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Improving Oil Recovery Efficiency Using Corn starch as a Local Polymer for Enhanced Oil Recovery Processes

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ABSTRACT: Polymer flooding is a chemical enhanced oil recovery method that improves the recovery of oil by controlling the mobility of water to oil phase. It uses polymer solutions to increase the viscosity of the displacing water thereby decreasing water/oil mobility ratio (Speight, 2013). The volumetric and displacement sweep efficiencies are positively affected by polymer flooding. The viscosity of the aqueous phase is increased due to the molecular size and structure of the polymer used. The main objective of this research was to study the ability of cornstarch (local polymer) to recover additional oil after conventional water flooding. The objective was successfully achieved by injecting four different unconsolidated samples (sand pack) with cornstarch solution at varying concentration of 500ppm, 1000ppm, 3000ppm, and 9000ppm. From the results of the experiment conducted, it was deduced that Cornstarch has the ability to recover an additional volume of oil about half the volume of oil recovered during conventional water flooding (i.e. if 50% of oil initially in place was recovered during water flooding, cornstarch can recover 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. To reduce the adsorption effect of Cornstarch, it is recommended that the concentration of Cornstarch be measured after the flooding experiments for a better understanding of the adsorption mechanism of cornstarch.

KEYWORDS: Concentration, Corn Starch, Enhanced Oil Recovery, Mobility Ratio, Polymer Flooding, Recovery Factor, Sweep Efficiency, Unconsolidated Samples, Viscosity, Water Flooding

1. INTRODUCTION

Since oil production grows at a rate greater than reserve addition, there is a need to boost the reservoir energy, and this lies with sustaining production from existing fields. One of the ways to achieve this is by polymer flooding method. It is widely used since its inception in the 1960s, the main reason for its introduction is to remedy the problem pose by water flooding such as heterogeneity and high mobility ratio (M).

Hydrocarbon recovery occurs through three stages; primary recovery, secondary recovery and tertiary recovery (figure 1). In primary oil recovery phase, the hydrocarbon rise to the surface through the reservoir's natural energy, and also via artificial lift devices such as pump jacks. This is the initial stage for the extraction of oil and gas from a newly completed well set for production. Limited capital investment is needed for this initial phase of oil and gas production. About 5% to 10% of the oil in place can be extracted [6](Chaalal, 2018). Natural energy for oil recovery is produced by six driving mechanisms which include: gas cap drive, combination drive, rock and liquid expansion drive, water drive, gravity drainage drive and depletion drive. When reservoir natural energy is depleted, secondary recovery which is aimed at providing additional energy to boost or maintain the production level through injection of fluids is applied. Secondary recovery uses injections to re-pressurize the reservoir and displace oil to the producing well. The production of oil from Niger Delta sandstone reservoirs has advanced into the secondary phase and as time goes on there will be need to enhance oil recovery [5](Ogolo et al. 2017). This method seeks to improve the sweep efficiency between the injected fluid and the fluids in-place [1](Carcoana, 1992, as cited in Alvarado, 2010). However, oil is still left in the reservoir after secondary production either because it is trapped by capillary forces (residual oil) or it was bypassed. This unrecovered oil can account for a significant portion up to 70% of original oil initially in place (OOIIP), and as such if recovered can contribute significantly to the total revenue stream of the exploiting company.

As a solution to these drawbacks, a tertiary phase has emerged, known as enhanced oil recovery (EOR). In enhanced oil recovery, various materials are injected into the reservoir accompanied with water to improve fluid flow through the reservoir pore spaces. There are three major types of enhanced oil recovery technique such as chemical flooding (alkaline-surfactant-polymer flooding), gas (CO_2, natural gas or nitrogen) flooding, and thermal recovery or in-situ combustion. This phase can extract additional 20% to 30% of the residual oil within the reservoir. Enhanced oil recovery technique aim at reducing the interfacial tension (IFT) and capillary pressure acting between the reservoir fluids (oil and water). EOR implementation arises as a supplementary technology to conventional ones, optimizing the not-easily recoverable oil phase.

