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CHARACTERIZATION OF NIGER DELTA CLAYS FOR USE AS IMPROVED OIL RECOVERY: A CASE STUDY OF OBOBURU, EGAMINI AND AFAM

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Abstract

Enhanced oil recovery (EOR) is a promising technique that utilizes microorganism metabolic activities to enhance oil recovery from reservoirs. This laboratory investigation focuses on the synergy between Oboboru, Egamini and Afam clay at different concentrations (5 – 30 grams) in enhancing crude oil recovery. The results of the mineral contents shows that the clay sample's specific gravity and pH indicate the presence of montmorillonite mineral and slight acidity. Analysis of oxide composition reveals high levels of silicon oxide (SiO_2), followed by aluminum oxide (Al_20_3), magnesium oxide (MgO), and calcium oxide (CaO), with iron oxide (Fe_2O_3) being least abundant. These findings provide insights into the clay's composition. The study demonstrates that increasing the mass percent concentration of the nanoparticles reduces crude oil viscosity, with the lowest viscosity at 8.25 cP., the result of the density also reduced by 0.8876 g/cc for oboboru clay and 0.9668g/cc was recorded for Afam clay nanoparticle. the API gravity showed an increase of 37.744 °API for Afam clay nanoparticle and 27.7441 °API was recorded for Egamini. This suggests the beneficial effect of clay nanoparticles in improving flow characteristics and enhancing oil recovery. These findings contribute to understanding EOR techniques and highlight the potential of Oboboru clay between Oboboru, Egamini and Afam for enhancing crude oil recovery. The research offers valuable insights into clay-mineral-microbe interactions, paving the way for optimizing treatment strategies in the petroleum industry. Overall, this investigation explores the effects of Oboboru, Egamini and Afam clay nanoparticles on oil productivity during EOR, revealing the transformative potential of combining clay minerals and microbial activity in oil recovery processes.

Keywords: enhanced oil recovery, clay nanoparticles, petrophysical properties, Niger Delta.

INTRODUCTION

The successful completion of this Master's research project marks a pivotal milestone in my academic journey and professional advancement as a Petroleum Engineer. It represents not only the fulfillment of an important scholarly requirement but also the culmination of rigorous research, critical analysis, and practical insight into one of the most pressing challenges facing the petroleum industry today.

The Niger Delta Basin, widely recognized as one of Africa's most prolific and strategically significant hydrocarbon provinces, continues to play a crucial role in global energy supply and national economic development. Despite its vast resource endowment, a considerable number of reservoirs within the basin are presently confronted with declining production performance. This decline can be largely attributed to reservoir heterogeneity, unfavorable mobility ratios, high water cut, early water breakthrough, and inefficient areal and vertical sweep efficiency during primary and secondary recovery stages. These challenges have significantly limited ultimate recovery factors, thereby necessitating the adoption of innovative, technically viable, and economically sustainable enhanced oil recovery (EOR) strategies.
The motivation for this research stemmed from the urgent need to explore locally available and cost-effective materials that can serve as viable alternatives to imported chemical agents commonly used in

improved and enhanced oil recovery operations. Given the high operational costs associated with conventional EOR chemicals, as well as environmental and logistical considerations, the investigation of indigenous resources presents a promising pathway toward sustainable reservoir management and economic optimization.

Accordingly, this study focused on the systematic characterization of clay deposits obtained from Oboburu, Egamini, and Afam. Comprehensive mineralogical, geochemical, and physiochemical analyses were conducted to determine their structural composition, surface properties, ion-exchange capacity, thermal stability, and compatibility with reservoir conditions. The primary objective was to evaluate their potential suitability and performance efficiency in improved oil recovery applications. Through this multidisciplinary approach, the research provides valuable insights into the feasibility of utilizing locally sourced clay materials as functional agents in enhanced recovery processes, thereby contributing to both scientific knowledge and practical field development strategies within the Niger Delta region. Many oil-bearing reservoirs contain large quantities of fine particles, particularly clay minerals. Therefore, preliminary screening of the target formations is essential to identify potential production challenges and determine strategies to reduce their impact. In some cases, certain clay minerals may even be beneficially applied for mobility control, especially in heterogeneous reservoirs where thick residual oil is present.

This research aims to offer meaningful contributions to the application of clay nanoparticles, specifically Oboburu, Egamini, and Afam, in secondary recovery operations. The goal is to improve the productivity of crude oil wells within the Niger Delta region. By exploring and utilizing the distinctive characteristics of these clay materials, the study seeks to develop practical approaches that enhance well performance and increase recovery efficiency.

The importance of this research on the use of clays, specifically Oboburu, Egamini, and Afam as mud additives in Enhanced Oil Recovery (EOR) operations is broad and carries several key implications for the petroleum sector:

The study tackles the challenge of low-performing reservoirs by examining how clay additives may improve EOR efficiency. If proven effective, this could notably increase well productivity and boost overall crude recovery levels.

EOR techniques can help extract reserves that would otherwise remain unrecovered through primary production methods. This has major economic benefits, as it enhances the value of existing fields and prolongs their productive lifespan.

By assessing the suitability of particular clays as additives, the research supports better resource utilization. If they are shown to perform well, it may promote more focused and sustainable material use during EOR processes.

Successful EOR strategies can decrease the need for drilling additional wells, reducing environmental impacts associated with new exploration. This aligns with the industry's growing commitment to environmentally responsible development.

