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Effect of Plantain Stem Extract on Enhanced Oil Recovery in Specified Sand Aggregates

Johnbull Okperhie*[1], Praise O. Agbab[2], Michael C. Ogbue[3], Blessing E. Eboibi[4], Kigho M. Oghenejoboh[5]

[1-3]*Department of Petroleum Engineering, Delta State University, Abraka, Nigeria.*
[4-5]*Department of Chemical Engineering, Delta State University, Abraka, Nigeria.*

Corresponding author: okperhiejohnbull642@gmail.com (J. Okperhie)

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Abstract

Various techniques are employed to enhance oil recovery, with the primary goal of increasing hydrocarbon saturation and maximising oil extraction from reservoirs. Primary and secondary recovery methods typically recover only a fraction of the original oil in place, leaving significant amounts unrecovered. This study investigates the potential of plantain stem sap (PSS) as an alternative, non-toxic, and biodegradable chemical for enhancing oil recovery from sandstone reservoirs. Eight different core samples were used to evaluate the recovery factor of PSS and a sharp sand solution. The secondary recovery process was conducted using varying concentrations of PSS, including standalone and combined solutions (50% water and 50% PSS), which were further applied in the tertiary recovery stage. The core samples were characterised using SEM, FT-IR, and XRF, following ASTM methods. The results indicate that PSS can significantly enhance oil recovery, with maximum cumulative recoveries of 80.4%, 76.6%, and 73% achieved under different conditions. The minimum recovery of 62.1% was obtained for an oil-wet core sample with 50% PSS concentration, likely due to polymer adsorption on the rock surface.

Keywords: Enhanced oil recovery; plantain stem sap; sweep efficiency; recovery factor; sand aggregates

1. Introduction

The global demand for fossil fuels continues to rise despite the development of alternative energy sources. As energy consumption increases, improving oil recovery from reservoirs remains critical. Traditional recovery methods, including primary and secondary techniques, typically extract only a fraction of the original oil in place, leaving significant amounts unrecovered (Jalali et al., 2019). Consequently, there is a growing need for enhanced oil recovery (EOR) techniques to extract residual and immobile oil, ensuring maximum utilization of existing reserves.

Oil recovery occurs in three main stages: primary, secondary, and tertiary recovery. During primary recovery, natural reservoir pressure drives hydrocarbons toward production wells. However, as production continues, reservoir pressure declines, reducing the efficiency of oil extraction (Ramachandran et al., 2003). To mitigate this, secondary recovery methods, such as water and gas injection, help maintain reservoir pressure and improve oil displacement. Water and gas injection remain effective when the water cut and gas-oil ratio are not excessive (Planckaert, 2005; Saeed, 2018). Even with secondary recovery, a substantial volume of oil remains trapped within the reservoir, necessitating the implementation of tertiary recovery or EOR techniques (Gbadamosi et al., 2019).

EOR methods are classified into four main categories: thermal, miscible/immiscible gas injection, microbial, and chemical methods. Many newly discovered hydrocarbon fields contain oil that is not easily recoverable through natural pressure drive, increasing the demand for efficient extraction techniques (Adepehin et al., 2022). The oil industry and researchers continue to develop cost-effective and environmentally friendly solutions for maximizing oil recovery from mature and newly discovered fields.

Among EOR techniques, chemical methods have gained significant attention due to their ability to modify rock-fluid and fluid-fluid interactions, improving both sweep and displacement efficiencies. Chemical EOR involves the injection of surfactants, polymers, alkaline agents, and nanoparticles to enhance oil recovery by altering reservoir properties (Igoru et al., 2024). However, many conventional chemical agents are synthetic, non-biodegradable, and may react with formation minerals, potentially leading to reservoir damage (Igoru et al., 2024). Additionally, inorganic chemicals used in conventional EOR methods can contaminate groundwater, disrupt reservoir ecosystems, and pose economic and environmental challenges (Yayoo et al., 2021).

