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# Evaluation of $C_{10}$ Esters As Synthetic Base Fluids For Drilling Mud Formulation

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***Abstract:*** *$C_{10}$ esters obtained from octanoic acid and acetic acid were evaluated for their suitability as base fluids in oil and gas wells drilling mud formulation. Comparison of the physicochemical parameters of the esters with that reported in literature revealed an agreement between the two sets of values. Two mud formulations were designed from each of the esters and their rheology profile between 80 $^oF$ and 200 $^oF$ compared with that of a commercially available synthetic base fluid. The result of the rheological tests performed on all the drilling muds formulated indicated that with appropriate additives, the mud formulation using the two synthetic esters could perform as good as the reference fluid.*
***Keywords:*** *Esters; synthetic base fluids; drilling muds; rheology.*

## I. Introduction

Drilling fluids play an important role in the successful drilling of oil and gas wells. Some researchers have gone as far as comparing the role played by drilling fluid in oil exploration and exploitation activities to that of the blood circulation in the human body. In this analogy, the mud pump functions as the heart; the cuttings that are transferred from the borehole by drilling fluid represent the waste products excreted out of the body through the blood vessels, and the kidney and lungs function as the system for cleaning the mud (Al-Yasiri and Al-Sallami, 2015). It has been estimated that in oil exploratory and extraction activities, the cost of drilling operations is responsible for 50 to 80% of exploration finding costs, and about 30 to 70% of other field development costs (Khodja *et al.*, 2010).

Water-based mud (WBM) is the first mud of choice for drilling operations because of its cost effective, environmental friendly and non-hazardous nature. However, despite their environmental acceptability, conventional WBMs are less desirable for drilling operations relative to oil base muds (OBMs), more so in problematic shale formations since they are unable to stabilize shale zones when compared to other mud types. They also exhibit lower lubricity, and stability at high temperatures (Fink *et al*., 2012). Since the capacity of OBMs to stabilize the wellbore is superior to that of WMBs, they are often selected to solve problems arising from wellbore instability. However, the increased performance properties of OBMs relative to WBMs are also inherent with potential pollution problems (Fadairo *et al*., 2012). Thus, it became necessary that alternative base fluids with a combination of the superior performance properties of OBMs and improved biodegradability be developed. Having met these criteria, synthetic base muds have become the mud of choice for drilling through problem formations (Amorin *et al*., 2015).

The aim of this research is to bench mark the physicochemical properties of ethyl octanoate (EO) and octyl acetate (OA) with that of a commercial synthetic base fluid (CSBF), formulate drilling muds from these esters, and compare the rheology of the formulated muds at different temperatures with that of a reference mud formulated with the commercial synthetic base fluid.

## II. Experimental

### 2.1 Materials

The two ester base fluids utilized in the mud formulation were synthesized by the esterification reaction between octanoic acid, acetic acid, octanol and ethanol, while the reference fluid was supplied by Shell Nigeria Exploration and Production Company (SNEPCo). Commercially available lime, brine, gypsonite, organophilic clay and barite were used in the mud formulation. Equipments used include H1 2211 pH/ORP meter (Hanna Instruments), analytical weighing balance, Fann viscometer (Fann 35A Model), measuring cylinder, beakers, Hamilton beach mixer and cup, thermometer, and stop watch. The experimental work was divided into three different stages. The first stage was the determination of the physical properties of the synthetic esters and the commercial synthetic base fluid; the second stage involved the mud formulation; while the rheology test was carried out in the third stage.

### 2.2 Determination of the Physical Properties of the Esters

The physical properties of the esters as well as the commercial synthetic base fluid (CSBF) were analyzed following standard analytical techniques. This was done to ascertain the suitability of the esters synthesized as synthetic base fluids. The properties of interest include: pH, specific gravity (at room temperature and at 60$^o$F), viscosity at 40$^o$C, flash point, cloud point, fire point and pour point.