The work promotes the introduction of clay nanoparticles in EOR, reflecting progress in modern techniques and technological growth within the oil and gas field. This may open opportunities for further advancements and improvements in recovery methods.

Understanding how clays influence EOR performance provides valuable insights into addressing risks related to reservoir behavior. Identifying effective methods may help reduce issues such as poor production and operational challenges that often cause financial setbacks.

The research may help establish evaluation standards for clay nanoparticles in EOR, influencing recommended industry practices. Such information could assist companies in adopting or refining their enhanced recovery programs.

Improving oil extraction from existing reservoirs supports global energy stability by ensuring a reliable and efficient crude supply. This is especially essential in the Niger Delta, a major crude-producing region.

In conclusion, the significance of this study lies in its potential to improve and refine oil recovery processes, offering technological, economic, and environmental benefits to the industry.

I. Materials and Method

The following material and methods were employed in the course of this investigation

i. **Nanoparticle (Oboburu, Egamini and Afam clay):** These clay samples were gotten specifically from Oboburu community in Rumuepirikom, Egamini community in EmohUa and Afam community in Oyigbo.
ii. **Crude oil:** The crude oil was gotten from a well in the Niger Delta region and the exact source is not to be disclosed

iii. **Equipment and Apparatus**
   i. Measuring cylinder
   ii. Drying oven
   iii. Weighing balance
   iv. Thermometer
   v. Microscope
   vi. Incubator
   vii. Petri dishes
   viii. Inoculation loops
   ix. Test tubes
   x. Stopwatch
   xi. Grinder
   xii. Sieve assembly.
   xiii. Pycnometer
   xiv. Redwood viscometer
   xv. Cloud point and pour point refrigerator
   xvi. Flash point tester
   xvii. Air coolant

Experimental Procedure

This laboratory research was conducted in three stages to investigate the effects of nanoparticles on the petrophysical properties of crude oil. In the initial stage, we will conduct petrophysical tests on the crude oil to identify its properties and establish a baseline for any changes that may occur. The second stage will involve preparing the nanoparticles (Oboburu, Egamini and Afam clay) to be introduced into the crude oil sample. Finally, petrophysical tests conducted on the crude oil sample again after introducing the nanoparticles to determine any changes in its properties.

This experiment was carried out in the Petroleum Engineering Laboratory, Rivers State University.

Clay Sampling

Excavations were conducted at each site to a depth of 1.5 meters to obtain uniform samples. The collected samples were air-dried using the oven and sieved to achieve a size less than 150 µm. Subsequently, clay was specifically extracted from the samples obtained at the three test locations, labeled as samples (A – C) any impurities such as pebbles and grass roots were meticulously removed, and portions of each sample was carefully collected in polyether bags for laboratory analysis. The collected samples went through comprehensive characterization to determine their physical, chemical, rheological properties and metallic content.

Determination of Clay Physical Properties

The physical properties of the Clay samples will be determined under the following:

i. Moisture Content
ii. Ash Content
iii. Iodine Number
iv. pH Reading

Moisture Content Determination

The moisture content of the samples was determined using the oven drying method. A 1.0g sample was weighed in a Petri dish and placed in an oven at 105°C for two hours. The sample was removed, cooled in a desiccator, and weighed. The reheating process was repeated in 20-minute intervals, with cooling and weighing until a constant weight is achieved. The moisture percentage was calculated using the Equation 3.1.

$$Moisture\ (\%) = Loss\ in\ weight\ on\ drying\ x\ 100 \quad (1)$$

(3.1)

Ash Content Determination

For ash/ content, 0.1g of the sample was heated for 20 minutes, cooled, and weighed. This process was repeated until a constant weight is obtained, indicating complete ashing. The ash content was calculated using the formula:

$$\text{Ash } (\%) = \frac{Weight\ of\ Ash}{Weight\ of\ sample\ 1} \text{ x } 100 \quad (2)$$

(3.2)

Iodine Number Determination

To determine the iodine number, 0.5g of the sample was weighed and placed in a conical flask. After adding 10ml of 5% HCl, the mixture was agitated until wetted, followed by the addition of 100ml of the stock solution. An electric shaker will be used for agitation for one hour, and the mixture was filtered. A 20ml aliquot was titrated with 0.1m sodium thiosulphate using starch as an indicator. The concentration of iodine absorbed was calculated as the amount of iodine absorbed in milligrams.

$$I(mg) = (B - SB \times VMW \times 253.81) \quad (3)$$

(3.3)

Where B = Volume of thiosulphate solution required for Blank

S = Volume of thiosulphate solution required for sample titration.

W = Mass of sample

M = Concentration (Mol) of Iodine solution 253.81 which is the atomic mass of Iodine

V= 20ml aliquot.

pH Determination

The pH determination involves weighing 0.25g of the sample, adding 25ml of distilled water, stirring for one hour, allowing the sample to settle, and then measuring the pH using a pH meter.

