

Laboratory Investigation on the Effects of Okochiri clay as Nano Particles and Staphylococcus During Microbial Enhanced Oil Recovery (MEOR) Application

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Abstract

This study Investigates a comparative analysis of the impacts of Staphylococcus bacteria and Okochiri clay as nanoparticles on enhanced oil recovery (EOR) techniques. The aim of the research was to evaluate the effectiveness of these agents in facilitating the displacement of crude oil from reservoirs. The properties of the crude oil and clay were initially assessed, with the crude oil density reported at 0.937, viscosity at 1.1, specific gravity at 0.937, and API gravity at 20.2, providing crucial insights into the characteristics of the crude oil. The mineral content of the Okochiri clay was determined, revealing the presence of silicon oxide (SiO₂) at 48.16%, aluminum hydroxide (Al₂O₃) at 26.49%, calcium oxide (CaO) at 3.631%, iron at 15.80%, magnesium at 7.76%, and sodium at 7.00%. The specific gravity of the clay sample was measured at 2.36, with a pH of 3.2, indicating the composition and acidity of the clay sample. Comparative analyses were conducted to assess the effects of bacteria and clay nanoparticle on the crude oil properties. The density of the crude oil decreased from 0.9328 to 0.915 with increasing concentrations of Staphylococcus bacteria, while the clay demonstrated a faster reduction in crude oil density. The API gravity of the crude oil increased with the addition of both bacteria and clay, signifying an increase in the oil's viscosity. Moreover, the viscosity of the crude mixture with bacteria indicated a peak at 10ml, followed by a reduction as the concentration increased, while the viscosity of the crude mixture with clay decreased consistently as the clay concentration increased from 5g to 30g. The study provides valuable insights into the potential applications of Pseudomonas bacteria and Okochiri clay in EOR strategies, highlighting their respective impacts on crude oil properties and recovery. However, further investigations into their long-term efficacy, field applicability, compatibility with diverse reservoir types, techno-economic feasibility, and environmental implications are recommended for a more comprehensive understanding of their practical implementation in the oil and gas industry.

Keywords: Investigation, Laboratory, Clay Nanoparticles, Okochiri, Microbial and Enhanced Oil Recovery

1. INTRODUCTION

The global demand for energy continues to rise, and as conventional oil reserves become increasingly depleted, the search for advanced techniques to enhance oil recovery from reservoirs has gained paramount importance. Enhanced oil recovery (EOR) methods have emerged as crucial strategies to extract a larger proportion of the remaining oil from reservoirs that have undergone primary and secondary recovery methods. Among the diverse EOR techniques being explored, the implementation of microbial-assisted processes and the utilization of natural minerals like clay have shown promising potential in improving oil recovery efficiency. Staphylococcus bacteria can influence wettability

characteristics, interfacial tension, and other factors that directly impact oil recovery. Research has shown that these microbial activities can lead to improved displacement of oil and increased oil recovery percentages from reservoirs.

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, i. metal oxide nanoparticles such as silica, alumina, and ii. titania have been widely explored due to their stability iii. iv.

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

Nanoparticle (Okochiri clay)

Crude oil

Bacterial (***Staphylococcus***)

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 (Okochiri 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

$$\text{Density (g/cm}^3\text{)} = \frac{\text{filled pycnometer (W}_2\text{)} - \text{empty Pycnometer (W}_1\text{)}}{\text{Volume of pycnometer(V)}}$$

(1)

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

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

(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).

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

2.2.3 Clay Nanoparticle preparation

To prepare the okochiri 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 ultrasonication 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.

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

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 Staphylococcus and Okochiri 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 Staphylococcus. 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 Staphylococcus. 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 Okochiri 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 okochiri nanoclay and Staphylococcus 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 Staphylococcus. The thorough assessment involved analyzing and measuring the extent of enhancement brought about by the introduced nanoparticles and microbes in the crude oil sample using a flooding system shown in Figure 1.



