Petroleum Science and Engineering
2024; Vol. 8, No. 1, pp. 16-26
https://doi.org/10.11648/j.pse.20240801.13

Research Article

Experimental Investigation of the Suitability of *Afzelia africana* and *Colocasian esculenta* as Alternative to *Hydroxyethyl cellulose* in Enhanced Oil Recovery

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Abstract

Polymer flooding is a chemical enhanced oil recovery where polymer is injected into the reservoir to recover oil that remained in the reservoir after the primary and secondary recovery mechanisms, improves oil recovery by reducing the water mobility ratio and increases the viscosity of the displacing fluids for sweep displacement efficiency of the reservoir. Synthetic polymers are widely used chemical enhanced oil recovery. However, there is a big concern about the high cost of these polymers which can result to high cost of oil production and environmental concerns due to the toxic nature of these polymers. Hence, there is need to source for local polymers that can be environmentally friendly, less expensive and can serve as a mobility control agent in enhanced oil recovery. In this study, experimental analysis was carried out to improve hydrocarbon productivity using *local polymers* such as *Afzelia Africana, Colocasian esculenta and* compared with synthetic polymer *Hydroxyethyl cellulose*. Characterization (FTIR and SEM) of these polymers were carried out to determine the functional groups and the morphology. Rheological behavior of these polymers was investigated. Core-flooding experiment was conducted on the local polymers and the synthetic polymer to examine the potential of these polymers in enhanced oil recovery. The results of the study showed that the samples contained hydroxyl group (OH), carboxyl group (COOH), and amine (NH_3) based on the functional groups. The scanning electron microscopy test showed that the samples are mesoporous and crystalline in nature. The rheology test results showed that the samples exhibit shear thinning behavior and a non-Newtonian fluid. The core-flooding experiment showed that *Afzelia Africana* had oil recovery of 8.4%, 14.4% and 17.6%. More so, *Colocasian esculenta* had oil recovery of 6.8%, 14.0% and 17.2% while the synthetic polymer had oil recovery of 9.6%, 14.8% and 19.2% for different polymer concentrations of 0.2wt%, 0.3wt% and 0.4wt% respectively. The results from this study showed that the local polymers compared favorably with the synthetic polymer in enhanced oil recovery.

Keywords

Afzelia africana, *Colocasian esculenta*, *Hydroxyethyl cellulose*, Characterization, Core-Flooding

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Received: 8 January 2024; **Accepted:** 24 January 2024; **Published:** 29 February 2024

1. Introduction

As global energy for oil demand grows, oil reserves are depleted and new large reserves are not available, enhanced oil recovery (EOR) from matured fields becomes more and more important [1]. Secondary recovery methods are introduced much earlier in the life of a field when the natural energy drive of the reservoir had reached its economy limit [2]. Chemical oil recovery is applied to reservoirs as a tertiary recovery method when water-flooding has reached its recovery efficiency limit, which is estimated to be approximately 30-40% of the original oil in place [11]. Enhanced oil recovery (EOR) using chemical method involves the injection of polymer in solution as a displacing fluid into an oil reservoir in order to mobilize the crude oil that is trapped in the reservoir rocks. The displacing fluid mostly in solution with water are generally used for mobility control [14]. Chemical enhanced oil recovery process using polymer flooding is mostly given attention because of its ability in exploring residual oil by primary and secondary recovery methods [8]. Polymers are used to increase the water viscosity, the mechanism of enhanced recovery based on polymer flooding involves, decreasing the mobility ratio difference existing between displacing fluids (water) and displaced fluids (oil), in order to reduce the fingering effects [10]. The displacing phase can have the mobility ratio equal to or lower than the mobility ratio of the oil phase [7]. The oil/water mobility ratio (M) is 1 when the oil displacement by the water phase occurs in a piston-like pattern. In addition, if mobility ratio (M) is greater than 1, more mobile water phase can finger through the oil, causing early water breakthrough and poor sweep efficiency [16]. The main characteristic of polymers includes; resistance to mechanical degradation in shear, high molecular weight and complete solubility in water. In addition, it should be non-toxic, inexpensive, and ability to tolerate high salinity and high temperatures reservoirs [19]. Polymer flooding has shown to be an alternative method to reducing production of water by improving the mobility ratio of the displacing fluid and thus, achieving better swept efficiency [3]. More so, in sandstone reservoirs, the application of polymer flooding had proved to be an efficient enhanced oil recovery method as a result of improved sweep efficiency when water is added [6]. Polymer flooding exhibits low interfacial tension in the oil phase, good mobility control, showed complete solubility in water [4].

In addition, polymer addition into the formation increases fluids (water) viscosity and provides a more favorable mobility ratio. Different techniques of oil production have shown that the primary and secondary oil recovery process cannot mobilize all the trapped oil in the reservoir [13]. Utilization of biopolymer for enhanced oil recovery methods is recently becoming a trend for oil recovery processes [5]. However, various categories of polymers that are water soluble have been reported and are classified into two groups such as: synthetic and biopolymer [15]. One of such biopolymers is *Hydroxyethyl cellulose* (polymer), it has been applied in the oil recovery as a recovery agent and showed great improvement in oil recovery [6]. Polymer flooding is the most commonly applied chemical enhanced oil-recovery-technique (tertiary recovery) [17]. It was estimated that two-thirds of the oil originally in place could remained in the reservoir after the primary and secondary recovery methods [18]. This remaining amount of oil has focused the attention of industries and researchers on developing new techniques referred to as tertiary oil recovery methods to improve hydrocarbon production [10]. The injection of polymer is chemical enhanced oil recovery (EOR) method and has become the most promising method for effective oil recovery. Local polymers have showed to be effective in mobility control, viscosity reduction and wettability change [9, 12]. The focus of this research work is to characterize and carry out rheology study of *Afzelia Africana, Colocasian Esculenta and Hydroxyethyl Cellulose* and its recovery performance in enhanced oil recovery.

