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Laboratory Investigation on the Effects of Oboboru clay as Nano Particles on the Productivity of Apara Field During Microbial Enhanced Oil Recovery (MEOR) Application

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Abstract
Microbial enhanced oil recovery (MEOR) is a promising technique that utilizes microorganism metabolic activities to enhance oil recovery from reservoirs. This laboratory investigation focuses on the synergy between Oboboru clay and Acinebacter sp. in enhancing crude oil recovery. 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 volume of Acinebacter sp. reduces crude oil viscosity, with the lowest viscosity at 30 mL injection. This suggests the beneficial effect of Acinebacter sp. in improving flow characteristics and enhancing oil recovery. Comparing the effectiveness of adding Oboboru clay separately and with Acinebacter sp., it is observed that varying the volume of Acinebacter sp. alone shows a slightly greater decrease in viscosity, indicating the potential superiority of microbial treatment alone. These findings contribute to understanding MEOR techniques and highlight the potential of Oboboru clay and Acinebacter sp. 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 clay nanoparticles on Apara Field productivity during MEOR, revealing the transformative potential of combining clay minerals and microbial activity in oil recovery processes.

***Keywords**: Investigation, Laboratory, Nanoparticles, Microbial and Enhanced Oil Recovery*

1. INTRODUCTION

Microbial Enhanced Oil Recovery (MEOR) is a promising approach to increase oil recovery from reservoirs that have undergone primary and secondary recovery methods by utilizing microorganisms that can change the properties of crude oil and reservoir rock. Microbial Enhanced Oil Recovery involves the utilization of microorganisms to alter the properties of reservoir fluids and facilitate the extraction of trapped oil. This method has gained traction due to its potential to recover additional oil that conventional methods leave behind. MEOR has been studied for several decades, and it has been shown to be an effective method for recovering residual oil from mature oil fields. However, the efficiency of MEOR is limited by several factors, such as the availability of nutrients, the growth rate of microorganisms, and the ability of microorganisms to penetrate deep into the reservoir (Belyaev *et al*., 2019).

These bacteria are known for their ability to produce biosurfactants, which can reduce interfacial tension, enhance oil mobilization, and increase oil recovery rates. Acinetobacter sp. is versatile and can thrive in various environmental conditions, including high salinity and temperature commonly found in petroleum reservoirs.

Nanoparticles, with their unique physical and chemical properties, have a size range of 1-100 nanometers, making them suitable for various applications, including oil recovery. In microbial enhanced oil recovery (MEOR), nanoparticles can enhance the performance of microorganisms by providing nutrients, improving mobility, and altering the properties of crude oil and reservoir rock (Zhang et al., 2019).

The demand for sustainable and eco-friendly energy resources has led to the development of microbial-enhanced oil recovery (MEOR) as a cost-effective and environmentally sound approach (Shingala *et al.*, 2020).

Microorganisms can degrade heavy oil fractions, produce acids, solvents, gases, and selectively plug pathways, among other mechanisms (She et al., 2019).

Clay minerals are naturally occurring nanomaterials with a layered structure that possess a high surface area and strong adsorption capabilities, making them ideal candidates for altering fluid behavior and enhancing microbial activities. Clay nanoparticles offer great potential in microbial-enhanced oil recovery (MEOR) due to their unique properties and capabilities (Zhang et al., 2019).

Acinetobacter sp. is a genus of bacteria that has gained attention in the field of microbial enhanced oil recovery (MEOR) due to its potential application in improving oil recovery efficiency (Bodour & Maier, 2002).

Several studies have introduced Nanoparticles as an effective agent for changing properties of rock and fluid system. Many researchers reported achievement of greater amounts of oil during application of Nanoparticles (Sun *et al*., 2017).

Numerous studies have investigated the effects of various types of nanoparticles on fluid-fluid interactions and interfacial tension. For instance, metal oxide nanoparticles such as silica, alumina, and titania have been widely explored due to their stability and tunable surface properties (Kumar *et al*., 2019; Bhattacharjee *et al.*, 2021).

