Formulation and Characterization of Hybrid Biopolymeric (Starch) Solution Synthesized from Purple Yam and Sweet Potato Peels

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Abstract
Biopolymers such as starches enhance the viscosity of injected fluids, leading to a favorable mobility ratio during chemical enhanced oil recovery. This study focused on combining starches extracted from the peels of purple yam and sweet potato, evaluating the characteristics of this hybrid biopolymer and comparing it to partially hydrolyzed polyacrylamide (HPAM). The extraction process involved sun drying, grinding, soaking, and sieving the peels to recover starch through precipitation. These starches were then dispersed in brine at varying concentrations and their physicochemical properties were accessed. The pH, viscosity, and weight were measured at different temperatures to understand the thermal behavior of the hybrid biopolymer solutions. The findings showed that the starches fully dissolved in brine across all tested concentrations and temperatures, confirming good compatibility. The hybrid biopolymer (starch blend) exhibited a highly unusual and favorable pH response: an upward shift in pH (13.9 @ 90°C) from acidity to alkalinity at 0.15% concentration. Viscosity of the starch blend (hybrid polymer) showed a moderate reduction from 6.50cp @ 30C to 4.50cp @ 90°C displaying good thermal stability. The solution exhibited a non-Newtonian behavior. Fourier Transform Infrared (FTIR) spectroscopy was performed to analyze the hybrid starch solution, with results compared against HPAM. Both materials exhibited similar absorption peaks corresponding to key functional groups. For the hybrid biopolymer, peaks at 1636 and 3336 cm^{-1} were linked to C=C, N-H, and -OH vibrations, while HPAM showed peaks at 1647 and 3230 cm^{-1}, indicating the presence of C-O and N-H bonds within acrylamide compounds. The results suggest that the hybrid biopolymer lack toxic acrylamide, and offers a more environmentally friendly alternative while maintaining functional groups essential for mobility control and IFT reduction during EOR applications.

Keywords: *Starches, Biopolymers, Characterization , Mobility Ratio, Oil Recovery.*

I. INTRODUCTION

Due to the ongoing high demand for crude oil as a major energy source, the oil and gas industry must investigate every technological option that is commercially viable in order to maximize field recovery and preserve oil price equilibrium. This is due to the fact that as production increases in response to the rising need for energy, the reservoir's primary energy decline, leaving behind over 50% of the original oil in place. The technology known as enhanced oil recovery method is mostly used in oilfields to increase productivity when primary

(using the natural reservoir drive energy) and secondary recoveries (waterflooding or gas flooding) have been exhausted (Agi 2019). Using techniques like chemical injection, miscible injection, microbiological injection or thermal recovery, this technology has been refined over time and may now be used. The potential of chemical enhanced oil recovery to increase the microscopic displacement efficiency through a variety of mechanisms, including wettability alteration, fluid physical property changes, gravity drainage, and a decrease in interfacial tension, has drawn attention in recent research. Due to its effectiveness in recovering residual oil through primary and secondary recovery methods, polymer and surfactant flooding is one of the chemical enhanced oil recovery processes that is getting a lot of attention (Fadairo et al. 2018).

The most widely used method of chemical flooding, polymer flooding, has the benefits of being inexpensive, easily manipulated, and having noticeable impacts. Because of its viscoelastic qualities, polymer flooding was found to be the most viable application and approach for improving crude oil recovery in the oil and gas sector. Generally, Polymers are viscoelastic in nature with pseudo plastic and shear thickening behaviour when subjected to shear stress in porous media. Polymers improve the viscosity of the injected fluid, promoting a more favorable mobility ratio within the reservoir. As a result, they help recover bypassed and unswept oil by mitigating or eliminating viscous fingering, which leads to enhanced oil recovery efficiency. Additionally, the viscoelastic properties of polymer macromolecules enable them to extract oil films trapped in narrow reservoir pores through pulling and stripping mechanisms. Polymers also contribute to oil recovery by disproportionately reducing water permeability—achieved through swelling—which limits water flow without significantly impacting oil flow. The implementation of polymers in enhanced oil recovery (EOR) also leads to a substantial decrease in the volume of water required for injection. Furthermore, their presence reduces water production (water cut) at the production wells. A wide range of polymers has been explored for EOR applications. These are generally classified into two main categories: natural polymers (biopolymers) and synthetic polymers. Biopolymers, typically obtained from plant-based sources, are considered environmentally friendly and are derived from both renewable and non-renewable resources (Sreena and Nathanael, 2023). In contrast, acrylamide-based polymers represent the synthetic group commonly employed in EOR. They possess favorable rheological and viscoelastic characteristics and feature carboxylate and amide functional groups along the polymer chain. Among synthetic polymers, partially hydrolyzed polyacrylamide (HPAM) is the most widely used in oilfield operations. Other synthetic variants include polyacrylamide (PAM) and hydrophobically associating polyacrylamide (HAPAM). However, these synthetic options often face limitations in environments with high salinity, low pH, high temperatures, or high shear rates, and they are less environmentally sustainable and more expensive. The biopolymer Xanthan is another expensive commercial polymer that has the problem of degradation (Uzoho et al., 2015). Al-Jaber et al., 2023 investigated enhanced oil recovery using polymeric nanofluids synthesized from cassava and purple yam tubers. This study includes the collection of purple yam and sweet potato peels, extraction of starches from these peels, blending starches to produce hybrid biopolymeric (starch) solution, and characterizing using Fourier transform infrared spectroscopy (FTIR) and rheological property (apparent viscosity) measurement with respect to varying temperatures and concentrations.