2. Materials and Methods

2.1. Samples, Reagents and Chemicals Used

1) Afzelia africana (Akparata as local polymer)
2) Colocasian esculenta (Cocoyam as local polymer)
3) Hydroxyethyl cellulose (as synthetic polymer)
4) Crude oil sample
5) Core samples
6) Brine (Nacl)

2.2. Laboratory Equipment

1) Core flooding equipment
2) FTIR machine
3) SEM machine
4) OFITE®'s viscometer (8-speed)

Figure 1. *Afzelia Africana (local polymer).*

Figure 2. *Colocasian esculenta (local polymer).*

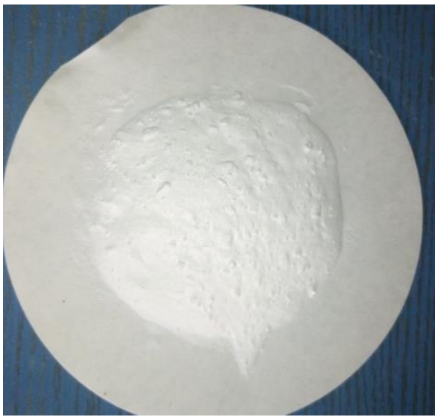

Figure 3. *Hydroxyethyl cellulose (HEC) (Synthetic polymer).*

2.3. Methods

2.3.1. Sample Collection

The proposed local polymers (*Afzelia africana and Colocasian esculenta*) were purchased from new market in Owerri, Imo state, Nigeria. The synthetic polymer (*Hydroxyethyl cellulose*) was bought from Onitsha, Anambra State. The synthetic polymer was used for comparison of results with the proposed local polymers as showed in Figure 1-3.

2.3.2. Preparation of the Local Polymers

Afzelia Africana was washed and sun-dried to remove any sand contaminant and bacterial attack. It was heated in a oven of temperature of 60 ˚C in order to remove the outer layers of the seed. The sample was grinded using grinding machine to ensure homogeneity of the sample. The *Colocasian Esculenta* was washed and stored in a dry place to avoid any bacterial attack. It was grinded to smaller particles in order for the samples to completely dissolve in water. All the samples were dissolved in water at different concentrations of 0.2wt%, 0.3wt% and 0.4wt% respectively.

3. Characterization of the Polymers

3.1. Fourier Transform Infrared Spectroscopy Analysis

The FTIR analysis was carried out on the local and synthetic polymer in order to determine its functional groups. The Fourier Transform Infrared Spectroscopy machine was warmed for 20 minutes and the machine was dried with water so that the samples will not be affected. A drop of the sample was placed in the machine which was attached to the Fourier Transform Infrared Spectrometer coupled to a computer. 2.5g of the samples (local and synthetic polymer) was measured and placed on the FTIR machine to determine the functional groups of the samples. The samples which was placed on top of the machine and irradiated by infrared lamp source at one end of the spectrometer and each sample was analyzed between ranges of $1000cm^{-1}$- $3500cm^{-1}$.

Scanning electron microscopy analysis was carried out on the samples to determine the surface topography and morphology of the materials. It provides the details of the structures of the samples. 2.5g of both the local and synthetic polymer was placed on the SEM machine which was attached to a computer and the sample surface structure was obtained.

3.2. Rheology Test

Rheology test was carried out on the local polymers (*Afzelia Africana and Colocasian Esculenta*) and the synthetic polymer (*Hydroxyethyl Cellulose*) in order to determine the rheological behavior (Newtonian fluid/non-Newtonian fluid or shear thinning/shear thickening), plastic viscosity, apparent viscosity, shear rate and shear stress. The equipment used for rheology studies was OFITE®'s viscometer (8-speed). Each of the samples *Afzelia Africana, Colocasian Esculenta and Hydroxyethyl Cellulose* was poured into a cup attached to the viscometer. The different speeds of 600, 300, 200, 100, 60 and 30 rpm (revolution per minute) at different polymer concentrations of 0.2%wt, 0.3wt%, 0.4%wt respectively was observed while the dial readings were taken at different intervals of 600, 300, 200, 100, 60 and 30 rpm. In addition, the experimental study was conducted under atmospheric condition.

3.3. Formulation of the Core Flooding Fluid

The different samples both the local polymers (*Afzelia Africana and Colocasian Esculenta*) and the synthetic polymer (*Hydroxyethyl Cellulose*) were dissolved in low salinity water of 2000ppm, 3000ppm and 4000ppm at different polymer concentrations of 0.2wt%, 0.3wt% and 0.4wt% respectively. The Niger Delta sand pack was used in the preparation of the cores for flooding. Crude oil sample used were collected from the Niger Delta oil field and was analyzed using rheometer to determine the specific gravity, density, viscosity and the API standard of the oil.

Table 1. Concentration of polymer injected.

Concentrations of polymer	Salinity of polymer (ppm)
Conc. at 0.2 wt.%	2000
Conc. at 0.3 wt.%	3000
Conc. at 0.4 wt.%	4000

3.4. Experimental Procedures

Figure 4. Core-flooding experimental set-up.