Chemical Test Properties

A 0.1 g portion of each sample was weighed and placed into a Teflon crucible. The sample was then treated with a mixture of Aqua regia and Hydrofluoric acid (HF), where Aqua regia is composed of Hydrochloric acid and Nitric acid (Trioxonitrate V) in a 3:1 volumetric ratio. The ratio of HF to Aqua regia used was 2:1, and this mixture was added to the weighed sample in the crucible. The crucible was covered and heated in a fume chamber at 100 °C until a clear, milky solution formed. During heating, additional Aqua regia and HF were added as needed to prevent the sample from drying out. After achieving a transparent solution, it was allowed to cool and subsequently transferred into a 250 ml volumetric flask. The volume was adjusted to the 250 ml mark using distilled water. The resulting digested solutions were then used for the determination of oxides.

Determination of the Oxides Using Atomic Absorption Spectrometer (AAS)

After sample digestion, elemental quantification was performed following the recommended standard procedures. Atomic absorption spectroscopy (AAS) measurements were carried out using a Varian Spectra AA-10 spectrometer. For the determination of metal oxides, excluding Silicon (SiO_2), Calcium (CaO), and Aluminum (Al_2O_3), an air-acetylene flame was employed. In contrast, Silicon (SiO_2), Calcium (CaO), and Aluminum (Al_2O_3) were analyzed using a nitrous oxide-acetylene flame at a temperature of 2250 °C. The spectrometer's automated control system managed the fuel-to-oxidant gas ratio, while pure water was used as the blank. Additionally, an atomic absorption spectrophotometer model 1233 with an air-acetylene flame was used for the analysis of Iron (Fe_2O_3), Potassium (K_2O), Sodium (Na_2O), and Magnesium (MgO) oxides. The results obtained were then used to calculate their respective percentages.

Specific Gravity Determination

The specific gravity of the clay sample has already been calculated using the following steps. First, the empty measuring cylinder was weighed, and the weight was recorded as (W_1). Then, the clay sample was filled into the empty cylinder up to 25ml, and its weight was measured and recorded as (W_2). Water was added to the clay sample up to 50ml, and the mixture was properly mixed. The resulting mixture was weighed and recorded as (W_3). The cylinder was then emptied and cleaned thoroughly. Distilled water was poured into the clean, empty cylinder up to 50ml, and its weight was measured and recorded as (W_4). Using these recorded weights, the specific gravity of the clay sample was calculated using the formula.

$$\frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)} \quad (3)$$

(3.4)

Determination of Petrophysical Properties of Crude Oil

- **Determination of Crude Oil Density and API Gravity**

A clean and dry pycnometer was obtained. The mass of the empty pycnometer will be measured using a balance, and the value was recorded as W_1. The pycnometer was filled with crude oil, taking care to avoid introducing air bubbles. The filled pycnometer was weighed using the balance, and the value was recorded as W_2. The density of the crude oil was calculated using the recorded mass and the known volume of the pycnometer (V).

$$Density\ (g/cm^3) = \frac{filled\ pycnometer\ (W2) - empty\ Pycnometer\ (W1)}{Volume\ of\ pycnometer (V)} \quad (4)$$

(3.5)

$$Specific\ gravity\ (S.G) = \frac{Density\ of\ crude\ oil}{Density\ of\ water}.$$

(3.6)

$$API\ gravity = \frac{141.5}{S.G} - 131.5$$

(3.7)

- **Determination of Crude Oil Viscosity**

The viscosity measurement of crude oil was conducted using a clean and calibrated Redwood viscometer that was set up on a level surface. A representative sample of crude oil, which was prepared to be homogeneous and free from impurities, was filled up to the specified level in the viscometer cup. The bath surrounding the cup was filled with water to maintain the desired temperature of the crude oil. A clean and dry beaker was placed below the viscometer cup to collect the crude oil as it dropped from the orifice. The orifice of the viscometer cup was opened, and the timer was started as soon as the oil started to flow out. The timer was stopped when the lower meniscus of the oil reached the 50ml mark on the beaker, and the efflux time was recorded. The viscosity of the crude oil was then calculated by multiplying the efflux time (t) by the viscometer constant, giving us the kinematic viscosity value.
Dynamics viscosity (cp) is a product of density (g/cm^3) and kinematics viscosity (Cst).

$$Viscosity = \left(0.26(t) - \frac{171}{t}\right)\ \rho$$

(3.7)

- **Determination of Crude Oil Flash Point**

A representative crude oil sample was collected and filtered if necessary to determine its flash point. The prepared sample was placed into a clean, dry test cup, ensuring the thermometer bulb was fully immersed. The sample was then heated gradually at a controlled rate while being observed for vapor formation. As soon as vaporization became noticeable, the thermometer reading was carefully monitored. An ignition source was brought near the surface of the crude oil when the temperature approached the expected flash point. The temperature at which a brief flash or momentary flame appeared on the sample's surface was recorded as the flash point.

- **Determination of Crude Oil Cloud Point and Pour Point**

To determine the cloud point and pour point of the crude oil, a representative sample of the crude oil was obtained. A sufficient amount of the crude oil sample was poured into a clean and dry test tube. The test tube with the crude oil sample was then placed into the air coolant. The temperature was gradually reduced at a controlled rate, typically 1-2°C per minute. The sample was continuously monitored for the appearance of cloudiness. The temperature at which the crude oil sample became visibly cloudy was recorded as the cloud point. Additionally, the temperature at which the liquid sample ceased to flow or exhibited a significant increase in viscosity was recorded as the pour point.

