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# Experimental Study on Enhanced Oil Recovery Using Local-Alkaline-Polymer

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***Abstract***
*Improvement in oil productivity is one of the Oil and Gas industry's challenges. About 60% of crude Oil still lay trapped in the reservoir even after primary and secondary recovery process have been completed, hence the need for a method that further improves recovery. In this study, flooding experiment was conducted at the laboratory in the Department of Petroleum and Gas Engineering, University of Port-Harcourt Nigeria to investigate the use of locally sourced alkaline and polymer materials in improving oil recovery using different concentrations. Palm bunch ash and Abelmoschus-esculentus were the locally sourced alkaline and polymer materials used in this research work respectively. The efficiency of the Palm bunch ash and Abelmoschus-esculentus solution was tested using different concentrations. Seven plug samples were prepared, saturated with formation brine of 10,000ppm salinity and crude was flowed through the plug samples. The samples were individually flooded with brine for secondary recovery process and palm bunch and Abelmoschus-esculentus mixture for tertiary recovery. The results obtained showed that the sample-A2 with concentration of 5gram of alkaline with 2gram polymer in 400ml with the PH value of 11.30 gave the highest recovery of 84.36% compared to other samples investigated. The local alkaline and polymer materials gave better results when used separately than some blend of alkaline and polymer solutions. These local materials are effective as enhanced oil recovery agents and can as well substitute synthetic chemicals if refined and modified. It is recommended that further studies should be carried out to investigate other locally alkaline - polymer sourced materials.*
***Keywords: Abelmoschus-esculentus, Alkaline, Brine, Core Flooding, Enhanced Oil Recovery, Polymer***

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## I. INTRODUCTION

Enhanced Oil Recovery (EOR) or tertiary oil recovery is the extraction of crude oil from an oilfield that cannot be further extracted by primary (natural drive) or secondary (reservoir repressurizing) recovery method [1]. During primary production which is the first phase of the oil production, the well is produced naturally without the addition of anything to the formation, the natural pressure from the earth enables the oil to flow to the well-bore. Oil recovery by pure pressure depletion results in an oil recovery of about 20% of original oil in place (OOIP) depending on the characteristics of the rock formation such as the initial pressure and the compressibility of the reservoir fluids. This means that up to 80% of the oil may remain in the rock unless additional technology is applied to improve the oil recovery. The primary depletion mechanism are rock and fluid expansion, solution gas drive, water influx, gas cap, or gravity drainage, and combination of multiple sources of energy [2].

Usually, the secondary recovery is the next step in the oil field life cycle, when the oil production declines because of hydrocarbon production from the formation, the secondary oil recovery process is employed to increase and balance the pressure required to drive the oil to production wells [3]. The secondary recovery process involves the injection of gas or water into the oil-bearing formation to maintain reservoir pressure in order to improve production of oil. Waterflooding which helps in the maintenance of the reservoir pressure to recover more oil leaves approximately two thirds of the original oil in place (OOIP) as un-swept and residual oil in reservoir for further recovery [4]. The water used for this step is mostly recycled water from the water separated from the oil during the oil production operations. Water, typically saltwater, is found in the formation with the oil and natural gas. This water is separated, collected during production and re-injected into the oil-bearing formation for pressure maintenance. As oil fields age, they produce more water as a percentage of the overall fluid recovered, the application of secondary recovery has the potential to recover an additional 15 to 20% of the original oil in place.

In the tertiary recovery, chemicals and thermal energy are usually introduced into the reservoir to improve oil recovery by fluid mobility and interfacial tensions to improve flow. The application of enhanced oil recovery (EOR) methods is to increase the sweep efficiency in the reservoir using chemical injectants that help enhance reservoir energy and reduce the remaining oil saturation below the level achieved by conventional injection methods [5].

Of recent, studies has proved that the use of locally sourced materials can be used to enhanced oil recovery ([6], [7], [8], [9], and [10]). [6] performed a study using alcohol (palm wine), mixture of water and alcohol (palm wine) and starch mixtures in various ratios to find out the ideal ratio that recovers oil most from the sand. Experimental results show that a mixture of alcohol and starch can enhance oil recovery, for alcohol and water oil recovery increase with increase in alcohol content of the mixture. This could be attributed to reduction in interfacial tension between oil and water. [7] used locally sourced polymer from Starch and ogbono 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. They concluded that the good result is due to the increasing viscosity property of the material used.

