**Performance Analysis of Oil Based Muds Formulated from Standard Base Oil and Diesel Based Oil**

**Oloro Obarhire John, Akpotu Daniel ,Uti Kelly Erumu**

Chemical and Petroleum Engineering Department, Faculty of Engineering, Delta state University

joloroeng@yahoo.com

**ABSTRACT**

The investigation of various composition of diesel base mud reveal comparable performance to that of the industrial base oil that have been used successfully in drilling. In this work, diesel-water volume was alternated from 250ml:100ml, 200ml:150ml and 150ml:200ml with equal weight of bentonite and other additives and compared with the industrial oil base mud. The viscosity values of the three compositions of diesel base muds revealed incomparable performance characteristics to that of the industrial oil base mud. Mud density values were 8.92ppg, 8.80ppg, 8.83ppg and 8.85ppg for Industrial oil base mud, sample A, sample B and sample C respectively and all fall within API minimum-maximum range of 8.65ppg-9.60ppg. Sand content of all the samples were the same at 1.0ml. Filtrate volume recovered was lowest with the industrial oil base mud at 8.0ml while it was 11.1ml, 12.0ml and 12.5ml for sample A, sample B, and sample C respectively. The wall building capacity of the mud was higher with 0.8 inch for the industrial oil base mud while it was 0.61-inch, 0.60 inch and 0.58 inch for sample A, sample B and sample C respectively. The effect of “n” and “K” on the samples were calculated from viscosity values and results show that all the samples were non-Newtonian since “n” values were less than 1.0 which is very effective for better hole cleaning with industrial oil base mud at 0.6394, while it was 0.6276, 0.6087 and 0.7457 for sample A, sample B and sample C respectively. “K” values were greater than 1.0 which shows effective annular velocity for cuttings transport at 3.60, 3.6721, 3.7872 and 1.5140 for industrial oil base mud, sample A, sample B, and sample C respectively.

Keywords: Drilling fluid, Yield Point, Formation, Cuttings, Mud

**INTRODUCTION**

Drilling fluid plays an invaluable role. These roles consist of but are not restricted to transporting the drill cuttings , cooling and lubricating the drilling bit by way of the drill string to lessen its wear, shutting off permeable formations by forming an resistant, comparatively thin mud cake at the borehole wall of the penetrable formations, producing an overbalanced drilling condition to control the formation pressure, hold drill cuttings in suspension when circulation is interrupted(Okorie et al.2015 and Okorie 2019). Drilling mud forms an important part of drilling processes and the factors consider in suitable fluid choice include drilling performance, expected well condition, the safety of personnel, cost, and mud cuttings discarding (Okoro et al. 2015 and Kevin et al. 2019).

Drilling mud must be formulated to minimize difficulties connected with formation damage, well chemistry, and other well instabilities. A task challenging mud engineers is how to control and stabilize mud properties to improve drilling operation at the lowest cost possible. Works has shown that a group of mud additives is available to treat most of the important doubts in the wellbore, but the question will be how cost-effective these additives are per foot drilled, after the formulation of the drilling mud system (Evelyn et al. 2018 and Chinwuba et al.2020).

The main function of drilling mud is to remove cuttings during the drilling process. Viscosity is by far, the most needed property of the drilling fluid to aid it to perform its needed task. The viscosity property of the mud helps in well cleaning and also aid in the suspension of drilling cuttings when circulation of the fluid is put on hold. It is important to monitor and continuously adjust the viscosity of the drilling fluid (Dankwa et al. 2018 and Amorin 2019). Oil-based muds have high-quality results over the years during a drilling operation. Some of its advantages over water-based muds are high drilling rates, lowered drill pipe torque and drag, less bit balling, and reduction in differential sticking. Notwithstanding the success it has recorded in the drilling industry, it is still essential to select from a variety of oils as the base fluid for an optimum operation delivery. Hence in this paper oil-based mud will be formulated from standard base oil and diesel base oil. The aim is to test for operational parameters of drilling fluid such as mud density, sand content, rheological properties, and filtration properties.

