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Enhanced Oil Recovery usıng Fermented Sap (Palm Wıne) on Niger Delta Reservoir

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Abstract

Enhanced oil recovery (EOR) is essential for maximizing oil extraction from reservoirs. This study investigates the effectiveness of fermented sap (palm wine) as a natural surfactant for EOR in sandstone reservoirs, comparing it against the conventional synthetic surfactant sodium dodecyl sulfate (SDS). Laboratory experiments assessed oil recovery efficiency, interfacial tension (IFT) reduction, and wettability alteration. Results showed that the palm wine surfactant achieved an oil recovery efficiency of 69.3% of the original oil in place (OOIP) which is significantly higher than the 48.23% obtained with SDS. The palm wine surfactant also reduced IFT to 2.48 mN/m, compared to 3.73 mN/m for SDS, and altered wettability from oil-wet to water-wet, decreasing the contact angle from 135° to 70°, while SDS reduced it from 135° to 80°. These findings suggest that the natural bio surfactants in palm wine, such as saponins and proteins, effectively enhanced oil recovery by reducing IFT and altering wettability. The study concludes that palm wine surfactant is viable eco-friendly alternative to synthetic surfactants for EOR applications

1. Introduction

The continuous surge in global energy demand underscores the imperative for the oil and gas industry to enhance hydrocarbon recovery from existing reservoirs. Enhanced Oil Recovery (EOR) techniques have become pivotal in this context, aiming to extend the productive life of oil fields by extracting oil that primary and secondary recovery methods leave behind. Primary recovery methods exploit the natural reservoir pressure to drive oil to the surface, typically resulting in the extraction of only about 10-15% of the original oil in place (OOIP) [1]. As reservoir pressure depletes, secondary recovery methods such as water flooding and gas injection are deployed to maintain pressure and improve oil displacement, increasing the recovery factor to approximately 20-40% of [2]. Despite these efforts, a significant portion of the oil remains trapped within the reservoir, necessitating advanced EOR techniques.

2EOR techniques are designed to alter the physical and chemical properties of the reservoir fluids and rocks to mobilize the remaining oil. Among these techniques, chemical EOR, which involves the injection of surfactants, polymers, or alkalis, has shown particular promise in reducing interfacial tension and modifying the wettability of reservoir rocks to enhance oil mobility [3]. The environmental impact and cost-effectiveness of EOR methods have driven interest in the use of natural surfactants derived from renewable resources as a sustainable alternative to synthetic chemicals. Natural surfactants, such as saponins from plants and various biopolymers, have demonstrated potential in enhancing oil recovery while minimizing environmental risks [4] [5] [6] [7]. The application of local polymer, cassava starch and potato starch as mobility control agent on chemical EOR has been investigated [8]. They authors conducted a laboratory experiments to evaluate the rheological properties of the polymer solutions and their wettability to enhanced oil recovery. Their results showed that the polymer solutions improved oil recovery by 15-20% compared to water flooding. Locally sourced polymer, guar gum as a mobility control agent in chemical EOR has been explored [9]. Kumar et al (2017) investigated the use of locally sourced polymer guar gum as a mobility control agents in chemical EOR. They conducted laboratory experiment to evaluate the rheological properties of the guar gum solution and its ability to enhance oil recovery. They showed that guar gum solution improved oil recovery by 12-18% compared to water flooding [9]. The use of local asaphaltene as a heat generating agent in thermal in thermal EOR has been under study [10]. They authors [10] prepared asphaltene samples and evaluated their thermal conductivity, specific heat capacity, combustion kinetics. They then conducted core flooding experiments to evaluate the effectiveness of the asphaltene in enhancing oil recovery. They authors concluded that local asphaltene improved oil recovery by 25-30% compared to water flooding. They concluded that local asphaltene can be used as an effective heat generating agent in thermal EOR.