### 2.3 Mud Formulation

The mud formulation using the synthetic esters and the CSBF was carried out based on the American Petroleum Institute (API) recommended practice 13B (2014), which provides standard test procedure for investigating the physical and rheological properties of oil based muds.

Two different mud formulations were designed with the two esters synthesized. A reference mud with the CSBF was also designed with the same quantity of base fluid and additives, under the same experimental conditions. The formulated mud consists of the ester or commercial base fluid (as base), organophilic clay, primary emulsifier (as alkalinity agent), secondary emulsifier, lime (fluid loss control agent), brine (the salinity source), gypsonite (emulsifier) and barite (weighting agent). The mud properties of interest are the viscosity at different viscometer revolutions (from 3 rpm to 600 rpm), plastic viscosity (PV), yield point (YP) and gel strength. The summary of the quantities and functions of the base fluids and additives used in formulating the muds is presented in Table 1.

**Table 1:** Additives and their Function in the Mud Formulation

| S/N | Component | Function of Additives | Specific Gravity (SG) | Quantity |
|---|---|---|---|---|
| 1 | Ester / CSBF | Continuous Medium | 0.87 | 210.00ml |
| 2 | Organophilic Clay | Viscosifier | 1.77 | 20.00g |
| 3 | Primary Emulsifier | Alkalinity Agent | 2.13 | 12.00g |
| 4 | Secondary Emulsifier | Emulsifier | 0.93 | 7.00ml |
| 5 | Lime | Fluid Loss Control | 2.60 | 7.00g |
| 6 | Brine | Salinity Source | Mixed | 15.00ml |
| 7 | Gypsonite | Emulsifier | 0.92 | 3.00g |
| 8 | Barite | Weighting Agent | 4.20 | 76.00g |
| | **TOTAL** | | | **350.00ml** |

### 2.4 Mud Rheology Test

The rheology of the muds formulated with the ester base fluids, including the mud formulated with CSBF was investigated between 80 $^o$F to 200 $^o$F, at 20 $^o$F increments. This was done to simulate the increase in temperature during drilling operations as the down hole depth increases.

## III. Results And Discussion

### 3.1 Physicochemical Properties of the Base Fluids

Comparison of the physicochemical properties of the esters with the reference fluid showed that the pH of EO was 6.73; pH of OA was 4.64; while the reference fluid had a pH of 7.02. A neutral or basic pH is more desirable for a base fluid than an acidic pH as this will impact on the pH of the mud formulated from the fluid (Drilling Fluid Processing Handbook, 2005). Thus, the low pH of OA is undesirable. However, this value could be increased by subjecting the esters to a more vigorous work up procedure with aqueous basic solutions.

The specific gravity (SG) at room temperature ranged between 0.855, 0.864 and 0.808 while the kinematic viscosity was 4.10, 3.50 and 3.00 for EO, OA and CSBF respectively. The pour point was below -4.00 for all the base fluids. The flash point and fire point of the reference fluid however, recorded much higher values relative to the two esters. A summary of these physicochemical properties are presented in Table 2.

**Table 2:** Physicochemical Properties of the Base Fluids

| Properties | EO | OA | CSBF* |
|---|---|---|---|
| pH | 6.73 | 4.64 | 7.02 |
| Temperature (˚C) | 30.20 | 30.00 | 30.10 |
| Density (SG) | 0.855 | 0.864 | 0.808 |

| | | | |
|---|---|---|---|
| | | | |
| SG at 60˚F | 0.860 | 0.870 | 0.813 |
| Viscosity at 40˚C (cSt!) | 4.10 | 3.50 | 3.00 |
| Flash point (˚C) | 169.60 | 171.72 | 219.00 |
| Fire point (˚F) | 191.00 | 199.00 | 260.00 |
| Cloud point (˚C) | 19.00 | 20.00 | 17.00 |
| Pour point (˚C) | <-4.00 | <-4.00 | <-4.00 |

*CBSF = Commercial Synthetic Base Fluid
! cSt = centi-Stokes = Cp ÷ SG

The specific gravity and flash point obtained for the esters were also compared with that reported in literature. This comparison showed that there was a close agreement between the values obtained from this research and the literature values. Table 3 summarizes these findings.