**Rheological Concepts**

Rheology is the science of distortion and flow of substance. Making a measurement on a fluid, it is likely to find how that fluid will flow under a different condition together with temperature, pressure, and shear rate(Jingyu,et al. 2016 ; Wenyu and Guoliang , 2018; Yang Y, Li, X. and Su, W 2020, Yang Y, Li, X. and Su, W.2020). The viscosity of a fluid (µ) is defined as the ratio of the shear stress (τ) to that of the shear rate (γ). Mathematically,

𝜇 = (1)

The unit of viscosity can be stated as Newton seconds/m2 or Pascal seconds or poise (dyne.s/cm2 ). Also, the shear stress (τ) is defined as the force required to sustain the movement of a particular type of fluid flowing through an area. Mathematically,

𝑠ℎ𝑒𝑎𝑟 𝑠𝑡𝑟𝑒𝑠𝑠 (𝜏) = (2)

The unit is N/m2, Pascal, or Dynes/cm2. Shear rate 𝛾 is given as the rate of change of velocity when one layer of fluid passes over an adjacent layer divided by the distance between them. It is expressed in sec-1.

**Yield Point**

Yield Point is a amount of the electrochemical or attractive force in a fluid. It is that part of the resistance to flow that may be controlled by proper chemical treatment. Mathematically, it is expressed as:( Folayan et al. 2017; Hussein et al. 2020).

𝑌𝑃 = 𝜃300 − 𝑃𝑉 (3)

The unit is lb. /100ft2 or Pa.s

Where PV is the plastic viscosity in lb. /100ft2.

Plastic Viscosity is described as that part of the restriction to flow caused by mechanical friction. It is expressed as 𝑃𝑉 = 𝜃600 −𝜃300. The unit is centipoise (cp).

Power Law Model

Most drilling fluids exhibit behavior that falls between the behaviors described by the Newtonian Model and the Bingham Plastic Model. This behavior is classified as pseudoplastic. The relationship between shear stress and shear rate for pseudoplastic fluids is defined by the power-law mathematical model,

τ = K γn (4)

n = 0.5 log (5)

K = (6)

Where τ = shear stress

K = consistency factor

γ = shear rate

n = flow behavior index

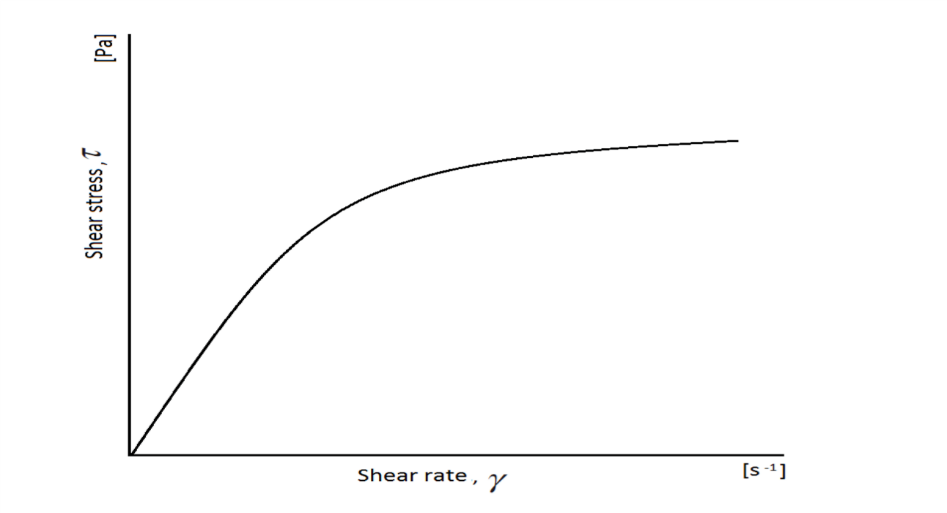


Figure 1: Consistency curve of shear stress versus shear rate for the Power-law model

Figure 1 illustrates the flow curve for a pseudoplastic fluid. Normally, K is called the consistency factor and defines the thickness of the fluid and is to a certain degree analogous to effective viscosity. If the drilling fluid becomes more viscous, then the constant K must increase to adequately describe the shear stress/shear rate relationship.

