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Laboratory Investigation on Enhanced Oil Recovery Using Local Alkaline – Polymer for Niger – Delta Region

Atiatobe, Fabian Ashiwel[1], Mbachu Ijeoma Irene[2]
[1, 2] Petroleum and Gas Engineering University of Port Harcourt, Rivers, Nigeria.

ABSTRACT: Approximately sixty percent of crude oil still lay trapped in the reservoir even after primary and secondary recovery processes have been completed, hence the need for a method that further improves recovery. To increase oil recovery and encourage utilization of local content, locally source alkaline and polymer materials were used to improve oil recovery in this study. The local alkaline and polymer used are plantain peel ash and corn starch respectively. The efficiency of the plantain peel ash and corn starch solution were tested using different seven core samples. The core samples were individually flooded with brine (salt and water) for secondary recovery process and different concentrations of plantain peel ash and corn starch both in stand-alone and in combined form were used for tertiary recovery. The results obtained from the experimental work showed that sample-B5 with 0.2g of plantain peel ash and 0.2g of corn starch in 100ml of brine gave the highest cumulative recovery of 86% as to compare to samples B1 and B2 which has the cumulative recovery of 70% and 78% respectively. Sample-B7 which has the highest concentration of corn starch (0.4g/100ml) gave the lowest recovery of 65% due to polymer adsorption on the rock surfaces which alters the rock wettability. The assessment of formation damage was done by evaluating and determining the permeability change after tertiary flooding. The concentrations with plantain peel ash have reduced permeability change. These locally sourced materials can replace synthetic enhanced oil recovery (EOR) chemical when properly modified and refined, and they are also cheap and environmentally friendly.

KEYWORDS: Alkaline-Polymer, Corn Starch, Enhanced Oil Recovery, Plantain Peel Ash, Permeability Change

1. INTRODUCTION

After the application of primary and secondary recovery, the literature shows that huge volumes of oil remain in a reservoir [1, 2, 3]. The remaining oil-in-place otherwise known as residual or immobile oil is the target of enhanced oil recovery (EOR) [4]. The enhanced oil process interacts with the reservoir rock and oil system to create conditions favorable for residual oil recovery such as: increase the capillary number, increase drive water viscosity, reduce capillary forces, reduce oil viscosity, reduce interfacial tension, provide mobility-control, oil swelling and alteration of the reservoir rock wettability [5].

Enhanced oil recovery methods are majorly classified into thermal and non-thermal. The thermal method involves the application of heat into the reservoir as to raise the temperature of the heavy oil and reduce its viscosity and residual oil/water saturation by steam distillation. Example of thermal process are stream drive, cyclic steam simulation and in-situ combustion. Non-thermal enhanced oil recovery uses other processes other than heat energy to increase oil recovery, example are improved waterfloods, chemical and microbial methods. Chemical method uses polymers, alkaline, nanoparticle and surfactant to improve recovery [6, 7]. Chemical method has been proffered to improve oil recovery due to its ease of application and high efficiency. The chemicals tune the fluid–fluid and/or rock–fluid properties of the reservoir to aid oil recovery. Depending on the type of chemical utilized, the fluid–fluid and/or rock–fluid interaction causes a higher pore-scale displacement efficiency or enhances the sweep efficiency in the reservoir. Of the numerous chemical EOR methods, polymers and alkaline have distinct properties and high efficiency.

Recently, studies have showed that the use of locally sourced chemical agents can be used to enhanced oil recovery [8, 9, 10, 11, 12, 13]. [8] performed a study using alcohol (palm wine), mixture of water and alcohol (palm wine) and starch mixtures in various ratios as to ascertain the best method for oil recovery. The experimental results showed that alcohol and starch mixture gave a better recovery as to compare with alcohol and water mixture. It was also observed that the mixture of alcohol and water increases oil recovery but there is an increase in alcohol content in the oil recovered. This could be attributed to interfacial tension reduction between oil and water. [9] used locally sourced polymer from starch and ogbono (Irvingia gabonensis) seed to increase viscosity of brine. The maximum recovery recorded were 3.9cc, 2.8cc, and 3.7cc for starch, ogbono and XCD polymer respectively at 2.0cp with corresponding breakthrough time of 44, 22 and 45 seconds respectively. The authors reported that those local materials are good agent for enhanced oil recovery because of their ability to increase brine viscosity. [10] evaluated the efficiency of local alkaline (palm bunch) with some of the conventional alkaline such as Sodium Hydroxide (NaOH), Potassium Hydroxide (KOH) and Sodium carbonate (Na_2CO_3). The experimental result showed that KOH recovered 74%, NaOH recovered 66%, Na_2CO_3 recovered 59% while local palm bunch recovered an average of 64%. [11] analyzed and inspected the effect of using locally sourced material (palm wine) to enhance oil recovery of hydrocarbons in a completed well. Alake used alcohol to resolve the limiting capillary effects by lowering the interfacial tension thereby mobilizing the residual oil left after water flooding.