**Table 3:** Comparison of the Literature and Experimental Values of the Specific Gravities and Flash Points of the Ester Base Fluids

| **Samples** | **Properties** | | | |
|---|---|---|---|---|
| | **Specific Gravities** | | **Flashpoints** (°F) | |
| | Literature value (25$^o$C) | Experimental value ( 30$^o$C) | Literature value | Experimental value |
| EO | 0.867 | 0.855 | 167.00 | 169.60 |
| OA | 0.865 - 0.869 | 0.864 | 179.00 | 171.72 |

Literature Data Adapted from https://www.thegoodscentscompany.com/data/rw100346.html, retrieved 20/05/2016

## 3.2 Mud Rheology

The results of the mud rheology test for the three drilling muds formulated with the three different base fluids are represented in Tables 4, 5 and 6.

**Table 4:** Mud Rheology of EO at Different Temperatures

| **RPM (Ø)** | **80°F** | **100°F** | **120°F** | **140°F** | **160°F** | **180°F** | **200°F** |
|---|---|---|---|---|---|---|---|
| 600 | 23 | 22 | 22 | 21 | 21 | 21 | 20 |
| 300 | 13 | 13 | 12 | 12 | 12 | 12 | 11 |
| 200 | 08 | 08 | 07 | 07 | 07 | 06 | 05 |
| 100 | 07 | 04 | 04 | 04 | 04 | 04 | 03 |
| 60 | 04 | 03 | 03 | 03 | 03 | 02 | 02 |
| 30 | 03 | 03 | 02 | 02 | 02 | 02 | 01 |
| 6 | 02 | 02 | 01 | 01 | 01 | 01 | 01 |
| 3 | 02 | 02 | 01 | 01 | 01 | 01 | 01 |
| PV (cP) | 10 | 09 | 10 | 09 | 09 | 09 | 09 |
| YP(lb/100ft$^2$) | 03 | 04 | 02 | 03 | 03 | 03 | 03 |
| 10’’(lb/100ft$^2$) | 03 | 02 | 02 | 02 | 02 | 01 | 01 |
| 10’(lb/100ft$^2$) | 05 | 04 | 04 | 02 | 02 | 01 | 01 |

**Table 5:** Mud Rheology of OA at Different Temperatures

| **RPM (Ø)** | **80°F** | **100°F** | **120°F** | **140°F** | **160°F** | **180°F** | **200°F** |
|---|---|---|---|---|---|---|---|
| 600 | 37 | 23 | 22 | 18 | 15 | 15 | 14 |
| 300 | 20 | 20 | 17 | 12 | 12 | 8 | 7 |
| 200 | 14 | 14 | 12 | 5 | 4 | 4 | 4 |
| 100 | 10 | 7 | 7 | 3 | 3 | 3 | 3 |
| 60 | 7 | 6 | 5 | 2 | 2 | 2 | 2 |
| 30 | 5 | 4 | 3 | 2 | 2 | 1 | 1 |
| 6 | 3 | 2 | 2 | 1 | 1 | 1 | 1 |
| 3 | 2 | 2 | 2 | 1 | 1 | 1 | 1 |
| PV (cP) | 17 | 3 | 5 | 6 | 3 | 7 | 7 |
| YP(lb/100ft$^2$) | 3 | 17 | 12 | 6 | 9 | 1 | 0 |
| 10’’(lb/100ft$^2$) | 2 | 2 | 2 | 1 | 1 | 1 | 1 |
| 10’(lb/100ft$^2$) | 2 | 2 | 2 | 2 | 2 | 1 | 1 |