The “n” constant shows that the degree of non-Newtonian behavior that a fluid displays over a defined shear rate range. As “n” reduces from one, the fluid turn out to be shear-thinning or pseudoplastic. This means the viscosity of the fluid will decrease with increasing shear, and increase with a reduction in shear rate. Lowering the “n” constant improves hole cleaning performance by increasing the effective annular viscosity and flattening the annular velocity profile (Emine et al. 2019)

**MATERIALS AND METHODS**

The materials used in this project work are as follows:

1. Bentonite: This is a type of foreign clay used for spud mud formulation. Bentonite clay is usually used for mud formulation whether it is water-based mud or oil-base mud.
2. Base oil: An industrial base oil was sourced for and used to validate the results of diesel oil.
3. Diesel oil: Oil-based mud was formulated from diesel oil using an emulsifying agent.
4. Emulsifying Agent: An emulsifying agent (Morning fresh soap) was used for the preparation of diesel base mud.
5. Barite: This is a weight additive to the mud formulated.
6. Filtrate loss reducing agents: Filtrate loss agents such as Carboxyl Methyl Cellulose (CMC) were blended into the whole mud and the effect of filtrate loss on all the compositions of oil-based mud was carefully monitored.

**Equipment**

1. Weighing scale: For measuring the desired weights of materials during mud formulation.
2. Mud Mixer: This is used for blending bentonite, water, and other additives.
3. Mud Balance: Mud balance was used to measure the density of mud in pounds per gallon (ppg).
4. Filter Press Machine: A low-pressure low temperature (LPLT) filter press machine was used to ascertain the rate of fluid loss from the whole mud.
5. Sand Content Kit: The volume of sand present in both samples of mud was measured with the use of a sand content kit. The ml of sand or % of sand was recorded accordingly.

**Procedure/Methodology**

To achieve the aim of this work, the followings were strictly followed:

**Spud Mud Formulation/Beneficiation:**

Preparation of the Mud Samples: Three mud samples (diesel-based oil muds) of different compositions except for the industrial base oil used were prepared.

See Table 1 for the quantities of the various components that made up the compositions. The diesel oil sample was first measured and poured into a mixer cup and then placed under a mud mixer. The specified quantities of water, emulsifier, and bentonite were then separately added to the oil in the mixer cup and stirred continuously. Finally, Barite was weighed and added to the mixture until it was finally well blended into a smooth paste. The above process was repeated using different compositions of diesel and water while other components remain unchanged.

Mud beneficiation is a deliberate addition of chemicals and other additives to the fresh (or spud) mud to alter the quality of the mud.

The method to adopt for this work is the American Petroleum Institute’s Recommended Practice for testing oil-based mud (**API RP-13A**).

**Table 1 Mud composition**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Oil base mud type** | **Oil (ml)** | **Water (ml)** | **Bentonite (g)** | **Barite (g)** | **CMC (g)** |
| Industrial grade | ------ | ------- | 24.5 | 8 | 10 |
| Sample A | 250 | 100 | 24.5 | 8 | 10 |
| Sample B | 200 | 150 | 24.5 | 8 | 10 |
| Sample C | 150 | 200 | 24.5 | 8 | 10 |

The equipment and mud properties to be tested are shown in Table 2

Table 2: Equipment/Mud Properties

|  |  |
| --- | --- |
| **Equipment: Manufacturer and Model Number.** | **Mud Property** |
| Mud Balance: Baroid, Model No.: NL 3034 SS / 001 | Mud Density |
| Sand content kit: Fann, **Part No**. 209657 | Percentage/Volume of sand present in the sample |
| Rheometer:FANN, Models 35A/SR-12 | Rheological properties of mud |
| Filter Press machine: Fann, Part No. 207228 | Filtrate volume, filter cake thickness |

**Tests**

**Mud Density**

The Baroid mud balance was used to determine the density (or weight) of the mud. The mud balance was first cleaned up and standardize before usage. This was done to ensure accurate readings were obtained from the instrument.