In related study, the use of local coal as fuel source in-situ combustion EOR has been experimented [11]. They authors [11] prepared coal samples and evaluated their combustion kinetics, heat of combustion, and fuel gas composition. Core flooding experiment was conducted to evaluate the effectiveness of coal in enhancing oil recovery. Their results showed that the coal improved oil recovery by 20-25%.. In another study, Microbial EOR using local microorganism has been explored [12]. Local microorganisms, pseudomonas aeruginosa, were used to degrade the heavy oil. Microbial cultures and their biodegradation, kinetics, biomass production and oil degradation products were evaluated. Core flooding experiment to evaluate the effectiveness in EOR was conducted. Results showed that microorganisms improved oil recovery by 15-20% [12]. In similar development, CO2 was deployed in the Middle Eastern oil field using local CO_2 [13]. The authors [13] investigated the use of local sources to enhance oil recovery. They conducted laboratory experiments to evaluate the CO_2 flood performance and its ability to enhance oil recovery. They prepared CO_2 samples and evaluated their purity, density and viscosity. Conducted core flooding CO2 experiment were performed to evaluate. They concluded that CO2 improved recovery by 10-15% compared to water flooding.

Nitrogen EOR has been applied in a Brazilian oil field using locally sourced nitrogen and results showed that nitrogen EOR increases oil recovery by 30% [14]. Palm wine, a traditional beverage in many tropical regions, is obtained from the sap of palm trees. The fermentation process of palm wine results in a complex mixture of organic compounds, including natural surfactants [15]. These surfactants possess the ability to reduce interfacial tension and modify the wettability of reservoir rocks, making them potentially effective for EOR applications. Recent studies have underscored the potential of using locally sourced natural materials in EOR. For instance, [16] demonstrated the efficacy of palm bunch ash as an alkaline agent in increasing oil recovery from sand samples, while [17] conducted flooding experiments using palm bunch ash and Abelmoschus esculentus polymer, yielding promising results in oil recovery enhancement. Additionally, studies [18] [19] [20] have explored various natural and bio surfactants, highlighting their efficacy in enhancing oil recovery

This study aims to investigate the potential of palm wine as a natural surfactant for enhancing oil recovery in sandstone reservoirs. The study's objectives include characterizing the chemical properties of fermented sap relevant to its surfactant capabilities, determining the optimal conditions for its application in sandstone formations, and comparing its performance with conventional surfactants used in EOR. The hypothesis driving this research posits that the unique composition of fermented sap can effectively enhance oil recovery while offering a more sustainable and cost-effective alternative to synthetic surfactants. The significance of this study lies in its potential to introduce an innovative, environmentally friendly EOR method that leverages locally available resources, thereby reducing the environmental footprint and supporting local economies.

By exploring the use of fermented sap in EOR, this research aspires to contribute to the development of novel and sustainable methods for enhancing oil recovery, ultimately aiding in meeting the world's growing energy demands. The findings from this study could pave the way for broader applications of natural surfactants in the petroleum industry, promoting a shift towards greener and more sustainable EOR practices. The relevance of this study is further emphasized by recent global efforts to reduce the environmental impact of oil extraction and improve the sustainability of industrial processes [21]. Enhanced understanding of natural surfactants like palm wine could revolutionize EOR practices, providing the industry with tools to address both economic and environmental challenges [22] [23] [24][25][26][27]

2. Methodology

This study evaluates the effectiveness of fermented sap (palm wine) as a surfactant for enhanced oil recovery (EOR) from sandstone reservoirs. The methodology encompasses the preparation of core samples, formulation and characterization of the palm wine surfactant solution, execution of core flooding experiments, and comprehensive data analysis. The following sections detail each step to ensure reproducibility and accuracy.

2.1 Materials and Equipment

The following materials and equipment are utilized in the experimental process:

- Sandstone Core Sample: Cylindrical sandstone cores,3.55 cm in diameter and 15.4 cm in length
- Weighing Balance: Analytical balance with an accuracy of ±0.001 g for precise weight measurements.
- Measuring Cylinder: Graduated cylinders (50 mL and 100 mL) for accurate volume measurements.
- Funnel: Laboratory funnel for transferring liquids.
- Palm Wine: Fresh palm wine, fermented under controlled conditions to ensure consistent surfactant properties.
- Brine: Synthetic brine solution with a salinity of 20,000 ppm to simulate reservoir conditions.
- Crude Oil: Heavy crude oil with an API gravity of 15.6, representative of the reservoir.
- Core Flooding Equipment: Core flooding apparatus, including a core holder, high-pressure pumps, and pressure transducers.