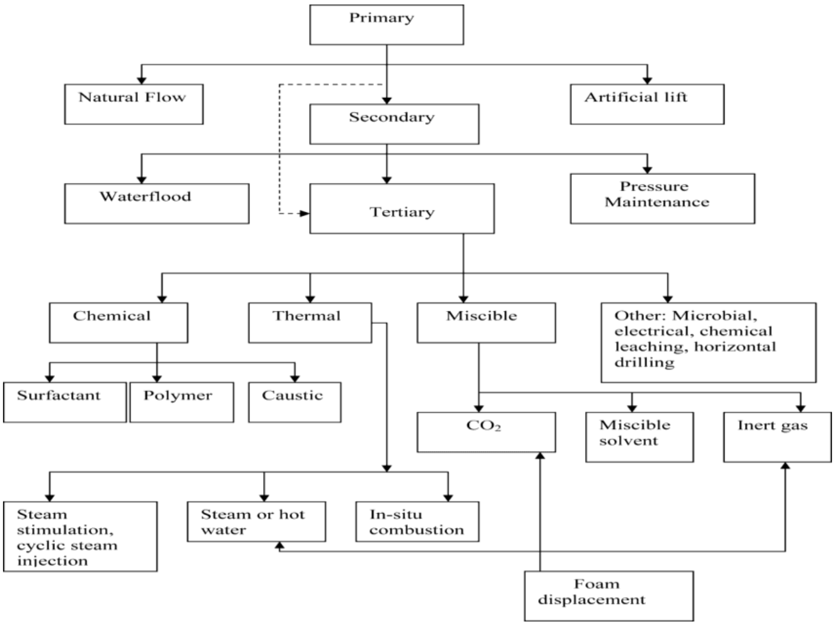


Fig. 1. Conventional Oil Recovery Mechanisms

For enhanced oil recovery technique to be effective, injected fluids must be more viscous than water, like the well-known solutions based on water-soluble polymers. It is important to note that fluid flow behavior is directly related to the chemical structure of the used polymers, as well as the influence of external parameters, such as concentrations of salts and surfactants, and temperature.

1.1 Polymer Flooding

Polymer flooding is a common technique used for injecting polymer solution into reservoir formations, and has proved to be successful in other parts of the world [3](Sorbie 2000; Silva et al. 2007; Morel et al. 2010; Nezhad and Cheraghian 2015, cited in, Lopez et al., 2017). The polymer functions as a mobility control agent during the polymer flooding process and provides better displacement and sweep efficiencies [9](Al-Hajri et al., 2018). Polymer flooding has proven successful in different types of reservoirs. Moreover, comparing to other enhanced oil recovery techniques, polymer flooding is simpler and efficient.It is aimed at reducing the mobility ratio (i.e less than 1) by increasing the water viscosity and reducing the relative permeability of water in the reservoir. There are several benefits associated with polymer flooding which includes improving the mobility of the injected fluid, less water needed for injection as compared to water flooding, enhancing vertical and areal sweep (volumetric sweep) efficiencies, and low cost enhanced oil recovery technique [10](Firozjaii and Saghaf, 2020). Despite the fact that polymer flooding has tremendous benefits in oil recovery, there are still some drawbacks (formation damage and injectivity loss) associated with this process as a result of polymer adsorption to the rock surfaces [4](Pereira, 2019). By three major mechanisms such as improving the viscosity of the water/brine, reducing water/brine permeability via swept areas, and covering larger volume of the reservoir formation, polymer flooding can enhance the sweep efficiency [7](Kumar, 2020).

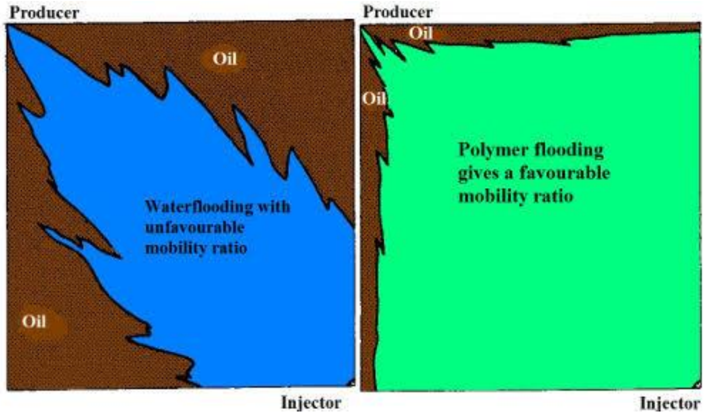


Fig. 2. Polymer flooding

1.1.1 Screening Criteria for Polymer Flooding

The most crucial criteria to select the appropriate polymer are its ability to generate a viscous solution at the minimum concentration. Two commercial polymers such as hydrolyzed polyacrylamides (HPAM) and xanthan gums are commonly used in practice in the oil and gas industry for chemical enhanced oil recovery applications [7](Kumar, 2020). Since the interaction between polymers and salts present in the reservoirs produces changes in the rheological behavior of the solution, proper selection of the additive must be taken into consideration. Starch is a biopolymer that is soluble in water, and can be used as an additive in enhanced oil recovery technologies. Within this context, the low cost, worldwide availability, biodegradability and high eco-friendly character make starch as a good candidate for developing additives to be used in the oil industry. At this point, it is important to note that additives obtained from natural polymers compete with those derived from synthetic ones.

Thus, the selection of additives to be used in EOR technologies must be based not only on its functional properties but also on its price and availability. Particularly, in the case of starches, their price is mainly associated to their production costs.