[8] compared the efficiency of local alkaline (palm bunch) with other conventional alkaline Sodium Hydroxide (NaOH), Potassium Hydroxide (KOH) and Sodium carbonate ($Na_2CO_3$), after the experiment it was found that KOH recovered 74%, NaOH recovered 66%, $Na_2CO_3$ recovered 59% while palm bunch recovered an average of 64%. [9] analyzed and inspect the effect of using locally sourced material (palm wine) to enhance the recovery of hydrocarbons in complete wells. He used alcohol to resolve the limiting capillary effects lowering the interfacial tension there by mobilizing the residual oil left after water flooding. [10] performed a sand pack oil displacement flooding using fourteen local samples. The local materials (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) were screened for chemical flooding. They found that the best performing local materials alkaline, surfactant and polymer gave additional displacement efficiency of 17.3%, 5.2% and 18.7% respectively while blend of local materials alkaline, surfactant and polymer gave a maximum displacement of 96.7%, 93.5%, 95.2% and 90%.

Lately, the use of local materials is a highly welcome technology in the oil and gas industry globally because they are cost effective and environmentally friendly. This work aimed at studying the effectiveness of local alkaline (palm bunch), polymer (Abelmoschus-esculentus) and different alkaline-polymer (palm bunch-Abelmoschus) concentrations in enhancing oil recovery using Niger Delta formation.

## 1.1 Enhance Oil Recovery Methods

Thermal method, miscible method, and chemical method are the most common enhance oil recovery techniques.

### 1.1.1 Thermal Method

This involves the use of hot water, steam or in-situ combustion to increase the temperature of the reservoir. When the temperature of the reservoir is increased the viscosity of the crude reduces thereby enabling flow of fluid.

### 1.1.2 Miscible Flooding Process

The displacing fluid and residual oil mix to form a single phase. Here the interfacial tension is zero and the capillary number turns infinite, and the microscopic displacement efficiency is maximized. This process maintains reservoir pressure and improves oil displacement because the interfacial tension between oil and water is reduced due to the introduction of miscible gases into the reservoir. Miscible process can be categorized into two types such as single contact and multi contact miscible flooding.

Liquefied petroleum gas or alcohols is injected fluids in single contact miscible flooding. The injected fluid is miscible with residual oil immediately in contact. While in multiple contact or dynamic miscible process the injected fluids are usually methane, inert fluids, or an enriched methane gas supplemented with $C_2$ - $C_6$ fractions [11].

### 1.1.3 Chemical Flooding Process

This process involves the addition of one or more chemical compounds to an injection fluid either to reduce the interfacial tension between the reservoir fluid and injecting fluid or to improve the sweep efficiency of the injected fluid. The injected chemicals reduce the surface tension of the remaining oil and push the oil towards a producing well. Chemical flooding includes: Alkaline flooding, Surfactant flooding, Polymer flooding and Alkaline surfactant polymer flooding.

**(i) Alkaline Flooding**

Alkali flooding is an enhance oil recovery (EOR) technique that utilizes an alkali (an alkali is a basic compound which may be an ionic salt of an alkali metal or alkaline earth metal) in improving oil recovery factor. During alkaline flooding, the alkaline reacts with the naphthenic acids in the reservoir to form surfactant (soap). Alkaline flooding method is distinct from other enhance oil recovery (EOR) methods on the basis that the chemicals that aid the oil recovery are generated in situ during the EOR process by saponification reaction. Saponification reaction is defined as the reaction between an organic acid and caustic alkali to form soap indicated by the reaction in Equations (1) and (2). Figure 1 shows an illustration of the chemical model for the alkali–oil chemistry in the reservoir rock. The organic acid is obtained from the acidic component of the crude oil. The generated soap acts as an in-situ surfactant to reduce (IFT) interfacial tension between oil and gas, reduce capillary pressure, alters wettability and emulsify the crude oil, thereby, improving oil recovery. The injection of alkaline into the reservoir makes the reservoir more water wet, thus increasing the flooding effectiveness [12].

$$Na_2O + H_2O \longrightarrow 2NaOH \quad (1)$$
$$K_2O + H_2O \longrightarrow 2KOH \quad (2)$$

