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Short Communication

Performance Evaluation of Polyol Esters from Palm Oil as a Lubricant for Bentonite Suspension Drilling Fluid

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Abstract

This study evaluated the potential use of three polyol esters (POEs) derived from palm oil as a lubricant in bentonite suspension drilling fluid. Three different POEs were investigated, which are pentaerythritol ester (PEE), trimethylolpropane ester (TMPE), and neopentylglycol ester (NPGE). It was revealed that POEs reduced the coefficient of friction (COF) in bentonite suspension by more than 80%. However, TMPE and NPGE undesirably caused foaming and altered the gel texture of the suspension. PEE showed the best performance as it produced the highest lubricity and the lowest effect on the suspension texture. The decrease of COF might increase the drilling efficiency and prevent the lubricity-related drilling problems. The findings of this investigation will be used for future applications of POE from palm oil in wider mud formulation.

Keywords

drilling fluid, bentonite suspension, polyol ester lubricant, mud lubricity, tribology

1 Introduction

High lubricity drilling fluids or muds are always desired in oil and gas drilling operation. They can minimize the friction between the drill pipes and the wellbore wall, increase the penetration rate, and prevent drilling problems such as stuck pipe, wear and tear. Lubricants are usually added to the mud to increase the lubricity and to provide protective film for the drill pipe [1,2]. The recommended effective lubricant concentration is between 1 to 3% [3]. High lubricity, low corrosivity, high lubricant film strength, high solubility, high thermal and oxidative stability, and environmental friendly are among the properties drilling mud lubricant should provide. Common lubricant used in mud system include polyalphaolefins and polyalkylene glycols. However, both of the lubricants have several shortcomings, such as small viscosity range, low polarity, and poor miscibility [4].

Research into the potential use of low toxic polyol ester (POE) as drilling mud lubricants has not been given a great attention [3], despite their high performance and biodegradability in general lubricant application [5,6]. Firstly, the oxidation and thermal stability of this type of lubricant has been improved by replacing glycerol with alcohol that does not contain ß-hydrogen atoms [7]. It is known that oil-based lubricants are effective as boundary lubricants due to their high polarity [4]. Moreover, if added to the water-based mud, nonionic material such as POE would not produce ions in the aqueous solution. Thus, they are mostly compatible with other materials and are suitable to use with high salinity water (i.e. brine encountered during drilling). Other attractive properties of POE that make them convenient for drilling muds include high flash point and fire point, which is advantageous for transportation and storage purposes, and low pour points that prevents the lubricant to become solid during drilling in cold weather.

In this study, the lubricating effect of different kind of polyol esters on bentonite suspension was measured as coefficient of friction (COF). Bentonite suspension was chosen as the base drilling mud because this type of mud has poor lubricity but economical. It simply comprises of bentonite, as known as montmorillonite clay, and water. Bentonite has the natural thixotropic properties where it flows under dynamic conditions and forms a gel under static conditions. POEs are hygroscopic lubricants (i.e. they absorb water), which makes them theoretically compatible for water-based mud. Concisely, this study contributes in a new application of polyol ester lubricant, in oil and gas drilling exploration. The finding in this study would be useful as a preliminary data for future implementations of POE in wider mud formulation.

2 Experimental methods

2.1 Polyol ester lubricants

Three different high viscosity POEs, which are pentaerythritol ester (PEE), trimethylolpropane ester (TMPE), and neopentylglycol ester (NPGE), were used as lubricant additives. The POEs were produced from a palm oil methyl ester through transesterification. The properties of PEE, TMPE, and NPGE, are presented in Table 1. PEE contains 52% w/w of tetraester and 36% w/w of triester, while TMPE mainly consists of 97% w/w triester. Meanwhile, NPGE has approximately 90% w/w of diester.

2.2 Bentonite suspension preparation

This study used an American Petroleum Institute (API) grade treated Bentonite in compliance with API 13A [8]. The bentonite was obtained from Scomi Oiltools Sdn. Bhd. Treated bentonite hydrates more than untreated bentonite, provides viscosity, and forms effective filter cake. It mainly contains the clay minerals of smectite. Additionally, it is commonly used to achieve high viscosity mud and reduce fluid loss in water based mud.