The core-flooding experiment was conducted under operating reservoir temperature (80 ˚C and pressure (100 psi). In this experiment, two approaches were applied. In the first stage, low salinity water (waterflooding as secondary recovery method) was used as the displacing fluid to recover oil. In the second stage, the local polymer (*Afzelia Africana and Colocasian Esculenta*) and the synthetic polymer (*Hydroxyethyl Cellulose*) were used as a displacing fluid (tertiary recovery method) to recover additional oil. The core flooding experiment were repeated at different concentrations of the polymer (0.2 wt%, 0.3wt% and 0.4wt%) respectively. Figure 4 shows the experimental set-up of the core-flooding process.

4. Results and Discussions

Table 2. Result of crude oil analysis.

Parameters	Values
Specific gravity (g/cm^2)	0.85
API (°C)	35.0
Viscosity (cp)	1.03
Density (g/cm^2)	0.85

Table 2 showed the results of the sample crude oil properties determination used in the experimental analysis. The table showed that the API of the crude oil is 29.25℃ and viscosity is 1.53. which implied that the crude oil is slightly viscous. Table 3 presents the properties of the core samples used, which showed that the porosity and permeability of the core sample used are porous and permeable for fluid flow in the reservoir.

Table 3. Core parameter.

Core sample	Porosity (%) $\left(\frac{pore\ volume}{bulk\ volume}\right)$	Permeability (md)
A_1F	33.95	180
A_2F	25.22	195
A_3F	28.48	182

Table 4. Result of rheology test of local and synthetic polymers.

S/no	Speed (rpm)	*Afzelia African* Dial reading (Ib/100ft^2)			*Colocasian esculenta* Dial reading (Ib/100ft^2)			*Hydroxyethyl cellulose* Dial reading (Ib/100ft^2)		
		0.2wt%	0.3wt%	0.4wt%	0.2wt%	0.3wt%	0.4wt%	0.2wt%	0.3wt%	0.4wt%
1	600	98.3	100.8	105.8	95.7	96.4	98.6	103.2	105.6	110.8
2	300	67.5	69.4	71.7	60.5	63.3	66.5	70.6	74.5	77.4
3	200	64.2	65.5	67.3	58.3	61.7	64.9	66.8	69.4	73.3
4	100	60.1	62.0	65.0	54.8	58.9	60.5	62.0	64.4	71.2

S/no	Speed (rpm)	*Afzelia African* Dial reading (Ib/100ft^2)			*Colocasian esculenta* Dial reading (Ib/100ft^2)			*Hydroxyethyl cellulose* Dial reading (Ib/100ft^2)		
		0.2wt%	0.3wt%	0.4wt%	0.2wt%	0.3wt%	0.4wt%	0.2wt%	0.3wt%	0.4wt%
5	60	55.2	58.9	60.2	50.2	55.4	58.4	58.5	60.5	66.9
6	30	51.3	55.3	57.8	48.6	52.4	56.7	54.2	57.8	62.3
7	Consistency factor	2.33	2.39	2.18	0.99	1.41	1.90	2.30	3.30	3.02
8	Flow behavior index	0.54	0.54	0.56	0.66	0.61	0.57	0.55	0.50	0.52

Table 4 showed the rheological behavior of both the local polymer and the synthetic polymer. The table shows the dial reading of the different samples at RPM of 600, 300, 200, 100, 60 and 30 respectively. It is observed from the table that increases in RPM causes increase in the dial reading for all the samples. The results showed that increase in shear rate causes increase in shear stress for all samples. The results of the flow behavior index (n) and consistency factor (k) for all the samples suggest that both the local and synthetic polymers exhibit a non-Newtonian fluid behavior. However, for non-Newtonian fluids the shear rate to shear stress relationship is non-linear.

Table 5*. Result of core-flooding oil recovery using local polymer (Afzelia Africana).*

Concentrations	Core samples	Oil recovery (%)	Total oil in place (mil)	Total oil recovered (mil)
Water-flooding	B_1F	36.8	25.0	9.2
Conc. at 0.2wt%	B_1F	8.4	25.0	2.1
Conc. at 0.3wt%	B_1F	14.4	25.0	3.6
Conc. at 0.4wt%	B_1F	17.6	25.0	4.4

Table 5 is the results of the core-flooding experiment with *Afzelia Africana* polymer. The results from the table suggest that the local polymer showed a positive effect on oil recovery at different polymer concentrations of 0.2wt%, 0.3wt% and 0.4wt% respectively. Waterflooding had oil recovery of 36.8%, however, additional oil recovery was observed when the polymer was injected into the reservoir having oil recovery of 8.4%, 14.4% and 17.6% respectively for concentrations 0.2wt%, 0.3wt% and 0.4wt%.

Table 6*. Result of core-flooding oil recovery using local polymer (Colocasian esculenta).*

Concentrations	Core samples	Oil recovery (%)	Total oil in place (mil)	Total oil recovered (mil)
Water-flooding	B_2F	33.6	25.0	8.4
Conc. at 0.2wt%	B_2F	6.8	25.0	1.7
Conc. at 0.3wt%	B_2F	14.0	25.0	3.5
Conc. at 0.4wt%	B_2F	17.2	25.0	4.3

Table 6 Shows oil recovery at different concentrations of *Colocasian esculenta* polymer. Initial flooding applying waterflooding had oil recovery of 33.6%. Polymer flooding using locally sourced polymers brought incremental oil recovery was when the polymer was injected having recoveries of 6.8%, 14.0% and 17.2% respectively at different polymer

concentrations.