Figure 1: Enhanced Oil Recovery Setup

3. RESULTS AND DISCUSSION

3.1 Staphylococcus 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.

Sampl e	W ₁ (g)	W ₂ (g)	W ₃ (g)	W ₄ (g)	SG	p H	Miner al
Okoc hiri Clay	77.5	109.2	113.1	182.5	2.36	3.2	Smect ite

The table1 shows the results The table provides information about the Okoshiri sample. It has specific gravity of 2.36, indicating that its relatively light weighted. The low pH value of 3.2 suggests that the sample is acidic in nature. The mineral composition of this sample is identified as Smectite, which is a group of clay minerals known for their swelling properties and high cation exchange capacity. The samples weight measurements (W₁, W₂, W₃, W₄) show variations, which might be attributed to samples heterogeneous nature or experimental error.

3.2 Oxides present in Okochiri clay

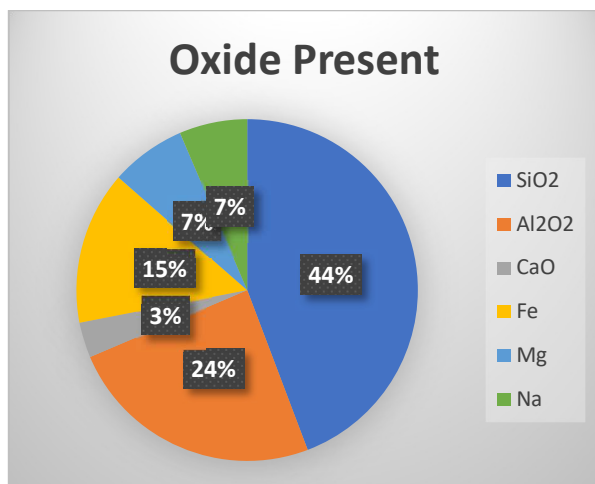


Figure 2: shows a pie chat of the oxides present in okochiri clay sample in their percentage of occurrence.

From the Figure 1, The chart presents the chemical composition of a clay mineral, with silicon oxide as the predominant component at 48.16%, providing structural stability, followed by aluminum oxide at 26.49%, contributing to water and nutrient retention. Minor components include calcium oxide at 3.631%, influencing pH and nutrient availability, iron as 15.80%, responsible for the clays color and chemical properties. Magnesium at 7.76% and sodium as 7.00% which affects the cation exchange capacity and swelling properties, respectively.

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

Crude Oil Properties	Results
Density	0.937
Viscosity	1.1
Specific Gravity	0.937
API Gravity	20.2

Table 2 presents the results of various properties analyzed for the crude oil sample. The density of the crude oil is reported as 0.937, indicating the mass per unit volume of the oil. The viscosity is measured as 1.1, representing the oil's resistance to flow. The specific gravity, reported as 0.937, indicates the density of the crude oil relative to the density of water. The API gravity of 20.2 suggests that the crude oil is relatively heavy. These properties collectively provide valuable insights into the characteristics of the crude oil, aiding in decision-

making processes related to transportation, processing, and refining.