- **Enhanced Oil Recovery (EOR) using Clay Particles**

The experimental investigation was carried out using a laboratory-scale enhanced oil recovery (EOR) setup designed to replicate wellhead and reservoir conditions. The system comprised a carbon dioxide (CO_2) cylinder to maintain reservoir pressure, a 12-liter stainless-steel pressure vessel representing the reservoir, a connecting flowline fitted with control valves simulating wellhead components, and a downstream collection container for temporary fluid storage. A condenser was positioned before the collection vessel to condense any entrained gases prior to fluid separation.
A mixture of 3 liters of crude oil and 7 liters of water (carrier phase) was prepared in a mixing vessel and homogenized before being transferred into the reservoir vessel, following initial characterization of the crude oil. Prior to loading, the flowline and reservoir vessel were thoroughly flushed and verified to be free of residual fluids and particulates. After introducing the crude oil–water mixture, the system was allowed to stabilize.

At the beginning of each recovery cycle, the CO_2 pressure valve was opened to apply a constant injection pressure while the flowline control valves were simultaneously activated, and the stopwatch was started. After 10 seconds, the pressure and flowline valves automatically closed. The produced fluid, consisting of recovered oil and water, was collected, measured, and recorded. Following phase separation, the water cut and individual fluid volumes were determined, and the petrophysical properties of the recovered oil were analyzed.
The crude oil–water mixture was then recharged into the reservoir vessel, followed by the addition of 0.02 liters of bacterial culture. The system was allowed a 24-hour reaction period, after which the same recovery procedure was repeated.
This methodology was subsequently extended to assess recovery performance using water containing different concentrations of clay nanoparticles. The reservoir vessel was filled with nanoparticle-enhanced water, pressurized with CO_2 to simulate reservoir conditions, and recovery data were collected for each EOR cycle. All measurements were analyzed to evaluate the effect of nanoparticle concentration on oil recovery efficiency.

II. RESULTS AND DISCUSSION

This chapter presents and analyzes the experimental results obtained from the characterization of the crude oil sample and the clay nanoparticles sourced from Oboburu, Egamini, and Afam. The results are organized to show the baseline properties of the crude oil prior to treatment, followed by the physical, chemical, and mineralogical characteristics of the clay samples. Subsequent sections detail the influence of varying concentrations of the clay nanoparticles on key petrophysical parameters of the crude oil, including density, viscosity, API gravity, and flow rate. These results form the basis for evaluating the effectiveness of the clay nanoparticles
as potential agents for enhanced oil recovery.

Petro-physical Properties of the Crude Oil Sample

Table 4.1: Petro-physical properties of the crude oil sample at initial condition

D	T	DV	TP	FP	API	CP	PP
0.901	217	12.496	28	58	15.54	5.7	-0.45

D=Density, T=Time, DV=Dynamic Viscosity, TP=Temperature, FP=Flash point, API=API Gravity, CP=Cloud point, PP=Pour point

In Table 4.1, oil viscosity, density, API gravity, flash point and specific gravity evaluations all initially conducted at standard conditions revealed that flow properties of the crude sample demonstrated a typical black oil behavior as these evaluated parameters were in the magnitude of 0.901g/cm^{3}oil density, 15.54 ^{O}API oil gravity and a 1.0292 specific gravity. With the sample taking an average drain time of 217 seconds for 50 ml of crude, the dynamic viscosity of the crude at standard conditions in the magnitude of 5.64 cp confirms that the oil sample at these conditions is completely free from lighter – ends hydrocarbon and as such, internal flow resistance for the oil is in a high magnitude. 5.7^o C and -0.45^{o}C of cloud and pourpoint. 58^{o}C of flash point was recorded as shown on Table 4.1.

Determination of the Physical and Chemical Properties of the Clay Particles

Table 4.2: Characterization of Oboburu Clay Nanoparticle

S/N	PARAMETERS	PKS AC	UNIT
1	IND	1.57	mg/g
2	Bulk Density	8.2	g/cm3
3	Ash Content	2.2	%
5	pH	6.1	^{O}C
6	Particle Size	15	nm

Table 4.3: Characterization of Egamini Clay Nanoparticle

S/N	PARAMETERS	PKS AC	UNIT
1	IND	1.40	mg/g
2	Bulk Density	6.2	g/cm3
3	Ash Content	3.5	%
5	pH	3.6	°C
6	Particle Size	15	nm

Table 4.4: Characterization of Afam clay Nanoparticle

S/N	PARAMETERS	PKS AC	UNIT
1	IND	1.32	mg/g
2	Bulk Density	7.2	g/cm3
3	Ash Content	1.2	%
5	Ph	6.4	°C
6	Particle Size	15	nm

From the physical and chemical that was conducted on the clays, it was observed that Oboburu clay had the highest of Iodine number of 1.57mg/g followed by Egamini clay which recorded 1.40 mg/g and the least was recorded for Afam. 8.2 g/cm^3 bulk density was recorded for Oboburu, 6.2 was recorded for Egamini clay and 7.2 was recorded for Afam. Egamini clay had the highest ash content followed by Oboburu and the lowest was recorded for Afam clay. Afam clay had the highest pH of 6.4°C followed by 5.5°C for Egamini clay and 3.6°C for Oboburu.

Mineral Content for Egamini Clay

Table 4.5 presents the result for clay mineral determined using specific gravity method.