[12] screened fourteen (14) local material for chemical flooding. The local materials they investigated are Potash, Elaeis guineensis, Musa sapientum, Khaya ivorensis, Nkankan, Carica papaya's leaves, Cocos nucifera, Kai kai, Vernonia amygdalina, Abelmoschus esculentus, Brachystegia eurycoma, Detarium microcarpum, Irvingia gabonensis and Mucuna flagellipes. The authors reported that the blend of local alkaline – surfactant - polymer materials gave a maximum displacement than when used individually. [13] published a work on improving oil recovery using corn starch as a local polymer. Cornstarch solution was injected into four different unconsolidated sand pack samples at different concentration of 500ppm, 1000ppm, 3000ppm, and 9000ppm. From the experiment conducted, result indicated that Cornstarch recovered an additional 25% of the residual oil after water flooding. Also, higher concentrations of cornstarch reduce the recovery factor due to polymer adsorption on the rock surfaces which alters the rock wettability. The authors recommended that the concentration of Cornstarch should be measured after the flooding experiments for a better understanding of the adsorption mechanism of cornstarch.

[5] did a study on enhanced oil recovery using local alkaline (Palm bunch ash) – polymer (Abelmoshus esculentus) solution. The authors tested the efficiency of the Palm bunch ash and Abelmoschus esculentus solution with different concentrations. The sand pack samples were individually flooded with brine for secondary recovery process and palm bunch and Abelmoschus esculentus mixture for tertiary recovery. The results obtained from the experimental work showed that the sample-A2 with concentration of 5g: 2g to 400ml with the PH value of 9.7 gave the highest oil recovery of 84.36% compared to other samples investigated. The authors concluded that the synergy effect of Alkaline – Polymer blend in improving oil recovery cannot be overemphasis. They concluded that local materials, alkaline and polymer gave better results when used separately than some blend of alkaline and polymer. [14] insisted that the injection of Polymer alone won't be able to alter the residual oil saturations, but the combined effect of both water flooding and alkaline flooding will result to a higher oil recovery. [15] showed that the combined techniques of various chemicals gave higher recoveries because of their synergy acting together in porous media, which improves the sweeping efficiency.

The results of the literature review on various experiments conducted on local polymers and alkaline, when used separately or as a mixture showed that local materials can be used for enhanced oil recovery. However, many limitations are associated with local polymer such as Irvingia gabonensis, Brachystegia eurycoma and Detarium microcarpum, cassava starch and Abelmoschus Esculentus as to compare to local alkaline like palm bunch ash and plantain peel ash. Some of the shortcomings of local polymer as reported in the literature include, formation plugging, microbial attack, degradation, and shear thinning. The synthetic HPAM which is currently in use in the industries is susceptible to high temperature and salinity and its synthetic nature makes it harmful to the environment, and the biopolymer xanthan has the problem of degradation. Currently, operating companies take advantage of the combined alkaline–surfactant or alkaline - polymer mixture effect. Natural alkaline (plantain peel ash) and polymer (corn starch) which were sourced locally is a good candidate for developing additives for chemical enhanced oil recovery for Niger Delta region. These local materials can serve as EOR agent because they are less expensive, environmentally friendly, and most importantly ability to increase brine viscosity and control mobility. Hence, this study aimed at enhancing oil recovery using locally sourced plantain peel ash and corn starch for Niger – Delta region.

2. TERTIARY RECOVERY (CHEMICAL METHOD)

The target of tertiary recovery is the residual oil left behind after the secondary recovery process has become uneconomical. An EOR process may involve injection of miscible gases, chemicals, and thermal energy into the reservoir to displace additional oil. Three main classes of enhanced oil recovery currently being applied in the oil and gas industry are thermal, chemical, and microbial methods. Chemical recovery is tertiary recovery of interest in this study. Fig. 1 gives the broad classification, challenges, and mechanism of enhanced oil recovery.

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Chemical methods comprise the use of polymers, surfactant, foam and alkaline to enhance oil recovery. The mechanisms of chemical methods vary, depending on the chemical materials added into the reservoir. The chemical methods may provide one or several effect of interfacial tension (IFT) reduction, wettability alteration, emulsification, and mobility control [3].