1.2 Conventional Polymers Used in Enhanced Oil Recovery

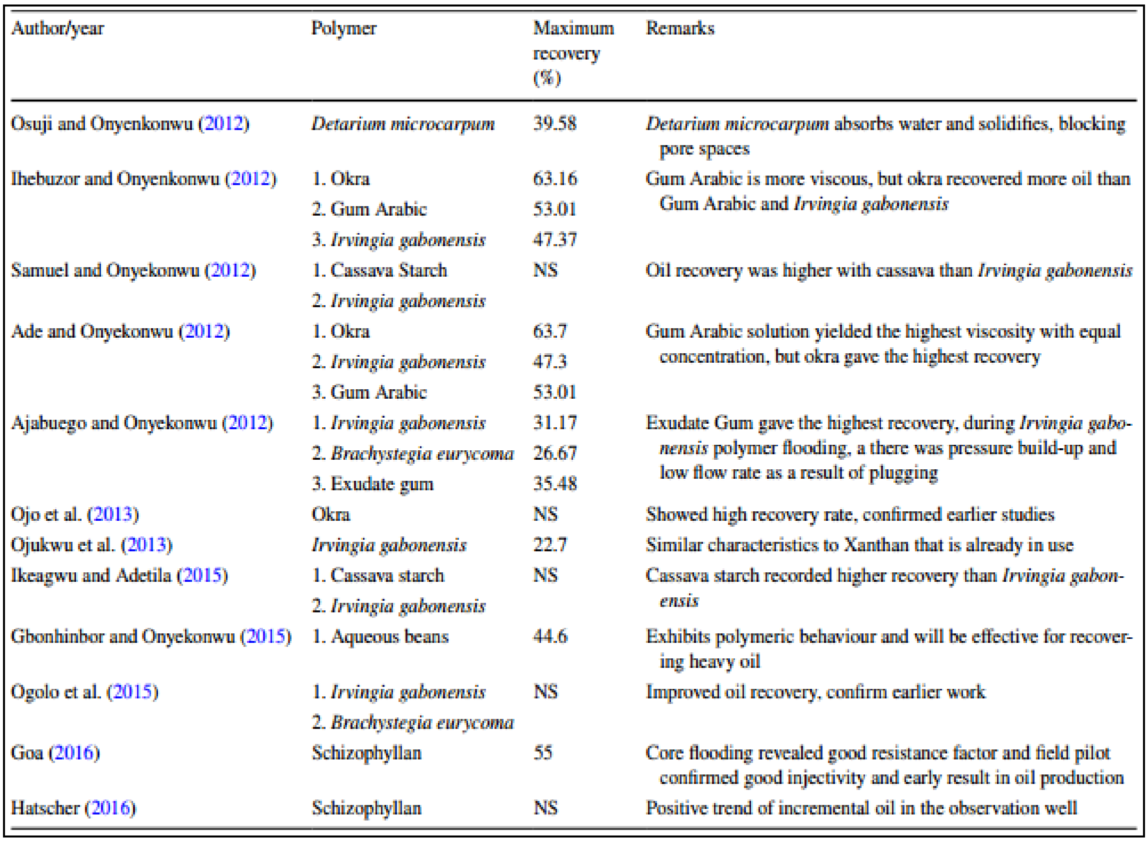
There are two main groups of polymer in conventional polymer flooding: synthetic and biopolymer. Partially hydrolyzed polyacrylamide (HPAM), is the most widely used synthetic polymer for polymer flooding and is a linear water-soluble polymer. The implementation of HPAM is relatively easy and can improve significantly the oil recovery rate under standard reservoir conditions. At high temperatures and high salinities, partially hydrolyzed polyacrylamide (HPAM) is shear-sensitive [11](Scott et al., 2020). If the polymeric material begins to degrade, the viscosity modification effects are reduced. As a result, other synthetic polymers, many of which are derivatives of polyacrylamide have been considered for polymer flooding. There has been significant interest in hydrophobically modified polyacrylamide (HMPAM) used for enhanced oil recovery in recent years [11](Scott et al. 2020). HMPAM polymers are primarily composed of a polyacrylamide backbone but also contain a small number of hydrophobic groups along the polymer chain.

1.3 Local Polymers Used in Enhanced Oil Recovery

The most important issue in polymer flooding is the way to improve oil recovery effectively and the way the flooding process is assessed. The injection of Polymer alone won’t be able to alter the residual oil saturations, but the synergic effect of both water flooding and polymer flooding will result to a higher oil recovery over time. Local polymers considered are mostly bio-polymers like Gum Arabic, Guar Gum, Achi, Okra, Ogbonno, Ukpo and Offor. Gum Arabic is far more viscous but Okra when used for polymer flooding recovered more oil (63.16% maximum recovery) than Gum Arabic (53.01% maximum oil recovery) and Irvingia gabonensis at 47.37% maximum oil recovery [8](Ihebuzor & Onyenkonwu, 2012, as cited in Agi et al., 2017). Cassava starch recorded higher oil recovery than Irvingia gabonensis when used as polymer flooding [8](Ikeagwu & Adetila, 2015, as cited in Agi et al., 2017). Aqueous beans used as a natural polymer recorded effective heavy oil recovery [12](Gbonhinbor and Onyekonwu, 2015, as cited in Agi et al., 2017). Brachystegia eurycoma (26.67% maximum oil recovery), Irvingia gabonensis

(31.17% and exudate gum were used for polymer flooding, and exudate gum (35.48% maximum oil recovery) gave the highest recovery [8](Ajabuego & Onyekonwu, 2012, as cited in Agi et al., 2017).