Recent studies have explored bio-based surfactants as environmentally sustainable alternatives for EOR. For example, Smith et al. (2019) investigated the effectiveness of saponin, a natural surfactant extracted from Quillaja Saponaria (soapbark tree), in altering the fluid behavior of oil-wet sandstone cores. Their study demonstrated a reduction in the contact angle from 135° (oil-wet) to 45° (water-wet) and an increase in oil recovery by 25% during secondary flooding. Similarly, Emadi et al. (2017) examined the effects of cedar extracts combined with nano-silica and found that incorporating natural surfactants improved interfacial tension (IFT) reduction and oil displacement efficiency. Other plant-based surfactants, including those derived from Sapindus laurifolius (Singh et al., 2021) and Sapindus mukorossi (Chhetri et al., 2009), have shown promising results in lowering IFT and enhancing oil recovery.

Despite these advances, limited research has been conducted on the potential of plantain stem sap (PSS) for EOR applications, particularly in sand aggregate formations. While previous studies indicate that natural surfactants can improve oil displacement and reduce IFT, achieving complete transition to a water-wet state remains a challenge. Therefore, this study aims to evaluate the effectiveness of PSS as a bio-based alternative for enhancing oil recovery in sand aggregate formations.

2. Materials and Methods

2.1 Materials and Preparations

The materials used in this study include plantain stem, corn flour, crude oil, and sharp sand. The plantain stems were obtained at Oleh, southern Nigeria. The sample plantain stems were dried under the sun by first removing the outer fibrous layers until the softer juicy inner core is obtained, then washed thoroughly with clean water, and thereafter sliced with a knife into pieces and placed on a clean mat for drying. As a result of the weather, it was dried for 4-7 days, turning the pieces over daily for equal drying, and thereafter the dried plantain stem was stored in an airtight container. The dried stem samples were ground into a fine powder using a mortar and pestle, and the powder was sieved to ensure uniform particle size.

Preparation of the plantain stem sap solution: 0.2 g and 0.4 g of the sap were dissolved in 100 ml of distilled water. The sap was first extracted from the plantain stem using a white cloth, filtered into a rubber cup, and then further filtered to remove particulate matter. A small amount of glycerol was added to enhance the concentration (Chhetri, 2009; Saxena et al., 2021). Similarly, an aqueous corn flour solution was prepared by dissolving 0.2 g and 0.4 g of corn flour in 100 ml of distilled water. The crude oil sample was sourced from the Niger Delta region of Nigeria. The sharp sand was collected from Delta State University, Oleh Campus. The sand was thoroughly washed under running water for 30 minutes to remove impurities. It was then dried under sunlight until constant moisture content was achieved. Finally, the dried sand was sieved into two grain size fractions: 1180 µm (0.118 cm) and 600 µm (0.06 cm).

2.2 Phytochemical Analysis of Plantain Stem and Plantain Stem Extract

The plantain stem bark and PSS were subjected to phytochemical analysis to determine the classes of secondary metabolites such as alkaloids, tannins, terpenoids, glycosides, phenolics, flavonoids, steroids, and carbohydrates (Akpabio et al., 2012; Ekeke et al., 2019; Obi et al., 2019).

The tannin in the plantain stem bark and plantain stem sap was determined by the procedure described by Association of Official Analytical Collaboration (AOAC), in 1989. The amino acid contents, total flavonoids, and alkaloids were estimated according to previous studies (Tabasum et al. 2016 and Smith et al. 2019), while the saponins and glycosides were estimated following Fanin et al. 2014 and Amadi et al. (2004), respectively.

2.3 FT-IR, SEM, and XRD Analyses

The PSS was analyzed with Fourier transform infrared spectroscopy (FT-IR) according to the method explained previously (Smith et al., 2019). The structural morphology of the plantain stem was examined using scanning electron

microscopy (SEM) (Phenom ProX, Phenom World, Eindhoven, The Netherlands) as described by Goldstein (2018). The XRD (X-ray diffractometer) analysis of the plantain stem bark was carried out to determine the various elements and phase distribution. By employing X-ray fluorescence (XRF) analysis, the elemental composition of the sharp sand was identified.