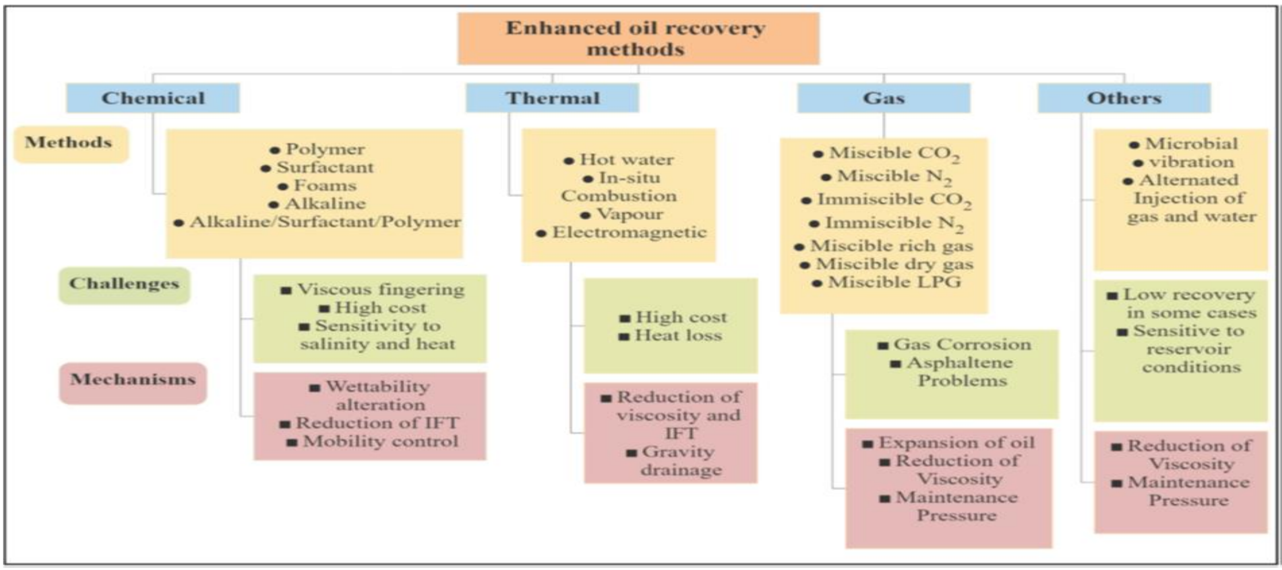

Fig. 1 Flowsheet of enhanced oil recovery methods, challenges, and mechanisms [14]

2.1. Polymer flooding

Polymers are used to reduce the mobility ratio of water – oil by increasing the water viscosity which improves the volumetric sweep efficiency during EOR processes. There are two main groups of polymers in conventional polymer flooding: synthetic and biopolymer. Partially hydrolyzed polyacrylamide (HPAM) is the most widely used synthetic polymer for polymer flooding and is a linear water-soluble polymer. The implementation of HPAM is relatively easy and can significantly improve oil recovery rate under standard reservoir conditions. Natural and biopolymers are gaining significant interest for their application in chemical EOR because of their eco-friendly nature [6].

A few of the recently used biopolymers are xanthan gum, gum Arabic, guar gum, Abelmoschus esculentus, Irvingia gabonensis, brachystegia eurycoma, corn starch, okobo, akparata, cocoyam starch, cassava starch, Mucuna pruriens, okobo and akparata, [16] and [17] reported in their research work that majority of natural polymers contain major and trace elements such as Potassium, Calcium, Manganese, Iron, Nickel, Copper, Zinc and Sodium which are the active ingredient that give them the ability to enhance oil recovery. Advance in this research will lead to a replacement of synthetic chemicals with local materials which will lead to increase in profit and a better life for the populous who will take it as an opportunity to invest in its. The polymer used in this research is corn starch with the chemical formula of $(C_6H_{10}O_5)_n$ and is usually made up of 27 percent amylose and 73 percent amylopectin.

2.2 Alkaline flooding:

It is a type of chemical enhanced oil recovery method where synthetic chemicals such as sodium hydroxide, sodium orthosilicate or sodium carbonate are injected into a reservoir to enhance oil recovery. The injected alkaline reacts with the naturally occurring organic acids in the oil and forms surfactants inside the reservoir. The surfactants eventually play a big role by reducing interfacial tension between oil and water which contributes to increase oil recovery [18]. Alkaline flooding agent has an advantage over surfactant flooding agent because of its cost effectiveness. The alkaline agent leads to the displacement of crude oil by raising the pH of the flooding water.