Furthermore, Wu et al. (2020) explored the use of graphene oxide nanoparticles to modify fluid-fluid interactions and interfacial tension. The study demonstrated that graphene oxide nanoparticles effectively reduced interfacial tension between oil and water, facilitating the displacement of oil from porous media.

Nanoparticles have also been investigated for their potential to enhance MEOR processes. Various types of nanoparticles have been used, including clay nanoparticles, metal oxide nanoparticles, and carbon-based nanoparticles (Hosseini *et al.*, 2020).

Zhang et al., (2020) investigated the effects of interfacial interactions on the thermal properties of polymer-nanoparticle hybrids. They synthesized polyvinyl alcohol (PVA)-coated graphene oxide

(GO) nanoparticles and incorporated them into a PVA matrix. The results showed that the interfacial interactions between the PVA matrix and PVA-coated GO nanoparticles significantly enhanced the thermal conductivity of the hybrids.

Oyewole et al., (2020) evaluated the potential of clay nanoparticles as an additive for MEOR in a laboratory setting. The researchers conducted core flooding experiments to measure the impact of clay nanoparticles on oil recovery using microbial consortia. The study found that the addition of clay nanoparticles improved the efficiency of MEOR by enhancing the growth and activity of microorganisms.

Ovuede et al., (2020) evaluated the effect of clay nanoparticles on MEOR using Bacillus subtilis as the microbial agent. The researchers conducted core flooding experiments to measure the impact of clay nanoparticles on oil recovery under different conditions. The study found that the addition of clay nanoparticles improved the efficiency of MEOR by enhancing the growth and activity of Bacillus subtilis.

2. MATERIAL AND METHOD

2.1 Materials and Equipment Used in the course of the laboratory investigation

i. Nanoparticle (Oboboru clay)
ii. Crude oil
iii. Bacterial (Acinetobacter sp)
iv. Pycnometer
v. Redwood Viscometer
vi. Measuring cylinder
vii. Air coolant
viii. Pensky Martins Flash Point Tester

2.2 Method

This laboratory research was conducted in three stages phases

i. To investigate the effects of nanoparticles and microbes on the petrophysical properties of crude oil. In the initial stage, petrophysical tests on the crude oil to identify its properties and establish a baseline for any changes that may occur.
ii. Preparation of nanoparticles (Oboboru clay)
iii. culturing of microbe (Acinetobacter sp.) to be introduced into the crude oil sample.

2.2.1 Density and API Gravity Determination

A clean and dry pycnometer was obtained. The mass of the empty pycnometer was measured using a weighing balance, and the value was recorded as (W_1). The pycnometer was filled with crude oil, gently to avoid introducing air bubbles into the pycnometer. The filled pycnometer was weighed using the weighing 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) as shown in equation 1

$$Density\ (g/cm^3) = \frac{filled\ pycnometer\ (W2) - empty\ Pycnometer\ (W1)}{Volume\ of\ pycnometer (V)} \quad (1)$$

$$Specific\ gravity\ (S.G) = \frac{Density\ of\ crude\ oil}{Density\ of\ water} \quad (2)$$

$$API\ gravity = \frac{141.5}{S.G} - 131.5 \qquad (3)$$

2.2.2 Viscosity Determination

The viscosity measurement of crude oil was conducted using a clean and calibrated Redwood viscometer that was set up on a level surface. The crude oil 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).

$$Viscosity = \left(0.26(t) - \frac{171}{t}\right)\ \rho \qquad (4)$$

2.2.3 Clay Nanoparticle preparation

To prepare the Oboboru clay nanoparticles, a sample of the desired clay material was obtained. The clay sample was thoroughly cleaned to remove any visible impurities or debris. The clay sample was then dried thoroughly to eliminate any moisture content. The dried clay was ground into a fine powder using a mortar and pestle or a mechanical grinder. The powdered clay was then sieved using a mesh sieve with the desired pore size to obtain particles of uniform size. The clay powder was then dispersed in a suitable solvent or dispersing agent to create a suspension, enhancing dispersion through ultra-sonication if needed. Filtration technique was used to eliminate any remaining impurities or larger particles from the suspension. The resulting clay nanoparticles were then dried by evaporating the solvent. Finally, the prepared clay nanoparticles were characterized to confirm their size and morphology.

