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Formulation and Evaluation of Synthetic Drilling Mud for Low Temperature Regions

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Abstract: The temperate world such American and Canada are extensively increasing environmental legislations against oil-based muds and increasing exploratory activities in the offshore, it imperative to develop an oil based drilling muds that have resistance to the weather and relatively stable rheological properties at low temperature of -5oC to 20oC. This study investigates the use of non-edible algae oil to formulate ethyl biodiesel as based fluid for drilling mud that can perform the same function as convectional oil based drilling fluid and as well comply with the HSE (Health, safety and environment) standard in the temperate region and offshore environment. Experimental tests were performed at temperature condition of -5oC to 20oC on the synthetic ethyl biodiesel oil based mud samples so as to evaluate the rheological properties of the drilling mud formulations. The synthetic oil based was obtained from offshore drilling company and was used as control experiment. The following tests were run on these muds including; viscosity pH, gel strength, density and filtration tests at varied temperature and constant pressure and toxicity test to determine their usability in the defined conditions.

The results obtained showed that ethyl biodiesel mud had a lower viscosity than the industrial biodiesel mud, which implied lesser resistance to the flow of the mud. It also had a more stable density than the industrial variant, smaller mud cake thickness, higher gel strength and pH than the industrial variant. Likewise, the toxicity test proved that the ethyl biodiesel mud was more biodegradable than the industrial variant.

This study helps in surface facilities storage of synthetic based muds and their use during drilling operation in relatively low temperature region of -5oC to 20oC. Also enable the drilling engineer to refine their procedure and better manage the risk associated with the use of oil based mud in such region.

Introduction

With new developments in the drilling engineering sector of the global oil industry, mud should necessarily fulfil three requirements according to Khodja et al. (2010), and should be: easy to use, not too expensive and environmentally safe. It will also not be erroneous to include correct rheology as a requirement. Therefore, there is a constant conflict in the mud selection program concerning the particular mud to choose in order to fulfil adequately all the requirements at once.

It is notably without argument that oil-based muds fare better than water-based muds in nearly all aspects of concern except in terms of environmental issues and costs, which includes financial costs. Such issues and costs arise from non-biodegradability of the mud, the disposal and treatment of oil-based muds. This is the reason that their widespread application in the industry is checked by Environmental Agencies leading to development of synthetic variants that will comply with the standards set in relation to disposal.

The temperate world has some of the strongest environmental policies attached to the disposal of wastes from oil-based muds. The temperate regions, beginning with the US in the 1970s and 1980s called for stringent policies against the disposal of mud wastes to save their environment from toxicity.

For temperate countries, muds must be able to have viscosity that can be maintained over long periods of time, which implies a small change in viscosity per temperature increase or decrease. This must also correspond to surface conditions in which muds are kept. To expand, muds need to be resistant to temperature change as they should not gel up but have constant viscosity or have slight viscosity decrease. This proves useful for the storage of oil that can be re-used.

The temperate world is home to an undeniable amount of the oil that is in the world, it also accounts for a significant percentage of the world oil drilled and also the in terms of reserves today. However, weather patterns in that region affect the productivity of oil ventures leading to less than optimal results. Likewise, environmental sanctions also limit the use of oil-based muds in temperate nations since their disposal is considered harmful to their biosphere. The problem at hand is how temperate regions can create weather-resistant muds that will be active downhole yet conform to environmental standards. This research will seek to bridge two extremes into a single formulation.

Literature Review

In our industry, it is observed that the developments that occur do so because of certain restrictions on the use of some particular technology and respective governments pushed these changes (Khodja et al., 2010; Fadairo et al., 2012c). This has increased the need for flexibility in the formulations and consideration of performance in specific situations (Khodja et al., 2010). Relating the concept of specific performance of drilling fluids have been an age-long consideration and has been expressed (Anderson et al., 2009) severally in the views of several researchers but none have had zero impact (Apaleke et al., 2012; Behnamanhar et al, 2014).

A study undertaken by Bleier et al. (1993) in conjunction with the United States Environmental Protection Agency (EPA) focused on the state of the environment then and stressed that budding technologies be adopted to meet with the future projections as their studies, which encompassed biodegradability, toxicity and the effects of ions and salts, were conducted and even proffered techniques for waste minimization.