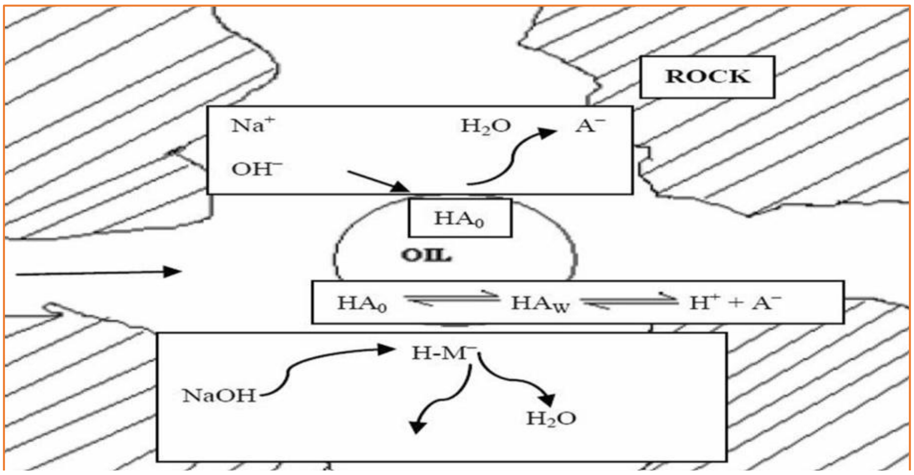

**Figure 1. Schematic on mechanism of alkali flooding ([13])**

These alkalis include sodium metaborate ($NaBO_2$), sodium carbonate ($Na_2CO_3$), sodium hydroxide (NaOH), sodium bicarbonate ($NaHCO_3$), plantain peel ash, potash and palm bunch ash.

**(ii) Surfactant Flooding**

Surfactants are known to be surface active agents like soap and detergent. Their hydrophilic and hydrophobic nature reduces the interfacial tension between the oil and water. Surfactant flooding has been proven as the EOR technique used for mobilizing residual oil trapped in the reservoir [14]. The purpose of surfactant injection into reservoir for improving oil recovery factor is to alter the fluid/fluid interaction by reducing (IFT) interfacial tension between the oil and brine, and fluid/rock properties via wettability alteration of the porous medium. There are four types of surfactant namely the anionic, cationic, non-ionic and zwitter ionic.

**(iii) Polymer Flooding**

The polymer flooding process, involves the injection of high molecular weight water-soluble polymers along with the water slug to increase the viscosity of the injectant. This incremental viscosity of the injectant accelerate and give room for the mobility and conformance control of the injected slug and eradicates viscous fingering phenomena [15].Consequently, early water breakthrough normally encountered in waterflooding process is suppressed and an increase in oil recovery factor is achieved. Polymer flooding has been implemented successfully in many oilfields either on a pilot scale or commercial scale for several decades. Additionally, polymer flooding has maintained an increasing importance to the current energy market. The most notable contribution is the reported increase in oil production of 300,000 bbl /day from Daqing oil field in China.

Generally, two major classifications exist for polymers used during polymer flooding recovery operations, namely, synthetic polymers and biopolymers. Typical examples of synthetic polymers are polyacrylamides and its derivatives such as partially hydrolyzed polyacrylamide (HPAM), hydrophobically associating polyacrylamide (HAPAM), and copolymers of acrylamide [16]. On the other hand, biopolymers include xanthan gum, scleroglucan, hydroxy-ethylcellulose, carboxymethylcellulose, welan gum, guar gum, schizophyllan, mushroom, polysaccharide, cellulose, and lignin.

**(iv) Alkaline-Surfactant-Polymer (ASP) Flooding**

The ASP flooding is one of the main methods in chemical enhanced recovery. Similar to other chemical EOR, alkaline-surfactant-polymer is used to improve the mobility ratio and increase the capillary number. This achieved by making the interfacial tension (IFT) between the displacing and the displaced phase's small, usually by about 1,000 folds [17]. This type of flooding combines chemicals that are considered perfect solution to improve the mobility ratio and capillary number. Thus, this method can enhance the oil production with the improvement of both the sweep and displacement efficiency. Alkali is one of the main components in alkaline-surfactant-polymer (ASP) flooding and it is used to decrease the adsorption of the surfactant on the reservoir rock. It creates an in-situ surfactant due to the alkali reaction with the acidic oil. The in-situ surfactant and the injected surfactant can reduce the interfacial tension (IFT) to ultralow values hence reducing the capillary number and the trapped oil can be produced [18]. Generally, surfactant is expensive and it is not feasible if the adsorption rate was very high. This results in the prevention of oil trapping and mobilization of immobile oil. According to [19], it is found that ASP flooding is a more cost-effective alternative to the conventional micelle-polymer flooding. Due to the similarity in the properties of alkali and surfactant that reduced the IFT, the combination of those two chemicals will be in favor to reach the goal of ultralow IFT. One of the functions of polymers is to increase the viscosity of the displacing fluid thereby, improve the sweep efficiency. Furthermore, polymer can also ensure the control of a good mobility for the flooding thus increasing the sweep efficiency. It also has a special property called polymer viscoelastic behavior where it exerts a larger pulling force on oil droplets or oil films due to the stress at the surface between oil and polymer. Over time, the force increases until it reaches a point where the force generated is powerful enough to recover oil from unrecovered pore thus, residual oil saturation decreases. Overall, ASP flooding is expected to recover between 16 to 19 % from the original oil in place [20].