Table 1. List of studies on oil recovery using natural polymer flooding



Author/year	Polymer	Maximum recovery (%)	Remarks
Osuji and Onyenkonwu (2012)	*Detarium microcarpum*	39.58	*Detarium microcarpum* absorbs water and solidifies, blocking pore spaces
Ihebuzor and Onyenkonwu (2012)	1. Okra 2. Gum Arabic 3. *Irvingia gabonensis*	63.16 53.01 47.37	Gum Arabic is more viscous, but okra recovered more oil than Gum Arabic and *Irvingia gabonensis*
Samuel and Onyekonwu (2012)	1. Cassava Starch 2. *Irvingia gabonensis*	NS	Oil recovery was higher with cassava than *Irvingia gabonensis*
Ade and Onyekonwu (2012)	1. Okra 2. *Irvingia gabonensis* 3. Gum Arabic	63.7 47.3 53.01	Gum Arabic solution yielded the highest viscosity with equal concentration, but okra gave the highest recovery
Ajabuego and Onyekonwu (2012)	1. *Irvingia gabonensis* 2. *Brachystegia eurycoma* 3. Exudate gum	31.17 26.67 35.48	Exudate Gum gave the highest recovery, during *Irvingia gabonensis* polymer flooding, a there was pressure build-up and low flow rate as a result of plugging
Ojo et al. (2013)	Okra	NS	Showed high recovery rate, confirmed earlier studies
Ojukwu et al. (2013)	*Irvingia gabonensis*	22.7	Similar characteristics to Xanthan that is already in use
Ikeagwu and Adetila (2015)	1. Cassava starch 2. *Irvingia gabonensis*	NS	Cassava starch recorded higher recovery than *Irvingia gabonensis*
Gbonhinbor and Onyekonwu (2015)	1. Aqueous beans	44.6	Exhibits polymeric behaviour and will be effective for recovering heavy oil
Ogolo et al. (2015)	1. *Irvingia gabonensis* 2. *Brachystegia eurycoma*	NS	Improved oil recovery, confirm earlier work
Goa (2016)	Schizophyllan	55	Core flooding revealed good resistance factor and field pilot confirmed good injectivity and early result in oil production
Hatscher (2016)	Schizophyllan	NS	Positive trend of incremental oil in the observation well

(**Source:** Agi et al.,2017),

1.4 Propensity for Corn Starch Based Polymer for Enhanced Oil Recovery

There has been research on the properties and characteristics of polymers that make them effective for EOR. What makes an effective polymer? An effective polymer will exhibit the following characteristics: a) high viscosity at low polymer concentrations, b) low interfacial tension with regards to the oil- phase, c) characteristics that enhances the viscosity of the water flood thereby improving volumetric sweep efficiency and d) ability to function well in high salinity and temperature regimes. [13]Raffa, et al. (2016) stated that the polymer should be an effective viscosifier for the aqueous phase, and should possess features such as: very high molecular weight, ability to resist mechanical degradation in shear, and complete solubility in the aqueous phase (water); they also added, that these polymers should be inexpensive, non-toxic and have the ability to tolerate high salinities and high temperatures. When starch is combined with plasticizers such as water or glycerin then it performs much better under heat. In particular, at temperatures ranging from 90-180 °C, and under shear, it readily melts and flows. This may be attractive for use in EOR as the thermal stability of starch and its plasticizers is greater than that of the conventional polymers now being used like Xanthan Gum and Polyacrylamide. Rheological measurements were conducted to observe the change in shear viscosity of the polymer when applied under a range of reservoir conditions. From the result obtained, it was observed that the shear viscosity of the xanthan gum solution was less sensitive to higher temperatures and salinity than partially hydrolyzed polyacrylamide (HPAM) solution. This indicated that xanthan gum injection is more effective than HPAM under reservoir conditions of higher salinity [14](Jang et al, 2015).

1.5 Limitations of Conventional and Local Polymers Used for Enhanced Oil Recovery

It is important to note that if polymer concentration and viscosity is too high during flooding, the rock strata may be blocked, and if polymer concentration and viscosity is too low, it will affect the mobility ratio [15](Sun et al., 2020).