2.4 Experimental Procedure

The experimental study was conducted based on previous reports (Lake et al., 2023; Igoru et al., 2024). Briefly, the apparatus was assembled by securely attaching the hose to the burette. The hose was then connected to the core via a pipe, while the other end was inserted into a conical flask to collect the fluid, which was pumped through the hose using a peristaltic pump. A sample sand with a grain size of 0.118 cm was used to fill the core, which was then compacted to ensure complete filling of all spaces and prevent fingering during the experiment. The core was sealed with cotton wool at both ends to prevent spillage or leakage and then closed with a cork. Then 250 cm^3 of water was placed in a beaker and used to flood the core through the hose, assisted by the peristaltic pump set at a flow rate of 10 rpm. A schematic representation of the experimental setup is shown in Figure 1.

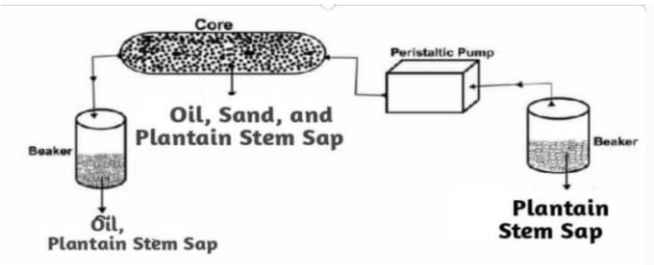

Figure 1: Schematic View of Experimental Setup (Field Source)

The following parameters were defined and obtained based on a previous study by Igoru *et al*. (2024)

V_1 = Bulk volume of sand in the core sample

V_2 = Volume of water in a beaker before initial flooding of core sample.

V_3 = Volume of water in the beaker after initial flooding of core sample.

$V_4 = V_2 - V_3 = V_{wi}$ = Initial volume of water accumulated in the core

$V_{wi} = V_4$ = Initial volume of water accumulated in the core

$V_p = V_4$ = Pore volume of sand in the core sampleϕ

$\frac{V_p}{V_4}$ = Porosity of sand in core sample 1

Table 1: Core Samples

Properties	Samples							
	A_1	A_2	A_3	A_4	B_1	B_2	B_3	B_4
PSS Conc. (%)	100	50	100	50	100	50	100	50
Sand Type	Sharp Sand	Sharp Sand	Sharp Sand	Sharp Sand	Sharp Sand	Sharp Sand	Sharp Sand	Sharp Sand
Grain Size (cm)	0.118	0.118	0.118	0.118	0.06	0.06	0.06	0.06
Nature	Water wet	Water wet	Oil wet	Water wet	Water wet	Oil wet	Oil wet	Oil wet
Bulk Volume (cm^3)	90.850	90.850	90.850	90.850	90.850	90.850	90.850	90.850
Crude Oil Viscosity	8.4cp	8.4cp	8.4cp	8.4cp	8.4cp	8.4cp	8.4cp	8.4cp

3. Results and Discussion

3.1 Characterization of Plantain Stem Sap (PSS)

The results obtained from the qualitative phytochemical analysis of PSS are presented in Table 2. As shown in the table, the qualitative phytochemical analysis of PSS reveals several consistent patterns. This Steroids, phenols, xanthoproteic compounds, and flavonoids were consistently observed in PSS in present studies and previous ones, as shown in Table 2. Alkaloids, triterpenoids, and glycosides were abundantly present in the analysed samples, suggesting their significance in plantain's chemistry. This finding is in agreement with those of Herminsul *et al*. (2024), Okareh *et al*. (2015), and Adepoju (2015). Also, the saponin, lipid, and steroid content was within the range of previous studies, as shown in Table 2.