**Table 6:** Mud Rheology of CSBF at Different Temperatures

| **RPM (Ø)** | **80°F** | **100°F** | **120°F** | **140°F** | **160°F** | **180°F** | **200°F** |
|---|---|---|---|---|---|---|---|
| 600 | 58 | 37 | 34 | 31 | 27 | 25 | 23 |
| 300 | 31 | 22 | 21 | 17 | 16 | 14 | 12 |
| 200 | 23 | 17 | 15 | 13 | 12 | 9 | 9 |
| 100 | 14 | 12 | 9 | 8 | 6 | 6 | 6 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 60 | 9 | 6 | 4 | 6 | 5 | 5 | 4 |
| 30 | 7 | 5 | 3 | 2 | 3 | 2 | 2 |
| 6 | 3 | 5 | 3 | 2 | 3 | 2 | 2 |
| 3 | 3 | 4 | 3 | 2 | 3 | 2 | 1 |
| PV (cP) | 27 | 15 | 13 | 14 | 11 | 11 | 11 |
| YP (lb/100ft$^2$) | 4 | 7 | 8 | 3 | 5 | 3 | 1 |
| 10 sec (lb/100ft$^2$) | 1 | 3 | 2 | 2 | 3 | 2 | 2 |
| 10 min (lb/100ft$^2$) | 3 | 3 | 3 | 2 | 3 | 3 | 3 |

It was observed that the mud viscosity of all the muds formulated in this work reduced at higher temperature and shear rate. This is in line with results reported in literature (Adekomayo *et al.*, 2011; Olatunde *et al.*, 2012). However, an unusually high viscosity is an undesirable mud property which could lead to increased pump pressure, reduction in mud circulation and a decrease in drilling rate ( Adekomayo *et al.*, 2011). The muds formulated with the synthetic esters recorded lower viscosity relative to the reference at all the temperatures and shear rates investigated. However, it was observed that the EO formulated mud displayed better temperature stability at all temperature and shear rates relative to the OA formulated mud. However, though it is still less stable than the mud formulated with the reference fluid. An increase in mud viscosity for the muds formulated with the synthetic esters could be achieved by increasing the quantity of organophilic clay viscosifier used in the mud formulation (Growcock and Patel, 2011). The variation of the mud viscosity with temperature is represented in figures 1to 3.