From the results of the literature review on various experiments conducted on local polymers, it is evident that local materials can be used for enhanced Oil recovery processes. However, Ogbono (local polymer) exhibit polymeric behavior, causes pressure buildup and low flowrate due to formation plugging, and its recommended for recovery of slightly heavy crude. Achi and ofor are stable at high temperature but suffers microbial attack. Cassava starch and okra exhibits shear thinning behavior; a major cause of polymer potential degradation, and gum Arabic yielded an extremely high viscosity; which can result to problems of reduced injectivity. Also, 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.

2. STATEMENT OF PROBLEM

Polymer flooding improves the recovery o rf oil by controlling the mobility of water to oil phase. However, polymers used in the oil and gas industries are imported from other countries, as such it takes a lot of time and money before these polymers get to their destination of use, couple with the fact that some need to be used within 6 month of purchase which is a major problem in the oil and gas industry. Hydyrolysed polyacrylamide (HPAM) is currently used in the oil and gas industry but is susceptible to high temperature and salinity. HPAM has a synthetic nature which makes it harmful to the environment [8](Agi, 2017). Furthermore, HPAM channeling can take place in high permeability zone leading to premature polymer loss from the wellbore, as a result affect oil phase displacement [3](Lopez et al., 2017). The biopolymer xanthan has the problem of degradation, and both are very expensive. Natural polymer (corn starch) which can be sourced locally is a good candidate for developing additives for chemical enhanced oil recovery in the Niger Delta region due to the fact that it is readily available, less expensive and eco-friendly. Hence, this study involving experimental work, seeks to determine the suitability of corn starch based polymer as enhanced oil recovery agents and also find out to what extent increasing water viscosity by the addition of the local polymer can recover oil through control mobility ratio.

3. AIM/ OBJECTIVES OF THE STUDY

This study aims at verifying the effect of using corn starch to improve oil recovery efficiency during enhanced oil recovery (EOR) activities. The objectives of this study are:

- To formulate a local polymer (corn starch) that will be able to control mobility during enhanced oil recovery (EOR).
- To ascertain the suitability of using corn starch as an oil recovery chemical agent, and also to investigate the effect of varying concentrations of corn starch on the oil recovery factor.

4. MATERIALS AND METHODS

Polymer injection into porous medium (i.e., core flooding tests) is a useful testing procedure to check the propagation of the macromolecules through core plugs from the reservoir. It is important to note that core flooding testing will not give information on the following aspects:

- During polymer core flooding testing, wellbore effects such as completion, flow rates, presence of micro fractures, and damage formation, among others, cannot be evaluated. An example is the polymer shear-thickening behavior observed in the laboratory that will probably never occur in the field when considering the presence of micro fractures created after completing the well (i.e., perforations, stress changes) or during the water flooding stage.
- Polymer core flooding testing does not provide information on true polymer overall retention values. It is important to note that petrophysical properties of reservoirs like porosity and permeability defer from one layer to another (heterogeneity of reservoirs), and as a result of this fact, polymer retention in the field will be likely greater than what is observed experimentally in the laboratory. This chapter presents the method used in conducting this research work. Unconsolidated samples were prepared and characterized in terms of porosity and permeability using liquid saturation method and constant head permeability test. Then, oil is injected into the simulated reservoir (Sand pack). Finally, the oil recovery process is instigated: flooding begins with a primary water (or brine) injection, followed by a Biopolymer (corn starch) solution injection, and chased with a secondary water

(or brine) injection. During each injection step, the differential pressure is recorded. Also, the volume of oil recovered during each step is measured. This allows for the determination of oil recovered after brine injection and the additional oil recovered after the injection of Biopolymer.

4.1 Preparation of Unconsolidated Sand Pack

Unconsolidated Sand packs were prepared according to industry specification using sand from the shallow part of Amassoma River in Niger Delta region. The sand was washed and sieved to remove every form of debris. Extra thick foil sheet of dimensions (14.5×8.5) were cut and folded into cylindrical shape and the base ends were covered with filter mesh of 50µm to prevent sand production.

The diameter of the cylindrical shaped foil sheet was measured using a manual venier caliper and the weight of the filter mesh and foil were measured with an electronic weighing balance. The prepared foil sheet was loaded with sand and distilled water was poured on it for proper compaction of the sand particles. The prepared samples were dried at a temperature of 1700°C in a 15 min cycle oven for four cycles and weighed; this was repeated until a constant weight (dry weight of sample) was achieved. Measurement of the weight, diameter and length of the dry unconsolidated sample were taken and recorded.