However, Lee’s work on synthetic muds was overwhelmingly theoretical and was only focused on his work in the Gulf of Mexico at the time. An error in his analysis is in his belief that toxicity of a substance reduced with the increase in carbon number as against a decrease in the carbon number. Toxicity and bioaccumulation on the surface actually signify a more viscous substance. Lighter compounds will actually have less bioaccumulation on the surface because of their volatility over heavier component. The reason for less bioaccumulation is the fact that the lighter components or products have less aromatic components in their structure with the reduction of the carbon number (Khodja et al., 2010; Fadairo et al., 2012a).

Talalay and Gundestrup (2002) looked at drilling mud design from a different standpoint and studied the mud in relation to the geographical location of the drilling site. This work was an extension of their research work of 1999. In this they considered a number of factors that could lead to optimal mud design for the polar region and by extension in the temperate region. They established that the parameters for drilling for the region must focus on the following namely frost-resistance, stability, sufficient viscosity and environmental friendliness. Talalay and Gundestrup introduced that the viscosity and density of the mud was the central to the realization of the conceptual design for the drilling mud for most of these parameters with the exception of frost-resistance. The viscosity they believed could affect the total drill time and they opined that low viscosity was necessary to achieve optimal drill rate and hence they disqualified the use of silicone oil, as it was highly viscous at sub-zero temperatures. Likewise, for a mud to be stable they pointed that the mobile phase should be unable to disintegrate easily, that implies that the properties must not change considerably during storage, transportation and use in the borehole. However, practical research implies that a biodegradable mud will naturally maintain stability through addition of a weighting agent (Ramirez et al., 2005).

For a mud to be frost-resistant and in extension weather-resistant, they believed that compounds with low-temperature will achieve such desire. They pointed out that the freezing point of the mud must be greater than the minimal temperature in the borehole and at the surface and that the pour point must be low to avoid gelling of the mud. A mud’s resistance to external conditions will also reflect storability of the mud. Talalay and Gundestrup (2002) adjudged that paraffin- (kerosene-) based muds are the best for the region due to the presence of naphthenes and due to slight density change of kerosene with temperature.

However, they believed that kerosene would have long residence time in the environment if the mud were discharged. Khodja et al (2010) and Fadairo et al. (2012a) disputed this view of kerosene having a long residence time as stated earlier in this review section. Fadairo et al. (2012a) further expressed their view that the degradability of the mud could affect the health of the environment. This is because degradation of mud in the sediments is affected by the temperature, oxygen content and energy.

Another aspect many reviewers had defined mud usability in the area of temperature and pressure of which they concluded rheology to be the center of such mud design such as Santoyo et al. in 1999 and Amani in 2012. Santoyo et al. (1999) sought to derive a mathematical correlation between viscosity and temperature and this was achieved by an experimental evaluation of 11 muds with different compositions that were chemically characterized. They posited that current models had underestimated the true viscosity value and acknowledged that temperature needed to be considered when measuring the viscosity of drilling muds. The exclusion of temperature variation, they believed constituted an error to viscosity graphing and measurement. Their work was modeled for geothermal wells, which can be likewise correlated for the oil well too. The study was done only on high-temperature wells that are water-based and likewise, the study did not account for surface conditions in which the muds would be kept and the work neither considered the environmental impact of the formulated muds.

Fadairo et al. (2012b) incorporated an environmental view into his work, which can be seen as an extension to an earlier work. In this, they sought to determine by the use of Artificial Neural Network on the Matlab platform and MS Excel with the application of extrapolation, the relationship between density and temperature through the use of three muds namely Jatropha, canola and diesel. For the canola based mud had the slightest density change over a wide temperature margin of 290°C but Jatropha according to the previous study had a better toxicity level while Jatropha had the highest pH (Fadairo et al., 2012a,b) and this would ensure stability and cause bentonite to be lightly affected (Fadairo et al., 2012c). However, viscosity change in diesel mud is smaller than the Jatropha mud (Anawe et al., 2012). This implied that the combination of environmental factors with density variation could not be expressly achieved without shortfalls at their objectives. Culling from the previous work, the Jatropha and canola muds were still more biodegradable than diesel muds and this still placed synthetic muds over oil-based muds (Fadairo et al., 2012a). Fadairo et al. (2012b) had a correlation that yielded a quadratic function of density against temperature much similar to the work of Santoyo et al. (1999) that derived a quadratic equation relating viscosity and temperature (Santoyo et al, 1999; Fadairo et al., 2012b).