Table 4.5: Clay mineral determination using specific gravity

Sample	W_1 (g)	W_2 (g)	W_3 (g)	W_4 (g)	SG	pH	Mineral
Egamini	68.58	90.48	118.27	131.37	2.38	3.6	Gibbsite

The table shows the results of determining the specific gravity of the Egamini clay sample, which was found to be 2.38. The pH of the sample was measured to be 3.6 which shows that the clay is acidic. Based on these results, it was determined that the mineral present in the sample is gibbsite based on the specific gravity matching.

Exchangeable Cat Ions

Figure 4.1 below shows a chart of the exchangeable cat ions found in Egamini clay

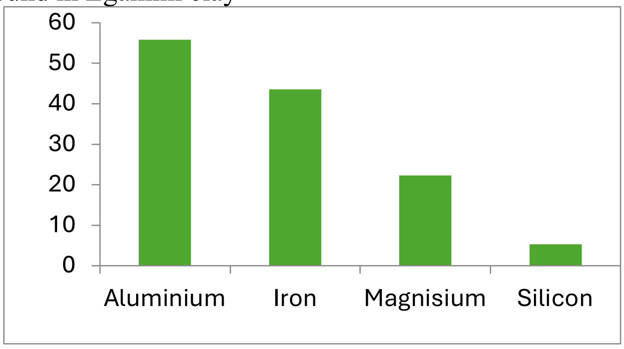

Figure 4.1: Exchangeable cat ions in Egamini clay sample

Oxides Present

Figure 4.2 shows a pie chat of oxides present in Egamini clay sample in percentages of their occurrence.

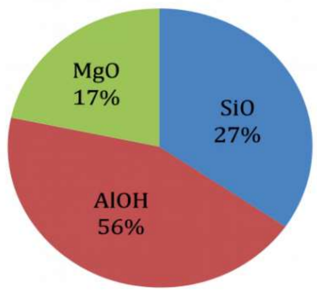

Figure 4.2: Oxides present in Egamini clay sample

From the result presented on Figure 4.1 and 4.2 shows that aluminum hydeoxide (AlO_2O_3 makes up most of the oxides in Egamini clay sample followed by silicon oxide (SiO_2) and the least is magnesium oxide (MgO_2).

Mineral Content for Oboburu Clay and Ionic Content Result

Clay Mineral

Table 4.6 present the result the result for clay mineral determined using specific gravity method. The calculations of specific gravity are shown in Appendix B1

Table 4.6: Clay mineral determination using specific gravity

Sample	Oboburu clay
W_1(g)	68.15
W_2(g)	94.68

W_3(g)	135.12
W_4(g)	118.27
S.G	2.74
pH	6.1
Refractive Index	2.505-1.532
2v angle	6^o-34^o
Mineral	Montmorillonite

Table 4.6 shows the results of the specific gravity of Oboburu clay sample which was found to be 2.74. The pH of the clay sample is 6.1, suggesting that it is slightly acidic. Based on these findings, it can be inferred that the mineral present in the clay is montmorillonite matching it with the specific gravity. See appendix A1 for chart.

Oxides Present in Oboburu Clay
Figure 4.3 shows a pie chat of the oxides present in Oboburu clay sample in their percentage of occurrence.

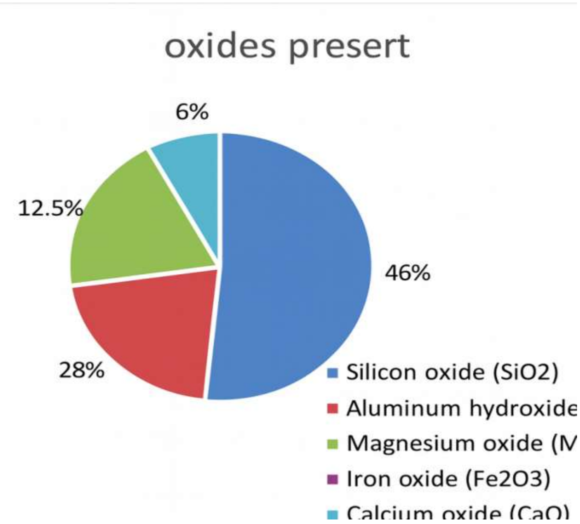

Figure 4.3: Oxides Present in Oboburu Clay Sample

Cations Present in Oboburu
Figure 4.2 shows a chart of the cations present in Oboburu clay sample

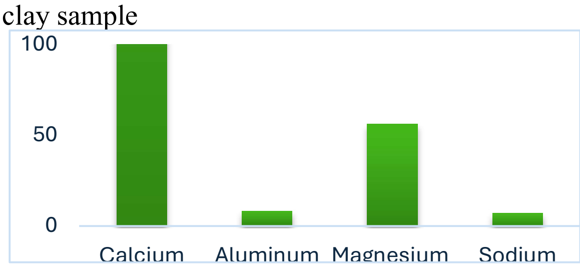

Figure 4.4: Cations Present in Oboboru Clay

From the result shown on Figure 4.3 and 4.4, silicon oxide (SiO_2) is the most abundant oxide in the Oboburu clay sample followed by aluminum oxide (Al_20_3), magnesium oxide (MgO) and calcium oxide (CaO) respectively with iron oxide (Fe_2O_3) as the least oxide present in the Oboburu clay sample.

Mineral Content for Afam Clay
Table 4.7 presents the result of clay mineral of Afam clay sample, determined by matching the specific gravity of the clay with known specific gravity ranges of clay.