Local alkalis are materials that contain oxides or carbonate ions of sodium and/or potassium [16]. These materials when dissolved in water form its hydroxide or carbonate ions. Such local materials are ash of palm bunch, plantain peel, coco pod, saw dust and akanwu. These local materials have the tendency of reacting with the acidic constituents of crude, majorly the organic acids

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in the crude to form an insitu - soap, which reduces the interfacial tension between oil and formation water. The local alkaline used in this research is plantain peels ash and was found to contain 9.72% of sodium and 76.93% of potassium, indicating its suitability for enhance oil recovery purposes.

2.3 Chemical EOR Combined Techniques

Combing properties of polymers, alkaline and surfactants give a new products and trends in chemical enhanced oil recovery. The new developed processes are: Surfactant-Polymer (SP), Alkaline-Surfactant (AS), Alkaline-Polymer (AP), Alkaline-Polymeric Surfactant (APS), Alkaline-Surfactant-Polymer (ASP), Polymer-Alternating-Gas (PAG) or Surfactant-Alternating-Gas (SAG or FAWAG), and Alkaline-Surfactant-Alternating-Gas (ASAG). This new technique combined their individual properties to mobilize the residual oil by decreasing interfacial tension (IFT), increasing capillary number, enhancing microscopic displacing efficiency, improving mobility ration, and increasing macroscopic sweep efficiency [12, 19, 20]. This work takes advantage of a combined properties of polymer and alkaline to increase oil recovery.

3. METHODLOGY

3.1 Equipment and Materials

3.1.1 Equipment

Encapsulated plug sample (unconsolidated Sand-packs), Venire caliper, Density bottle, PH meter, Hydrometer, Thermometer, Canon U-tube Viscometer, Electronic Weighing balance, Stopwatch, Retort Stand, Pump, Flooding Pump Setup, Core-holder, Sieve and Stirrer.

3.1.2 Materials

The materials utilized in this research work are local alkaline (plantain peel ash), local polymer (corn starch), brine (mixture of industrial salt, Potassium Chloride, and water), sand core, crude oil.

Brine Preparation: Laboratory prepared brine of 30g/L concentration was used which contain 29.52g sodium chloride (NaCl) and 0.48g potassium Chloride (KCl) in distilled water. The brine has the density of 1.0211g/cm^3.

Preparation of Corn Starch Aqueous Solution: The corn starch (polymer) used in this research was gotten from Everyday supermarket Port Harcourt, River's state, Nigeria. 0.2g and 0.4g of corn starch were dissolved in equal volume of 100ml distilled water as to get the aqueous solution.

Preparation of Plantain Peel Ash / Solution: The plantain peel (Alkaline) was gotten from plantain fruit, sunned to dry, and burned to complete combustion. The powdered residue was sieved to remove impurities as well as larger ash particles as to get a smooth powdered material. The plantain peel ash solution was obtained by dissolving 0.2g and 0.4g in equal volume of 100ml distilled water.

Alkaline - polymer solutions were prepared with different concentrations ratios of plantain peel ash and corn starch in 100ml distilled water as shown in (Table 3).

Crude Oil Properties: The crude oil sample was obtained from a field from Niger Delta of Nigeria and has the following properties: specific gravity of 0.860, density of 0.8958g/cm^3, viscosity of 43.022cP and ^{o}API gravity of 33.99 at the 20^{o}C.

3.2 Experimental Procedure

- The seven unconsolidated Niger - Delta core (plug) samples were cleaned and fully dried in an oven.
- The weight, length and diameter of each core was measured (Table 2).
- The cores were fully immersed or saturated in a brine water as to measure the saturated weight of various core sample.
- The pore volume of each core sample was calculated by subtracting the saturated weight from dry weight and the result was divided by the brine solution density (Equation 1 and Table 4).
- The porosity was determined by using the result obtained from bulk volume (Table 2) and pore volume (Table 4) using Equation 2.
- The flooding experiment started by injecting crude oil into the core to displace the brine solution. It should be noted that not all the brine solution was displaced, and the remaining water is known as connate water.
- The same quantity of oil that entered the unconsolidated core is equivalent to brine solution displaced from the core sample at constant flow rate.

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- The brine was injected (secondary recovery) into the core to displace crude oil and the amount of oil recovered was measured and recorded. The laboratory brine water injection was a control experiment.
- Other laboratory experiments were carried out following the above procedures. The water breakthrough time was recorded.
- The different concentrations of alkaline and polymer solution EOR agents (Table 5) were injected into the core until no oil could be recovered at the residual oil saturation.
- Finally, the unconsolidated core was removed from the core-holder and re-weighted, the recovered oil was measured and permeability was determined using Equation 3.