Amani (Amani, 2012; Amani and al-Jubouri, 2012) in two works looked at the effect of temperature and pressure on water-based muds and the rheological properties of oil-based muds under high pressure and temperature. He believed that rheological properties could be altered to achieve formulations that consider the temperature and pressure and must not fail. This is considerably an extension of the work conducted by Ibeh et al. (2008) and in line with Talalay and Gundestrup (2002). He (they) had stressed that the viscosity and yield point were evident in low temperature (250°F and below) but they increase with pressure increment. However, an area of alternate perspective is in the fact that Santoyo et al. (1999) and Fadairo et al. (2012) in their works had quadratic relationship with temperature and viscosity and density respectively (Santoyo et. al, 1999; Fadairo et. al, 2012b) while Amani (and al-Jubouri) (2012) believed the relationship of viscosity and temperature was more of an exponential one with both pressure and temperature (Amani, 2012; Amani and al-Jubouri, 2012).

However, a shortcoming in the work done by Fadairo et al. (2012b) was that the work did not account for time change or temperature change and pressure variation. Amani accounted for these parameters in his own work. In retrospect, the two research views were focused on only high-temperature and high-pressure wells and conventional wells and did not account for low temperature regions.

As for the use of biodiesel in synthetic drilling mud, Ismail et al. (2014) visually showed that rice bran oil was the most degradable and most non-toxic amongst other vegetable oils. This was based on a study conducted by the same to show the application of biodiesels in drilling muds. This was done with an environmental leaning in view. They undertook a study of the biodiesel-based muds in relation to the physical properties and toxicity. They stated that the vegetable biodiesel-derived muds fulfilled all the physical quality requirements of their tests. Likewise, Fadairo et al. (2012c) undertook another comparative study, which can be assumed to be an extension of the team's previous works and they undertook a study using inedible plants such as Jatropha, Moringa, algae and canola as the continuous phase in their experiment. Their work exposed that the inedible oils prove to have better filtration properties than diesel but algae had the lowest gel strength, plastic and apparent viscosity of the inedible oil-based muds and had the highest pH which would ensure hole stability and reduce wear rate during drilling. This experiment proved that the unicellular "vegetable" algae had preferable qualities when it came to their viscosity parameters followed by canola then Moringa and then Jatropha. This continues as a line of thought that vegetable oils have better qualities than the conventional diesel (Fadairo et al., 2012c; Ismail et al., 2014). In terms of toxicity research, Ismail et al. (2014) conceived a study on toxicity based on effect of fish namely sea bass and red snapper while Fadairo et al. (2012c) used bean seedlings.

This paper is considerably an extension of the works of Talalay and Gundestrup (2002), Khodja et al. (2010) and Fadairo et al. (2012a, b, c). Elements from Amani (2012) and Amani and al-Jubouri (2012) as well as Ismail et al. (2014) will be incorporated into the methodology framework of this research.

Methodology

Materials and Equipment

The following reagents and materials were utilized; Bentonite, Barite, Water, Algae, Bean Seeds, Cork, Filter Papers, Soxhlet Extractor, Mass Balance, Conical Flasks, Rotary Viscometer, pH Meter, Separating Funnel, Mixer, Hot Plate, Stirrer, API Filter Press, Mud Balance, Resistivity Meter, Beakers, Heating Mantle, Retort and Clamp, Measuring Cylinder, Condensers, Round-Bottom Flasks, Reagent Bottles, Mortar and Pestle, Spatula, Vernier Caliper, Oven, Cleveland Open Cup Flash Tester, Ethanol, Methanol, Sodium Hydroxide and N-Hexane.

Procedure

Algae Collection

The algae were sourced from the gutters within the University complex.

Ethyl biodiesel Preparation

The biodiesel was prepared in the laboratory. First the algal oil was extracted from the algae using a hexane extraction process with the aid of a Soxhlet's extractor. The extracted oil was distilled to remove the hexane so as it could be reused in further extractions.

Fatty acid experiment was conducted on 7ml of distilled algal oil, which is used to determine the viability of the transesterification process.

The remaining portion of the algal oil was trans-esterified using KOH as the catalyst. At this point a mixture of coconut and algae was used, as the portion was small. The mixture of the ester and glycerin was placed in a separating funnel and left for 12 hours to separate.

The separated biodiesel was washed with warm water and then separated to remove any entrained glycerin. The final product was then stored.

This stored biodiesel was mixed in proportions with the ethanol to produce ethyl biodiesel. Subsequently, a flash point test was conducted on the "ethyl biodiesel".

Mud Preparation

The mud was prepared to a set density of 9.5 ppg. This was determined from the mud used for comparison.