Table 7. *Result of core-flooding oil recovery using synthetic polymer (Hydroxyethyl cellulose).*

Concentrations	Core samples	Oil recovery (%)	Total oil in place (mil)	Total oil recovered (mil)
Water-flooding	B_3F	39.2	25.0	9.8
Conc. at 0.2wt%	B_3F	9.6	25.0	2.4
Conc. at 0.3wt%	B_3F	14.8	25.0	3.7
Conc. at 0.4wt%	B_3F	19.2	25.0	4.8

Table 7 presents the results of the performance of *Hydroxyethyl cellulose.* The table shows that waterflooding had oil recovery of 39.2% while additional oil recovery of 9.6%, 14.8% and 19.2% respectively was observed when hydroxyethyl cellulose was injected at different concentrations.

Figure 5 is the comparison of results of oil recovery for both the local polymers and the synthetic polymer. The plots indicate that *Hydroxyethyl cellulose* had the highest oil recovery as synthetic polymer. However, the local polymers compared favorably with the synthetic polymer which showed that the local polymers can also be suitable for enhanced oil recovery application in the Niger Delta fields.

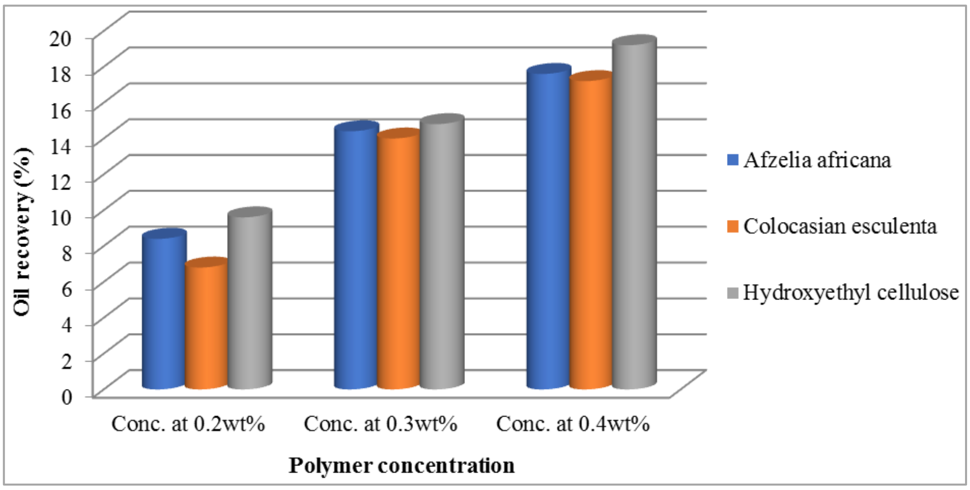

Figure 5. *Comparison of oil recovery of the local polymers and the synthetic polymer at different concentrations.*

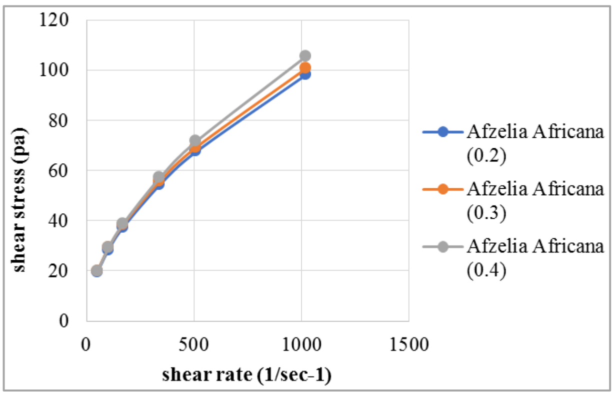

Figure 6. *Shear stress against Shear rate for Afzelia Africana.*

Figures 6-7 showed that the flow behavior of *Afzelia Africana* is shear thinning. Shear thinning is the decrease in viscosity as shear rate increases. Figures 8-9 are the results of the *Colocasian esculenta* rheological behavior. The plots indicate that increases in shear rate results to increase in shear stress which indicate a non-Newtonian fluid behavior. Figures 10-11 are the results of the rheological behavior of *Hydroxyethyl cellulose* as synthetic polymer; and they indicate a non-Newtonian fluid behavior of the synthetic sample. It is worth noting that when n is less than 1, it suggests that the fluid is shear thinning, when n is equal to 1, the fluid is a Newtonian fluid, and when n is greater than 1, the fluid is shear thickening fluid. It can be observed from table 4 that n is less than 1 for both the local polymers and the synthetic polymer. It is interesting to note that shear thinning is observed when there is a decrease in viscosity as shear rate increases.