3.3 Microbial Enhanced Oil Recovery Process

3.3.1 Effect of Bacteria on the Density of the Crude Oil

Figure 3 shows a plot of Density against varying concentration of Staphylococcus

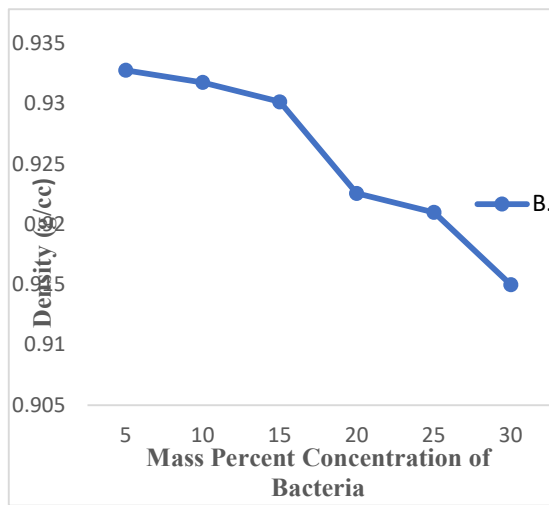


Figure 3: Effect of Bacteria on Density

From Figure 3 it shows the effect of bacteria on the crude cause a decrease in the density of the crude after each concentration. The density decreases from 0.9328 at 5ml to 0.915 at 30ml

3.3.2 Effect of Clay Nanoparticle on the Density of the crude oil.

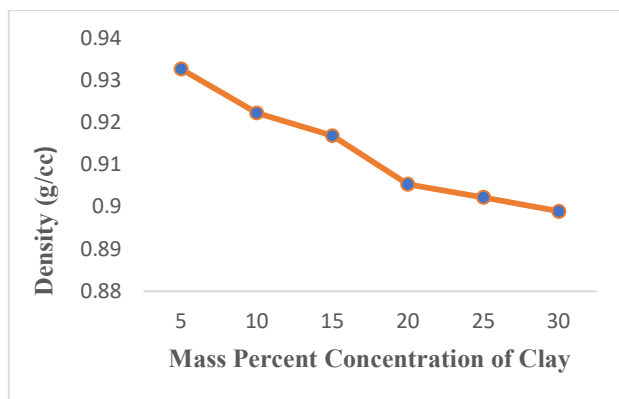


Figure 4: Effect of Clay Nanoparticle on Density shows the effect of clay on the crude. The clay acting as nanoparticle causes a decrease in density of the crude after each concentration. Unlike the bacteria, clay act faster in reducing the density of the crude.

3.3.3 Effect of Bacteria on the API Gravity of the Crude Oil

Figure 5 shows the effect of bacteria on the API of the crude oil

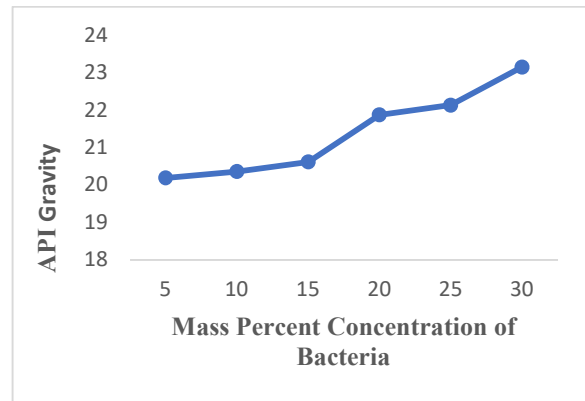


Figure 5: A plot of API vs Mass Percent of Bacteria

Figure 5 shows the API gravity of the crude + bacteria at various concentrations. The API is a measure of how heavy or light petroleum liquid is compared to water. If its API gravity is greater than 10, it is lighter and floats on water, if less than 10 it is heavier and sink. The API gravity of the crude increases as the concentration of bacteria increases making the crude more viscous to flow.

3.3.5 Effect of Clay Nanoparticle on the API Gravity of the Crude Oil

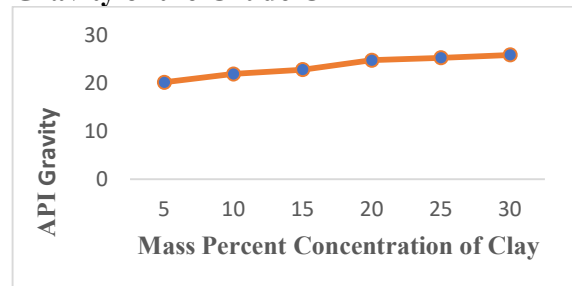


Figure 6: A plot of API vs Mass Percent of Clay Nanoparticle

Figure 6 shows the API gravity of the crude + clay at various concentrations. The API is a measure of how heavy or light petroleum liquid is compared to water. The API gravity of the crude increases as the concentration of bacteria increases making the crude more viscous to flow. The API of the crude increases from 20.19 at a concentration of 5g to 25.89 at 30g concentration.