The mud was formulated in the ratio of 50% oil, to 30% water to 9% barite to 7% clay to 3% salt to 1% emulsifying agent.

Tests were run on the mud obtained to make comparative analysis with an industrial-obtained drilling mud. The tests included viscosity, gel strength, filtration and density tests as well as a toxicity test.

The viscosity and gel strength tests were done using a rotary viscometer, while the filtration test was done using an API Low-Pressure Filter Press and the Density test was done using a mud balance.

The toxicity test is an environmental test that analyses the effect of the muds on growth of plants (bean) seeds in days of exposure.

Results and Discussion

Lipid Content and Phytochemical Analysis of Algae

According to the conditions the sample species was subjected to in this study, the Spirulina platensis sample was seen to have a lipid yield of 8.57% by weight of the Spirulina platensis powdered. The experiment obtained 710 grams of dried and powdered algae after a bucket weight equivalent. It can be implied that the conditions in which the Spirulina was obtained affected the overall yield of the species, such conditions being the weather (the algae collected during the dry season which was likewise very humid and cold), lighting conditions of the environment and lack of nutrients for the algae. Likewise, the yield was small and could have been improved through catalyst use (H.I. El-Shimi et al., 2013).

The phytochemical properties of the mud such as the density, the acid value and percentage of free fatty acid were analyzed in the lab and are outlined in Table 1.0. These data were used to distinguish the extracted oil for the production of biodiesel. Due to the yield obtained the biodiesel could not be formed from the algae obtained alone and a mixture with coconut was used to further the experiment.

Temperature Effect on Density

As depicted in the plot of temperature against density in Fig. 1.0, it can be seen that for the industry-obtained synthetic mud the density saw a slight density increase overall through a 22°C rise in the mud temperature from -1°C through to room temperature from 9.4 to 9.5 ppg. This indicates that the arithmetic linear density change per 1°C temperature rise is 0.0045ppg/°C. However, for the ethyl biodiesel formulated mud there was a more marginal rise in the density in the ethyl biodiesel based mud from 9.45ppg to 9.5ppg within the same temperature rise of 22°C. This implies that the density drop in the formulated mud is lower than the biodiesel mud by 50% over the same temperature range. Therefore it means that the fluid will become compact earlier due to a drop in average temperate region temperatures.

In looking at the industrial mud, the density increased by 1% over the temperature range (-1° and 21°C) while the ethyl biodiesel density increased by 0.5% over the same range. The rationale behind this density change is that the formulated mud has a longer time for molecules to be compacted than the biodiesel variant.

The more stable density of ethyl biodiesel based mud implies that the mud can maintain necessary hydrostatic pressure over reduced temperatures and carry cuttings leading to better cleaning of the hole.

Table 1.0: Phytochemical Properties of *Spirulina Platensis*

Properties	Unit	Value
Dried Powder Weight	g	710
Lipid Weight	g	60
Lipid Content	%	8.45
Lipid Density	$g.m^{-3}$	875
Acid Value	mgKOH/g	49
Free Fatty Acid	%	24.5

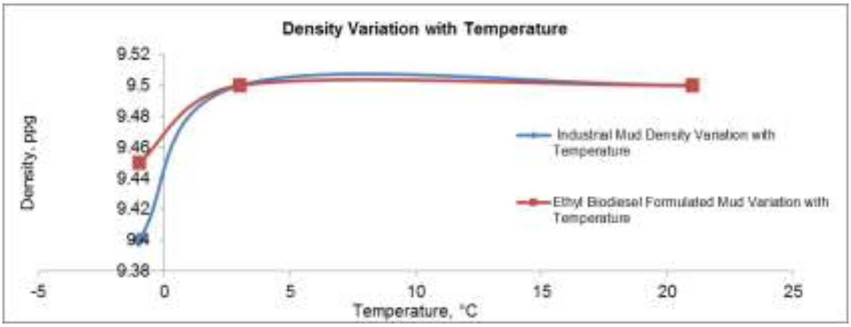

Figure 1.0: A Plot of Density Variation against Temperature

Temperature Effect on the Mud Viscosity

For the industrial synthetic base mud, it can be seen that the dial readings greatly increased with the decrease in temperature but for the formulated mud, the dial readings slightly increased with a decrease in temperature. Culling from Figure 2.0, at 600RPM and 300RPM at -1°C the dial reading was 179 and 110 while at 3°C the dial reading was 85 and 64 and at 21°C it was 138 and 78 respectively for the industrial mud and for the formulated mud, the dial read for 600RPM and 300RPM at -1°C. However, there was only a slight increase in the plastic viscosity of the biodiesel mud over the same range of temperature decrement, that is, from 60 cp at 21°C to 69cp at -1°C as seen in Fig. 3.0. The apparent viscosity of the biodiesel mud rose by 20.5 cp over the same range of temperature decrease also as noticed in Fig. 4.0 while the apparent viscosity for the ethyl biodiesel based mud increased by 9cp over that same temperature range.