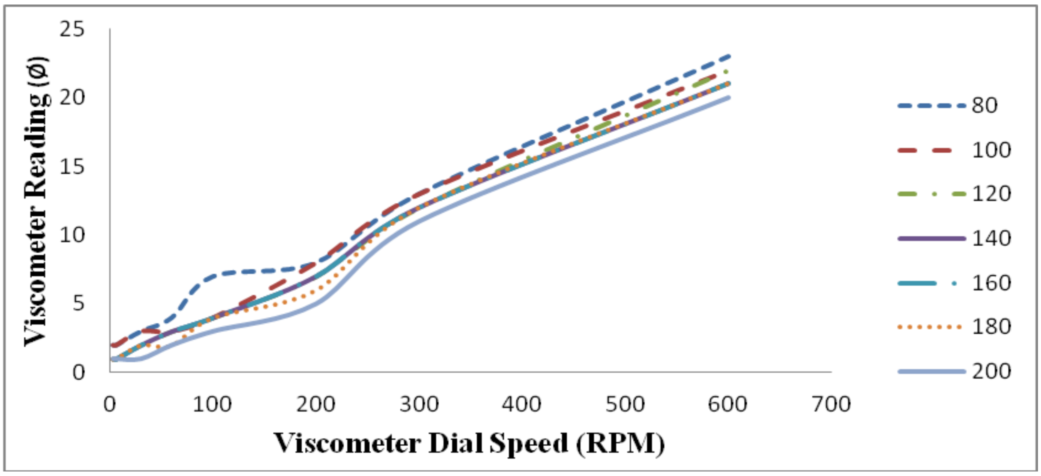


**Fig 1:** Viscosity of EO Based Mud at Different Temperatures

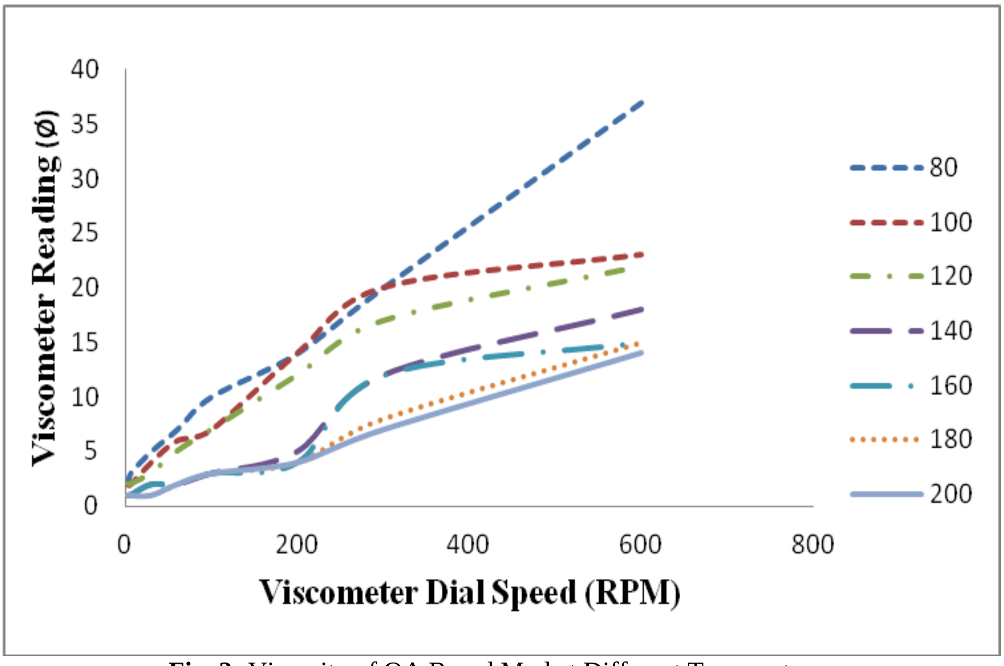


**Fig. 2:** Viscosity of OA Based Mud at Different Temperatures

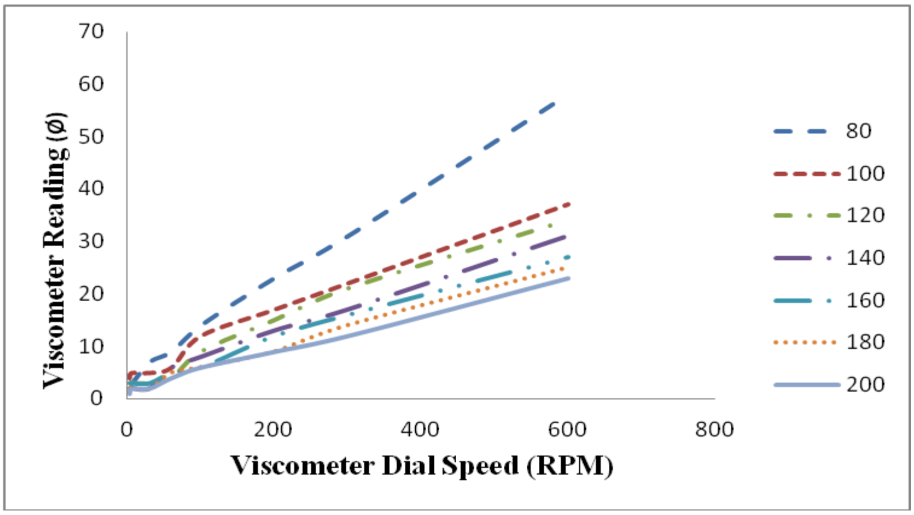


**Fig. 3:** Viscosity of CSBF Based Mud at Different Temperatures

### 3.2.1 Yield Point, Plastic Viscosity and Gel Strength

The YP, PV and gel strength of the ester based drilling muds were compared to both the reference mud and API recommended values as presented in Table 7.