Pore Volume Equation: $PV = \frac{W_{sat.plug} - Weight_{dry\ plug}}{P_{NaCl}}$ (1)

Where; $W_{sat.plug}$ = weight of saturated plug, $Weight_{dry\ plug}$ = weight of dry sample, P_{NaCl} = density of Brine

Porosity: $Porosity, \emptyset = \frac{P.V}{B.V} \times 100\%$ (2)

Where, P.V = pore volume, B.V = bulk volume

Permeability: $K = \frac{Q\mu_{NaCl/KCl} L_{plug} 14700}{A_{plug}\Delta P}$ (3)

Where, Q = flow rate, μ_{NaCl} = viscosity of NaCl/KCl (Brine), L_{plug} = length of plug, A_{plug} = cross section area of plug, ΔP = differential pressure and K = permeability.

4. RESULTS AND DISCUSSION

The results of the experimental study on the effect of alkaline and polymer locally sourced agents on enhanced oil recovery are presented in this section. The local alkaline and polymer materials used are plantain peel ash and corn starch respectively.

4.1. Results for Petro-physical Properties for Various Core Samples

The bulk volume for each core sample as indicated in Table 2 represents the total sand volume used to form the core sample excluding the volume of the screen. The grain size of the sieved formation used in preparing the encapsulated plug is of about 425μm. The results obtained from measurement of the bulk volume of each plug samples ranges from 65.10 to 70.88 cm^3 (Table 2).

Table 2. Bulk Volume of Encapsulated Plug

Plug samples. ID	Screen thickness (cm)	Total length of plug (cm)	Actual length of plug (cm)	Plug diameter (cm)	Plug radius (cm)	Bulk volume (cm^3) $\pi r^2 h$
A1	0.03	7.88	7.85	3.36	1.68	69.60
A2	0.03	8.12	8.09	3.34	1.67	70.88
A3	0.03	7.78	7.75	3.36	1.68	68.72
A4	0.03	7.55	7.52	3.34	1.67	65.89
A5	0.03	7.46	7.43	3.34	1.67	65.10
A6	0.03	7.66	7.62	3.34	1.67	66.76
A7	0.03	7.58	7.52	3.34	1.67	65.88

The pore volume is the total volume of small openings/spaces in the bed of the adsorbent particle. It's an indication of the volume of fluid that can be occupied by the pore space. The higher the pore volume /porosity the higher the volume of fluid that can be contained in the core and the better the reservoir formation. The results of the calculated pore volume of the core samples varies from 24.91 to 29.40cm^3 (Table 3). The porosity of the porous medium (Sand pack) was calculated from the bulk Volume (Table 2) and pore volume of the samples using Equation 2. The porosity result is shown in Table 3.

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Table 3. Pore Volume of the Plug Samples

Plug samples ID	Wt. of screen + foil (g)	Wt. of screen + foil +dry plug (g)	Wt. of dry plug (g)	Wt. of screen + foil+ saturated plug (g)	Wt. of saturation within the plug (g)	Density of sat. fluid +NaCl/KCl 30000 ppm(g/cm^3)	Pore volume cm^3	Porosity (%)
A1	33.44	154.36	120.92	184.18	29.32	1.0211	28.71	41.25
A2	31.88	153.62	121.74	183.64	30.02	1.0211	29.40	41.48
A3	32.42	150.28	117.86	179.18	28.90	1.0211	28.30	41.18
A4	33.42	150.28	114.73	175.72	27.57	1.0211	27.00	40.78
A5	31.70	135.30	103.60	160.73	25.43	1.0211	24.91	38.26
A6	33.60	145.38	111.78	172.26	26.88	1.0211	26.32	40.00
A7	32.36	148.47	116.11	175.81	27.34	1.0211	26.77	41.00

Density is the mass of object per unit volume. It measures how dense a fluid can be. The results of density of the formulated fluids using different concentrations of corn starch (CS) and plantain peel ash (PPA) are showed in Table 4. The density measurement is important because it will be used to determine the fluid kinematic viscosity.