It can be seen that the Fig. 5.0 and 6.0 above that between dial speed of 200 and 300 rpm there is a sharp and slight change in the dial readings at all temperatures with greater deviation at lower temperatures. This shows that within that transition it takes more torque to overcome viscous friction at those speeds. At the varied temperatures it implies that both muds are Arrhenius temperature-dependent fluids. The higher the viscosity, the lower the temperature and vice versa. The viscosity, which is a function of the activation energy, is inversely related to the temperature (Amani, 2012). The ethyl biodiesel based mud has less surface tension than the industrial mud as seen by the lower viscosity of the mud as against the temperature.

The abrupt changes in the dial readings at that dial speed is caused by possible change in the activation energy at isothermal conditions caused by increased torque during rotations.

The plastic viscosity of the ethyl biodiesel based mud only saw a 5cp rise in the decrease of temperature against the 20cp rise of the biodiesel variant. This slight plastic viscosity drop in the ethyl biodiesel based mud is seen as better because there would be an increase in the faster drilling rate as against the slower drilling rate in the industrial mud as a result of increased wear and tear. The drop in plastic viscosity of the ethyl biodiesel based mud from lower -1°C to the room temperature is 44.4% lower than the industrial mud. The stability of the biokerosene mud also causes more enhanced performance in reduced temperatures including reduced trip time. For the plastic viscosity, the industrial mud decreased 13% over the 21°C-rise while the ethyl biodiesel based decreased 15.6% over the same temperature rise. This implies that although the plastic viscosity of the ethyl biodiesel based is lower than the industrial mud, the viscosity will reduce faster despite the profile above. Likewise, for the apparent viscosity of the industrial mud, the viscosity at 21°C was 22.9% lower than the viscosity at -1°C; however the ethyl biodiesel based mud had an 8% decrease in viscosity at 21°C. However, the relationship of the mud viscosity displayed a more exponential relationship as against a quadratic relationship as stated by previous works. This exponential relationship was still closely related to the Bingham format.