#### 1.1.4 Microbial Enhanced Oil Recovery (MEOR)

It is a microbial process. Here microbes and nutrients are injected into reservoir fluids to generate polymers and surfactant. MEOR is biological based technology consisting in manipulating function or structure, or both, of microbial environment existing in oil reservoirs. MEOR Flooding involves: Injecting of microbes/nutrients in reservoir, incubation, growth proliferation and generation of metabolites and mobilization of oil.

## II. EXPERIMENTAL DESCRIPTION

### 2.1 Materials and Method

The materials used in this work are Crude oil, Brine (mixture of industrial salt and water), Palm Bunch and Abelmoschus-esculentus.

Equipment: Encapsulated plug sample (unconsolidated Sand-packs), Vernier caliper, Density bottle, PH meter, Hydrometer, Thermometer, Canon U-tube Viscometer, Electronic weighing balance, stop watch, Retort stand, Pump, Flooding Pump Setup, Core-holder, Sieve and stirrer.

The crude oil sample was obtained from a field from Niger Delta of Nigeria, and has the following properties; specific gravity of 0.912, density of 0.8718g/cm$^3$, viscosity of 8.2858cP and $^o$API gravity of 23.65 at the 29$^o$C. The sand pack was prepared using sand grain size between 65 to 205 macrons. They were saturated with brine and its bulk volume, porosity and permeability were calculated using Equations 3 to 5. Table 1 shows the properties of the test fluids employed in this experiment.

$$PV = \frac{W_{sat.plug} - W_{dry\ plug}}{\rho_{NaCl}} \quad (3)$$

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

$$Porosity, \emptyset = \frac{P.V}{B.V} \times 100\% \quad (4)$$

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

$$K = \frac{Q\mu_{NaCl}L_{plug}14700}{A_{plug}\Delta P} \quad (5)$$

Where;
Q = flow rate, $\mu_{NaCl}$ = viscosity of NaCl (Brine),
$L_{plug}$ = length of plug
$A_{plug}$ = cross section area of plug
$\Delta P$ = differential pressure
$K$ = permeability

**Brine Formulation:** The brine was formulated by using industrial salt which has 99.9% pure NaCl with molecular weight of 58.44. The salt was dissolved in water and properly stirred using a stirrer as so get homogenous solution. Its concentration was10grams of NaCl in 1000ml of distilled water. The concentration is considered as moderate salinity for sea water. The brine has the density of 1.0105g/cm$^3$.

**Preparation of Palm Bunch Ash:** Palm bunch ash is a local alkaline material derived naturally from palm tree. This bunch ash have been used and recognized by researchers as a good and cheap source of alkaline for enhanced oil recovery.

- The palm fruit bunch was obtained from palm tree.
- It was cut, and the fruit was separated from the palm bunch.
- The palm bunch was exposed to sunlight to dry
- When properly dried, burn and allow for complete combustion.
- The powdered residue was sieved to remove impurities as well as larger ash particles and stored in a beaker.

**Preparation of Abelmoschus-esculentus extract**: It is a tropical vegetable that serves as a source of polymer. It is recognized by researchers as a local source of polymer.

- Abelmoschus-esculentus was cut, dried, grinded and sieved to obtain a finer and powdery form.
- The required weight was measured with electronic weighing balance and was put into a beaker.

Alkaline-polymer solutions was prepared with different concentrations of powered bunch ash and abelmoschus-esculentus in 400ml distilled water (Table 3)

### 2.2 Experimental Procedure

i. Encapsulated core plug samples of the unconsolidated Niger Delta sand formation samples were prepared and saturated with laboratory brine.
ii. Pore volume, bulk volume and porosity were measured using saturation method. Table 2 shows the results of pore and bulk volume and porosity.
iii. The saturated sand –packs were used for oil displacement flooding experiment in a horizontal position.
iv. The fluid from the inlet pipe were pumped into the core-holder using positive displacement pump.
v. The flooding experimental started with a desaturation process using crude oil sample as the displacing fluid. The displacing fluid displaces the laboratory brine in the sand-pack until irreducible water saturation at a fixed rate is obtained and the break through time was recorded.
vi. A control experiment was carried out by injecting the laboratory brine.
vii. Other experiments were conducted following the procedure above. The time for water breakthrough was taken as the outlet pipe. The oil recovered and brine produced were recorded.
viii. Polymer – alkaline enhanced oil recovery extract was also injected until zero oil could be recovered at the residual oil saturation. Recovered oil was recorded.
ix. After which, the unconsolidated sand-pack was removed from the core-holder and weighted.