Table 2. Measured unconsolidated samples data

SAMPLE	WEIGHT OF MESH AND FOIL (g)	LENGTH (cm)	DIAMETER (cm) $D_2 + D_1$	External Diameter(D_2)	Ineternal Diameter (D_1)	Area of sand pack sample(cm^2), A=(D_2 -D_1) * L
A	3.16	6.76	4.29	3.21	1.08	14.3988
B	3.12	6.22	4.29	3.31	0.98	14.4926
C	3.64	6.53	3.97	2.93	1.04	12.3417
D	3.54	5.52	4.19	3.34	0.85	13.7448

Fig. 3. Picture showing the various steps in unconsolidated sand pack preparation

4..1.1 Liquid Saturation Method for Porosity Estimation

The unconsolidated sample was placed in a sieve assembly and sieve analysis was carried out. Binding materials are weighed. Thickness and diameter was measured and recorded. After that, the weight of the dry unconsolidated sample was measured and recorded, sandpack was then saturated using a vacuum pump with brine solution of 250ppm. Finally, the weight of the saturated sample is measured and recorded. Further information on porosity is calculated manually using equations below:

$$V_b = \frac{\pi d^2 L}{4} \quad \text{……………………………… (1)}$$

$$V_p = \frac{W_{sat} - W_{dry}}{\rho_w} \quad \text{…………………………. (2)}$$

$$\Phi = \frac{V_p}{V_b} \quad \text{……………………………...(3)}$$

Where;

W_{sat} = wet weight of sand grains, g
W_{dry} = dry weight of sand grain, g
V_b = bulk volume of sand pack, cm
V_p = pore volume, cm
d=diameter of sand pack, cm
Φ = porosity of sand pack

4.1.2 Constant Head Permeability test

This technique was carried out by flowing single phase fluid horizontally through a sample. It was performed in the laboratory under surface conditions. Apparatus includes a hassler type core holder, displacement pump, control valves, flow lines, pressure gauges and a fluid measuring device. The experiment involves pumping a liquid of known viscosity through a 100% saturated sand pack. The flowrate is held constant, while the corresponding pressure drop across the sample is recorded. Consequently, the absolute permeability can be deduced using Darcy's equation. The constant head permeability test can measure permeability of samples greater than 10mD.

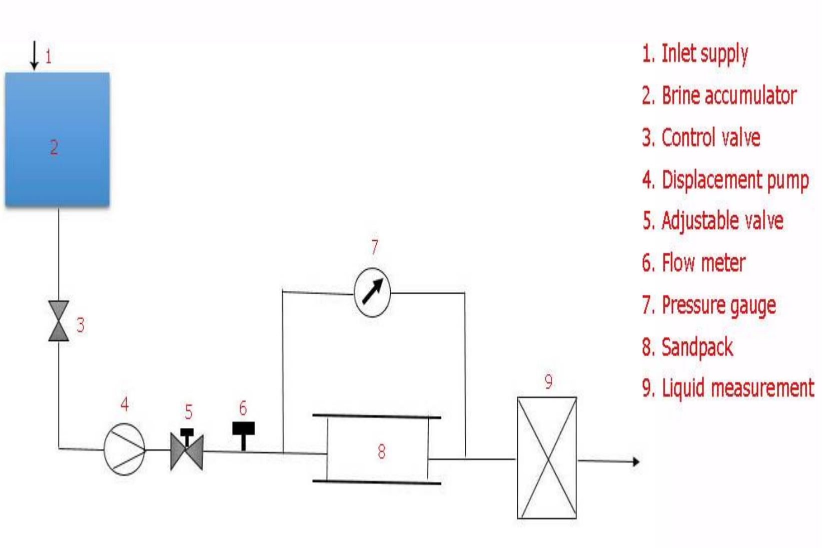


Fig. 4. Schematic Diagram of a Sensitive manometer

4.2 Preparation of Brine and Cornstarch Solutions

The cornstarch solution was prepared by adding calculated quantity of powdered cornstarch to distilled water. Similar procedure was used in preparing the Brine solution.

4.2.1 Preparation of Brine Solution

Brine solution of 250ppm concentration (least salinity of Niger Delta reservoir) was prepared by dissolving 0.25g of sodium chloride (NaCl) with molecular weight of 58.44g and specifications of 99.5% minimum assay (ex Cl) After ignition, maximum limit of impurities, 105°C1.0% loss on drying at, 0.02% sulphate (So_4), 0.002% Ammonia (NH_3), 0.002% Iron (Fe), 0.005% Lead(Pb), and 0.02% potassium (k) in 1000ml of distilled water. The solution was stirred till the salt was completely dissolved in water. This brine (salt solution) with density 1.027g/cc and viscosity 0.9039cp was prepared to represent the oilfield water.