Table 4. Density of Brine, Crude, and the Alkaline-Polymer solution

Fluid ID	Fluid concentration	Wt. of density bottle (g)	Wt. of bottle + fluid (g)	Wt. of fluid (g)	Volume of density bottle (ml)	Density of fluid (g/cm^3)
B1	CS 0.2g/100ml	23.31	80.30	56.99	56.05	1.0168
B2	PPA 0.2g/100ml	23.31	80.32	57.01	56.05	1.0171
B3	CS/PPA 0.4g:0.2g/ 100ml	23.31	81.20	57.89	56.05	1.0328
B4	CS/PPA 0.2g:0.4g/ 100ml	23.31	81.26	57.94	56.05	1.0337
B5	CS/PPA 0.2g:0.2g/ 100ml	23.31	81.25	57.94	56.05	1.0337
B6	PPA 0.4g/100ml	23.31	80.30	56.99	56.05	1.0168
B7	CS 0.4g/100ml	23.31	81.13	57.82	56.05	1.0316
B_{brine}	Brine of 30,000 ppm	23.31	80.54	57.23	56.05	1.0211
B_{oil}	33.99^0API	23.31	73.48	50.17	56.05	0.8951

The measure of fluid's internal resistance to flow is dynamic viscosity while kinematic viscosity is a ratio of dynamic viscosity to density. The higher the fluid's viscosity the more it's resistance to flow. One of the characteristics of a good EOR agent is one that can increase the viscosity brine. The results of kinematic and dynamic viscosities of the brine, crude oil and various local alkaline-polymer solution concentration used in this study are showed in Table 5. The crude oil sample has the viscosity of 43.0224cp, brine has 5.2053cp, plantain peel ash, corn starch, and plantain peel ash – corn starch mixtures have their viscosity ranges from 74.60 to 22.17cp.

Table 5. Result for Viscosity of the Flooding Sample and Crude

Fluid ID	Temp. (^OC)	Efflux time (sec)	Density of fluid	Viscometer constant 150/60lb	Kinematic viscosity	Dynamic viscosity cp
B1	30.0	599.0	1.0168	0.03641	21.8110	22.1775
B2	30.0	1205	1.0171	0.03641	43.8769	44.6272
B3	30.0	800.0	1.0328	0.03641	29.1299	30.0854

B4	30.0	1547	1.0339	0.03641	56.3300	58.2396
B5	30.0	1982	1.0337	0.03641	72.1694	74.6015
B6	30.0	1320	1.0168	0.03641	48.0600	48.8600
B7	30.0	923.0	1.0316	0.03641	33.6000	34.6600
B_{brine}	30.0	140.0	1.0211	0.03641	5.0977	5.20530
B_{oil}	30.0	1320	0.8951	0.03641	48.0644	43.0224

Permeability is the ability of the core sample to allow fluid to flow through it. It was measured by injecting water into core at a flow rate 0.9091 cm^3/sec and the pressure difference was recorded for every experiment. The permeability(K) of the sand packed was estimated using Darcy's law equation as shown in Equation 3 and Table 6.

Table 6. Result for Permeability of the Plug Sample

Plug sample ID	**Q cm^3/sec**	**Viscosity of brine 15000ppm (cp)**	**Length of plug (cm)**	**Plug radius (cm)**	**Area (cm^2)**	**Δρ (psi) Before EOR**	**Δρ (psi) After EOR**	**Permeability K(md) x 14700**	
A1	0.9091	5.2053	7.85	1.68	100.60	3.0	3.5	0.1231	1809.57
A2	0.9091	5.2053	8.09	1.67	102.41	3.0	3.5	0.1246	1831.62
A3	0.9091	5.2053	7.75	1.68	99.54	2.5	3.0	0.1474	2166.78
A4	0.9091	5.2053	7.52	1.67	96.43	2.5	3.0	0.1476	2169.72
A5	0.9091	5.2053	7.46	1.67	96.43	2.5	3.0	0.1474	2166.78
A6	0.9091	5.2053	7.62	1.67	96.43	2.5	3.0	0.149	2190.30
A7	0.9091	5.2053	7.52	1.67	96.43	2.5	3.0	0.147	2160.60

4.2 Recovery of Crude Oil by Water and Tertiary Methods

After performing the secondary and tertiary oil recovery, results obtained from the laboratory experiments using brine, local alkaline-polymer solution (plantain peel ash – corn starch solution), Alkaline (plantain peel ash solution) and Polymer (corn starch solution) respectively as the flooding agents are showed in the Table 7. The percentage of oil recovered during the secondary flooding process (water flooding) ranges from 50 to 65% indicating that up to 35% - 50% oil is remaining in sand pack, hence, the need for tertiary recovery. The result from tertiary recovery showed that sample B5 with equal concentration of 0.2g/100ml of plantain peel ash and corn starch in brine gave the highest cumulative recovery of 86% as to compare to samples B1 and B2 which has the cumulative recovery of 70% and 78% respectively (Figures 2 and 3). Samples B1 and B2 contain 0.2g/100ml each of corn starch and plantain peel ash respectively. This is because the plantain peel ash reacts with oil and formed in- situ surfactants that reduces the interfacial tension between oil and water, which also helped in reducing polymer adsorption on the rock surface. Sample B7 (0.3g/100ml) which has the highest concentration of corn starch gave the lowest recovery of 65% due to polymer adsorption on the rock surfaces which changes the wettability of the rock. The result agrees with the findings of [12] and [13] that there is a decrease in oil recovery at higher polymer concentration due to adsorption of polymer on rock surface.