Procedure:

* Remove the lid and fill the cup to the top with the sample to be tested. If air bubbles have been trapped in the mud, tap the cup briskly until they break out.
* Replace lid and rotate until firmly seated, making sure some mud squeezes out of the vent hole.
* Wipe mud from the exterior of the mud balance.
* Place mud balance on base with knife edges on fulcrum rest.
* Move rider until the instrument is in balance, as determined by the spirit level.
* Read mud weight and hydrostatic pressure or gradient at the edge of the rider nearest fulcrum.

**Mud Rheology (Viscosity)**

The Baroid Rheometer is standard equipment approved by the American Petroleum Institute (API) for the testing drilling mud viscosity. Drilling mud viscosity is tested for, to know the cutting carrying capacity of the mud (Emine et al. 2019).

Procedure:

1. Prepare the instrument for 12-speed testing by setting the gearbox shift lever.
2. Select the proper speed range with the speed shift switch.
3. To obtain the 600 rpm, 300rpm, 200rpm, 100rpm, 6rpm, 3rpm, place a recently agitated sample in a suitable container and lower the instrument heat until the rotor sleeve is immersed exactly to the scribed line. To hold in this position, tighten the lock screw on the left leg of the instrument. With the gear shift at a high-speed setting, rotate the crank for about 15 seconds, release to the 600 rpm setting and continue cranking. Repeat for other Rheometer speed settings of 300rpm, 200rpm, 100rpm, 6rpm, and 3rpm. The twelve -speed setting is shown in Table 3.

**Table 3 Twelve-Speed Testing Combinations- Models 35A/SR-12**

|  |  |  |  |
| --- | --- | --- | --- |
| **RPM** | **Gear Box Shift Lever** | **Speed Switch** | **Gear Shift Knob** |
| 600 | Left | High | Down |
| 300 | Left | Low | Down |
| 200 | Left | High | Up |
| 100 | Left | Low | Up |
| 60 | Right | High | Up |
| 30 | Right | Low | Up |
| 6 | Left | High | Center |
| 3 | Left | Low | Center |

**Measuring Gel Strength**

1. Stir the sample thoroughly at 600 rpm.

2. Set the gear shift knob to the 3 rpm position, and then turn the motor to the OFF position.

3. After the desired wait time, turn the motor to the ON position at low speed.

4. Read the dial at the moment the gel breaks as noted by a peak dial reading. The gel strength units are lb/100ft2.

**Filtration Properties**

One of the important properties of the drilling mud is its ability to deposit a thin filter cake on the wall of the formation drilled through. The instrument used for this analysis is the Fann Filter Press Machine.

Procedure:

* + 1. Assemble the following dry parts in this order: base cap, rubber gasket, screen, a sheet of filter paper, rubber gasket, and cell. Secure the cell to the base cap.
    2. Fill the cell with the sample to be tested within ¼-in of the top. (Filling the cell to within ¼-in of the top is necessary only to conserve the compressed gas). Set the unit in place in the filter press frame.
    3. Make sure the gasket is in place. Place the top cap on the cell and protect the unit in place with the T-screw.
    4. Place a dry graduated cylinder under the filtrate tube.
    5. With the regulator, T-screw in its maximum outward position (close position) opens the valve on the cell. Apply 100 psi pressure to the filter cell by rapidly screwing the regulator T-screw into the regulator. The timing of the test should begin now.
    6. At the end of 30 minutes, close the valve close to the cell rapidly and open the safety-bleeder valve. This releases pressure on the entire system. Return the regulator T-screw to its maximum outward position.
    7. Read the volume of filtrate collected in the graduated cylinder.
    8. The filter cake thickness is determined after the filter cell has been disassembled. The filter paper with the cake deposited on it is removed from the base cap, and the excess mud is washed from the cake. The filter cake thickness is measured and reported as thirty-seconds of an inch.