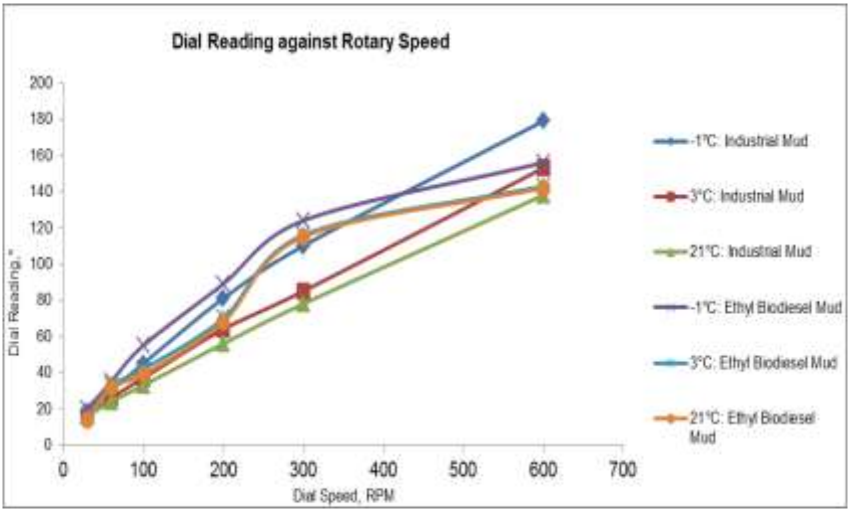

Figure 2.0: A Plot of Dial Reading against Rotary Dial Speed

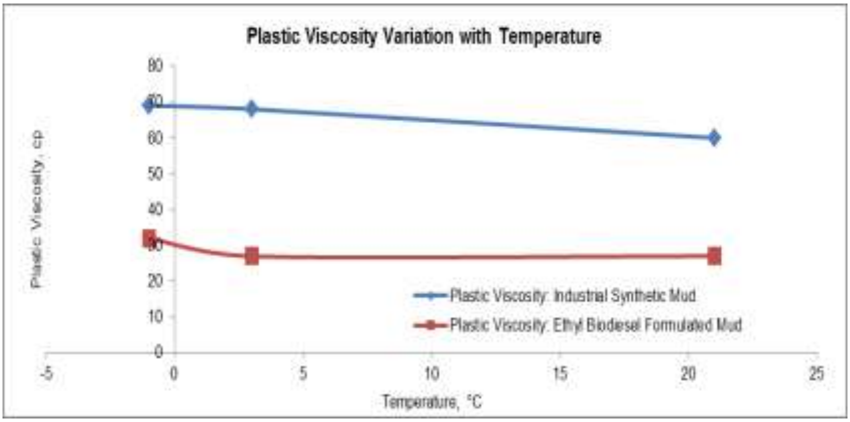

Figure 3.0: A Plot of Plastic Viscosity against Temperature

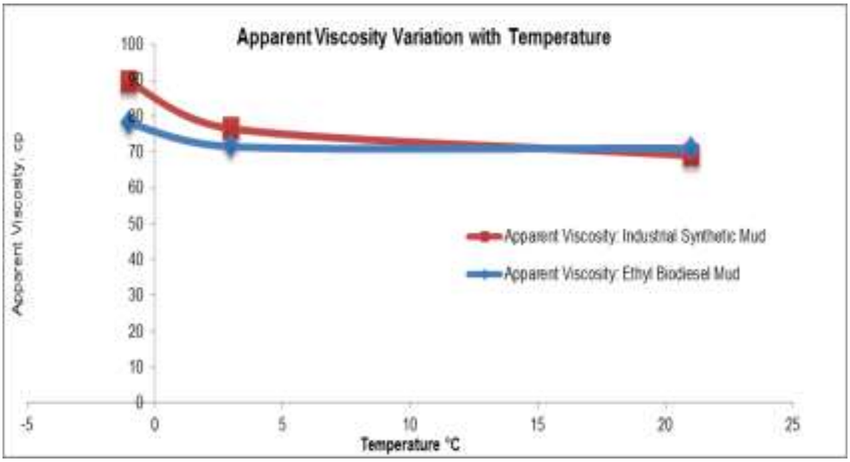

Figure 4.0: A Plot of Apparent Viscosity Variation against Temperature

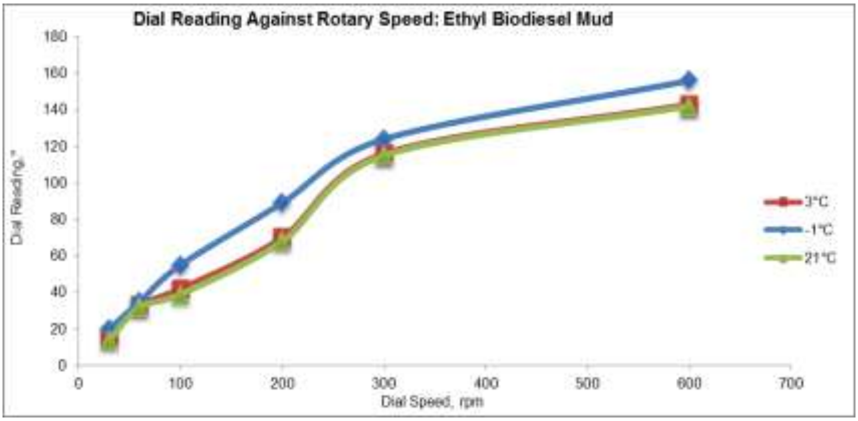

Figure 5.0: A Plot of Dial Reading against Rotary Dial Speed for Ethyl biodiesel Mud