**Table 7:** Recommended Values for YP, PV and Gel Strength (Amosa *et al.*, 2010).

| Mud Property | Recommended Value |
|---|---|
| Yield Point (lb/100ft$^2$) | Min = 5<br>Max = YP $\leq$3xPV |
| Plastic Viscosity (cP) | 8 - 35 |
| 10sec. gel strength (lb/100ft$^2$) | 2 - 5 |
| 10min. gel strength (lb/100ft$^2$) | 2 - 35 |

One major thrust of drilling fluid design is the ability to strike a balance between providing sufficient plastic viscosity and gel structure that is capable of suspending drill cuttings and also, maintain efficient hole cleaning (Maxey, 2011). Low plastic viscosity and yield point values, imply better performance of the mud, thus a mud with low PV and YP values at all temperatures is more desirable than one with a higher value (Amosa *et al.*, 2010). The plastic viscosity of the mud formulations using EO and CBSF fell within the API recommended values of 8 – 35 cP at all the temperatures investigated, while the OA based mud fell within the range only at 80 $^{o}$F. At higher temperatures, the OA based drilling mud failed to meet with the specification as the PV ranged between 3 cP and 7 cP (figure 4).

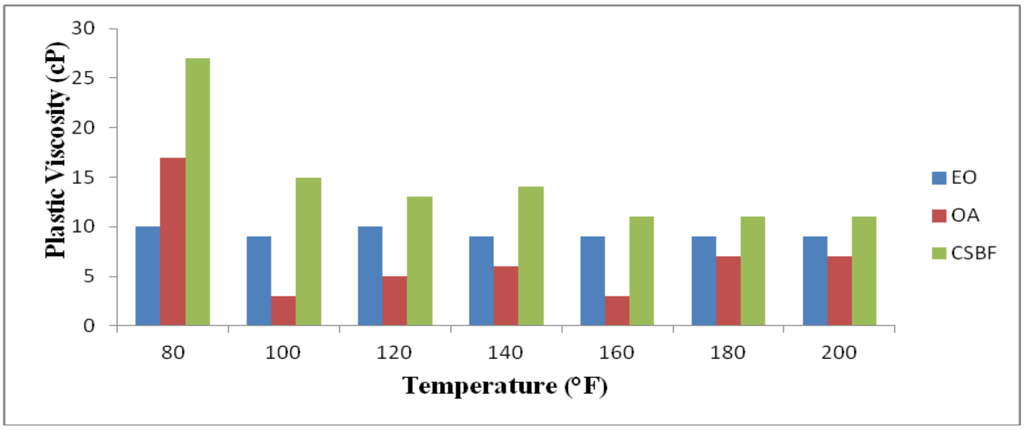


**Fig. 4:** Effect of Temperature on the Plastic Viscosity of the Muds

The yield point of the reference fluid was within the recommended values at100$^{o}$F, 120$^{o}$F and160$^{o}$F, while at the other temperatures investigated, they were below 5lb/100ft$^2$. The YP of OA formulated mud fell within range at all the temperatures investigated except at 80 $^{o}$F, 180 $^{o}$F and 200$^{o}$F. The EO formulated mud recorded the lowest yield point at all temperatures except at 200 °F. The low PV recorded for the muds within the temperature range studied implies that an oil well drilled with this kind of mud system will require lower pumping pressure to resume drilling activities after interruption of drilling operations, it can also lead to greater fluid flow in the annulus and improved hole cleaning capacity (Jorge *et al.*, 2014). The graphical representation is displayed in figure 5.