Table 2: Characterization of Plantain Stem Sap

Parameters	PSS	References		
	Present study	Herminsul *et al*. (2024)	Okareh *et al*. (2015)	Adepoju, (2015)
Tannim(mg/tannin)	1.67	3.16±0.01	-	-
Flavonoid(mEq/QE)	1.397		5.00±0.03	-
Phenoli Content (mEq/GAE)	1.095	2.65±0.02	-	-
Total Carbohydrate (mg/glucose)	1.464	-	3.00±0.03	-
Reducing Power (mg/glucose)	1.986	2.39±0.01	-	-
Total alkaloids	7.639	5.95±0.01	-	-
Saponin	5.819	-	6.00±0.04	-
Lipids	3.250	-	-	3.27+0.02
Steroids	0.530	0.30±0.01	-	-

3.2 FT-IR Analysis of PSS

The Fourier-Transform-Infrared Spectroscopy (FT-IR) of PSS is shown in Figure 2. As illustrated in the figure, a peak at 3272.6 cm^{-1} indicates O-H stretching vibrations, commonly associated with alcohols, phenols, and possibly carboxylic acids. (Singh *et al*. 2021). Peaks at 2918.5 cm^{-1} and 2851.4 cm^{-1} are associated with C-H stretching vibrations in alkanes. The presence of these peaks suggests aliphatic hydrocarbons in plantain. Moreover, the peaks at 2124.6 cm^{-1} and 1997.9 cm^{-1} represent C≡C stretching in alkynes or overtone/combination bands. The peak at 1636.3 cm^{-1} corresponds to C=O stretching vibrations mostly found in carbonyl compounds like aldehydes, ketones, carboxylic acids, or esters. Carbonyl groups enhance the polarity of the surface, promoting better interaction with water molecules and supporting a transition to a water-wet state, thereby increasing oil recovery (Zhang *et al*. 2021). The peak at 1457.4 cm^{-1} is due to C=C stretching vibrations, which are characteristic of alkenes or aromatic compounds. Aromatic compounds, though non-polar, can form part of larger polar structures that aid in wettability alteration (Guo *et al*. 2018). The peak at 1401.5 cm^{-1} is often associated with C-H bending vibrations in alkanes. The peak at 1308.3 cm^{-1} indicates C-H bending vibrations, often seen in methyl groups. The peak at 1241.2 cm^{-1} is due to C-O stretching vibrations commonly found in alcohols, ethers, or esters. The peak at 1032.5 cm^{-1} corresponds to C-O stretching vibrations, indicating the presence of alcohols, ethers, or esters. These polar groups increase surface hydrophilicity, enhancing water interaction and promoting water-wet conditions (Liang *et al*. 2019). The FTAP spectrum of the plantain stem bark sample reveals the presence of functional groups that are known to alter wettability. Hydroxyl, carbonyl, and ether/ester groups can increase hydrophilicity, form hydrogen bonds with water, and enhance surface polarity. These interactions promote the transition from an oil-wet to a water-wet state, facilitating enhanced oil recovery (Zhou *et al*. 2022; Liu *et al*. 2020; Liang *et al*. 2019). The functional groups identified, such as hydroxy, carbonyl, and ether/ester, have been reported to enhance surface hydrophilicity. These groups suggest modification of surface properties leading to improved oil displacement efficiency (Zhang *et al*., 2021; Zhou *et al*., 2022; Liu *et al*., 2020); promote water interaction; and shift the system from oil-wet to water-wet, facilitating enhanced oil recovery (EOR). Previous studies (Liu *et al*., 2020; Singh *et al*., 2021) highlighted their potential application in enhanced oil recovery (EOR) strategies. These functional groups were found in the PSS of the present study in agreement with previous studies that functional groups such as carboxyl, hydroxyl, and amine groups can significantly modify surface properties, improving oil displacement efficiency in reservoirs.