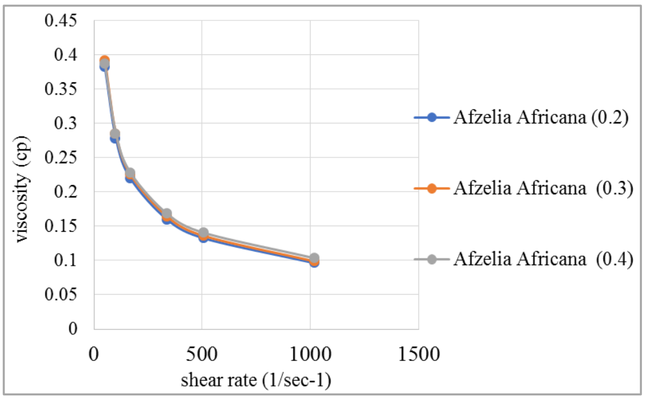

Figure 7. *Viscosity against Shear rate. for Afzelia Africana.*

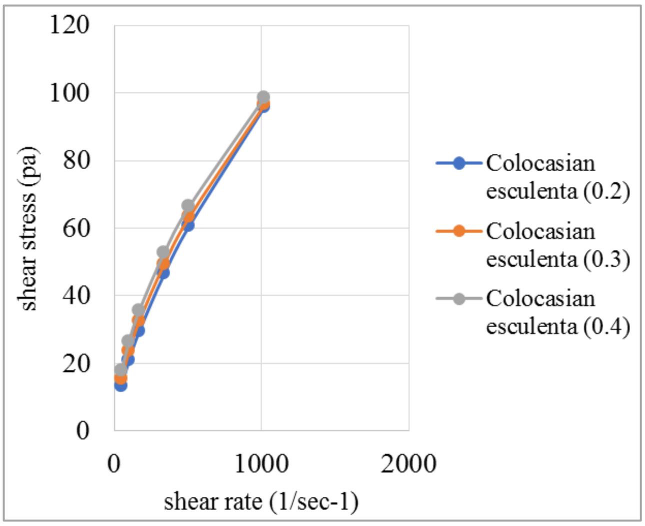

Figure 8. *Shear stress against Shear rate for Colocasian esculenta.*

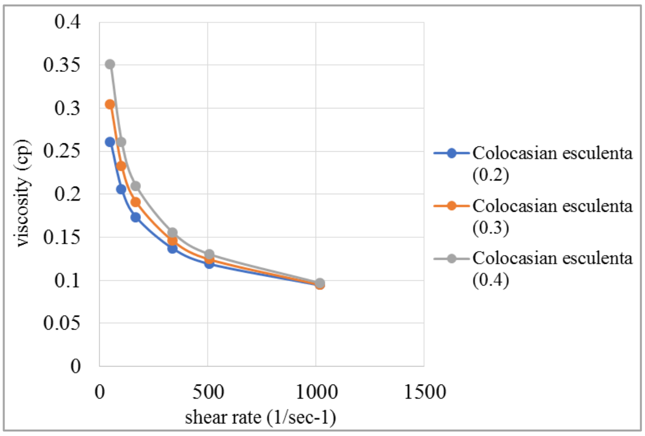

Figure 9. *Viscosity against Shear rate Colocasian esculenta.*

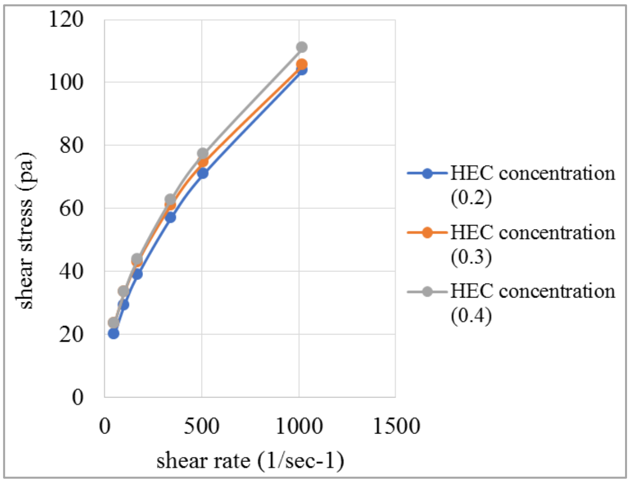

Figure 10. *Shear stress against Shear rate for Hydroxyethyl cellulose (synthetic polymer).*

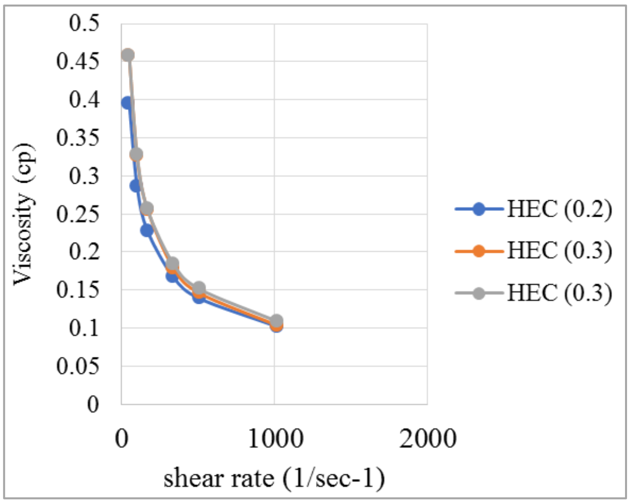

Figure 11. *Viscosity against Shear rate Hydroxyethyl cellulose (synthetic polymer).*

5. Characterization Results

5.1. Fourier Transform Infrared Spectrometry (FTIR TEST) Results

Figure 12, the band spectrum around 943.0 was assigned to the OH group due to the C=C stretch of the ethylene compounds. The bands around 1373.5 and 81.553 were assigned to the CH_2 due to the vibration of the cyclic ester COO stretch. There is also the presence of carboxylic group assigned to the 1457.0 and 86.572 due to the presence of the CO. Figure 13 indicate the absorption band around 721.2 and 77.271 was assigned the CN due to the stretching vibration of the amine compound. The band spectrum around 10791-48.690 was assigned the CO stretch of ether compound. The band around 1406.7-80.306 was assigned to the NH due to vibration of the amine compound. In addition, the absorption band around the 1654.0-95.410 was assigned the CO due to the cyclic ester compound. In addition, figure 14 is the absorption band around 1170.4 was assigned the CH group due to the presence of the methylene compound. The spectrum band around 1317.6-8641.5 was assigned the CO due to the carboxylic compounds. While the band around 1653.1 and 84.407 were assigned the CN (nitriles) due to the stretching of the vibration of the NH (amine). In addition, the spectrum band around the 2920.4 and 91.132 was assigned the OH group.