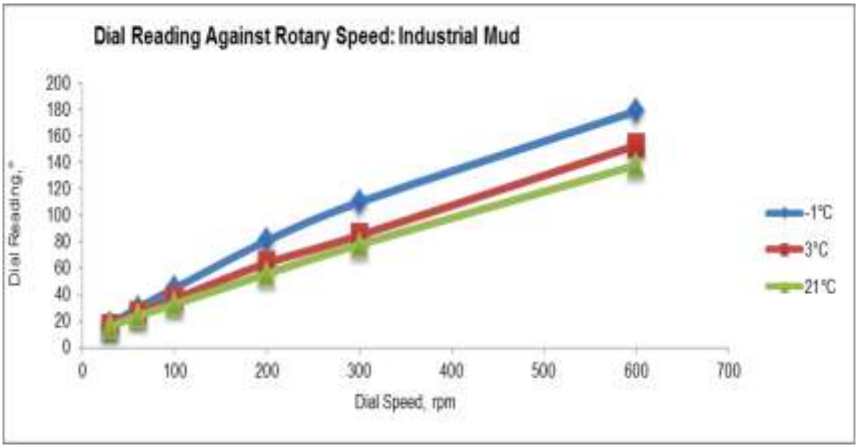

Figure 6.0: A Plot of Dial Reading against Rotary Dial Speed for Industrial Mud

Temperature Effect on Mud Gel Strength

It was seen that temperature of the mud affected the gel strength of the two muds quite differently. The ethyl biodiesel based mud had higher gel strength for the 10-second test than the biodiesel industrial variant. Also observed from Figure 7.0, it can be inferred that the gel strength of ethyl biodiesel after 10 minutes had an overall decrease with the lowest recorded ethyl biodiesel gel strength at 3°C, however the gel strength after 10 minutes was still higher than the ones of the industrial mud. This implies that the biofuel can carry and suspend cuttings more easily than the ethyl biodiesel can, although the change in the biodiesel mud gel strength is less pronounced over the temperature range than the ethyl biodiesel. It was noticed that there was a zero net change between the differential values across the temperature ranges after the 10-minute test but there was a 200% increase in differential value across the temperature range. The gel strength of the industrial mud decreased 22% and 16.7% respectively for the 10-minute and 10-second tests while the ethyl biodiesel based mud gel strength decreased 14% and 16.7% for the 10-minute and the 10-second tests.

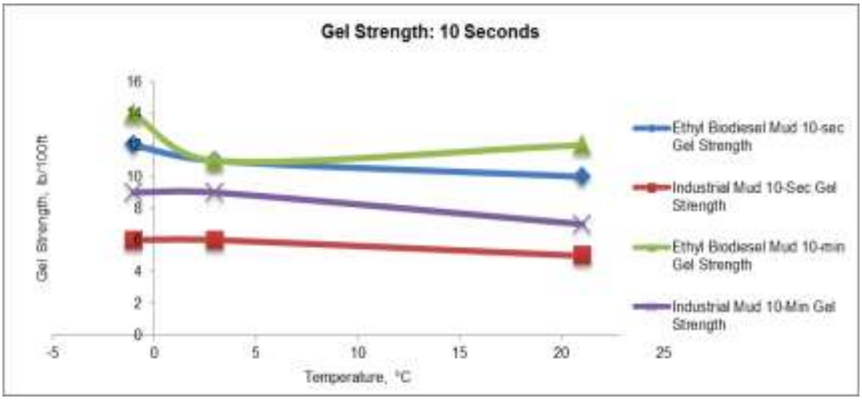

Figure 3.0: A Plot of Gel Strength (10-second and 10-minute) against Temperature

Low Pressure and Ambient Temperature Effect on the Mud Filtration Properties

It was observed that the effect of pressure also was varied for the muds. The ethyl biodiesel brought a lower thickness of mud cake at 0.1mm while the biodiesel brought a mud cake thickness of 0.2mm. This implies that the ethyl biodiesel based mud can contain the fluid in the reservoir enough not to damage the formation. The thicker mud cake can cause for the drillstring to be stuck so as not to let it rotate easily within the borehole. Likewise for the two muds there was negligible fluid loss after filtration for 30 minutes and this can be attributed to the low pressure and inability of the fluid to seep through the mud cake formed at such pressure. This implies, as seen from Figure 8.0, that the muds are not porous but the ethyl biodiesel based mud is selected over the diesel mud based on the thickness of the mud cake. The mud cake thickness of the ethyl biodiesel based mud falls well below the acceptable limit of $\frac{2}{32}$ inches at 0.0394 inches while that of biodiesel is 0.0787 inches that is 50% thicker than the ethyl biodiesel, which is also well above the acceptable thickness.

The volume of filtrates was negligible due to the pressure at which they were exerted.