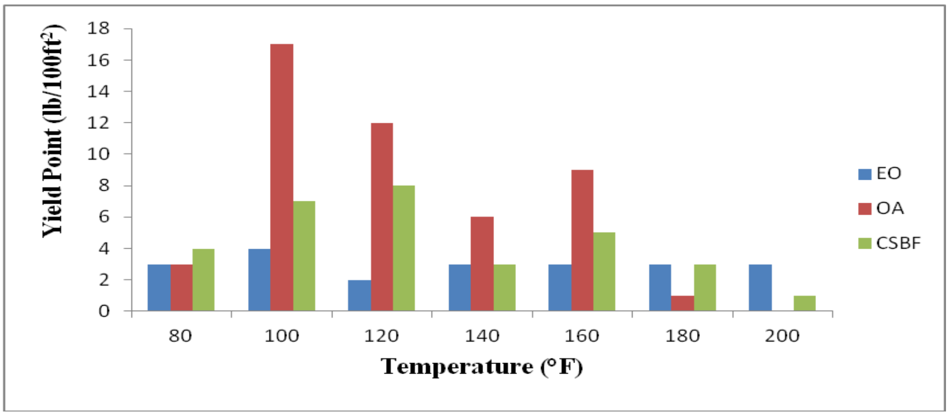


**Fig. 5:** Effect of Temperature on the Yield Point of the Muds

The gel strength is another important rheological property of drilling mud which determines the capacity of the mud to adequately suspend drill cuttings when drilling operation is temporarily halted (Olatunde *et al.*, 2012). Gel strength is a static property of muds, while PV is a dynamic property (Omole *et al.*, 2013). The effect of temperature on the gel strength of the muds formulated with the esters was plotted in figures 6 and 7. The reference mud formulation however, did not follow any noticeable trend in the variation of the 10 sec gel strength with temperature, but had a value of 1lb/100ft$^2$ at 80°F and fluctuated around 2, 1and 3 (lb/100ft$^2$) at higher temperatures. EO and OA mud formulations were within the lowest range of 2lb/100ft$^2$ between 80 °F to 160 °F, but reduced below the range at 180°F and 200°F.

The 10min gel strength of the EO formulated mud was higher than that of the reference and OA at 80 °F, 100 °F and 120 °F, but were equal at 140 °F. However from 160 °F to 200 °F, the CSBF recorded higher values of 10min gel strength than both ester based muds. The reference mud maintained constant 10min gel strength of 3lb/100ft$^2$ at all the temperatures under investigation except at 140°F where it decreased to 2lb/100ft$^2$. These values however, are still within the API recommended range. The low gel strength values obtained for all the mud formulations with the esters imply that relatively low pump pressure will be required to initiate fluid flow and resume drilling operations after it has been suspended for some time (Maxey, 2011). These results obtained from the 10 min and 10 sec gel strengths are presented in Figures 6 and 7.