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Table 7. Summary of the oil recoveries from samples

Plug sample ID	Oil initially in Place	Break thru. Time (sec)	Δρ at drainage (psi)	Secondary. Recovery (ml)	Conc. Of fluid for tertiary recovery (%)	Tertiary recovery (ml)	Cumulative recovery (ml)	Residual oil (ml)	Percentage Recovery (%)	Remarks
A1	26	60	8.0	17	B1	3	20	6	70.00	Good
A2	26	60	8.0	17	B2	4	21	5	78.00	High
A3	25	57	7.8	16	B3	3	19	6	76.00	High
A4	24	53	7.5	15	B4	3.5	18.5	5.5	77.08	High
A5	20	42	7.0	13	B5	3	16	4	86.00	Highest
A6	24	55	7.9	14	B6	3	17	7.8	71.00	Good
A7	25	48	7.7	13.5	B7	2.7	16.2	9.5	65.00	Lowest

From this experimental study, it can be found that the right combination of these local materials increases oil recovery (Figs. 2 and 3). For enhanced oil recovery design project, alkaline ratio should be higher than polymer as to reduce the blockage of pore volume that is normally caused by polymer as to achieve a desired target of high recovery. The good performance is due to the combined effect of alkaline in reducing interfacial tension and emulsifying the crude and polymer in improving mobility ratio. It was also observed that these materials both in stand-alone as well as in combined form increased the PH value and it affected recovery positively (Figure 4). The breakthrough time for concentration B5 which gave the highest recovery happened after 42 seconds which is early and impressive.

