss. As concentrations of SCB increased resulting in the filtration loss decreased. Table 4 presents the reduction the filter loss of drilling fluid mixing with SCB, which it is better than drilling fluid base, especially it can reduce the filter loss as 37.8 to 39.6% in the concentration of 3 and 5% SCB at 80 °C, respectively. Therefore, the concentration at 5% SCB showed the high potential of filtration loss control, indicating that the SCB could improve the filtration loss control of drilling fluid.

Decreasing of filtrate volume resulted from continuous mud filter cake deposition and compaction until the complete formation of a constant thickness and stable mud filter cake. From Figure 8 represented the thickness of mud filter cake depended on an increase in additive concentration and temperature. Mud filter cake character represented the slickness and toughness of SCB in the drilling mud as the cellulose improving the stability and lubricity of the mud filter cake.

## 3.4 Microstructure analysis

Microstructure analysis includes the morphology (texture), crystalline structure and orientation of the surface topography of the SCB, and the drilling fluid mixing with SCB. The morphology of SCB showed an irregular shape with rough surfaces, small porous textures, bars, and long fibrous sticks that texture affected the adsorbed fluid property (Figure 9A). After mixed with drilling fluid SCB interacts with thin sheets of bentonite clay as well as larger and smaller particles of barite (Figures 9B). The particles distributed on the surface of the mud filter cake making it stronger. However, they were unable to dissolve in water and the additives were visible as bars, resulting in the drilling fluid with SCB was heterogeneous.

## 4. Conclusions

Mineral composition of drilling mud mixed with 5% SCB dominantly was as the mineral to improve the viscosity and gel strength of the drilling mud mixed resulting from the MgO, $SiO_2$, $Al_2O_3$, CaO, and tobermorite ($Ca_5Si_6O_{16}(OH)_2 \cdot 4H_2O$) in SCB that increased the denser and more stable structure strength of drilling fluid. Performant of apparent and plastic viscosities also increases with the rising

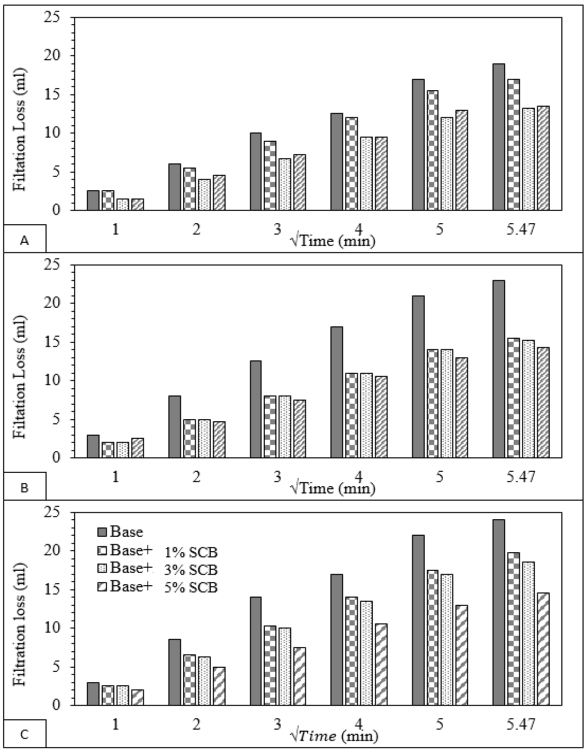


Figure 7. Filtration loss of drilling fluid with various concentration of SCB at (A) 30 °C, (B) 60 °C, and (C) 80 ºC.

Table 4. Filter loss reduction of drilling fluid mixing with various concentration of SCB at 30, 60, and 80 °C (measured thought 30-minutes).

| Temperature | Filter loss of drilling fluid (ml) | | | |
|---|---|---|---|---|
| | Drilling fluid base | Base+1% SCB | Base+3% SCB | Base+5% SCB |
| 30 °C | 19 | 17 | 13.8 | 13.5 |
| | % Filter loss Reduction | 10.5% | 30% | 29% |
| 60 °C | 23 | 15.5 | 15.3 | 14.3 |
| | % Filter loss Reduction | 32.6% | 33.5% | 37.8% |
| 80 °C | 24 | 19.8 | 18.5 | 14.5 |
| | % Filter loss Reduction | 17.5% | 23% | 39.6% |

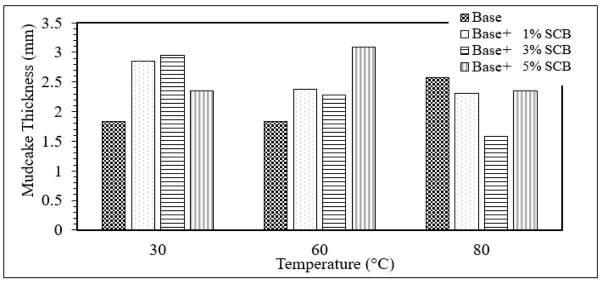


Figure 8. Mud filter cake thickness of drilling fluid with various concentration of SCB at 30, 60, and 80 ºC.

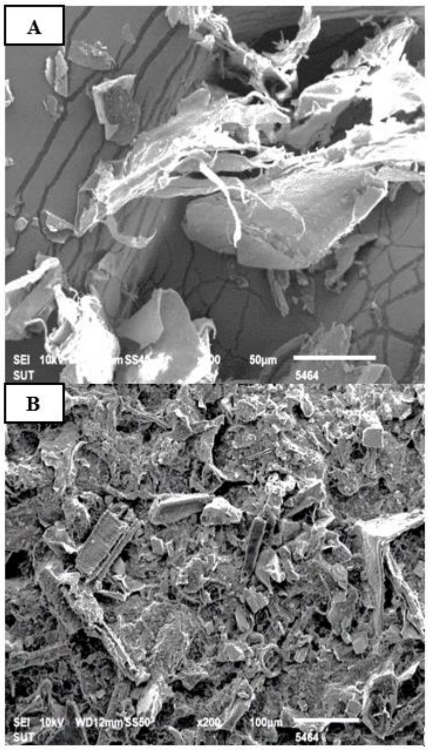


Figure 9. Surface topography of (A) SCB, and (B) drilling fluid with 5% SCB at 30 °C.

of concentration and temperature, and relate to the increasing trend of yield point and gel strength. The water-based drilling mud mixing with SCB showed pseudoplastic flow as the power-law model, slightly increasing on SCB concentration but reducing on the temperature. The API filtration result indicated drilling fluid mixed with SCB is better than water-based drilling fluid, which it can reduce the filter loss as respectively 37.8 to 39.6% in the concentration of 3 and 5% of SCB at 80 °C. The reducing of filtration loss and mud cake thickness improved with increasing SCB concentration and temperature resulting from the roughness surfaces and small porous textures of cellulose in SCB, involving to a high content of the cellulose and tobermorite. The gypsum, pyrolusite, and hematite in SCB have affected to pH value of drilling fluid resulting it was lower than the standard, which pH decreased as increasing of temperature and additive concentration. Therefore, the SCB is suitable to use as an additive for improving the rheological and filtration control properties of the drilling mud. The great improvement was observed in ascending order of drilling fluid with 5%>3%>1% of SCB. Moreover, drilling fluid mixed with SCB can be stored for a long time without easy degradation and rotten.

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