Properties of the filter cake such as texture, hardness, flexibility, etc., will be reported.

**Sand Content**

This simple test is used to determine the volume percent of sand-sized particles in a mud. The information is used to make adjustments in [solids control](https://www.netwasgroup.us/engineering-2/mud-handling-equipment.html) equipment.

1. Pour in mud into glass measure tube to. Add water to the next scribed mark. Place thumb over the mouth of the tube and shake strongly.
2. Put the mixture onto the clean screen. Add water to the tube and shake. Pour onto the screen. Discard the liquid that passes through the screen.
3. Carry out Step 2 again until the wash water is clean. Then wash sand retained on-screen to free any adhering mud.
4. Place the funnel on top of the screen assembly. Slowly invert assembly and insert the tip of the funnel into a glass tube. Wash sand back into the tube with a fine spray of water or a wash bottle.
5. Allow the sand to settle. Read and record volume percent sand from graduations on the glass measuring tube.

**RESULTS AND DISCUSSION**

The results obtained from the experiments in all the tests conducted in the laboratory are presented below. Four mud compositions were tested for. This was done to select a better composition whose mud properties will be closer to that of the industrial oil-base mud in terms of performance. Mud properties in focus in this work are; Mud density, sand content, filtration properties, and rheological properties.The industrial base oil and three diesel base oil was carefully formulated and the results presented in Table 4.

Table4: Results of Mud density, sand content, and filtration properties of Industrial base oil, Sample A, B, and C.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Base oil Type** | **Mud Density (ppg)** | **Sand Content (ml), %** | **Filtration property** | |
|  |  |  | **Filtrate Volume (ml)** | **Filter Cake Thickness (in)** |
| Industrial | 8.92 | 1 (0.4%) | 8 | 0.8 |
| Sample A | 8.8 | 1 (0.4)% | 11.1 | 0.61 |
| Sample B | 8.83 | 1 (0.4)% | 12.0 | 0.60 |
| Sample C | 8.85 | 1 (0.4)% | 12.5 | 0.58 |

Mud density values of all the samples tested to fall within the acceptable range but the industrial base oil was higher with 8.92ppg, others were 8.80ppg, 8.83ppg, and 8.85ppg for sample A, sample B, and sample C respectively.

Sand content (percentage of sand) for the samples was the same at 1ml which is 0.4% sand trapped with the mud.

Fluid loss from the mud samples was at 8ml, 11.1ml, 12ml, and 12.5ml for the industrial, sample A, sample B, and sample C respectively. The lowest fluid loss was recorded from the industrial base oil, closest to this was sample A. Filter cake thickness (wall building capacity) of the mud samples was 0.8 inches, 0.61 inches, 0.60 inches, and 0.58 inch. Industrial base oil has a better fluid retaining and wall building capacity.

Table 5: Rheological properties of Industrial base oil, Sample A, B, and C.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Dial Speed (rpm)** | **Mud Viscosity (Cp)** | | | |
| **Industrial** | **Sample A** | **Sample B** | **Sample C** |
| **600** | 62 | 54 | 53 | 47 |
| **300** | 38 | 36 | 33 | 31 |
| **200** | 21 | 19 | 17 | 16 |
| **100** | 12 | 10 | 9 | 8 |
| **6** | 3 | 3 | 3 | 2 |
| **3** | 2 | 2 | 2 | 1 |
| **PV** | 24 | 21 | 20 | 16 |
| **AV** | 31 | 27 | 26.5 | 23.5 |
| **YP** | 14 | 15 | 13 | 15 |
| **10 Seconds Gel** | 14 | 13 | 11 | 5 |
| **10 Minutes Gel** | 35 | 28 | 26 | 26 |
| **“K”** | 3.6 | 3.6721 | 3.7872 | 1.5140 |
| **“n”** | 0.6394 | 0.6276 | 0.6087 | 0.7457 |