Table 4.7: Clay mineral determination of Afam clay

Sample	Afam clay
W_1(g)	103.57
W_2(g)	126.81
W_3(g)	166.19
W_4(g)	182.32
S.G	4.41
pH	5.9
Mineral	Kaolinite

Exchangeable Cat Ions
Figure 4.1 below shows data of the exchangeable cat ions present in the clay sample.

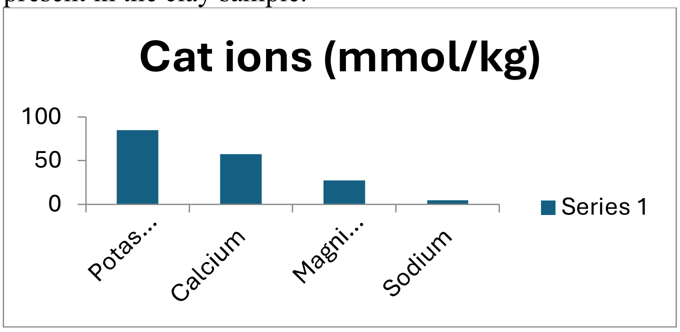

Figure 4.5: Exchangeable cat ions present in Afam clay sample

The Figure 4.5 shows the result for exchangeable cat ions present in Afam clay sample after analysis of the clay sample, the result shows that potassium ion is most dominant, followed by calcium ion, followed by magnesium ion and sodium ion as the least and its measured in mmol/kg.

Oxide Present
Figure 4.6 below shows a chart of oxides present in Afam clay sample.

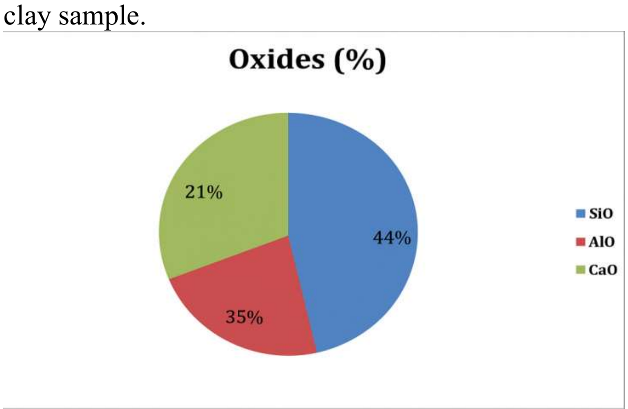

Figure 4.6: Oxides present in Afam clay sample

The Figure 4.6 shows the result for oxides present in Afam clay sample with silicon oxide (SiO) most dominant followed by calcium oxide (CaO) and aluminum.

Effect of Clay Nanoparticles on Density of the Crude Oil Sample

Figure 4.7 shows the effect of clay nanoparticle on density of the crude oil sample.

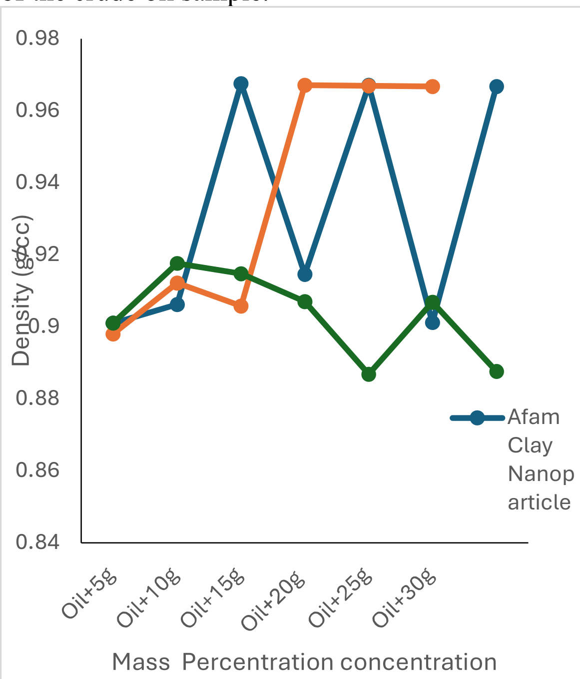

Figure 4.7: Effect of Clay Nanoparticles on Density

The density of the crude oil decreased rapidly from 0.901g/cc to 0.9062g/cc after 5g of Afam clay nanoparticle was introduced into the system. The density then increased by 0.0614g/cc when 10grams of the constituent (Afam clay nanoparticle) was added. A further decrease of about 0.053g/cc was recorded at 15gram of the same nanoparticle, however at 20g, a further increase of 0.9012 g/cc was observed. The density increased to 0.90671g/cc from 0.9012g/cc for 25 grams, the reason for the sudden increase in density could be because the optimum density has been reached.

For Egamini oxide nanoparticle, it shows that the density of the crude oil decreased rapidly from 0.901g/cc to 0.9176g/cc after 5 grams of the stated nanoparticle was introduced into the system. The density remained steady when another 5 grams of the constituent was added. A decrease of 0.91460g/cc was recorded at 15 gram of the same nanoparticle, however at 20 grams, the density decreased by 0.0046 and further decreased for 25 grams. For Oboburu oxide nanoparticles on the density shows that the density of the crude decreased from 0.901g/cc to 0.8876g/cc after 5grams of the stated nanoparticle was introduced into the system, signifying the nanoparticles had high effect on the oil. However, for 10grams of the mass percent concentration of the nanoparticles shows that the density increased to 0.89800 from 0.88760. Similarly, for 15g, the density increased to 0.91220 from 0.88760. An increase of 0.91260 was recorded for 20g and 0.91260 for 25grams which agrees with the work of Uranta *et al.,* (2022), that also found that an increase in the concentration of zinc and calcium oxide nanoparticles increase the density of heavy crude oil.