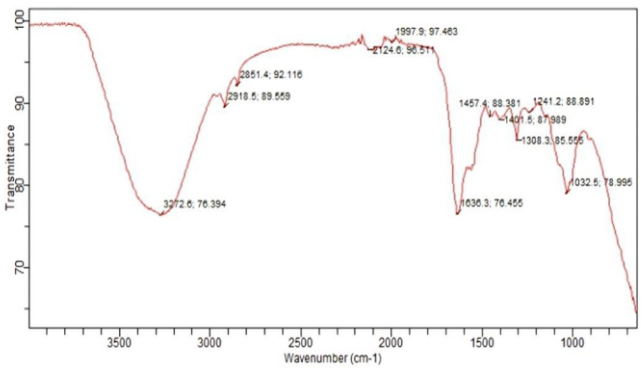

Figure 2: FT-IR Analysis of Plantain Stem Sap

3.3 X-Ray Diffraction (XRD) Analysis of PSS

The X-ray diffraction analysis spectrum for PSS is shown in Figure 3. The figure shows intensity peaks at various angles (2θ), each corresponding to different crystalline phases in the sample. The intensity counts per second (cps) indicate the quantity of X-ray photons detected, which correlates with the abundance of a particular phase. Their wettability alteration can significantly improve oil recovery by improving the efficiency of fluid injection processes (Saxena et *al*, 2018). Potassium, calcium, and magnesium (Sylvine, Marturite, and Epsomite) are minerals that alter the surface chemistry of reservoir rocks, potentially making them more water-wet. This enhances water-wetness, which improves oil displacement during EOR processes (Tang et *al.,* 2025). The analysis revealed the presence of Wihelmramsayite 26 (3) %, Mascagnite 24 (2) %, Urea, Syn 30 (2) %, Bischofite, Syn 10.0 (5) %, and 9.7 (5) % for Scholzite. Wihelmramsayite is a synthetic compound, of which such compounds could serve as tracers or surfactants in EOR processes. As mentioned previously, surfactants reduce surface tension, aiding in the mobilization of oil trapped in reservoir rocks. These compounds act as catalysts in the formulation of gels and other chemicals that help in modifying the viscosity of the displacing fluid and improving sweep efficiency. Moreover, urea and syn could be involved in the formation of alkaline agents used in alkaline flooding. Alkaline agents can react with certain crude oils to form surfactants in situ, which helps to reduce interfacial tension (Saxena et *al*, 2018).

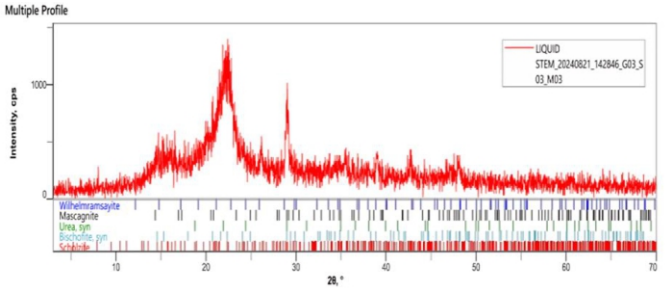

Figure 3: X-Ray Diffraction (XRD) Analysis of Plantain Stem Sap

3.3 X-ray fluorescence (XRF) analysis of sharp sand and Crude Oil

The X-ray fluorescence (XRF) analysis on sharp sand is shown in Table 4. As shown in the table, SiO_2 (silicon dioxide) is the dominant component of the sand with 95.2 %. This high percentage of SiO_2 reaffirms sharp sand is predominantly composed of quartz. Al_2O_3 (Aluminum Oxide) consists of 1.9%. Fe_2O (Iron (III) Oxide) content with 0.5% composition indicates a minor presence of iron-bearing minerals. CaO (Calcium Oxide) with a 1.2% composition suggests the presence of calcareous minerals, such as limestone fragments within the sand. The small amount (0.1%) of MgO (magnesium oxide) could be mostly due to a minor contribution from magnesium-bearing minerals. Similarly, the 0.3% K_2O (potassium oxide) suggests the presence of feldspar or mica minerals. A silt content of 0.2% represents a very small fraction of fine-grained particles. Organic impurities with 0.5% composition indicate the presence of organic material within the sand. A moisture content of 0.2% composition indicates the amount of water present in the sand.

The data obtained from petroleum crude oil analysis is presented in Table 5. The table shows that the crude oil has an API gravity of 17.8, indicating heavy crude, with a specific gravity of 0.95 and a density of 0.9 g/cm³. The sulfur content was found to be 0.5 %, suggesting a sweet crude oil (American Petroleum Institute, 2019). The pour point of 12°C suggests that the oil has a high temperature below which it ceases to flow. The water content was low (0.3%), which suggests minimal water contamination and good quality in this regard. Asphaltene content of 0.9% and carbon residue of 8.0% indicate that the crude oil has a significant number of heavy components. The 84.0 pas' viscosity is relatively high, indicating that the oil is quite thick and resistant to flow. This high viscosity is typical for heavy crudes.