The bentonite suspension was prepared by mixing 7.5% (w/v) of bentonite in distilled water using a Silverson mixer at 6000 rpm for 30 minutes. The mud was then being static aged at 90°C for 16 hours. This aging process simulates the condition that would be achieved by a field drilling mud during circulation under the bottom-hole temperature.

After that, distilled water was added to the aged mud while mixing until the resultant mud had the apparent viscosity in the range of 15 ± 1 centiPoise at 48.8°C, which is a good mud viscosity for general drilling purposes [9]. The viscometer used in this study was Fann rotational viscometer Model 35, which is the most common viscometer used for Bingham plastic fluids such as drilling fluids. The testing procedure was per API recommended practice 13B-1 [10]. One type of POE lubricant was added accordingly while being stirred for another 15 minutes.

2.3 Friction measurement

Friction was measured using the Fann Model 212 lubricity tester, which is the most common tester to measure the lubricating quality of drilling fluids. The schematic illustration of the lubricity tester is presented in Fig. 1. The tests were performed by applying a measured force with a torque arm to a rotating bearing cup that ran at 6.28 rad/s. This tester has a rotating ring and stationary block, which is pressed against one another through the torque arm, to simulate friction between a drill pipe and casing.

The drilling mud sample, approximately 150 ml, was poured into a stainless steel sample cup. The cup was placed on a cup stand and raised until the ring and block was immersed in the drilling mud. A fixed contact load of 16.95 N.m was used because the exact load under wellbore conditions is hard to determine.

Table 1 The properties of three different POEs

Properties	PEE	TMPE	NPGE
Viscosity at 40°C, cSt	68.4	45.7	21
Viscosity at 100°C, cSt	12.7	9.46	6.3
Pour point, °C	-20	-27	-14
Flash point, °C	302	216.5	300
Density, kg/m^3	0.93	0.91	0.89

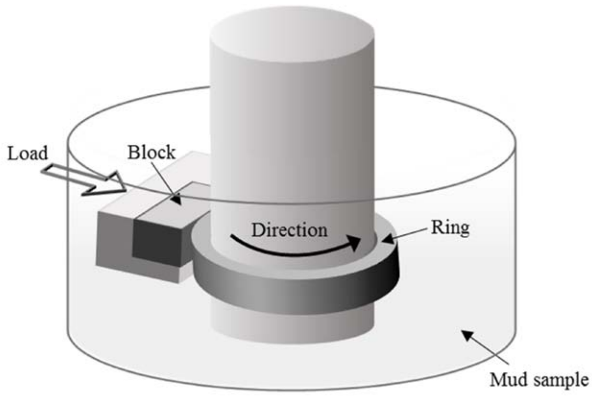

Fig. 1 A schematic of Fann Model 212 lubricity tester

The tests were performed at a room temperature. The torque reading was recorded after 5 minutes of sample run and the mud lubricity was expressed as COF. This friction measurement is necessary for determining the film strength of lubricant to the metal surface. These lubricity tests were conducted varying the lubricant type, which were PEE, TMPE, and NPGE, and lubricant concentration, which were 0.5 and 1%. The experiments were repeated three times. The average values were reported.

2.4 Mud density measurement

The mud density was measured using a mud balance at a room temperature. Mud density is expressed as specific gravity (S.G.). This measurement was taken in order to check whether the density changed after the addition of POE. Reduction in density might suggest foaming occur due to POE. Several studies have shown that some lubricants foam in mud [2,11]. The control of foam is an important factor for water-based mud since foaming is undesirable for this mud system.

3 Results and discussions

3.1 Effect of different lubricant on mud lubricity

The base mud, which contained no POE, was measured to have an average COF of 0.5. According to Livescu and Craig [12], the common mud COF should be around 0.24, which means the COF of untreated bentonite suspension is much higher and lack of lubricity.

At a low concentration of 0.5%, PEE, TMPE, and NPGE reduced the COF of the mud by 86.8%, 82.4%, and 80%, respectively. Increasing the lubricant concentration to 1% appeared to not improve the lubricity any further, hence higher lubricant concentration was not tested. The COF reduction by 1% of PEE, TMPE, and NPGE are 87.5%, 82.8%, and 80.4%. The lower COF means the lower force required to rotate a steel ring in contact with a steel block due to the improved lubricity property of the mud.