Table 5 is a result of all rheological properties of Industrial base oil for Sample A, B, and C. From the result, mud viscosity for sample A for each dial reading gave the highest values as also shown in Figure 2.

Figure 2: Graph of Rheometer speed versus Viscosity.

Table 6: Shear rates versus shear stress for Industrial oil base mud, sample A, sample B, and sample C.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Rheometer Speed (rpm)** | **Shear Rate (**γ**), S-1** | **Shear Stress (**τ**), Ib/100ft** | | | |
| **Industrial** | **Sample A** | **Sample B** | **Sample C** |
| 600 | 1022 | 302.4 | 284 | 257.1 | 265.6 |
| 300 | 511 | 194.1 | 184 | 168.6 | 158.4 |
| 200 | 341 | 149.9 | 142.7 | 131.8 | 117.2 |
| 100 | 170 | 96 | 92.2 | 86.3 | 69.7 |
| 6 | 10.2 | 15.9 | 15.8 | 15.6 | 8.6 |
| 3 | 5.11 | 10.2 | 10.2 | 10.2 | 5.1 |

The Shear rates versus shear stress for Industrial oil base mud, sample A, sample B, and sample C is shown in Table 6. From the result, for each dial reading for each sample, the shear stress for sample A gave the highest value as shown in Figure 3. Hence the frictional force sample A will be higher when compared with other sample. As the shear stress increases the shear rate also increases.

Figure 3: A graph of shear stress versus shear rate.

When n=1, the fluid is Newtonian and as n decreases the fluid becomes progressively more shear thinning.In other words, the shear stress-shear rate curve is straight line at n=1 and become more and more curved as n decreases in numerical value. The fluid flow behavior index “n” was less than 1 for the mud samples analyzed. Sample B fluid flow behavior index was lowest and will provide the best hole cleaning followed by sample A, industrial and sample C at 0.6276, 0.6394, and 0.7457. Sample B proves the best consistency coefficient of the mud samples “K” at 3.7872 followed by sample A, industrial and sample C at 3.6721, 3.60, and 1.5140.

**CONCLUSION**

Four different oil-based mud samples were formulated to ascertain the performance of each sample against others. An industrial oil-based mud used in the drilling industry was tested and compared with other diesel base oil formulated with various compositions. No single mud composition proves better in all the mud properties tested for. Sample C proves very poor in terms of cutting transport and effective viscosity and a great parameter in ensuring a better rate of penetration (ROP). Sample B proves better in cuttings transport and effective annular velocity from the results of “n” and “K” values. Industrial base oil proves better in mud density, lowered fluid loss, and better wall building (mud cake thickness). Sand content was the same in all the compositions.

**Recommendations**

From the results of the experiments conducted on the four samples

Though the results of the mud properties tested for across the four compositions in this project work prove satisfactorily in mud density, filtration properties sand content, and rheological properties except for sample C whose hole cleaning and cuttings transport index is weaker. From the results of this work, the following recommendations are made.

* All the mud samples should be subjected to high temperatures and pressure to observe a change of performance.
* At the room temperatures, sample C should be beneficiated with a viscosifier (viscosity-enhancing additive) if the and observe for a new “n” “K” value.