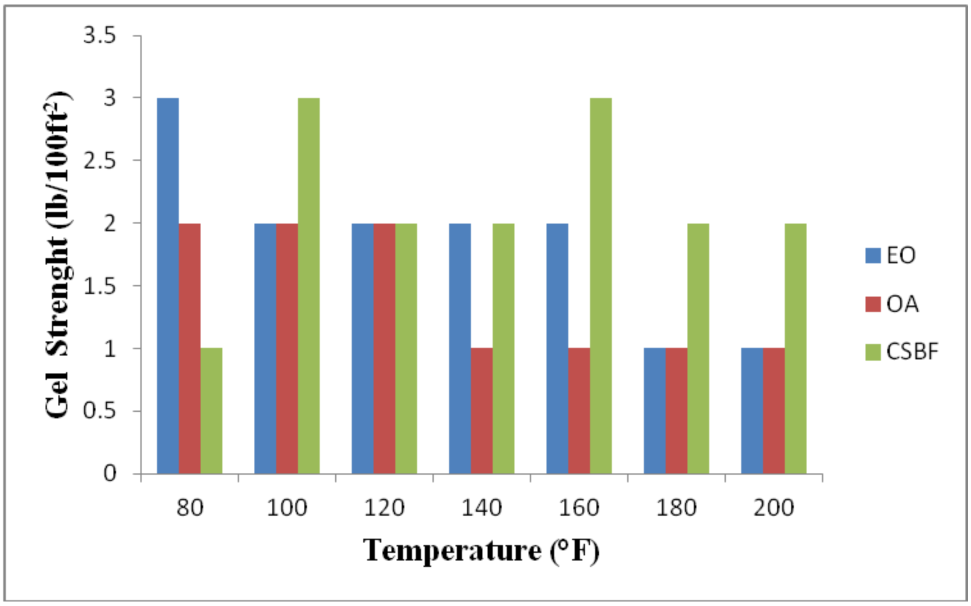


**Fig.6:** Variation of 10 Seconds Gel Strength with Temperature

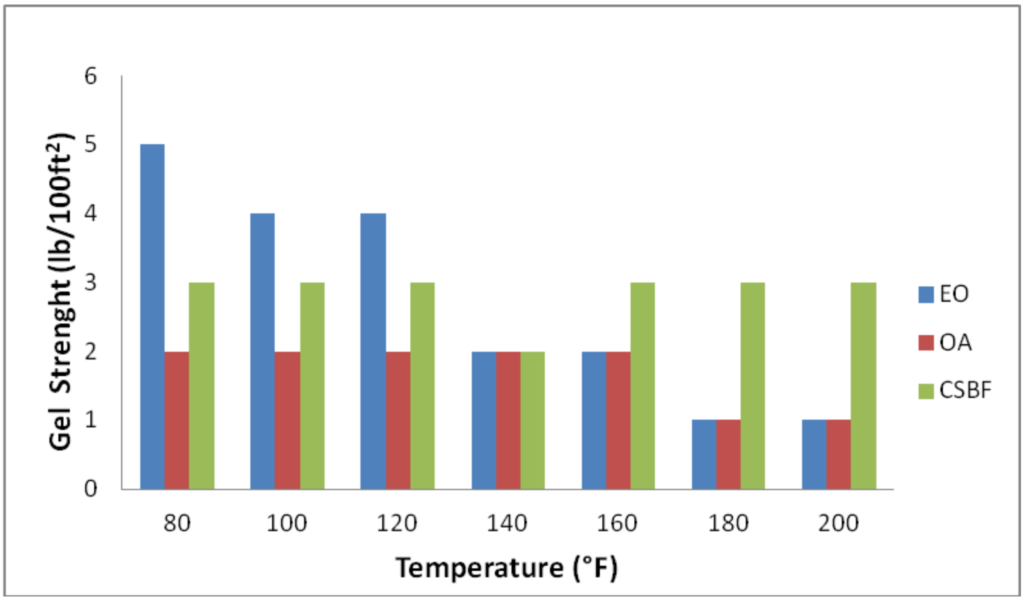


**Fig. 7:** Variation of 10 Minutes Gel Strength with Temperature

The lower rheological profile displayed by OA and EO formulated muds relative to the reference mud, could be attributed to their lower flash point and shorter carbon chain length when compared to the reference fluid. They have a total of ten carbon atoms in their chemical structure compared to the reference fluid (between 13C and 16 C). These two factors may have led to the faster degradation of the muds as the temperature was increased.

## IV. Conclusion

Based on the observations made in this work, it can be concluded that:

1. There is a close agreement between the physicochemical properties of the ethyl octanoate and octyl acetate used in this research with reported literature values.
2. Ethyl octanoate and octyl acetate can be used in drilling mud formulation.
3. Ethyl octanoate based mud had a better rheology profile than the octyl acetate based mud.
4. The ester based muds displayed low PV and gel strength values at all the temperatures investigated.
5. Lower flash point and shorter carbon chain length of ethyl octanoate and octyl acetate relative to the reference fluid may have contributed to the lower rheology profile of the ester based mud relative to the reference mud.
6. Increasing the quantity of appropriate additives used in formulating the mud, like organophilic clay can improve the rheology profile of the muds formulated with these esters.

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