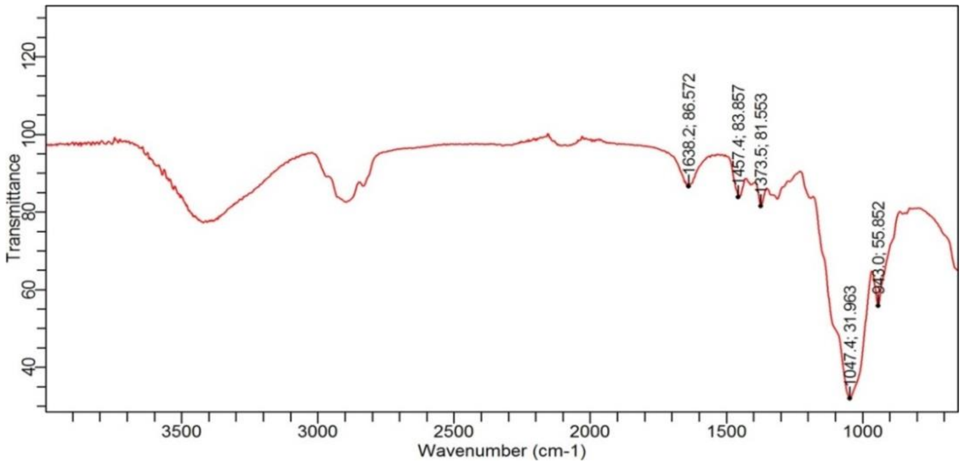

Figure 12. *Functional group of Afzelia Africana (Akparata).*

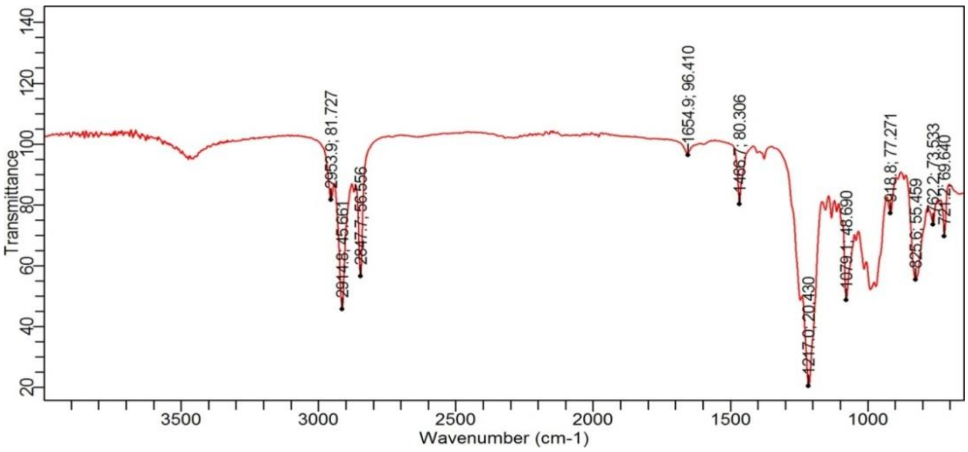

Figure 13. *Functional group of Colocasian esculenta (Cocoyam).*

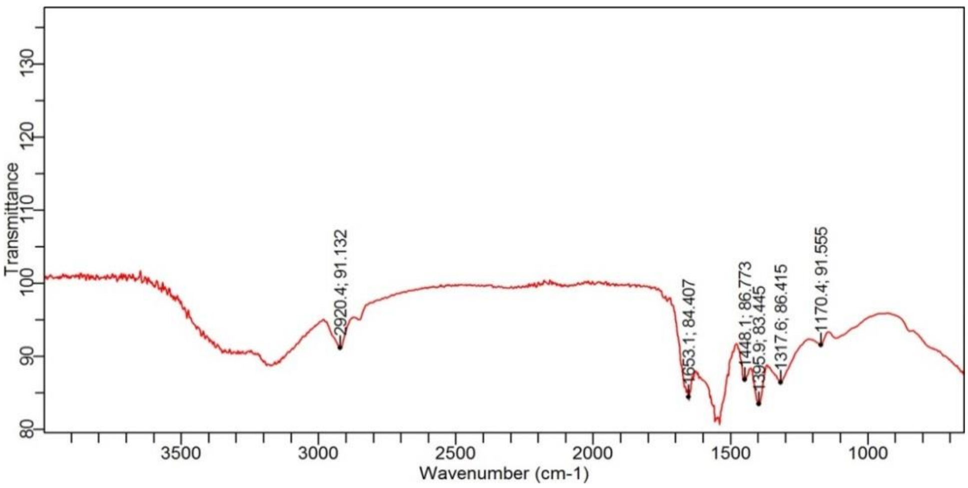

Figure 14. *Functional group of Hydroxyethyl cellulose (synthetic polymer).*

5.2. Scanning Electron Microscopy Test Result

Figure 15, the sample *Afzelia africana* was observed to be crystalline in nature and have interconnected microstructure between the molecules. While in figure 16-17, the samples *Colocasian esculenta and Hydroxyethyl cellulose* were observed to be mesoporous. The presence of the pore sizes makes the samples to be porous in nature.