2.2 Experimental Procedure

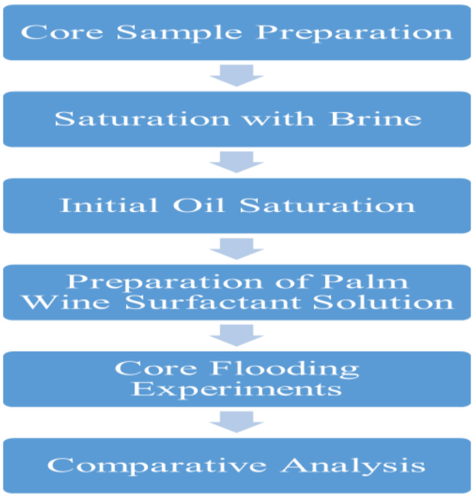

Figure 1: Flow diagram of the experimental Procedure

1. Core Sample Preparation

- Cleaning and Drying: Sandstone core samples are cleaned using Soxhlet extraction with toluene to remove residual hydrocarbons and impurities. Samples are then dried in an oven at 105°C for 24 hours.
- Weight Recording: The dry weight of each core sample is measured using an analytical balance.

2. Saturation with Brine

- Vacuum Saturation: Core samples are vacuum-saturated with brine to ensure complete pore space saturation. This process involves placing the samples in a desiccator connected to a vacuum pump for 24 hours.
- Saturated Weight: The dry substance weight (pore volume) in addition to saturated weight of the core samples was recorded. Bulk volume was calculated by the difference between dry and saturated weights. Equation (1) was used to calculate the porosity of the sample.

$$Porosity = \frac{Pore\,Volume}{Bulk\,Volume} \quad (1)$$

Where,
Pore volume = weight of dry substance
Bulk volume = weight of saturated sample – weight of dry sample
3. Initial Oil Saturation

- Crude Oil Injection: Brine-saturated core samples are mounted in the core holder, and crude oil is injected at a rate of 0.5 mL/min until no more brine is produced.
- Oil in Place Calculation: The original oil in place (OOIP) is determined by measuring the volume of brine displaced by the crude oil. Equations (2) and (3) were used to calculate the total volume of oil that saturated the core.

Calculating the OOIP
OOIP = Effluent Oil Volume (V_{o_i})
Where
V_{o_i} = Total volume of oil circulated or oil that saturated the core

$$V_{o_i} = A \times L \times \emptyset \times (1 - S_{W_i}) \quad (2)$$

$V_{o_i} = \frac{\pi d^2}{4}$ x L x Ø x $(1 - S_{W_i})$ (3)

4. Preparation of Palm Wine Surfactant Solution

- Fermentation: Palm wine is fermented for 7 days at room temperature. The fermentation process is monitored to ensure consistency in the surfactant properties.
- Filtration and Measurement: The fermented sap is filtered through a 0.45 µm filter to remove particulate matter. Properties such as pH, surface tension, and viscosity are measured using a pH meter, tensiometer , and viscometer , respectively.

5. Core Flooding Experiments

- Surfactant Injection: Core samples are remounted in the core holder, and the palm wine surfactant solution is injected at a rate of 0.2 mL/min. Pressure drop across the core and the volume of oil recovered are continuously monitored using pressure transducers and graduated cylinders.
- Completion Criteria: The flooding process continues until no significant amount of oil is recovered, indicating the end of the surfactant flooding phase.
- Cumulative Oil Recovery: The cumulative oil recovery is calculated as a percentage of the OOIP for both surfactant flooding and subsequent water flooding. Equation (4) was used to calculate the oil recovery factor.

Calculation of Recovery Factor

$$RF = \frac{\text{Total Recovery}}{OOIP} \times 100 \quad (4)$$

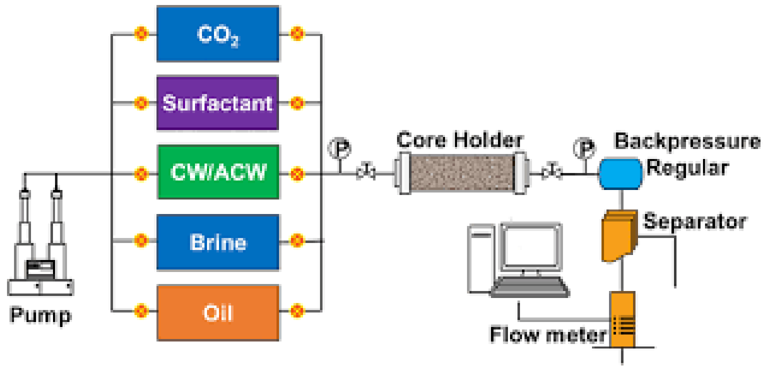

Figure 2: Core flooding after Xuefeng qu, 2018 [28]