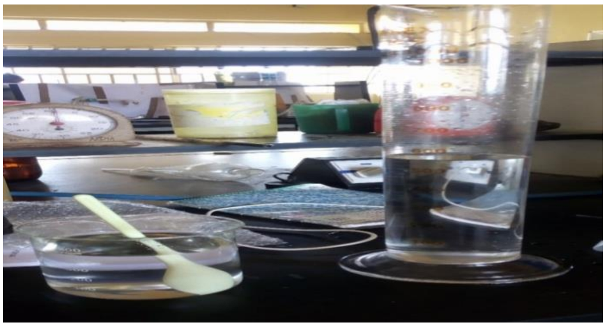


Fig. 5. Picture showing prepared brine solution

4.2.2 Preparation of Corn Starch Solution

Corn starch (processed flour) is the type of polymer used in this research. It was gotten from Ughelli local market, Nigeria. This was used to prepare five aqueous solutions of different concentrations (500ppm, 1000ppm, 3000ppm, and 9000ppm) in the presence of 10% oilfield water.

Fig.6. Picture showing powdered cornstarch and prepared cornstarch solution

4.3 Characterizing Crude Oil

The crude oil used in the experiments have the physical properties shown in Table 3.

Table 3. Physical properties of the crude oil

Property	DESCRIPTION
Physical state	Liquid
Color	Black
Viscosity(mPa-)	8.0969
Density(g/cc)	0.860
M_{db} (g)	23.08
M_{db+0} (g)	66.08
V_{db} (CC)	50
Specific Gravity	0.860

API Gravity (°API)	33.03
T_{efflux} (S)	1883
V_O (cSt)	9.4150

4.4 Experimental Procedures

4.4.1 Saturation of Samples

The prepared dried unconsolidated samples were submerged in a Brine solution and allowed to saturate under vacuum condition/ pressure until the samples were 100% saturated with Brine. Then, the saturated weight of the samples was measured and recorded and the samples dried again leaving 10% of Brine solution in it (connate water). Finally, the samples saturated with 10% of Brine solution were again saturated with 90% of crude oil. This was achieved using a vacuum pump, connecting hose, and an improvised vacuum chamber as shown below in Fig. 8.

Fig. 7. Pictures showing saturation of samples in Brine solution and crude oil

4.4.2 Porosity measurement

The porosity of the porous medium (sand pack) was estimated from the pore volume and bulk volume of the samples using the formulas given above. The Calculated porosity values are shown in table 4.

Table 4. Calculated Porosity data

SAMPLE	Wsat	Wdry	Vb (cc)	Vp (cc)	POROSITY %
A	147.01	121.47	97.7254	24.8685	25.45
B	141.07	116.57	89.9189	23.8656	26.54
C	133.31	110.15	94.4004	22.5511	23.89
D	117.68	97.4	76.1236	19.7468	25.94

4.4.3 Permeability measurements

Permeability measurements was performed by injection of water at a flow rate of 0.5cc/min ($0.5/60=0.00833 cm^3/s$) and the pressure difference was recorded for every experiment. The absolute permeability of the sand packed was calculated using Darcy's law equation as shown below:

$$q = \quad AK\Delta P/\mu L \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where,

Q: flow rate cm^3/s

K: the absolute permeability of the porous medium, Darcy

Δp: pressure difference across the porous medium, atm

A: Area of the porous medium, cm^2

μ: the dynamic viscosity of water, cp
L: the length of the porous medium, cm

Table 5. Calculated Permeability data

Sample	ΔP(atm)	A (cm^2)	K(md)
A	0.00397	14.3988	890
B	0.003	14.4926	1076
C	0.00968	12.3417	412
D	0.00155	13.7448	1953

4.4.4 Laboratory Sandpack Flooding Procedure

Two flooding experiment were performed as follows:

1. Brine water flooding. (No polymer in presence).
2. Cornstarch flooding

During the corn starch flooding experiments, the injection was done at a constant flow rate of 1ml/min using the Quizix pump, and pressure difference was recorded using a differential u-tube pressure gauge. The oil produced were collected in a graduated beaker cup and were measured using syringe with needle.

4.4.5 Oil Recovery Performance

For evaluating the effect of cornstarch on oil recovery efficiency, flooding experiments have been performed in the presence and absence of polymer. The variation of oil recovery factor with concentration as a function of Brine and polymer injection is shown in Fig 9 below. To determine the effect of cornstarch on oil recovery, four sets of sand pack flooding (Sample A, B, C and D) were conducted using different concentrations of cornstarch (500ppm, 1000ppm, 3000ppm and 9000ppm. The concentrations of Brine solution were kept constant for all samples. However, the recovery factor, RF in percentage after Brine injection was not constant (i.e. not in the same range) for all the samples. This is a major problem in the use of sand pack for flooding experiments, since a single sand pack cannot be reused. Hence, resulting to change in the simulated reservoir (sand pack) properties such as porosity, pore volume, and permeability; the determinant factors of oil recovery. In the case of cornstarch, a decrease in the RF was observed with an increased concentration of cornstarch, a trend commonly related to polymer adsorption on the sand particles.