## III. RESULTS AND DISCUSSION

The results of the experimental designed on the effect of alkaline and polymer locally sourced agents on enhanced oil recovery are presented in this section. The local alkaline and polymer used are palm bunch and Abelmoschus esculentus respectively.

### 3.1 Petrophysical Properties of the Formation

The bulk volume for each plug sample as indicated represent the entire volume of the sand used to form the plug sample excluding the volume of the screen. The encapsulated plug prepared uses a sieved formation having a grain size of about 425$\mu m$. The results for the measurement of the bulk volume of the plug samples ranges from 58.01 to 63.81 $cm^3$ (Table 1)

**Table 1. Bulk Volume of Encapsulated Plug**

| Sample | Thickness of the Screen (cm) | Total length of plug (cm) | Actual plug length (cm) | Plug diameter (cm) | Plug radius (cm) | Bulk Volume ($cm^3$) |
|---|---|---|---|---|---|---|
| *A*1 | 0.036 | 6.98 | 6.95 | 3.25 | 1.63 | 58.01 |
| *A*2 | 0.036 | 7.47 | 7.44 | 3.26 | 1.63 | 62.1 |
| *A*3 | 0.036 | 7.24 | 7.21 | 3.24 | 1.62 | 59.44 |
| *A*4 | 0.036 | 7.77 | 7.74 | 3.23 | 1.62 | 63.81 |
| *A*5 | 0.036 | 7.61 | 7.58 | 3.24 | 1.62 | 62.5 |
| A6 | 0.036 | 7.41 | 7.38 | 3.25 | 1.63 | 61.60 |
| A7 | 0.036 | 7.11 | 7.08 | 3.24 | 1.62 | 58.37 |

The pore volume is the total volume of small openings/spaces in the bed of the adsorbent particle (i.e. the plug samples). It's an indication of the volume of fluid that can be occupied by the pore space. The higher the porosity the higher the volume of fluid that can be contained in the plug. The results for the measurement of the pore volume of the plug samples varies from 24.54 to 28.75cm$^3$ and 32.98 to 36.51% for porosity (Table 2).

**Table 2. Pore Volume of the Plug Samples**

| Sample | Weight of screen + foil (g) | Weight of screen + foil + dry plug | Weight of dry plug (g) | Weight of screen + foil + saturated plug (g) | Weight of saturated plug (g) | Density of Fluid (g/cm$^3$) 10,000 ppm | Pore Volume (cm$^3$) | Bulk Volume (cm$^3$) | Porosity (%) |
|---|---|---|---|---|---|---|---|---|---|
| *A1* | 30.13 | 123.35 | 93.22 | 148.13 | 24.78 | 1.01 | 24.54 | 58.01 | 33.47 |
| *A2* | 30.5 | 142.37 | 111.87 | 170.49 | 28.12 | 1.01 | 27.84 | 62.1 | 34.26 |
| *A3* | 30.1 | 139.15 | 109.05 | 165.19 | 26.04 | 1.01 | 25.78 | 59.44 | 33.66 |
| *A4* | 32.17 | 149.64 | 117.47 | 178.68 | 29.04 | 1.01 | 28.75 | 63.81 | 35.06 |
| *A5* | 32.14 | 136.69 | 104.55 | 162.94 | 26.25 | 1.01 | 25.99 | 62.5 | 36.51 |
| **A6** | 31.54 | 138.84 | 107.30 | 165.69 | 26.85 | 1.01 | 26.58 | 61.60 | 35.02 |
| **A7** | 35.47 | 141.64 | 106.17 | 167.64 | 25.46 | 1.01 | 25.39 | 58.37 | 32.98 |

Density is the mass of object per unit volume. It indicates how dense a fluid is. The results of density of the brine, crude oil, alkaline, polymer and various alkaline-polymer solution with their different concentration used in this research study are showed in Table 3.