Table 1: X-ray fluorescence Analysis on the sharp sand

S/N	Properties	Composition, %
1	SiO_2	95.19
2	Al_2O_3	1.93
3	Fe_2O_3	0.52
4	CaO	1.16
5	MgO	0.12
6	K_2O	0.25
7	Silt Content	0.18
8	Organic Impurities	0.5
9	Moisture Content	0.15

Table 2: Data obtained from petroleum crude oil analysis

S/N	Parameters	Composition
1	API Gravity	17.8°
2	Specific Gravity	0.95
3	Density	0.9g/cm³
4	Sulphur Content	0.6%
5	Pour Point	12^0
6	Water Content	0.3%
7	Asphalting Content	0.9%
8	Carbon Residue	8.0%
9	Viscosity	84.0pa.s

3.5 Results of Oil Recovered

The experimental data obtained from the different core samples are presented in Table 1. Data for the core samples were obtained with a grain size of 0.118 cm, while 0.06 cm³ was used for the core sample. The results showed a pore volume of 37, while the porosity of the medium was 41.1%. The higher the pore volume, the higher the volume of fluid that can be contained in the core, and the better the reservoir formation. As shown in Fig. 4, for core samples, the recovery factor (RF) was between 52.9 and 63.6%, while 4.6 and 7.4% were achieved for tertiary recovery 1 and 1.5 and 5.4% for tertiary recovery 2. Similarly, for core samples, the RF was between 52.3 and 71.4%, while tertiary recovery 1 was between 3.5 and 6.7%, and 1.3 and 6.7% for tertiary recovery 2. Also, higher concentrations of core samples led to increased RF, microscopic sweep efficiency, and tertiary recovery I and II as observed for core samples—and—

Core samples with a 100% concentration of PSS led to more recoveries when compared to samples with a lower (50%) concentration. Irrespective of the core sample, there were more recoveries for tertiary recovery I and microscopic efficiency I when compared to tertiary recovery II and microscopic efficiency II, respectively. An increase in microscopic sweep recovery was found to correspond with an increase in the RF. Similarly, findings were reported by Zallaghi *et al*. (2021) and Shikaia *et al*. (2021) that reported oil recovery being closely related to the sweep and displacement efficiencies in oil reservoirs. This increase in recovery could be mostly due to a reduction in ITF and wettability alteration toward water-wet conditions. This suggests that PSS could be considered an effective chemical agent in enhanced oil recovery. Core samples of smaller grain size (0.06 cm) led to an increase in RF when compared to core samples of 0.118 cm, as shown in Figure 4. Suggesting smaller silica particles lead to incremental oil recovery by interfacial interaction reduction and wettability alteration. Zallaghi *et al*. (2018) observed maximum additional oil recovery when injecting a solution with 2000 ppm silica nanoparticle concentration. However, when the 5000-ppm concentration of nanoparticle solution was used for core flooding, there was an increase in pressure drop during the experiment, and the incremental oil recovery decreased. This could be one of the reasons why core sample B led to more oil recovery. This finding suggests that core plugging and a permeability reduction occurred, which could be attributed to the retention of nanoparticles in the rock due to the instability of the aqueous solution.