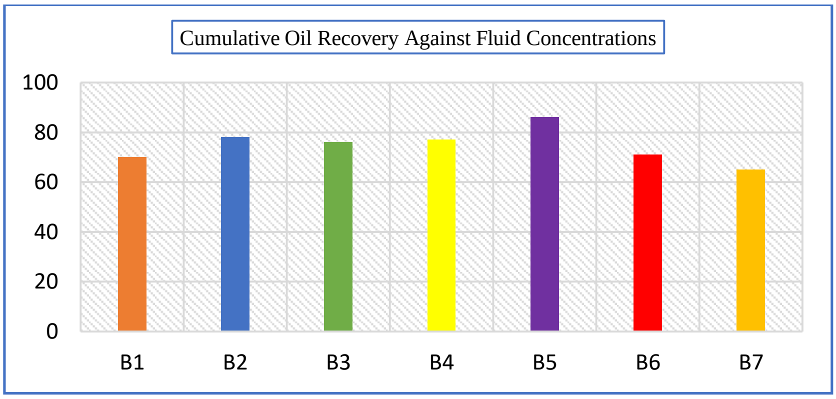

Fig. 2. Percentage recovery against Fluid concentrations

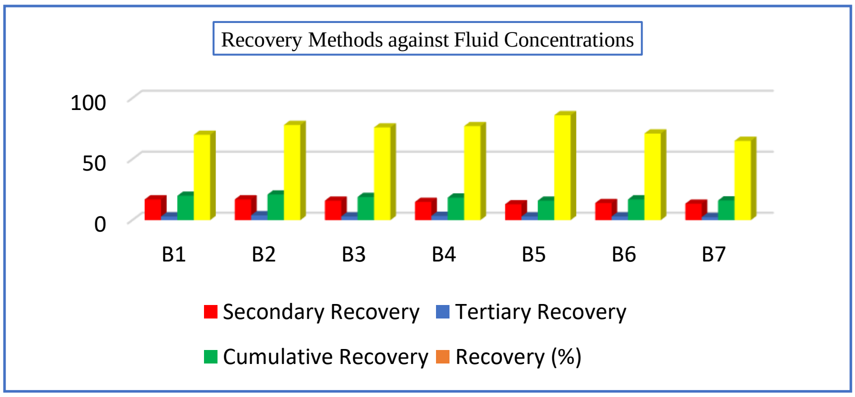

Fig. 3 Secondary, Tertiary, Cumulative recovery against Fluid concentrations

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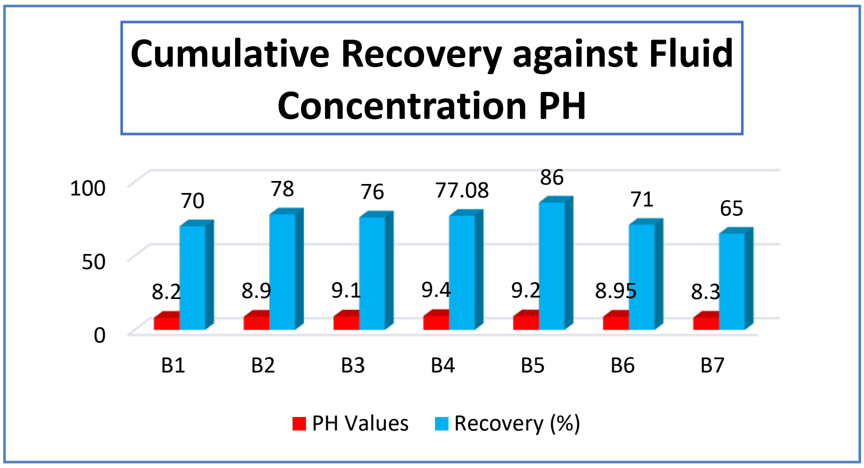

Fig. 4. Percentage Cumulative Recovery against Fluid PH

4. 3 Permeability Change Result

After the secondary and tertiary flooding, the core's permeability was determined as to evaluate the extent of formation damage caused by EOR agents. There is a significant decrease in permeability of the reservoir formation after the tertiary flooding most especially with fluid solution that contain polymer (corn starch) despite their good performance in enhancing oil recovery. Fig. 5 show the change in permeability for all the EOR agents studied. Permeability alteration for all the polymer, alkaline and polymer-alkaline concentrations evaluated ranges from 187.83 md to 992.19 md. The lowest value of 187.83 md permeability change was gotten from fluid concentration of 0.2g local alkaline in brine as to compare to 474.75 md of 0.2g polymer in brine. It was observed that the reduced permeability changes for the local alkaline used in this study both on stand-alone and in combination with polymer helped in reducing formation damage by forming in-situ surfactant that helps to reduce the adsorption of polymer on the formation surface.

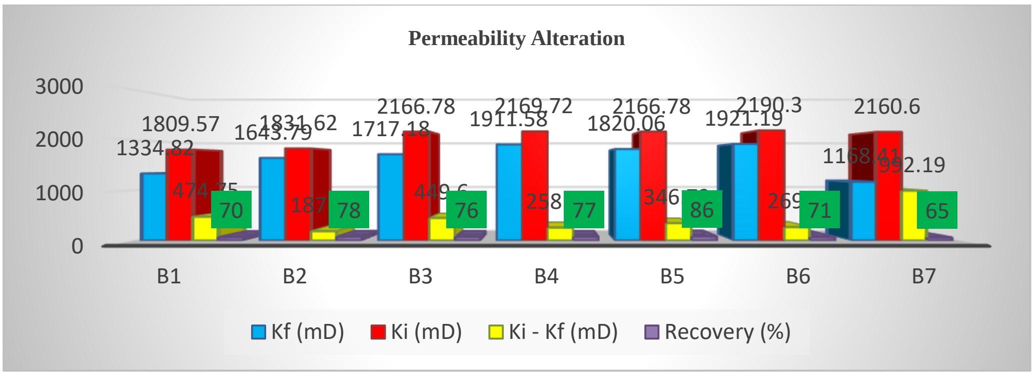

Fig. 5. Permeability Alteration for different concentration of EOR agents

5. CONCLUSION

Based on the experimental results obtained from this study, the following conclusions are reached.

- Injection of plantain peel ash and corn starch solutions into core samples produced more oil than brine injection.
- Standalone plantain peel ash solution increases recovery both at higher and lower concentration without much damage on formation.
- Standalone corn starch solution increase recovery only at lower concentration but gives better recovery at higher concentration when mixed with plantain peel ash. At higher concentration there is an increase in viscosity of the corn starch solution which block the pore space and reduces the effectiveness of corn starch solution.

- The combination of corn starch with plantain peel ash reduced formation damage drastically and gave a better recovery.
- Plantain peel ash – corn starch solution flooding utilized the properties of both agents to give over 20% incremental oil recovery over water flooding.

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