**Table 3. Density of Brine, Crude, and the Alkaline-Polymer solution**

| Fluid sample | Weight of density of bottle (pynometer) (g) | Weight of density bottle + sample (g) | Weight of fluid (g) | Volume of density bottle (cm$^3$) | Density of fluid (g/cm$^3$) |
|---|---|---|---|---|---|
| **Brine 10,000 ppm** | 24.25 | 74.46 | 50.21 | 49.69 | 1.0105 |
| **Crude oil** | 24.25 | 67.57 | 43.32 | 49.69 | 0.8718 |
| **A/P 2:5 400 ml** | 24.25 | 74.18 | 49.93 | 49.69 | 1.0048 |
| **A/P 5:2 400 ml** | 24.25 | 74.28 | 50.03 | 49.69 | 1.0068 |
| **A/P 5:5 400 ml** | 24.25 | 74.33 | 50.08 | 49.69 | 1.0078 |
| **A/P 1.5:3 400 ml** | 24.25 | 74.18 | 49.93 | 49.69 | 1.0048 |
| **A/P 4:3 400 ml** | 24.25 | 74. | 49.97 | 49.69 | 1.0056 |
| **A 5g 400ml** | 24.25 | 74.33 | 50.08 | 49.69 | 1.0078 |
| **P 5g 400ml** | 24.25 | 73.94 | 49.69 | 49.69 | 1.000 |

Dynamic viscosity is a measure of fluid's internal resistance to flow while kinematic viscosity is a ratio of dynamic viscosity to density. The higher the fluid's viscosity the more it's resistance to flow. The results of kinematic and dynamic viscosities of the brine, crude oil and various alkaline-polymer solution concentration used in this research study are showed in Table 4. The crude oil sample has the viscosity of 8.2858cp, brine has 0.9571cp, alkaline, polymer, and alkaline-polymer mixtures has their viscosity in the range from 0.8799 to 1.0925cp

**Table 4. Result for Viscosity of the Flooding Sample and Crude**

| Fluid Sample of Crude oil | Temperature ($^0C$) | Efflux time (sec) | Viscometer Constant 150/601B | Density of Fluid ($g/cm^3$) | Kinematic Viscosity ($m^3/s$) | Dynamic Viscosity (cp) |
|---|---|---|---|---|---|---|
| **Crude oil** | 29.00 | 26.00 | 0.036415 | 0.8718 | 9.5043 | 8.2858 |
| **Brine 10,000 ppm** | 29.00 | 26.01 | 0.036415 | 1.0105 | 0.9472 | 0.9571 |
| **A/P 2:5 400 ml** | 29.00 | 25.00 | 0.036415 | 1.0048 | 0.9104 | 0.9147 |
| **A/P 5:2 400 ml** | 29.00 | 24.00 | 0.036415 | 1.0068 | 0.874 | 0.8799 |
| **A/P 5:5 400 ml** | 29.00 | 27.00 | 0.036415 | 1.0078 | 0.9832 | 0.9909 |
| **A/P 1.5:3 400 ml** | 29.00 | 26.00 | 0.036415 | 1.0048 | 0.9468 | 0.9513 |
| **A/P 4:3 400 ml** | 29.00 | 26.40 | 0.036415 | 1.0056 | 0.9614 | 0.9667 |
| **A 5g 400ml** | 29.00 | 25.50 | 0.036415 | 1.0078 | 0.9286 | 0-9358 |
| **P 5g 400ml** | 29.00 | 30.00 | 0.036415 | 1.0000 | 1.0925 | 1.0925 |

Permeability is the measure of the interconnected pore space. This is the ability of the plug sample to allow fluid through it. The results of permeability of the plug samples used in this research study are showed in Table 5 and it ranges from 23.81 to 29.81 md

**Table 5. Result for Permeability of the Plug Sample**

| Sample ID | Flow rate ($cm^3/sec$) | Viscosity of Brine 10,000 ppm | Actual Length of Plug (cm) | Plug Radius (cm) | Area ($cm^2$) | Differential Pressure (psi) | Permeability (md) |
|---|---|---|---|---|---|---|---|
| ***A*1** | 0.075 | 0.9571 | 6.95 | 1.63 | 87.87 | 2.8 | 29.81 |
| ***A*2** | 0.075 | 0.9571 | 7.44 | 1.63 | 92.89 | 3.2 | 26.64 |
| ***A*3** | 0.075 | 0.9571 | 7.21 | 1.62 | 89.88 | 3 | 28.22 |
| ***A*4** | 0.075 | 0.9571 | 7.74 | 1.62 | 95.27 | 3.6 | 23.81 |
| ***A*5** | 0.075 | 0.9571 | 7.58 | 1.62 | 93.64 | 3.4 | 25.12 |
| **A6** | 0.075 | 0.9571 | 7.38 | 1.63 | 92.28 | 3.2 | 26.37 |
| **A7** | 0.075 | 0.9571 | 7.08 | 1.62 | 88.56 | 3.0 | 28.12 |