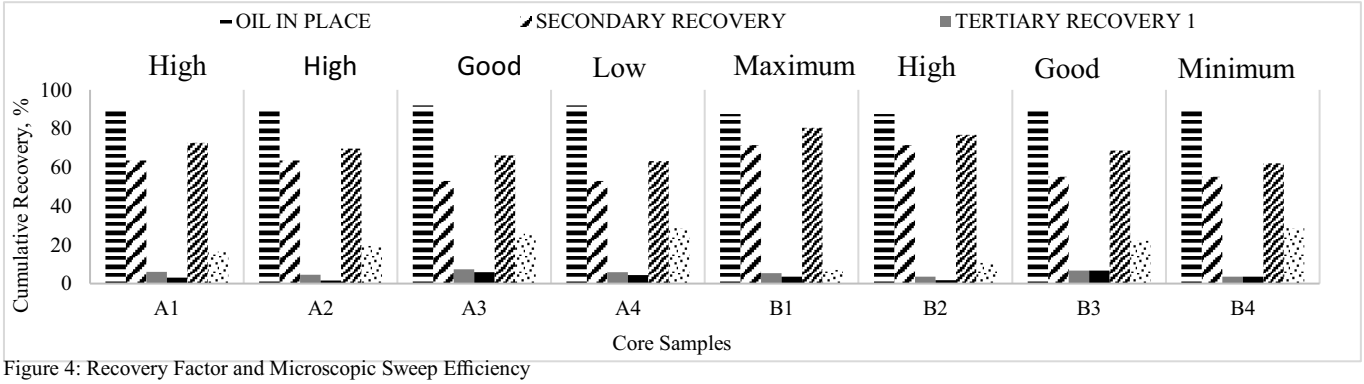

Figure 4: Recovery Factor and Microscopic Sweep Efficiency

A1: 100% PSS concentration, 0.118 grain size; nature: water-wet
A2: 50% PSS concentration,0.118 grain size; nature: water-wet
A3: 100% PSS concentration,0.118 grain size; nature: oil-wet
A4: 50% PSS concentration,0.118grain size; nature: oil-wet
B1: 100% PSS concentration,0.06 grain size; nature: water-wet
B2: 50% PSS concentration, 0.06 grain size; nature: water-wet
B3: 100% PSS concentration,0.06 grain size; nature: oil-wet
B4: 50% PSS concentration,0.06 grain size; nature: oil-wet

3.6 Recovery percentages (cumulative)

Figure 5 shows the cumulative recovery (CR) for PSS ranges from 62.1% to 80.4%, which was substantially higher when compared to conventional EOR methods. For example, polymer and surfactant flooding typically achieves a CR between 50 and 70% of the original oil in place (OOIP) (Billa *et al*. (2019). Jalali *et al*. (2019) reported that the use of *C. myxa* leaf extract led to 27% of OOIP. This could be due to the PSS reaction with oil and the formation of in-situ surfactant that reduces the IFT between oil and water, which could have also helped in reducing polymer adsorption on the rock surface. As shown in Figure 5, a 100% concentration of PSS yielded maximum CR for both core samples, water-wet and oil-wet conditions, in agreement with previous reports (Igoru *et al*. 2024, Liu *et al*. 2022). Igoru *et al*. (2024) observed higher concentrations of bitter leaf surfactant resulted in oil displacement efficiency. Their results showed cumulative recovery of 84%, 78%, and 87% at 100%, 50%, and 25%, respectively, of surfactant concentrations. Liu *et al*. (2022) reported higher concentrations of natural surfactants generally lead to enhanced oil recovery. In this study, core sample B2, water-wet with 50% concentration of PSS, and core sample A_1, water-wet with 100% concentration of PSS, led to a CR of 76.8% and 72.7%, respectively. Core sample B4, oil-wet with a 50% concentration of PSS, achieved the lowest recovery of 62.1%, perhaps due to polymer adsorption on the rock surfaces, which alters the rock wettability. Recovery for both core samples, irrespective of being in water-wet and oil-wet conditions, follows a similar trend concerning concentration. This phenomenon suggests that while wettability influences the absolute recovery values, the relative performance of PSS concentrations remains consistent across different wettability conditions. The decrease in oil recovery at higher polymer concentrations could be due to the adsorption of polymer on a rock surface. This finding suggests it is necessary to optimize the critical surfactant concentration for chemical solution injection in reservoirs. However, due to the heterogeneous nature of most reservoirs, finding this critical concentration might be a challenge (Zallaghi *et al*. 2018). The high CR observed with PSS suggests its potential efficiency in mobilizing and recovering oil. As mentioned previously, the RF for PSS from 52% to 73% suggests that up to 27% - 50% oil is remaining in the sand pack, hence the need for tertiary recovery. The RF of up to 73% was found to be higher than the recovery factors achieved with conventional methods, typically between 30 and 60%. This finding shows that recovery factors obtained from PSS suggest its potential as an effective EOR agent.