Effect of clay Nanoparticles on API Gravity of the Crude Oil Sample

Figure 4.8 depicts the effect of nanoparticles gotten from the clay samples on API gravity of the crude oil.

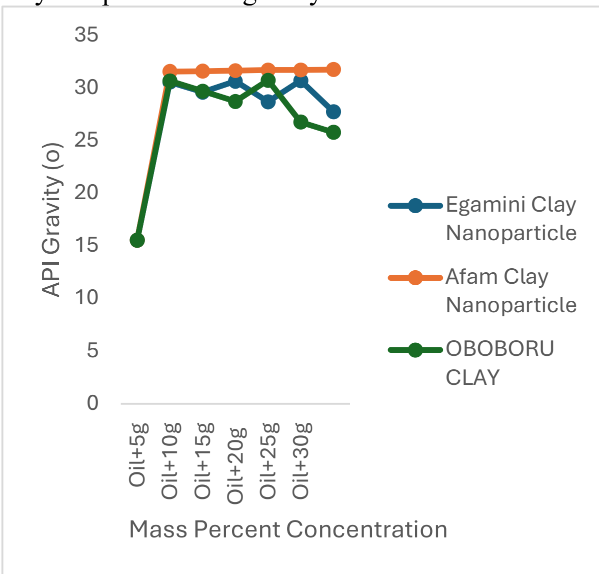

Figure 4.8: Effect of Clay Nanoparticles on API Gravity of the Crude Oil Sample

The API gravity of the crude oil showed a significant increase with the addition of Egamini clay nanoparticles. An initial 5 g addition raised the API from 15.540° to 28.7065°. Increasing the nanoparticle concentration to 10 g further increased the API by 2.9247°, while 15 g resulted in an API of 31.6312°. However, at 20 g, 25 g, and 30 g, the API gravities recorded were 27.7441°, 30.7065°, and 28.6876°, respectively.

For Afam clay oxide nanoparticles, a 5 g addition increased the API from 15.540° to 31.556°. When 10 g was added, the API slightly increased to 31.5936°, followed by a further minor increase of 0.0376° to 31.28126° at 15 g. A slight decrease of 0.0564° was observed at 20 g, but at 25 g and 30 g, the API increased again to 31.7065° and 31.7441°, respectively.

Oboburu clay oxide nanoparticles exhibited a different trend. At 5 g, the API increased from 15.540° to 30.658°. However, a decrease to 29.6876° was observed with 10 g. At 15 g, the API increased marginally from 23.1786° to 23.2124°, while 20 g led to a reduction of 0.7821°. At 25 g, the API rose again to 24.5128°. Additionally, several studies have highlighted clay nanoparticle effects on polymer-flooding systems for example, combining clay nanoparticles with polymer solutions has been shown to reduce polymer adsorption and improve mobility control during flooding, thereby enhancing oil recovery compared to polymer flooding alone.. Cheraghian et al.(2015). These observations are consistent with Nmegbu *et al.,* (2023), who reported that increasing the mass percent of silicon nanoparticles enhances the API gravity of heavy crude oil.

Effect of Clay Nanoparticle on Viscosity of the Crude Oil Sample

Figure 4.9 shows the effect of clay nanoparticles on the viscosity of the crude oil sample

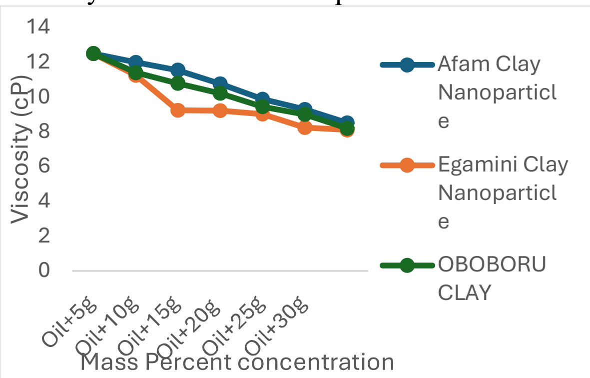

Figure 4.9: Effect of Clay Nanoparticles on Viscosity of the Crude Oil Sample

When Afam clay nanoparticle was added, the viscosity decreased from 12.496cp to 11.99 cp when 5grams was added. The viscosity decreased by 0.778cp when 10 grams of same was added. The viscosity decreased from 10.762 cP to 9.89 cP when 15 grams was added. A further decrease of 9.292, 8.517 was observed for 20grams and 0.60199 for 25 grams.

when 5-gram of calcium oxide nanoparticle was added to the viscosity decreased from 1.6cp to 0.54047. For 10 grams, the viscosity increased from 0.54047 to 0.541729, the viscosity decreased from 0.541729 to 0.53762 for 15 grams of egamini clay nanoparticle. The viscosity further decreased to 5.21494 for 25grams.