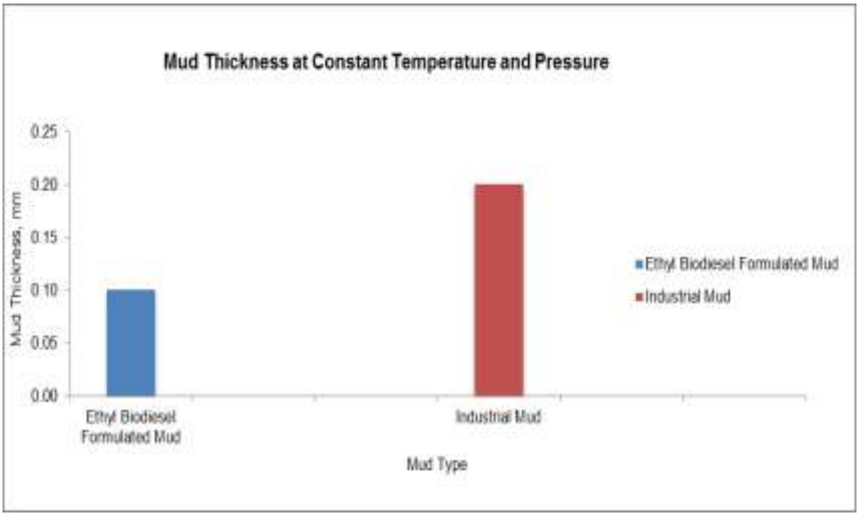

Figure 4: A Plot of Mud Thickness against Type of Mud

Effect of Exposure Time on Seed Growth

When bean seeds were exposed to the muds, the seeds started experiencing growth on the 4th day of the test. It was observed that the bean seed exposed to ethyl biodiesel grew much more than the one exposed to biodiesel (industrial). The height of the beanstalk exceeded 11 cm in 10 days while exposed to ethyl biodiesel and the beanstalk had a total growth of 8.9 cm in the same amount of days. This represents 24.7% more growth in the ethyl biodiesel based mud over the biodiesel industrial mud. Also the seed exposed to the ethyl biodiesel lasted 16.7% times longer than the one exposed to the industrial mud. This implies that the biodiesel is more toxic to the bean seeds than the ethyl biodiesel as shown on Figure 9.0, where the bean plant started to die after the 8th day when exposed to the biodiesel. This can be explained with the chemical structure of ethyl biodiesel, which has less aromatic components than the ethyl biodiesel.

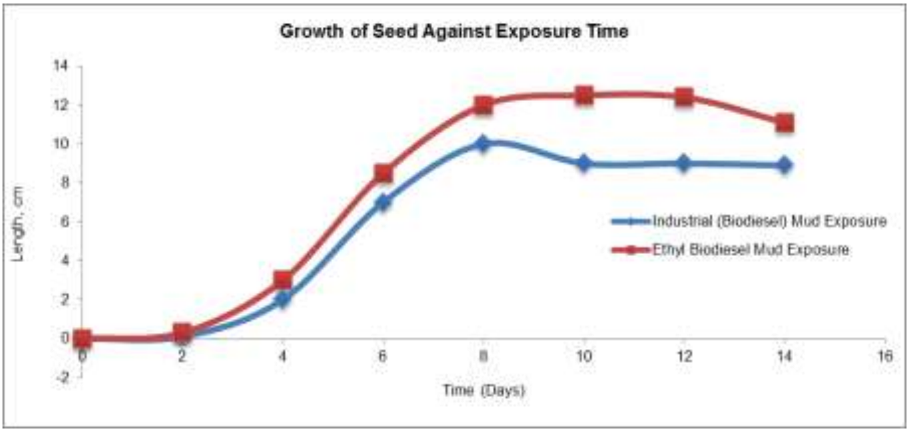

Figure 5: A Plot of Exposure Time against Seed Growth

Conclusion

From the undertaken research, it can be seen that the ethyl biodiesel based mud passed all the tests it was subjected to over the industrial mud. Although, both muds experienced rises in the viscosities over temperature decrease, the ethyl biodiesel had more stable viscosity readings over the temperature range examined. This has implications on the optimal drill rate being achieved faster in the mud than in biodiesel mud and this also has implication on the effects of the environmental temperatures being less due to that near slight change in the ethyl biodiesel based mud viscosity. In area of density, the ethyl biodiesel based mud had much lower density change, which is a requirement for temperate-region muds. This implies that the overburden pressure of the mud can be maintained at cold temperatures over the biodiesel mud. It was also noticed that the ethyl biodiesel based mud would not affect the environment due to higher biodegradation than biodiesel mud variant as the seeds exposed to the ethyl biodiesel based mud continued to grow even after 10 days in the soil.

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This draws the conclusions that the ethyl biodiesel based mud has better rheological and environmental properties than the industrial (biodiesel mud) at reduced temperatures.

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