**REFERENCES**

Aihie JO. (2019). Formulation of Water Based Drilling Fluid Using Local Mud Uwheru & Otor-

Udu Clay, Society of Petroleum Engineers:1-14. <https://doi.org/10.2118/198737-MS>

Akinwunmi EA, Okologume CW and Akin-Taylor AM. (2018). Improving the Rheological

Properties of Drilling Mud Using Local Based Materials. American Journal of Engineering

Research (AJER): e-ISSN: 2320-0847 ,Volume-7, Issue-9:58-63.

Amorin R., Opoku AP, Osei E. (2019). Evaluation of blended lime-stabilised spent synthetic-based

drilling mud and cement for oil well cementing operations. Advances in Geo-Energy

Research, 2019, 3(2): 141-148, doi: 10.26804/ager.2019.02.03

Chinwuba IK., Emeka OJ, Nnaemeka, U, Soromtochukwu IG, Chibuzor NP. (2020). Optimization

and Modeling of the Rate of Penetration in an Extended Reach Drilling Process, Petroleum

and Coal. 2020, Vol. 62 Issue 2: 299-308.

Dankwa OK , Opoku AP. and Tampuri, M. (2018) “Performance Evaluation of Local Cassava

Starch Flour as a Secondary Viscosifier and Fluid Loss Agent in Water Based Drilling

Mud”, Ghana Mining Journal, Vol. 18, No. 2: 68 – 76.

Emine A and Bayram AM.(2019).The Rheology and Performance of Geothermal Spring Water-Based

Drilling Fluids, Hindawi Geofluids ,Volume 2019, Article ID 3786293, 8 pages

https://doi.org/10.1155/2019/3786293

Evelyn BE, Emmanuel EO, AD, Sunny I. (2018). Optimizing aqueous drilling mud system

viscosity with green additives. (researchgate.net publication) Journal of Petroleum

Exploration and Production Technology:1-6.

Folayan JA, Anawe PL , Abioye PO and Elehinafe FB.(2017). Selecting the Most Appropriate

Model for Rheological Characterization of Synthetic Based Drilling Mud, International

Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 18 (2017)

:7614-7629

Hussein AD.and A.R. Mohammed ARM. (2020). Studying the Rheological Properties of Non-Newtonian

Fluids under the Effect of temperature Using Different Chemical Additives. Iraqi Journal of

Chemical and Petroleum Engineering, 21(2): 47-56. <https://doi.org/10.31699/IJCPE.2020.2.6>

Jingyu Xu and Aode H.(2016) Rheological study of mudflows at Lianyungang in China,

International Journal of Sediment Research,Volume 31, Issue 1, March 2016 :71-78.

<https://doi.org/10.1016/j.ijsrc.2014.06.002>

Kevin CI, Emeka EO, Princewill NO, Solomon AA, Nnanna O, Temilade A. (2019). Effect of

Mud Weight on Hole Cleaning During Oil and Gas Drilling Operations Effective Drilling Approach, The Open Petroleum Engineering Journal, ISSN: Volume 12, 2019 : 1874-8341 .

Okorie EA, Anietie NO and Francis DU. (2015) A Comparative Study of Diesel Oil and Soybean

Oil as Oil-Based Drilling Mud, Journal of Petroleum Engineering, Volume 2015 |Article ID 828451:1-10. | <https://doi.org/10.1155/2015/828451>

Okoro EE., Dosunmu A, Oriji B., Iyuke S. (2015). Impact of reversible invert emulsion drilling

fluid rheology on drilling productivity. SPE-178308-MS, Nigerian Annual Technical Conference and Exhibition:1-14.

Wenyu Y and Guoliang Y. (2018). Rheological Response of Natural Soft Coastal Mud under

Oscillatory Shear Loadings, Journal of Waterway, Port, Coastal, and Ocean Engineering

/Volume 144 Issue 4 - July 2018.

Yang Y, Li, X. & Su, W.(2020). Experimental Investigation on Rheological Behaviors of

Bentonite- and CMC-Conditioned Sands. KSCE J Civ Eng 24 :1914–1923.

<https://doi.org/10.1007/s12205-020-2035-5>