2.2.4 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.

$$\frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)} \qquad (5)$$

2.2.5 Identification of Clay Minerals

To identify the clay mineral in the sample, the specific gravity value obtained from the clay mineral sample was first recorded. A reference database that provides specific gravity values for various clay minerals was then compiled or accessed. This database was sourced from published literature, mineralogy textbooks, or reputable online resources. Specific gravity values were gathered from the reference database, and clay minerals with specific gravity values similar or matching to that of the sample were identified by referring to the database. The range of specific gravity values documented for each clay mineral species in the reference database was carefully considered. The degree of similarity between the specific gravity value of the sample and those in the reference database was assessed. Clay minerals that fell within the range of specific gravity values from the reference database were emphasized for further consideration or analysis.

2.2.6 Determination of Insitu Microbes and Culturing of Microbes

Acinetobacter sp was cultured by preparing a suitable culture medium based on the strain's nutritional requirements and growth characteristics. Weigh out the appropriate amount of medium powder or ingredients and dissolve them in distilled water, adjusting the pH to the optimal range for growth. Sterilize the medium using autoclaving or other sterilization methods, and allow it to cool. Inoculate the sterilized medium with a small amount of Acinetobacter sp. culture or a pure isolate obtained from a reliable source. Incubate the culture at the recommended temperature and conditions for Acinetobacter sp. growth. Monitor the culture regularly for signs of growth, such as changes in turbidity or colony formation. If necessary, subculture the growing culture into fresh media to maintain its viability. Throughout the process, maintain proper aseptic techniques to prevent contamination.

2.2.7 Evaluation of the Effect of Acinebacter sp and Oboboru Clay on Microbial Enhanced Oil Recovery

Two sets of experiments were conducted to enhance the microbial enhanced oil recovery process. In the first set, cultured Acinetobacter sp. was added to 200ml of the crude oil sample in varying concentrations (5ml, 10ml, 15ml, 20ml, 25ml and 30ml) and allowed to settle for 24 hours. A re-evaluation was conducted using a 50ml of the sample mixed with Acinetobacter sp. to assess its impact on the petrophysical properties of the crude oil. In the second set, another 200ml of the crude oil sample was measured into another beaker, and 10g of Oboboru nanoclay and cultured Acinetobacter sp. in varying quantities (5ml, 10ml, 15ml, 20ml, 25ml and 30ml) were added to the crude oil sample. After allowing the mixture to settle for 24hours, the petrophysical properties of the crude oil were reevaluated using 50ml of the sample mixed with oboboru nanoclay and acinebacter sp to determine any changes. The objective was to quantify the level of improvement achieved in microbial enhanced oil recovery through the introduction of cultured microbes, specifically Acinetobacter sp. The thorough assessment involved analyzing and measuring the extent of enhancement brought about by the introduced nanoparticles and microbes in the crude oil sample.

Belyaev, S., Mirzoyan, N., & Mogila, Y. (2019). Microbial enhanced oil recovery: Current status and future prospects. Journal of Petroleum Science and Engineering, 175, 781-789.

3. RESULTS AND DISCUSSION

3.1 Oboboru Clay Mineralogy and Ionic Content Result

Table 1 present the result the result for clay mineral determined using specific gravity method.

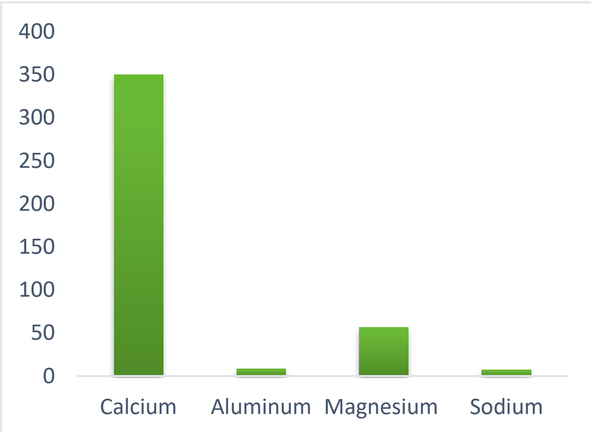

Table 1: Clay mineral determination using specific gravity.