3.3.6 Effect of Bacteria on the Viscosity of the Crude Oil

The plot of viscosity versus mass percent concentration of bacteria is presented in figure 7.

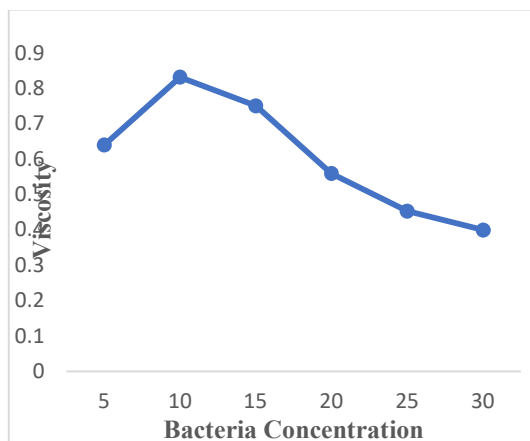


Figure 7: Comparative Analysis of Viscosity and Bacteria

Figure 7 shows the graphical representation of viscosity of the crude mixture at different concentrations with bacteria. Viscosity is a measure of fluid resistance to flow. A fluid with large viscosity resists motion because its molecular make up gives it a lot of internal friction. At 10ml the viscosity measures its highest point, however it reduces as the concentration increases from 15ml to 30ml.

3.3.7 Effect of clay nanoparticle on the Viscosity of the Crude Oil

The plot of viscosity versus mass percent concentration of clay is presented in figure 8

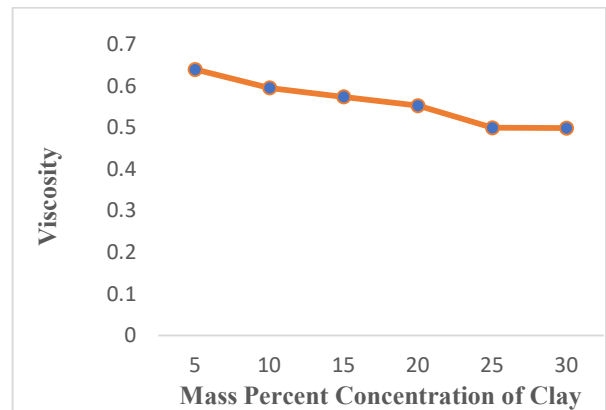


Figure 8: Comparative Analysis of Viscosity and Clay

Figure 8 shows the graphical representation of viscosity of the crude mixture at different concentrations with bacteria. Viscosity is a measure of fluid resistance to flow. A fluid with large viscosity resists motion because its molecular make up gives it a lot of internal friction. Unlike the bacteria, the viscosity of the crude reduces as the concentration of clay increases. The viscosity reduces from 0.64cst at 5g to 0.499cst at 30g concentration of the clay.

4. CONCLUSION AND RECOMMENDATION

4.1 CONCLUSION

- i. The mineral analysis identified the clay as Smectite, signifying its potential for enhanced oil recovery (EOR) and its capability to modify crude properties through nanoparticles.
- ii. Changes in crude oil density were observed in response to the introduction of Staphylococcus with an initial increase at lower concentrations (5-15ml) and a subsequent decrease at higher concentrations (20-30ml).
- iii. The mass percent concentration of the nanoparticles displayed an inverse relationship with the density of the crude oil, indicating the clay's effectiveness in reducing crude density.
- iv. The consistent decrease in crude oil density with increasing nanoparticle concentration underscores the role of clay minerals in

improving the fluidity and mobility of the crude oil within the reservoir for enhanced extraction.

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