II. AIM

The aim of this study is to formulate and characterize hybrid biopolymeric (starch) solution synthesized from purple yam and sweet potato peels.

III. OBJECTIVES

1. To produce and formulate starches from Purple yam and Sweet potato Peels.
2. To characterize the formulated hybrid biopolymer (starch) solution using FTIR analysis and comparing its properties with HPAM.
3. To investigate the effect of varying temperature on the apparent viscosity of the biopolymers (starches) at different concentrations.

IV. MATERIALS/METHODOLOGY (EXPERIMENTAL PROCEDURES)

This experimental study incorporated a comprehensive selection of laboratory equipment and organic substrates for starch extraction and characterization processes. Purple yam and sweet potato peels, obtained as agro-waste residues, served as the primary starch sources for biopolymer formulation. These peels were selected due to their high starch content and widespread availability in agricultural regions. Distilled water was utilized throughout the procedure to prevent contamination and ensure consistency in all aqueous reactions. A cylindrical plastic container facilitated the initial soaking and sedimentation processes in a controlled and confined environment.

The pulverization of sun-dried peels was accomplished using an industrial-grade grinding machine, yielding fine starch-rich powder. Separation of fibrous residues from the slurry was achieved using fine sieves and muslin filters. Sack bags provided shade and airflow during sun-drying, enhancing the dehydration efficiency of the extracted wet starch. The final dried starch was stored in airtight containers to prevent moisture absorption and microbial interference. A laboratory-grade blender was employed to refine the dried starch into uniform particle sizes suitable for further application.

Analytical measurements were conducted using a range of precision instruments to assess physicochemical properties under varied conditions. An NDJ-8S viscometer was employed to determine apparent viscosity across different temperatures and concentrations. pH levels of the starch solutions were accurately measured using a digital pH meter. A thermostatic water bath maintained fixed thermal conditions to simulate reservoir-like environments. Quantitative measurements of polymer mass and solution density were obtained using calibrated weighing balances and standard density bottles. Beakers and cylindrical cylinders were used to measure and mix reagents with precision. Sodium chloride (NaCl) was dissolved in distilled water to prepare a synthetic brine mimicking high-salinity conditions. Magnetic stirrers enabled uniform dispersion of starch in solution without introducing air bubbles. Additional tools such as spatulas and Petri dishes were used for sample handling and interim drying. Collectively, these materials ensured experimental accuracy, reproducibility, and reliability throughout the starch extraction and analysis process.

Starch extraction from purple yam and sweet potato peels

The starch extraction process commenced with the thorough cleansing of residual plant peels using potable water to eliminate extraneous materials. This preliminary step ensured the removal of dirt and surface contaminants that could compromise the purity of the end product. Following the cleaning stage, the peels were uniformly spread and subjected to natural sun drying over a ten-day period. This sun-drying phase facilitated significant moisture reduction, which is essential for effective grinding and subsequent processing.

Upon complete dehydration, the desiccated peels were pulverized into a fine particulate state using a mechanical grinding apparatus. The resulting powder was then immersed in clean water and allowed to steep for a duration of three consecutive days. This soaking phase was intended to initiate the release of starch granules from the cellular matrix of the biomass. After the designated soaking interval, the slurry was passed through a fine muslin cloth or precision sieve to achieve effective separation of insoluble fibrous residues from the starch-laden filtrate.

The obtained filtrate was carefully transferred into a clean basin and left in a static condition for approximately eight hours. This period enabled the gravitational sedimentation of starch particles, allowing them to settle at the bottom as a dense layer. Once sedimentation was complete, the supernatant liquid was gently decanted without disturbing the underlying starch layer. The moist starch residue was then evenly distributed on a clean drying tray and exposed to solar radiation for a full 24-hour cycle. This stage promoted thorough dehydration of the sediment to achieve a dry, usable state (Figure 1). Finally, the sun-dried starch was milled into a uniform fine powder using a dry blender and stored in an airtight container to preserve its physicochemical integrity for future applications.