Sample	W_1(g)	W_2(g)	W_3(g)	W_4(g)	S. G	pH	Refractive index	2v angle	Mineral
Oboboru clay	68.15	94.68	135.12	118.27	2.74	6.1	2.505-1.532	6^0 - 34^0	montmorillonite

The table shows the results of the specific gravity of oboboru 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.

3.2 Oxides present in Oboboru clay

Figure 1 shows a pie chat of the oxides present in oboboru clay sample in their percentage of occurrence.

Figure 1: oxides present in Oboboru clay sample.

From the Figure 1, it shows that silicon oxide (SiO_2) is the most abundant oxide in the oboboru clay sample followed by aluminum oxide(Al_2O_3), magnesium oxide(MgO) and calcium oxide(CaO) respectively with iron oxide(Fe_2O_3) as the least oxide present in the oboboru clay sample.

3.3 Crude Oil Characterization at Initial Condition

At the Initial Testing stage, the petrophysical properties tests were carried out on the crude oil sample. Table 2 present the results obtained from the petrophysical test conducted on the crude oil sample at initial condition.

Table 2: petrophysical properties of crude oil sample at initial condition

Density (g/cm³)	Time (seconds)	Kinematic viscosity (cst)	Dynamic Viscosity (c.p)	Temperature (ºc)	Flashpoint (ºc)	API Gravity	Cloud point (ºc)	Pourpoint (ºc)
0.8675	65.45	14.404	12.496	28	58	31.6124	5.7	-0.45

3.3 Microbial Enhanced Oil Recovery Process

Figure 2 shows a plot of Density against varying concentration of acinebacter sp

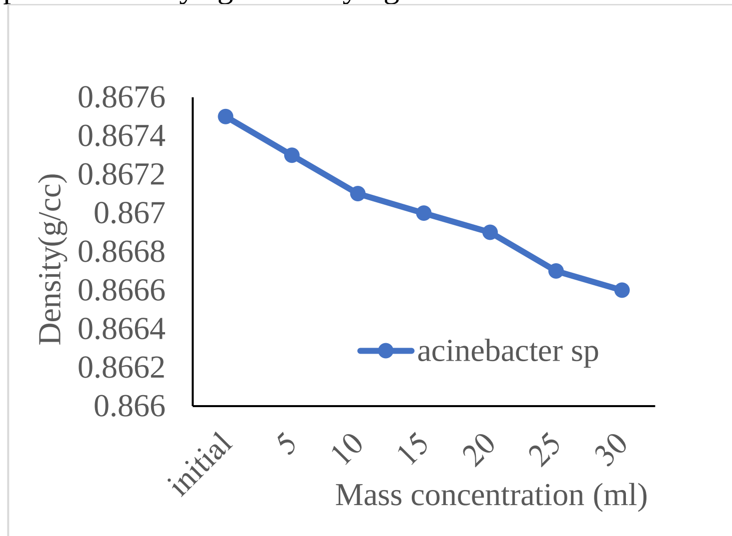

Figure 2: plot showing the variation of density at various mass concentration

Based on the results obtained, it can be observed that there is a change in the density of the crude oil at different concentration of Acinebacter sp.

The initial density of the crude oil was 0.8675 g/cm^3, As the volume of Acinebacter sp. Increased from 5 ml to 30 ml, there was a slight decrease in density, indicating that the presence of Acinebacter sp. did not significantly affect the density of the crude oil.

The effect of bacteria on the crude oil API Gravity is presented in Figure 3

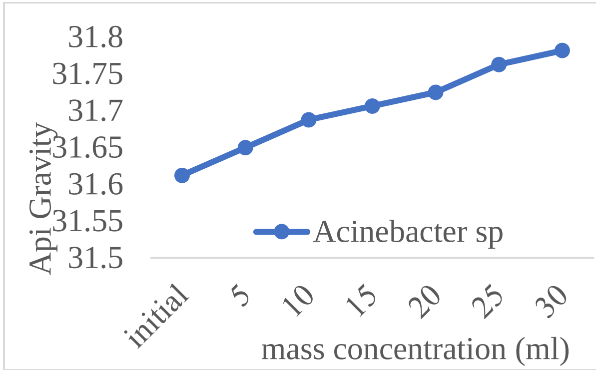

Figure 3: plot of API gravity against concentration

The graph shows the relationship between American petroleum institute (API) gravity and mass concentration of varying dosage of acinebacter sp on crude oil. The API gravity of the crude oil is inversely related to the density. As the API Gravity value increases, the density of the crude oil decreases. In the given sample data, the API Gravity values increased slightly as the quantity of Acinetobacter sp. was increased from 5ml to 30ml.