### 3.2 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 (Palm bunch - Abelmoschus esculentus), Alkaline (Palm bunch) and Polymer (Abelmoschus esculentus) respectively as the flooding agents are showed in Table 6 and Figure 2. The results obtained during the water flooding process shows the percentage oil recovery from 56 to 69%. From the results in Table 6, the solution of 5g of alkaline with 2 g of polymer in 400L of brine gave the highest recovery of 84.36% as to compare to the solution of 5g of polymer and 2g `of alkaline with the recovery of 69.38%. The solutions with higher concentration of polymer did not generally perform well as to compare with those with higher concentrations of alkaline. The individual chemicals performed better than the solutions with higher polymer concentration with oil recovery of 68.50% and 72.50% for polymer and alkaline respectively. It was observed from the experimental study that the higher concentration of alkaline gives higher oil recovery for alkaline-Polymer flooding. The good result is due to the effect of the alkaline in reducing interfacial tension and emulsifying the crude combined with the effect of the polymer in improving mobility ratio. It was also observed that the mixture with highest PH value gave the highest oil recovery (Figure. 3). Figure 4 shows the breakthrough time with different concentration investigated. It ranges from 34s to 48s, the concentration ratio that gave the highest recovery has the breakthrough time at 44s which is quite impressive.

**Table 6. Result of Oil Recovery with several A/P Solution**

| Sample ID | Conc. A/P to 400ml | OIIP (ml) | Secondary Recovery (ml) | Tertiary Recovery (ml) | Breakthrough time (s) | Cumulative Oil Recovery (ml) | Residual oil saturation (ml) | Percentage of oil Recovery (%) | PH |
|---|---|---|---|---|---|---|---|---|---|
| *A1* | 2:5 | 16.0 | 9.0 | 2.1 | 34.0 | 11.10 | 4.90 | 69.38 | 9.60 |
| *A2* | 5:2 | 17.9 | 12.5 | 2.6 | 44.0 | 15.10 | 2.80 | 84.36 | 11.30 |
| *A3* | 5:5 | 22.0 | 13.0 | 2.0 | 47.0 | 15.00 | 7.00 | 68.18 | 9.40 |
| *A4* | 3:1.5 | 23.0 | 14.0 | 3.40 | 48.0 | 17.40 | 5.60 | 75.65 | 10.50 |
| *A5* | 4:3 | 18.0 | 10.0 | 2.0 | 43.0 | 12.00 | 6.00 | 66.67 | 9.80 |
| A6 | 5 of A | 21.0 | 13.0 | 2.0 | 39.0 | 15.00 | 6.00 | 71.43 | 9.90 |
| A7 | 5 of P | 20.0 | 11.5 | 3.0 | 41.0 | 14.50 | 5.50 | 68.50 | 9.40 |