High COF reduction was mainly attributed to the strong attraction between the high polar POE molecules and positively charged metal surfaces, even at a very low concentration [1,13]. Higher polarity results in lower friction [7]. The POE molecules tend to line up and adhere on the metal surfaces creating a strong lubrication film [14]. The film remains adherent under the given surface pressures and increases the lubricity. In these tests, small quantity of POE possibly attached to the metal surface of lubricity tester, created a lubricant film, and stayed in the contact area. Accordingly, it is expected that the POE would provide a pressure-resistant film that is to the metal drilling pipe and casing.

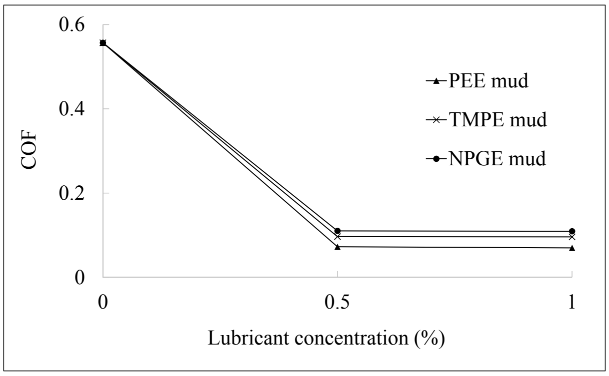

Fig. 2 Coefficient of friction of bentonite suspensions containing lubricants

As seen in Fig. 2, all the POEs result in the similar trend of COF reduction. However, PEE is shown to have the highest COF reduction, compared to TMPE and NPGE. Theoretically, the tetraester content in PEE should provide better lubricant properties [15], which is in accordance to the result of this study. Diester of NPGE and triester of TMPE are less lubricious, compared to tetraester. Improved head group and branching structure also increased the molecular weight of PEE, hence increased the lubricity. This finding is in the lines with the theory that says increased molecular weight improves the lubricity of an ester [16]. The molecular weight and shape of POE also affect the viscosity significantly. High molecular weight of PEE causes higher viscosity. As presented in Table 1, the viscosity of PEE is the highest among other lubricants. This might also play the essential role in resulting thicker lubricant film and lower COF. This is consistent with an earlier literature that suggested that the lubrication supply depends on the viscosity characteristic of the lubricants [17].

3.2 Foaming tendency

Foaming is not desirable in drilling fluid, especially in bentonite suspensions where the application mostly depends on its viscosity and gel characteristics. The presence of foam would disrupt the mud performance that leads to a decrease in pump efficiency, the flow properties alteration, cuttings removal/transport obstruction, and mud density reduced [18]. It has been studied that the more hydrophilic the ester, the higher foam exhibit [19]. Because of the hydrophilic nature of POE, the foaming tendency of NPGE, TMPE, and PEE was investigated.

The texture of the mud after the addition of 0.5 and 1% of lubricants is presented in Fig. 3. In Fig. 3(a), base mud is shown to have a thick and smooth texture. There was no foaming detected in the base mud. The effect of PEE on foaming tendency can be seen in Fig. 3 (b). Minimal foaming occurred in the mud. Soon after agitation process, big bubbles came closer to each other and broke easily. The texture of mud with PEE was very similar to the base mud, suggesting that PEE did not cause noticeable foaming.

After the addition of NPGE and TMPE, plenty of foam was produced in the mud after agitation. As bentonite suspension mainly consists of water, the hydrophilic molecules of certain POE are likely to form foam, which is also in accordance with the hypothesis above. In Fig. 3(c), NPGE produced small spherical foam where the foam filled with gas separated by thin films. Individual gas bubbles was observed on the top of the mud with sufficient space between each bubbles for the presence of lubricant layer. On the other hand, Fig. 3(d) shows that TMPE generated bigger foam that was separated by the viscous liquid films. The foam was deformed into polyhedral, instead of spherical shape. The foam produced by TMPE stayed far apart, preventing coalescence. Thus, the foam was more stable than those caused by NPGE or PEE. In addition, the mud texture became very thick after the suspension was left to stand undisturbed.

To support the foaming tendency caused by POE, mud density was measured and compared to the base mud. As shown in Table 2, the S.G. of muds containing TMPE and NPGE decreased markedly. The density reduction of the mud indicates there is foam/bubbles presence in the mud. In accordance with visual investigations earlier, the density of mud containing PEE reduced slightly. Even the mud with 0.5% of PEE had relatively similar density with the base, suggesting that there was no significant foaming. The results also show that increasing the lubricant concentration to 1% increases the tendency to foam which is shown by further reduction of density.

