EXPERIMENTAL STUDY OF COCONUT OIL AS AN ALTERNATIVE FOR MINERAL OIL IN OIL-BASED MUD

Dinesh Kanesan and Mohd. Fazriq Hafizin Bin Jamaludin
Department of Petroleum Engineering, Faculty of Engineering, Universiti Teknologi ETRONAS, Malaysia
E-Mail: dinesh.16001400@utp.edu.my

ABSTRACT

The study on vegetable oil-based drilling mud has gained much attention due to the detrimental effects of the conventional oil-based mud (OBM). The conventional OBM contains additives which can endanger the safety of personnel handling it. The objective of this study is to formulate a new OBM by using coconut oil as a base fluid and analyze whether coconut oil-based mud would be a viable option as opposed to conventional mineral oil. Coconut oil will be used as a substitute to the conventional base oil. The compared properties were rheological properties, yield point, gel strength and filtration loss properties. The mud density for both drilling mud is kept constant at 9.0 ppg for comparison purpose. Results obtained show that the Coconut OBM exhibited Bingham plastic rheological model with high yield point and gel strength compared to OBM. Furthermore, the mud filtration test results were 3.8 ml for Coconut OBM and 1.7 ml for OBM. The thicker mud cake of Coconut OBM would cause pipe to stuck compared to OBM thinner mud cake. In conclusion, Coconut OBM exhibit poor performance in mud rheology and filtrate loss with the exception of superior gel strength than OBM but it is not sufficient to replace OBM in any drilling operations.

Keywords: water-based mud, oil-based mud.

1. INTRODUCTION

Drilling fluid is an important component in any drilling operations. The success rate of any drilling operations depends on the efficiency of drilling fluid. The main function of drilling fluid is to deliver cuttings to the surface, maintaining bore hole pressure and reducing drill bit temperature which are key components for a smooth drilling procedure. Using the appropriate drilling fluid types will determine the success rate of drilling operations [1].

Overall there are two types of drilling fluid which are water-based mud (WBM) and oil-based mud (OBM) both having distinct advantages and disadvantages over one another. OBM demonstrates superior wellbore stability, low formation damage and temperature stability when compared to WBM. However due to the destructive nature of OBM which contains high aromatic components. Engineers tend to use WBM despite of its performance drawbacks [2]. WBM does not cause any significant harmful effect to the environment but its performance is not up to par with that of OBM [3]. The cost of WBM is relatively cheap but it has poor rheological properties causing it to be less effective in high temperature, prone to corrosion and poor lubricating properties. Such properties will not be effective to be use as drilling fluid therefore an alternative solution should be invented which can have the same performance as OBM but contributes little to none harmful effect to the environment.

Current approach as to mitigate the environmental hazard of OBM is the use of vegetable oil as a replacement for diesel oil in drilling mud formulation. In 2013, Malaysia is one of top 10 coconut producing countries in the world and Malaysia is placed at number 4 for industrial crop ranking. These readily available resources would be beneficial for designing a vegetable oil base mud drilling fluid [4]. OBM have proven to be superior than WBM in multiple aspects such as better shale inhibition, lubricity and thermal stability characteristics. However, using OBM drilling fluid would cause the carried cuttings at the surface to seep harmful chemicals through the ground and damaging any living organism including polluting the groundwater [5]. The cuttings contain heavy metals with concentration higher than natural occurring concentrations of sediments causing phytotoxicity, bioaccumulation and adverse effect to the environment [6]. Furthermore, the lack of practicing petroleum waste management in Malaysia and the absence of proper technology would amplify the hazardous effect of OBM [7].

Besides that, the cost of OBM is expensive due to the formulation involve in designing the drilling fluid. Also, the high gas solubility of OBM would cause difficulties for kick reading and any lost circulation event would raise the cost to use OBM in drilling operations [8]. In some instances, accidental spills of OBM could occur and the high aromatic components of these drilling fluid would cause adverse effect on human health. [9].

However, previous study has shown that the viscosity of vegetable oils is 5 times higher than diesel oil. This exceeds the requirement of API which is around 2.3 to 3.5 cp causing it to be incompatible for the usage of base fluid for mud formulation. The high viscosity would affect the mud rheology particularly the Plastic Viscosity (PV), Yield Point (YP) and Gel Strength which translates to low penetration rate, differential sticking, high equivalent circulating density also high pumping pressure to initiate flow [10].