6. Comparative Analysis

- Synthetic Surfactant Benchmarking: The same procedure is repeated using a conventional synthetic surfactant (e.g., Sodium Dodecyl Sulfate, SDS) under identical conditions. The performance of the palm wine surfactant is compared to this benchmark.

Analytical Techniques

1. Interfacial Tension (IFT) Measurement

The interfacial tension between the surfactant solution and crude oil is measured using a spinning drop tensiometer. Measurements are conducted at room temperature for consistency.

2. Wettability Tests

Contact angle measurements are performed using a goniometer to assess changes in wettability of the sandstone surface due to the surfactant.

This comprehensive methodology ensures a thorough evaluation of the potential of fermented sap (palm wine) as a natural surfactant for enhanced oil recovery from sandstone reservoirs. The detailed experimental procedures and analytical techniques are designed to provide robust and reproducible results, contributing valuable insights to sustainable EOR practices.

3. Results and Discussion

3.1 Characterization of the crude oil sample

The evaluated physical properties of the crude oil sample are shown in Table 1 while Table 2 enlists the calculated properties of the core samples

Table 1 Properties of the Crude Oil Sample

Physical Properties	*Values*
Density	*0.958*
API Gravity	*15.6*
Viscosity	*-*
Specific gravity	*0.962*

Table 2 Calculated Properties of the Core Sample

Sample	*Length (cm)*	*Diameter (cm)*	*Weight of dry core plus pack (g)*	*Weight of wet core plus pack (g)*	*Mass difference (g)*	*Porosity (%)*	*Bulk volume (cc)*
1	15.4	3.55	480.4	567	86.6	23	152.4

3.2 Oil recovery efficiency

Table 3 shows the volume of oil recovery versus pressure while Table 4 shows the oil recovery efficiency of palm wine surfactant when compared to the synthetic surfactant. Figure 2 shows the graphical comparison of palm wine sap and synthetic surfactant on ;oil recovery at varying pressure. It could be seen that palm wine surfactant is superior to the synthetic surfactant based on the final oil recovery utilizing the surfactants.The palm wine surfactant achieved a higher oil recovery efficiency of 69.3% of the original oil in place (OOIP) when compared to 48.23% with the synthetic surfactant. The palm wine surfactant's superior oil recovery efficiency can be attributed to its ability to effectively reduce IFT and alter wettability. The natural bio surfactants present in the fermented sap, such as saponins and proteins, are likely responsible for these effects. These compounds reduce IFT, facilitating the mobilization of trapped oil droplets within the porous sandstone.