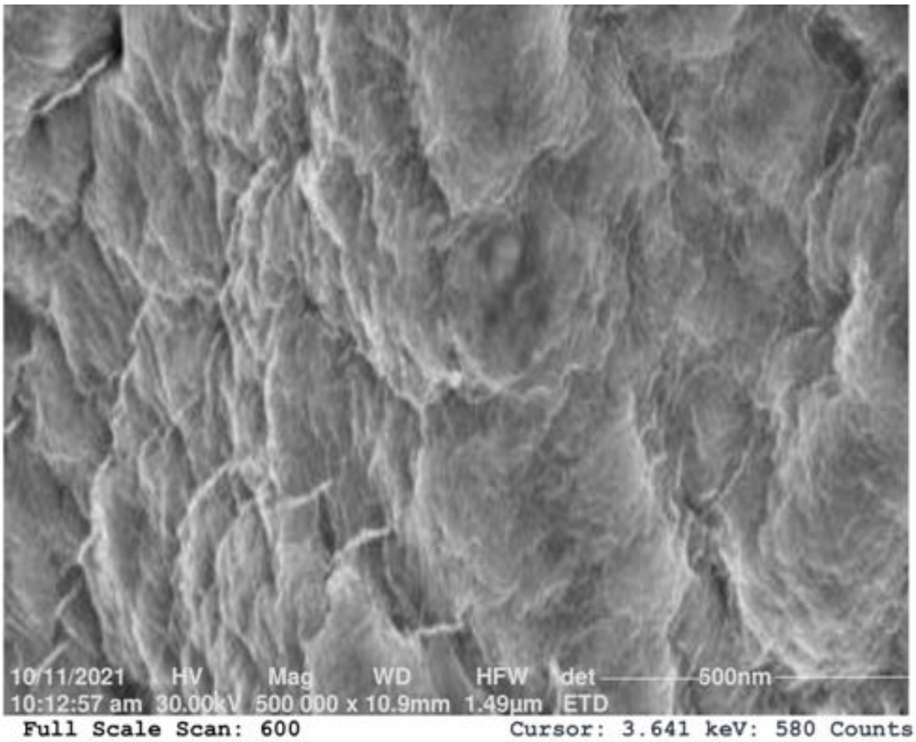

Figure 15. *Scanning Electron Microscopy of Afzelia Africana (Akparata).*

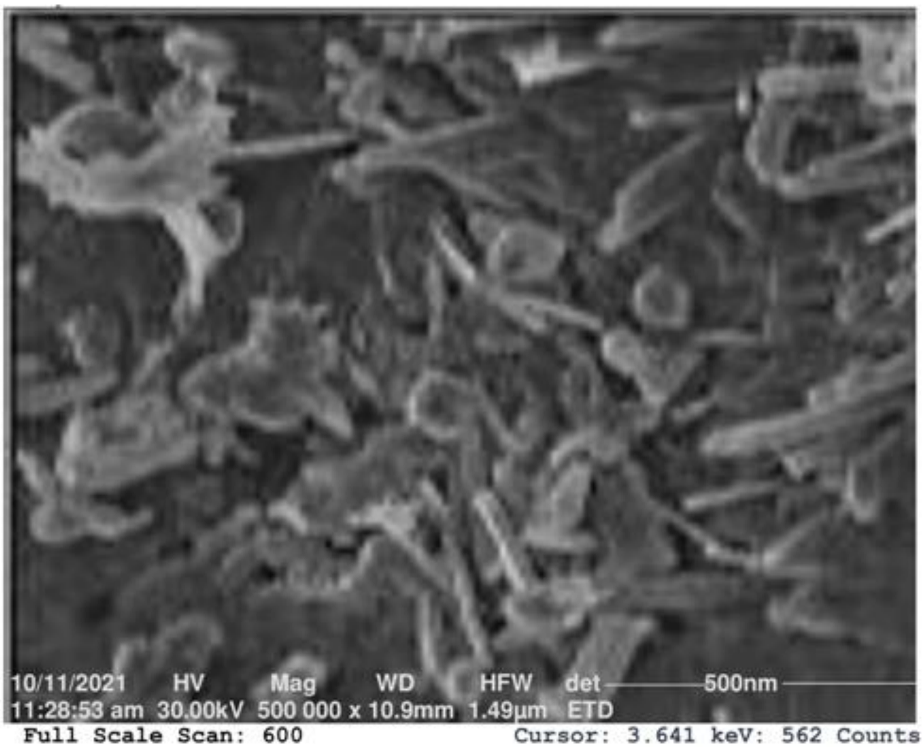

Figure 16. *Scanning Electron Microscopy of Colocasian esculenta (Cocoyam).*

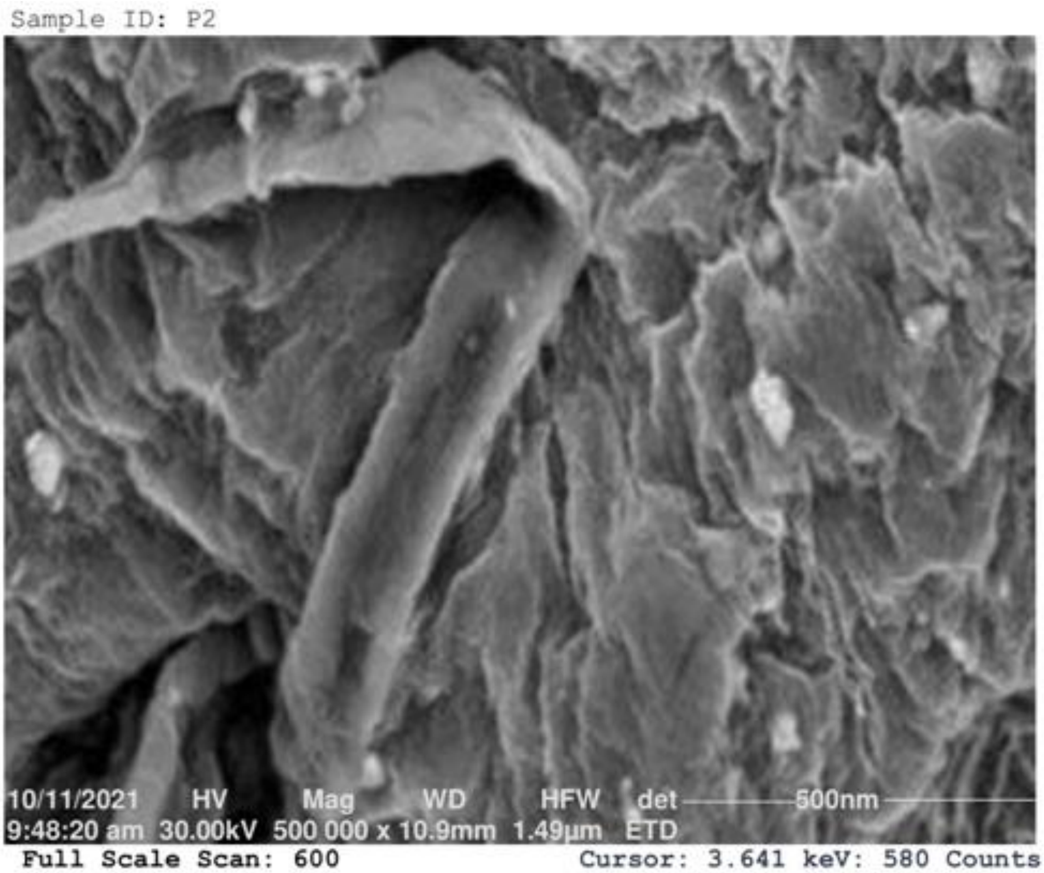

Figure 17. *Scanning Electron Microscopy of Hydroxyethyl cellulose (HEC).*

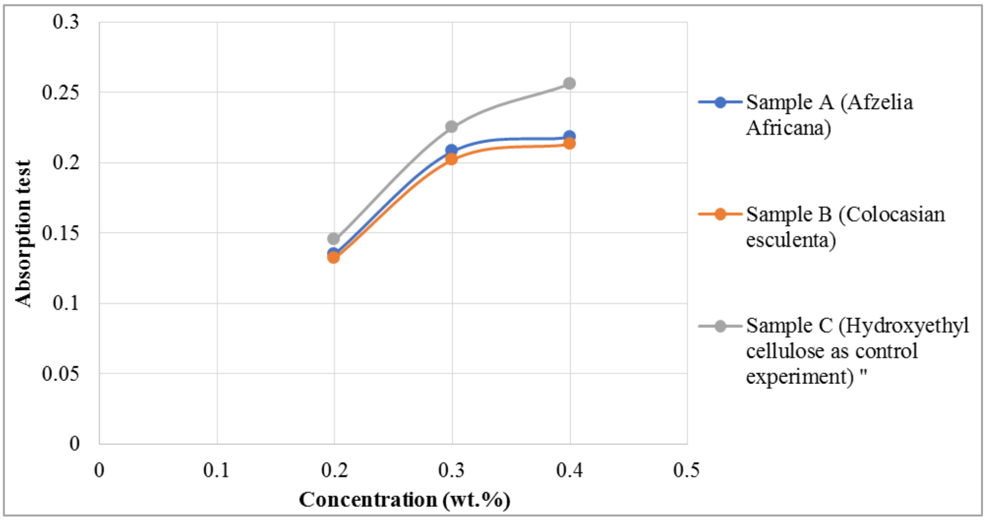

Figure 18. *Absorption test against concentration.*

Figure 18 showed the absorption test was carried out to determine the absorption rate of the local and the synthetic polymers. The results showed that absorption rate increases as concentration increases which suggest that higher polymer injection will lead to higher increase in absorption to the rock surfaces.

6. Conclusions

Based on the experimental study performed on this study, the following conclusions can be drawn;

1) *Afzelia Africana and Colocasian esculenta* as a polymer showed a positive effect in enhanced oil recovery and

compete favorably with the synthetic polymer (Hydroxyethyl cellulose).

2) Increasing polymer concentration can influence higher oil recovery due to mobility control of waterflooding resulting to improvement of reservoir sweep and gave an additional oil recovery of 8.4%, 14.4% and 17.6% for *Afzelia Africana* at concentrations of 0.2wt%, 0.3wt%, and 0.4wt% respectively, 6.8%, 14.0% and 17.2% for *Colocasian esculenta* and 9.8%, 14.8% and 19.2% for Hydroxyethyl cellulose respectively.
3) The characterization of the polymers showed the presence of carboxyl (COOH) and hydroxyl (OH) functional groups.
4) The rheological study on the samples showed they exhibit a non-Newtonian fluid and a shear thinning behavior.
5) The core-flooding experimental work conducted in this study showed that the local polymers enhanced oil recovery at different polymer concentrations of 0.2wt%, 0.3wt% and 0.4wt% respectively.

Acknowledgments

The authors wish to thank the Management of Federal University of Technology Owerri for the enabling environment and laboratory space to carry out this research work.

Conflicts of Interest

The authors declared no conflict of interest.

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