Based on this information, it can be inferred that the presence of Acinetobacter sp. in varying quantities may have a minimal impact on the density of the crude oil, resulting in a slight increase in API Gravity. Figure 4.5 shows a plot of viscosity against mass concentration.

The effect of bacteria on the viscosity of the crude oil is presented in Figure 4

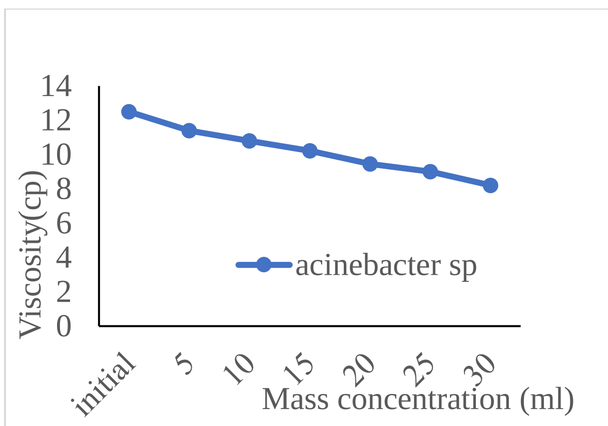

Figure 4: Plot of viscosity vs. mass concentration

The addition of Acinebacter sp. had a noticeable impact on the viscosity of the crude oil. As the volume of Acinebacter sp. increased, the viscosity decreased consistently. The lowest viscosity value of 8.208 cp was recorded at 30 ml of Acinebacter sp. injection, which is a significant reduction from the initial viscosity value of 12.496 cp. These results suggest that the presence of Acinebacter sp. has a beneficial effect on reducing the viscosity of crude oil. This reduction in viscosity can potentially improve the flow characteristics and enhance oil recovery processes. This implies that there is an inverse relationship between the volume of Acinebacter sp. (microbe) added to the crude oil and its viscosity. As the volume of Acinebacter sp. increases, the viscosity of the crude oil decreases. The reduction in viscosity suggests that Acinebacter sp. may possess properties or enzymes that can break down or modify certain components in the crude oil, leading to a decrease in viscosity.

3.3.1 Results of crude oil mixed with oboboru nanoclay and acinebacter sp

Figure 5 shows a plot of crude oil density against mass concentration.

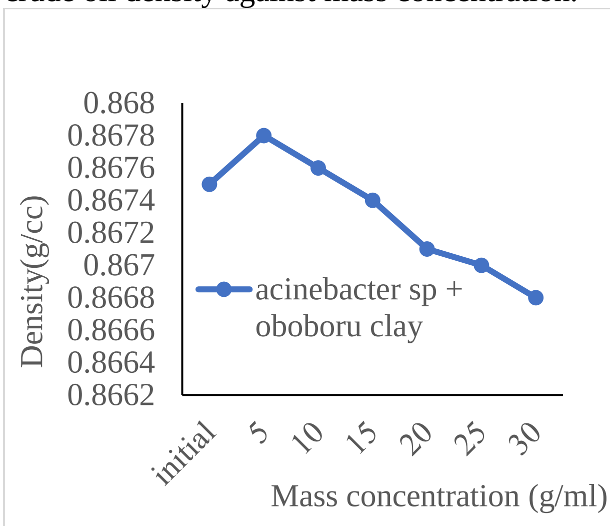

Figure 5: Plot of crude oil density vs. mass concentration

Based on the provided results, we can observe the effects on density when adding consortium of clay and Acinetobacter sp. to the oil sample. These additions resulted in minimal changes in density. The density of the crude sample was minimally affected by the nanoclay and bacteria. Figure 4 shows the plot of API gravity against mass concentration.