Different structures of POE may result in different foaming behavior. For instance, a straight-chained molecule causes more foaming tendency than the branched one. Branched-chain molecules have weak molecular interactions between the branch chains, resulting unstable foam that is easy to collapse. On the other hand, straight-chained molecules arrange themselves closer one another, accommodating a more stable foam [20]. NPGE and TMPE have a more straight chains, compared to PEE. Hence, it is possible that the molecules of NPGE and TMPE trap air bubble upon agitation and produce stable foam. PEE that has more branched-chain molecules might also generate foam, but the foam stability is poor. Hence, the foam in PEE added mud disappear soon after agitation.

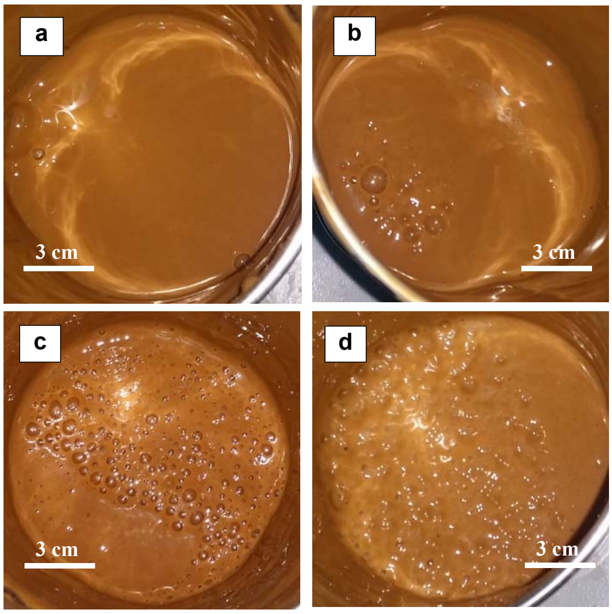

Fig. 3 The different texture of (a) base mud, (b) PEE added mud, (c) TMPE added mud, and (d) NPGE added mud

Table 2 The S.G. of the bentonite suspensions with the presence of 0.5% and 1% of lubricants

Conc. (%)	Base mud	PEE mud	TMPE mud	NPGE mud
0.5	1.03	1.02	0.94	0.97
1	1.03	0.97	0.86	0.91

Regardless, the precise nature of the chemical reaction between POE and bentonite suspension is still not well understood. The effect of POE is especially harder to conclude since the POE presented in a very small quantity in the mud. At this stage of study, it is assumed that TMPE and NPGE might act as the foaming agent/profoamer bentonite suspension due to their hydrophilic nature. This is also in regard that generally, fatty acid esters are nonionic surfactant that might act as dispersants, emulsifiers, wetting agents, or foaming agents.

Since both of TMPE and NPGE changed physical properties of the mud, the usage of both lubricants alone might not be favorable. Small amount of defoamer, i.e. nonionic organic liquid octanol, can be added to the system to solve the foaming issue. It is worth mentioning that the use of defoamer in water-based mud is very common.

4 Conclusions

High polar polyol esters investigated in this study, which are PEE, TMPE, and NPGE, were able to reduce the friction in bentonite suspension drilling mud by more than 80% at a concentration of 0.5%. On the basis of current results, PEE performed better as mud lubricant compared to TMPE and NPGE. PEE resulted in highest COF reduction and did not have significant foam tendency. TMPE and NPGE caused foaming and texture alteration of the mud. Therefore, defoamer additive should be added to the mud when using lubricants that cause foaming.

Unfortunately, there is no systematic understanding of the interaction between bentonite with POE in the present study. In addition, the complex and detailed interaction between POE and drilling pipe metal surface under rubbing condition indeed require further investigation. Further study on the state of POEs exist in bentonite suspension/bentonite surface would also be beneficial. Regardless, the fact that only a very small amount of POE needed to reduce the COF significantly would make an economical lubricant for drilling mud. For future study, it is encouraged to study the lubricity performance and compatibility of POE in a more complex water-based mud that consists of other mud additives, apart from bentonite alone.

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