Table 6. Recovery factor at breakthrough time

SAMPLE	RECOVERY FACTOR %		BREAKTHROUGH TIME (mins)	
	AFTER BRINE INJECTION	AFTER CORNSTARH INJECTION	AFTER BRINE INJECTION	AFTER CORN STARCH INJECTION
A	59	34	11	7
B	40	22	9	8
C	23.43	14.05	12	6
D	13.2	7.9	10	6

The recovery performance of the four samples after Brine injection are in descending order of 59%, 40%, 23.43%, and 13.2%. For cornstarch, 34% additional oil recovery was made at a concentration of 500ppm of cornstarch; this was achieved at the breakthrough time. The breakthrough happened after 7 minutes of cornstarch injection. At a concentration of 1000ppm, additional oil recovery was 22% after 8 minutes of injection. The least recovery was made at concentrations of 3000ppm and 9000ppm after 6 minutes of injection. The fluctuation in breakthrough time is due to change in pressure drop and permeability reduction. This is shown in Fig. 9 below.

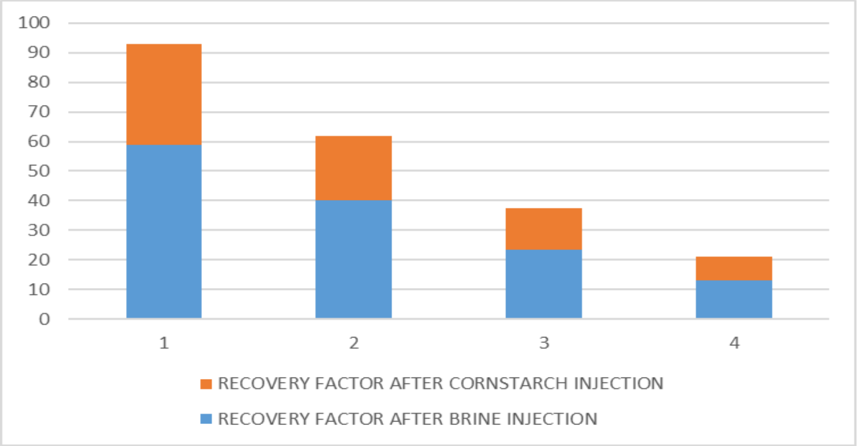


Fig. 8. Recovery factor of all flooding experiment at breakthrough time

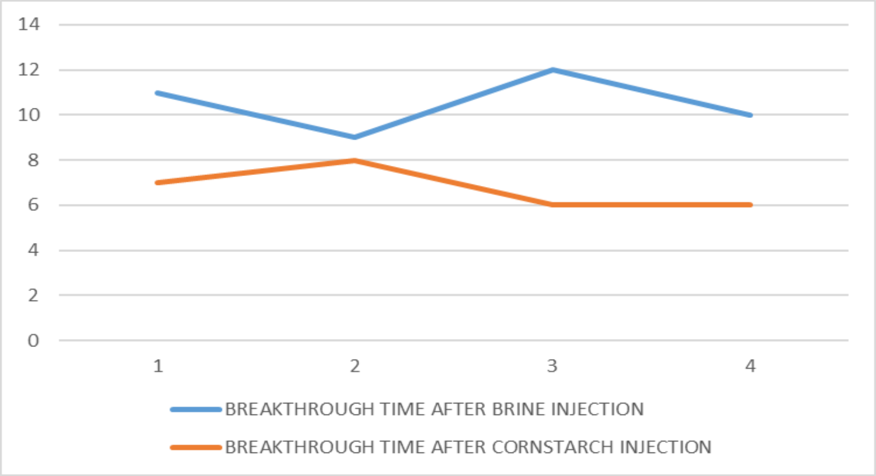


Fig. 9. Time at breakthrough of all flooding experiment

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The main objective of this research was to study the ability of cornstarch to recover additional oil after conventional water flooding. The objective was successfully achieved by injecting four different unconsolidated samples (sand pack) with cornstarch solution at varying concentration of 500ppm, 1000ppm, 3000ppm, and 9000ppm. The following conclusion were deduced from the results of the experiment:

- Cornstarch has the ability to recover an additional volume of oil about half the volume of oil recovered during conventional water flooding (i.e if 50% of oil initially in place was recovered during water flooding, cornstarch can recover an additional 25% of the residual oil after water flooding).
- Higher concentrations of cornstarch reduce the recovery factor. This occurs when undissolved particles of cornstarch in solution interact with the sand grains. This interaction causes the cornstarch to be retained in the sand pack (simulated reservoir), which reduce the effect of cornstarch and the recovery factor.

5.2 Recommendations

There is still area for more research:

- Effect of temperature and salinity on cornstarch rheological behavior through porous media should be studied to understand its ability to withstand high temperature and high salinity.

- concentration should be measured after the flooding experiments for a better understanding of adsorption mechanism of cornstarch.
- Water flooding experiment should be conducted using cores to know the amount of recoverable oil using a single Brine concentration.

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