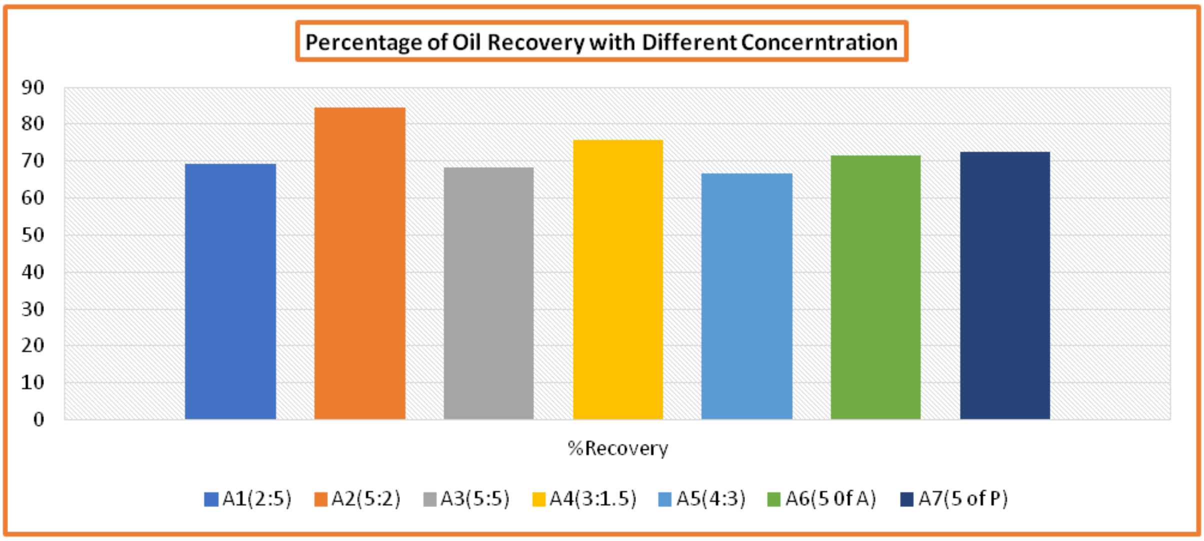


**Figure 2. A Plot of Percentage oil Recovery at Different Concentration**

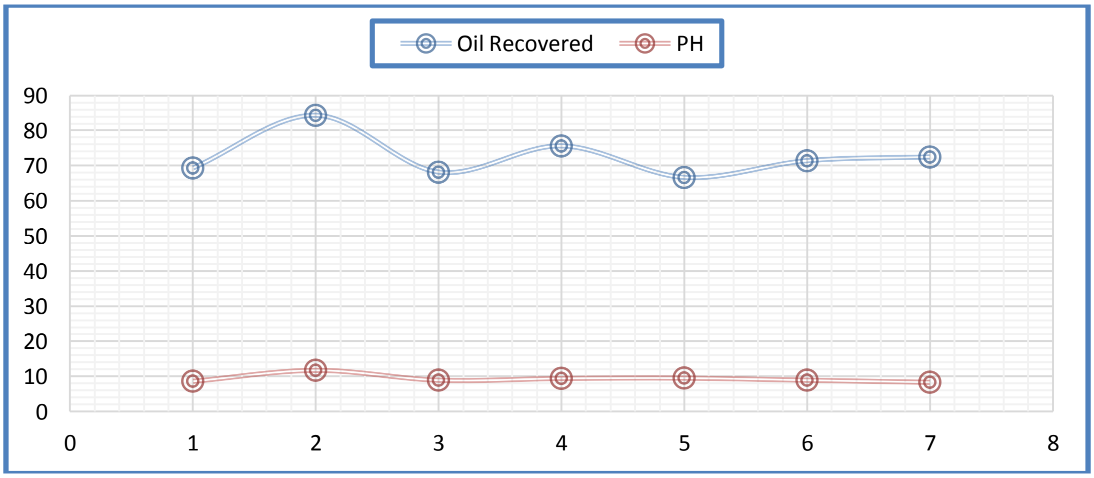


**Figure 3. PH concentration against Oil Recovered**

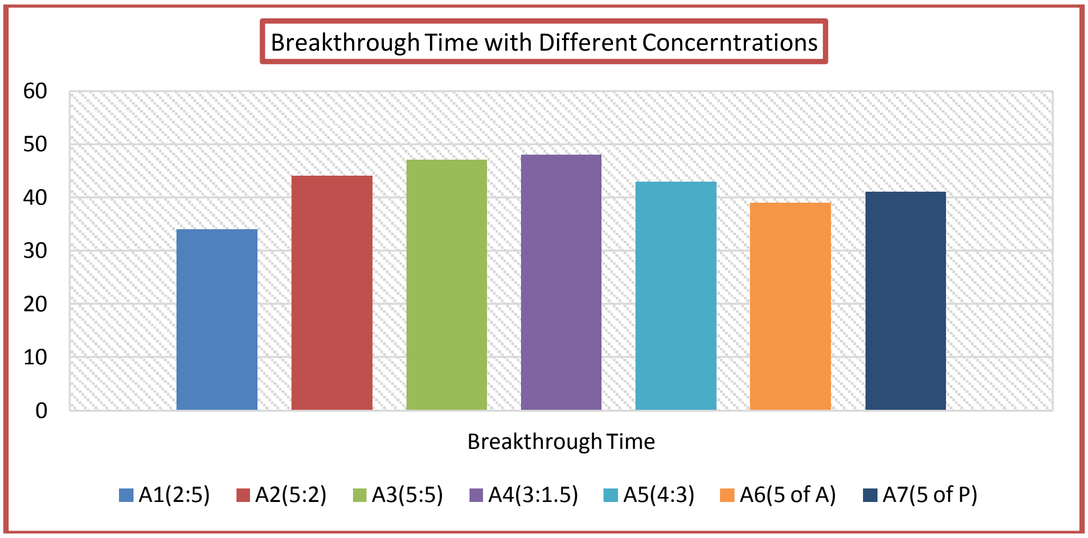


**Figure 4. A Plot of Breakthrough Time with Different Concentrations**

## IV. CONCLUSION

The application of local alkaline-polymer solution as the flooding agent for enhanced oil recovery has been demonstrated in this experimental work. The success of alkaline-polymer flooding involves reservoir engineering and geological studies as well as laboratory chemical formulation and monitoring. Based on this research, the following conclusions are made. The various concentration of local alkaline-polymer generally increased recovery but the concentration with higher alkaline ratio gave the highest recovery. The solution of 5g of alkaline to 2g of polymer gave the highest recovery of 84%. The solutions with the highest PH values also gave the highest recovery. The experimental study shows the important of ideal ratio for alkaline-polymer concentrations in oil recovery.

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