The basic building block for the vegetable oil-based OBM is vegetable oil consisting of triglycerides which are long fatty acid chains with unsaturated bonds.
with most common vegetable oil containing up to 12 fatty acids [11]. Vegetable oil is non-toxic as burning these types of oil emits a low amount of carbon dioxide and carbon monoxide emission, with the added benefit of being able to degrade in the environment [12]. Vegetable oil-based mud advantage over conventional OBM would be the superior thermo-physical properties. The flash and flame points of vegetable oils are superior relative to minerals oils which translates to a greater fire resistant. Consequently, the transportation, storage and handling of Vegetable OBM is safer and minimum operational issues related to low flash and fire points [13]. However, there are some drawbacks mainly due to higher viscosity of vegetable oils in comparison with diesel oil by 4 to 5 times higher rendering it unsuitable for mud formulation, multiple problems related to mud rheological properties [14].

2. MATERIALS AND METHODS

For this project virgin coconut oil (VCO) is chosen which comprises of:

Table-1. Fatty acid composition of VCO.

<table>
<thead>
<tr>
<th>Fatty Acid</th>
<th>Coconut Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>C6</td>
<td>0.69%</td>
</tr>
<tr>
<td>C12</td>
<td>48%</td>
</tr>
<tr>
<td>C14-C16</td>
<td>60.5%-63.6%</td>
</tr>
<tr>
<td>C18:1</td>
<td>5%</td>
</tr>
</tbody>
</table>

Having a higher content of oleic acid would have excellent oxidative stability which affects positively on thermo-physical properties however the oleic acid content is about 8% only as compared to Palm oil which has about 50% of oleic acid [10];[15]. Next, the mud is formulated by the following formulation in Table-2.

Table-2. Mud formulation.

<table>
<thead>
<tr>
<th>No.</th>
<th>Product</th>
<th>SG</th>
<th>Content</th>
<th>Mixing Time (min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Saraline 185</td>
<td>0.78</td>
<td>151.6 ml</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Coconut Oil</td>
<td>0.90</td>
<td>200 ml</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>CONFI-MUL P</td>
<td>0.87</td>
<td>2.0 ml</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>CONFI-MULS</td>
<td>0.88</td>
<td>7.0 ml</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>CONFI GEL</td>
<td>1.7</td>
<td>10.0 g</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>Lime</td>
<td>1.7</td>
<td>9.0 g</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>Water</td>
<td>1.0</td>
<td>87.4 ml</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>Calcium Chloride</td>
<td>1.22</td>
<td>30.8</td>
<td>15</td>
</tr>
</tbody>
</table>

The mud formulation comprises of different chemicals and additives to ensure the desired mud is obtained. Among the chemicals or additives used are base oil, fluid loss controller, viscosifier, emulsifier, brine and lime. The following chemicals and additives were used to achieve mud weight of 9.5 ppg for both OBM and Coconut OBM.

The mud is formulated by following the order number from 1 until number 9 with respect to each of its mixing time. All of the formulated should be weight using mud balance to ensure the correct mud weight is obtained.

2.1 Mud Rheology

Mud rheology is represented by PV, YP and apparent viscosity with each of them having distinct characteristics. PV is define as resistance of a mud to flow in as its resistance is affected by viscosity of fluid phase, size of solid and viscosity of fluid phase [16]. Next, YP is used to measure the ability of the mud to transport the cuttings from the annulus to the surface by adhering to the concept of electrochemical forces between particles [16]. Last but not least, apparent viscosity is the relationship between PV and YP either an increase nor decrease in one or both properties would affect the apparent viscosity as well [17].

Drilling mud can be group into Newtonian Fluid and Non-Newtonian Fluid [18]. For Newtonian fluid the viscosity is independent of shear rate while shear rate is a function for non-Newtonian fluid. Bingham Plastic theory is used to measure all the rheological properties of mud which are PV, YP and Apparent viscosity [19]. The theory indicates the a straight line when a graph of shear stress against shear rate is plotted [20]. The following equations are used in Bingham Plastic model:

\[ \tau = PV \left( \frac{\gamma}{300} \right) + YP \]  
\[ PV = R_{600} - R_{300} \]  
\[ YP = R_{300} - PV \]  
\[ \mu_a = \frac{R_{600}}{2} \]
shear stress (lb/100 ft²), \( \gamma = \) shear rate (sec\(^{-1})\), \( PV = \) plastic viscosity (cP), \( YP = \) yield point (lb/100ft²), and \( \mu = \) apparent viscosity (cP).