A1: 100% PSS concentration, 0.118 grain size; nature: water-wet
A2: 50% PSS concentration,0.118 grain size; nature: water-wet
A3: 100% PSS concentration,0.118 grain size; nature: oil-wet
A4: 50% PSS concentration,0.118 grain size; nature: oil-wet
B1: 100% PSS concentration,0.06 grain size; nature: water-wet
B2: 50% PSS concentration, 0.06 grain size; nature: water-wet
B3: 100% PSS concentration,0.06 grain size; nature: oil-wet
B4: 50% PSS concentration,0.06 grain size; nature: oil-wet

4. Conclusion

The study investigated the effectiveness of PSS in enhancing oil recovery across different core samples composed of sand aggregates. The findings indicate that regardless (RF). Notably, core samples with a smaller grain size achieved a maximum RF of 71.4% and a cumulative recovery (CR) of 90.6% with residual oil saturation below 28%. The overall CR ranged from 87.5% to 91.9%, which is significantly enhanced oil recovery (EOR) techniques. Although direct wettability measurements before and after PSS application were not conducted, the observed difference in oil recovery across water-wet and oil-wet conditions suggests that PSS contributed to improved oil mobilization and displacement. The study further demonstrates that while dilution reduces the efficiency of PSS, a 50% concentration exhibited substantial recovery potential, outperforming traditional methods. Additionally, FTIR and XRD analyses provide insight into the chemical interactions responsible for the enhanced recovery. The FTIR results confirm the presence of functional groups such as hydroxyl (-OH), carbonyl (C=O), and carboxyl (-COOH) groups, which are known to influence interfacial tension and oil displacement. The XRD analysis further suggests potential mineralogical interactions that may contribute to the improved recovery performance. Overall, this research highlights the potential of PSS as a sustainable and eco-friendly chemical agent for enhanced oil recovery. Beyond its effectiveness in oil displacement, the use of PSS presents an environmentally friendly alternative, reduces waste, and promotes sustainable resource utilization in petroleum recovery operations.

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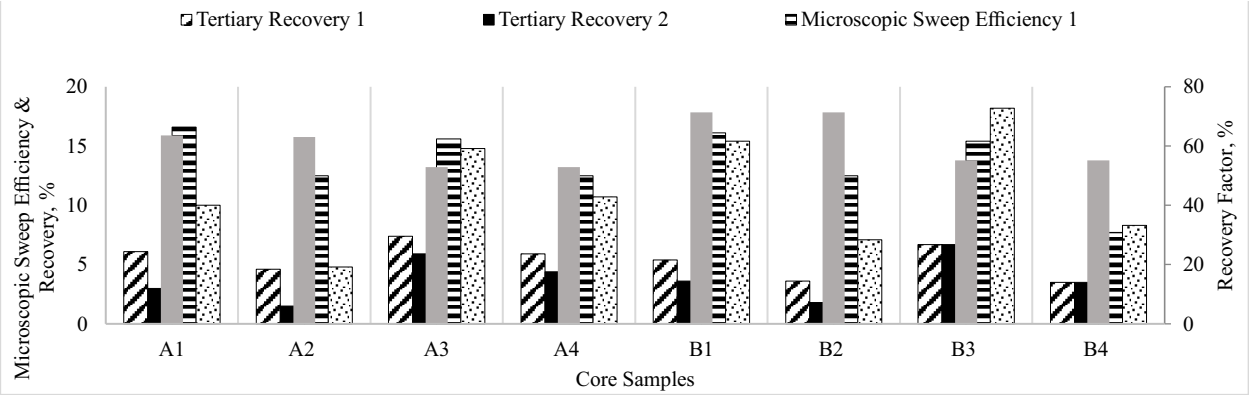

Figure 5: Cumulative recovery for different core samples

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