For Oboburu clay nanoparticle, the viscosity decreased from 12.49cp to 0.76891cp when 5grams was added, when 10-gram the viscosity decreased from 0.76891 to 0.72262. For 15 and 25 grams of nanoparticles, the viscosity increased to 0.73168 and later decreased to 0.70884. An increase of 0.03301 was recorded for 25 grams. Which agrees with Nmegbu *et al.,* (2023) that reveals that increase in mass percent concentration of silicon nanoparticle reduced the viscosity gravity of the heavy crude oil.

Effect of Clay Nanoparticles on the Flowrate of the Crude Oil Sample

The impact of the effect of nanoparticles on flowrate of the crude oil is presented in Figure 4.10.

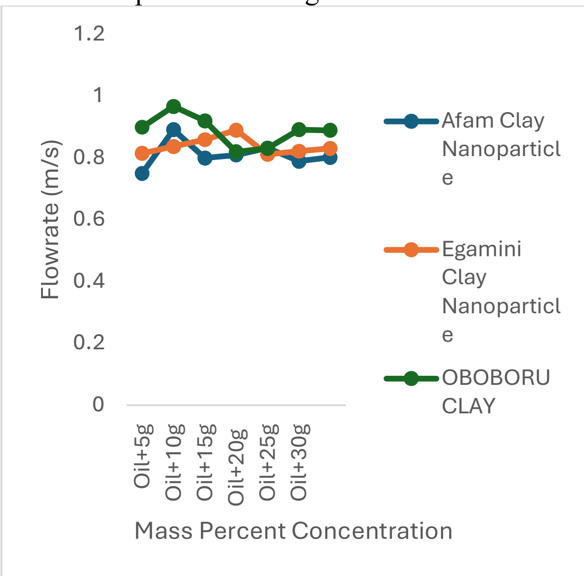

Figure 4.10: Effect of Clay Nanoparticles on the Flowrate of the Crude Oil Sample

The flow rate increased noticeably from 0.7 L to 0.896 L when 5 g of Afam clay oxide nanoparticles was added to the system. With 10 g of the nanoparticles, the flow rate rose slightly to 0.9 L, before gradually declining to 0.88 L at 15 g, 0.84 L at 20 g, and 0.78 L at 25 g.

The impact of Egamini clay oxide nanoparticles on the flow rate of recovered oil is illustrated in Figure 4.10. Introduction of 5 g of the nanoparticles increased the flow rate from 0.7 L to 0.8 L. The flow rate then rose slowly to 0.81 L at 10 g, 0.83 L at 15 g, and 0.86 L at 20 g, before slightly decreasing to 0.83 L at 25 g.

For Oboburu clay oxide nanoparticles, the trend shows a general increase in flow rate with rising nanoparticle concentration. At 5 g, the flow rate increased from 0.7 L to 0.89 L. A more substantial rise was observed at 10 g, reaching 0.97 L, and at 15 g, the flow rate peaked at 1.15 L. However, a decline to 1.0 L occurred at 20 g, followed by a sharp increase at 25 g.

III. CONCLUSION

The application of clay nanoparticles were used to alter the viscosity, API gravity, and interfacial tension between oil and water interface and lower the chemical adsorption onto reservoir rock surface which enables the enhancement of oil production. The conclusions are as follows;

i. The petrophysical properties of the crude oil were determined at initial reservoir conditions, and the results indicate that the oil is a typical black oil characterized by high viscosity.
ii. From the characterization of the physiochemical properties and nanoparticles of the clays, Oboburu clay nanoparticle had the highest physiochemical properties followed by Egamini clay, the least was recorded for Afam clay nanoparticle.
iii. For Oboburu clay CaO, Al_2O_3 MgO and SiO minerals were present in the clay, for Egamini clay the minerals content that were present are Al_2O_3 , FeO, MgO_2, and SiO were present and PbO, CaO, MgO and NaO_2 were present for Afam clay
iv. Increase in mass percent concentration of the clay nanoparticles (Egamini, Afam and Oboburu) decreases the density of the crude oil. The viscosity of the heavy crude decreased with increase in mass percent concentrations of the nanoparticles (Egamini, Afam and Oboburu).
v. The API Gravity increased with increase in mass percent concentration of the nanoparticles (Egamini, Afam and Oboburu).
vi. This research provides a significant contribution to knowledge by demonstrating, through controlled laboratory experiments, that locally sourced Niger Delta clays (Oboburu, Egamini, and Afam) can be processed into nanoparticles capable of enhancing the petrophysical properties of heavy crude oil. The study establishes measurable impacts of clay nanoparticle oxides on crude oil viscosity, density, and API gravity, confirming their potential to improve oil mobility and recovery efficiency.

Furthermore, this work closes an existing knowledge gap by providing experimental evidence that clay despite already existing in reservoir formations can function effectively as an enhanced oil recovery (EOR) agent when processed to nanoscale dimensions. The findings offer a cost-effective and locally available alternative to conventional EOR additives and lay a scientific foundation for scaling laboratory results into field-level petroleum recovery applications.

Recommendations
The following recommendations were made after the investigation on clay for oil recovery:

i. The use of clay nanoparticles in the Petroleum industry should be consider because it will rapidly increase the recovery of oil if put into practice in the industry.
ii. More clay nanoparticles should be tested to know the best in enhanced oil recovery.

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