In Figure-1, when shear rate is zero the YP can be determined indicating the minimum shear stress required to carry the cuttings back to the surface. A lower YP would represent the effectiveness of the drilling mud’s performance.

Gel strength is measured by the inter-particle forces which develops the gel that will formed once circulation is stationary [21] or can be defined as the shear stress at which the gel breaks. The importance of sufficient gel strength is its ability to suspend drill cuttings weighting materials during circulation. Both gel strength and YP both measure the attractive forces but with gel strength measuring the static attractive forces while YP measures the dynamic attractive forces. Also, the unit of measurement for gel strength is the same as YP.

The test was conducted using a viscometer with speed ranging from 600 RPM (rotation per minute) to 3 RPM. The samples were stirred at 600 RPM for 10 minutes for homogeneity and tested at 120° F. The readings taken will then be used to calculate for the Apparent Viscosity, YP and Gel Strength.

2.2 Mud Filtrate

Filtration is a relative measure of any liquid that could invade a permeable formation through deposited of mud solids. This liquid is describe as filtrate and the deposited solids are called mud cake. There are two standard filtration tests that measure the volume of filtrate collected after a 30-min period of time using filter paper [22]. These tests are the low-temperature low-pressure (LPLT) fluid loss test and the high-temperature high-pressure (HTHP) test which are in coherent with API standards.. Results are reported as the millilitres (ml). Filter cake thickness is measured and reported in units of 1/32 inch [23].

LPLT test is performed at normal room temperature with 100 psi. The more advanced test is the HTHP filtration test that is performed at a temperature closer to the bottom hole temperature and at a 500 psi differential pressure. The test was conducted using API filter press , the parameters set are 100 psi at room temperature for a duration of 30 minutes. The volume of filtrate produced from the mud is recorded at an interval of 5 minutes.

2.3 High Temperature Fluid Aging (Hot Rolling)

The high temperature fluid aging test consist of two main components which are the high temperature hot roller oven and the high temperature aging cell. The main objective of this experiment is to determine the effect of temperature on drilling mud as it circulate through a wellbore at reservoir pressure and temperature. This particular set up is under dynamic conditions where the drilling fluid will be constantly moving in the aging cells for a duration of 16 hours testing period at 300 °F and 100 psi.

Once the samples had successfully completed the experiment, the mud will undergo similar experiments previously for comparison purposes. Such experiments are the mud rheology and mud filtrate tests.

3. RESULTS AND DISCUSSIONS

3.1 Mud Rheology

The mud rheology was conducted and results for both mud were tabulated. Based on the graph in Figures 2 and 3, Coconut OBM exhibits a higher shear rate profile which translate to it having a higher viscosity than OBM. Larger value of viscosity would cause several drilling problems such as the rate of penetration, differential sticking or high equivalent circulating density. Also, both OBM exhibit a rheological model similar to the Bingham plastic model. This plastic model will not flow until the YP is exceeded after which the changes in shear stress are proportional to change in shear rate. The constant proportion is identified as PV.
Table-3. Plastic viscosity, apparent viscosity and yield point.

<table>
<thead>
<tr>
<th></th>
<th>OBM</th>
<th>Coconut OBM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic Viscosity</td>
<td>16</td>
<td>102</td>
</tr>
<tr>
<td>Apparent Viscosity</td>
<td>19</td>
<td>46</td>
</tr>
<tr>
<td>Yield Point</td>
<td>25.5</td>
<td>125</td>
</tr>
</tbody>
</table>

Table-4. Plastic viscosity, apparent viscosity and yield point (Hot Rolling).

<table>
<thead>
<tr>
<th></th>
<th>Hot Rolling</th>
<th>OBM</th>
<th>Coconut OBM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic Viscosity</td>
<td>4</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Apparent Viscosity</td>
<td>7</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Yield Point</td>
<td>7.5</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

Based on the Tables 3 and 4, YP for Coconut OBM is significantly higher than OBM. A high YP value indicates a non-Newtonian fluid which can carry the cuttings much better however excessive YP values will lead to high pressure losses as the drilling mud is being circulated. Higher pump pressure is required to operate using Coconut OBM due to the massive YP value. For the Apparent viscosity which is lower for OBM than Coconut OBM indicates shear thinning which meant a higher cutting carrying capacity. Also, pumping pressure would also decrease as an effect of shear thinning which is poorly demonstrated in Coconut OBM.