Table 3. Volume of Oil Recovery using Palm wine sap

Pressure (bar)	*Volume (ml)*
0.5	*2.5*
1.0	*3.5*
1.5	*4.0*
2.0	*4.3*
2.5	*5.2*

Table 4. Volume of Oil Recovery Using Synthetic surfactant

Pressure (bar)	*Volume (ml)*
0.5	*1.5*
1.0	*2.1*
1.5	*2.6*
2.0	*3.3*
2.5	*4.1*

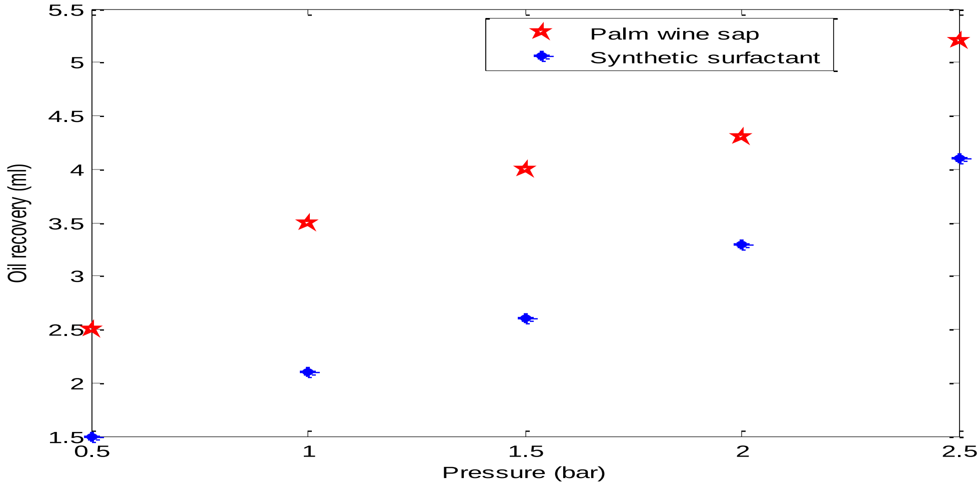

Figure 3. Comparison of palm wine sap and synthetic surfactant on oil recovery at varying pressure

Table 5 Cumulative Oil Recovery for palm wine sap and synthetic surfactant

Surfactant	*Final oil recovery*
Palm wine surfactant	*69.23*
Synthetic surfactant	*48.23*

3.3 Interfacial Tension (IFT)

The IFT measurement between the surfactant solutions and crude oil is depicted in Table 5. A significant reduction was observed for both surfactants . The palm wine surfactant achieved an IFT of 2.48 mN/m as compared to 3.73 mN/m for the synthetic surfactant. The interfacial tension measurement confirm that the palm wine surfactant significantly lowered the interfacial tension between the crude oil and brine, achieving an IFT of 2.48 mN/m compared to 3.73 mN/m for the synthetic surfactant. This reduction in IFT is crucial for enhancing oil recovery, as it reduces the capillary forces that trap oil within the rock matrix.

Table 6 Interfacial Tension (IFT) alteration for Palm wine sap and Synthetic surfactant

Surfactant	*IFT (mN/m)*
Palm wine surfactant	*2.48*
Synthetic surfactant	*3.73*

3.4 Wettability Alteration

Table 6 shows the contact angle for the palm wine surfactant-treated samples decreased significantly from 135° to 70°, while for the synthetic surfactant, the contact angle decreased from 135° to 80°. The wettability test signifies a noticeable shift from oil-wet to water-wet conditions in the sandstone cores treated with surfactants. The wettability tests further support the efficacy of the palm wine surfactant. The substantial shift from oil-wet to water-wet conditions, indicated by the reduction in contact angle from 135° to 70°, enhances the displacement of oil by water, leading to improved recovery. The wettability alteration was more pronounced with palm wine, with the contact angle reducing from 135° to 70°, compared to a reduction from 135° to 80° with the synthetic surfactant suggesting that the natural components in the fermented sap effectively modified the surface properties of the sandstone

Table 7 Wettability alteration for the Palm wine sap and Synthetic surfactant

Surfactant	*Initial Contact Angle (o)*	*Final Contact Angle (o)*
Palm wine surfactant	*135*	*70*
Synthetic surfactant	*135*	*80*

The experimental results obtained from the oil recovery efficiency, interfacial tension (IFT), and wettability alteration when compared with the conventional synthetic surfactants show that the palm wine surfactant significantly outperformed the conventional synthetic surfactant in enhancing oil recovery from sandstone reservoirs. The higher oil recovery efficiency, lower interfacial tension, and greater wettability alteration observed with the palm wine surfactant suggest it is a more effective agent for EOR.

4. Conclusion

The study demonstrated that fermented sap (palm wine) serves as an effective surfactant for enhanced oil recovery (EOR) in sandstone reservoirs. This superior performance is attributed to the natural bio surfactants present in palm wine, such as saponins and proteins, which significantly reduced the interfacial tension (IFT) and alter the wettability of the sandstone. It could also be deduced from the results that palm wine's natural components effectively modified the reservoir rock's surface properties, leading to enhanced oil recovery.

The use of natural surfactants like palm wine offers significant environmental and economic advantages, including biodegradability, non-toxicity, and local availability, which reduce the environmental footprint and costs associated with synthetic surfactants. This study reveals the potential of fermented sap (palm wine) as a viable and sustainable surfactant for enhanced oil recovery.

Future research should focus on optimizing the fermentation process, scaling up studies, and conducting comprehensive environmental and economic analyses to validate its broader application in the oil industry.

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