Figure 6 shows the effects of nanoclay and bacteria on the API Gravity of the crude Oil

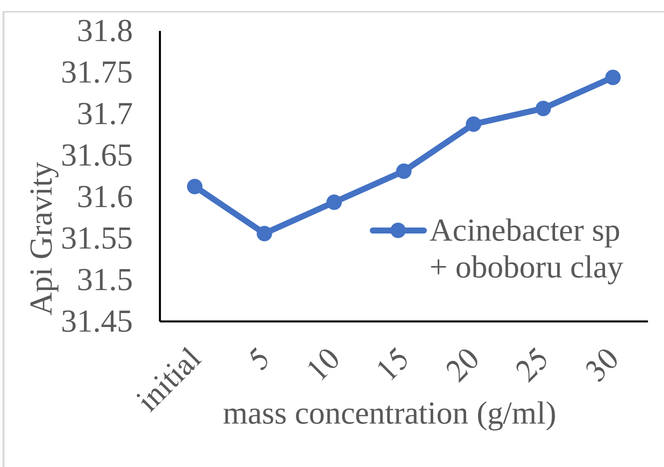

Figure 6. Plot of API gravity against mass concentration

From figure 5, the API Gravity of the crude oil decreased slightly as the quantity of Acinetobacter sp. in combination with Oboboru clay was increased from 5ml to 30ml. The initial API Gravity of the crude oil sample was 31.6124. However, when 2.5g of Oboboru clay and 2.5ml of Acinetobacter sp. were added to the oil, the API Gravity decreased to 31.5560 ^{o}API. As the volume of Acinetobacter sp. in combination with Oboboru clay was increased to 30ml, the API Gravity slightly increased to 31.7441 ^{o}API.

These results suggest that the combination of Acinetobacter sp. And Oboboru clay may have a minimal impact on the API Gravity of crude oil. Figure 4 shows a plot API Gravity against concentration.

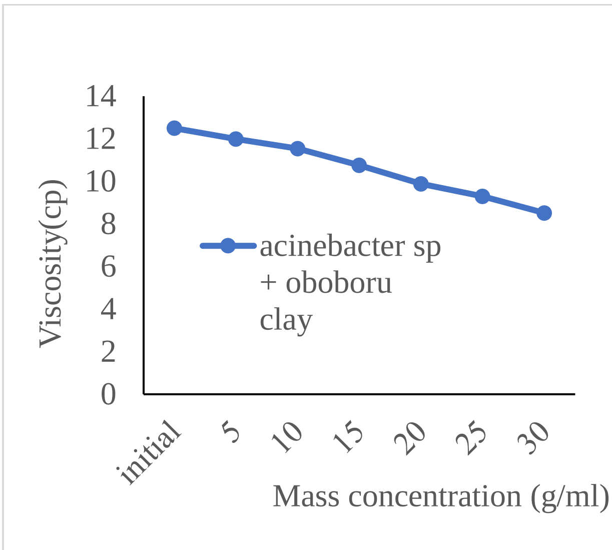

Figure 7: plot of viscosity against mass concentration

An interesting observation was the decreasing trend in both kinematic and dynamic viscosity at equal g/ml of both the nanoclay and the bacteria.This suggests that the additions contributed to a reduction in oil viscosity. As both consortium of nanoclay and bacteria was introduced to the oil, there was a decrease in viscosity from the initial conduction as 11.99 cP was recorded for 5g/ml and 8.517cP was recorded for 30g/ml respectably. This combination has the potential to enhance microbial enhanced oil recovery (MEOR) by reducing interfacial tension and promoting oil displacement through improved bacterial activity and reduced viscosity.

4. CONCLUSION AND RECOMMENDATION

4.1 CONCLUSION

i. The viscosity of the heavy crude sample decreased with increase in the mass percent concentration of (nanoclay and bacteria)

ii. The density of the heavy crude sample decreased with increase in the mass percent concentration of (nanoclay and bacteria)

iii. The API gravity increased with increase in the mass percent concentration of (nanoclay and bacteria)

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