The substantial value of PV for Coconut OBM will cause the flow of cuttings in the annulus hindered by the viscosity which will impede drilling’s performance. In conclusion, the parameters for this experiment signify that Coconut OBM will not execute its drilling mud function on par or better than OBM.

Figure-4. Gel strength.

Figure-5. Gel strength (Hot Rolling).

Gel strength for Coconut OBM based on Figures 6 and 7 manifested a poor result than OBM for both 10 seconds and 10 minutes. The gel strength of Coconut OBM exhibits a progressive gel structure demonstrated by the value of shear stress at 10 minutes were much higher than 10 seconds. This result portrays the gellation of Coconut OBM has fragile property which is desirable during drilling operation as the gel can easily be broken with lower pump pressure. On the other hand, OBM gelation strength is rapidly recovered with time which will lead to high circulation breakdown pressure with the additional requirement of higher pump pressure with the effect of an increase in cost.

3.2 Mud Filtrate

The filtrate volume collected for Coconut OBM is 3.8ml higher than 1.7ml of OBM based on Tables 4 and 5. This could be due to the water may not have completely emulsified in the Coconut OBM resulting in a higher filtrate volume. The filtrate produce from Coconut OBM could potentially lead to a differential stuck pipe and requires workover to rectify the issue.

Table-5. Mud filtrate properties.

<table>
<thead>
<tr>
<th></th>
<th>OBM</th>
<th>Coconut OBM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Volume (ml)</td>
<td>1.7</td>
<td>3.8</td>
</tr>
<tr>
<td>Cake Thickness (mm)</td>
<td>0.29</td>
<td>0.56</td>
</tr>
</tbody>
</table>

Table-6. Mud filtrate properties (Hot Rolling).

<table>
<thead>
<tr>
<th></th>
<th>Hot Rolling</th>
<th>OBM</th>
<th>Coconut OBM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Volume (ml)</td>
<td>0.6</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>Cake Thickness (mm)</td>
<td>0.12</td>
<td>0.32</td>
<td></td>
</tr>
</tbody>
</table>
In general, high filtrate volumes are associated with thick filter cake because the cake is formed by deposition of clay particles on the walls of the hole during filtrate loss to the formation. So the higher the filter volume, the thicker the filter cake which translate to less efficient the drilling mud.

Coconut OBM which has thicker mud cake than OBM will reduce the effective diameter of drilled wellbore subsequently increasing the surface area of contact between drill pipe and mud cake eventually leading to risk of stuck pipe. On the other hand, OBM which has thinner mud cake and excellent filtration properties will be effective in drilling operation.

Coconut Oil Based Mud is not a suitable replacement for conventional OBM. That being said Coconut OBM does perform better in some areas than OBM mainly the gel strength is better than OBM. This allows for a lower pump pressure operation which ultimately reduces the drilling operation cost. However, Coconut OBM’s mud rheology and mud filtrate properties cause this option unsuitable to replace OBM. The YP value for OBM is 25.5 while Coconut OBM is 125 which is excessively high with higher probability of stuck pipes. As for the cake thickness, OBM with 0.29 mm whilst Coconut OBM is 0.56 mm. The thicker mud cake would cause several drilling operation problems. The results prove that although using coconut is an environmentally friendly approach, the performance does not justify to use it in the field. OBM still reigns as the main choice for drilling mud followed by WBM. Coconut OBM has severe viscosity issue which renders it unsuitable for average reservoir conditions in Malaysia fields. However, the high viscosity issue could be turned around into beneficial for extreme reservoir conditions but further studies must be conducted to prove such claims.

The solution for the viscosity issue would be to apply trans-esterification which converts the vegetable oil into methyl ester, the can be applied as base fluid for mud formulation [24]. By responding vegetable oil with alcohol, this method decreases viscosity and aided by a catalyst namely hydrochloric acid and sodium hydroxide [25]. Further investigation that could be conducted would be varying the concentration of coconut oil use in the mud formulation along with different types of additives. The effect of varying concentration could potentially increase its capability in average reservoir conditions.

REFERENCES