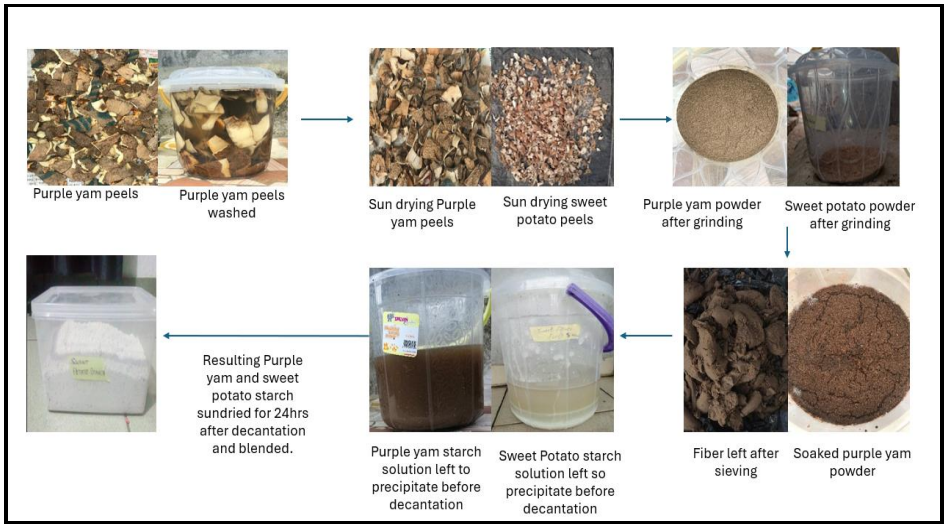

Fig. 1- Summary of the procedure for starch extraction from purple yam and sweet potato peels.

FTIR ANALYSIS OF HYBRID (STARCH) BIOPOLYMER

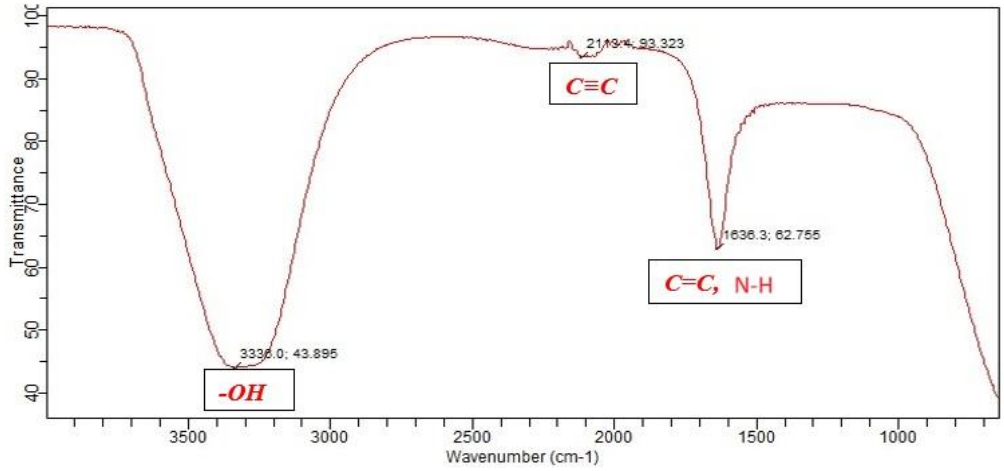

Fig. 6: FTIR analysis of formulated hybrid (starch) biopolymer from purple yam and sweet potato peels

The interpretation of the different bands of the spectrum obtained during the analysis by FTIR spectrometry of formulated hybrid biopolymer are based on the absorption peaks (or bands). Furthermore, using the corresponding absorption peak value in cm^{-1} wave numbers, we can use characteristic infrared absorption band chart (IR charts) to identify the different classes of compounds, their assignment (molecular bonds and functional groups), and intensities. The result of the characterized hybrid biopolymer (purple yam and sweet potato starch solution)

using FTIR analysis is displayed in Figure 6 above. The peaks at 1636 and 3336 cm^{-1} represent the stretching vibrations of the **C=C , N-H** and hydroxyl **(-OH)** functional groups respectively. These peaks confirm that there are alkenes, amines and carboxylic acids found in the formulated hybrid biopolymer solution. Also, the number of peaks is less than five showing that the analyzed biopolymer has a simple chemical structure. The absorption band at 2113.4cm-1 indicate the presence of alkynes (R-C≡C-H) class of compounds in the hybrid biopolymer solution.

FTIR Analysis of HPAM

Sid et al., 2023 characterized synthetic HPAM polymer using FTIR analysis, and the results are displayed in Figure 7 below. The absorption peaks at 1647 and 3230 cm^{-1} represent the stretching vibrations of the C-O (R-C(O)-NR'R") and N-H (R-C(O)-NH_2) amide groups respectively. These peaks confirm that the acrylamide group is present in the synthesized polymer. The absorption bands at 2963 and 2925 cm^{-1} indicate the stretching vibrations of the C-H bend (alkenes and alkyls) group, while the absorption bands at 2853 and 1457 cm^{-1} also correspond to the C-H bend in the polymer chain,. The absorption bands at 1116 cm^{-1} reveals the presence of −CN stretching.

Table 5: Main infrared bands observed in HPAM solution (**Source:** Sid et al., 2023)

Wave Numbers (cm^{-1})	**The Corresponding Link**
2800-2950	C-H
3500-3400	O-H
3230	N-H
900-1200	C-N
1647	C=O

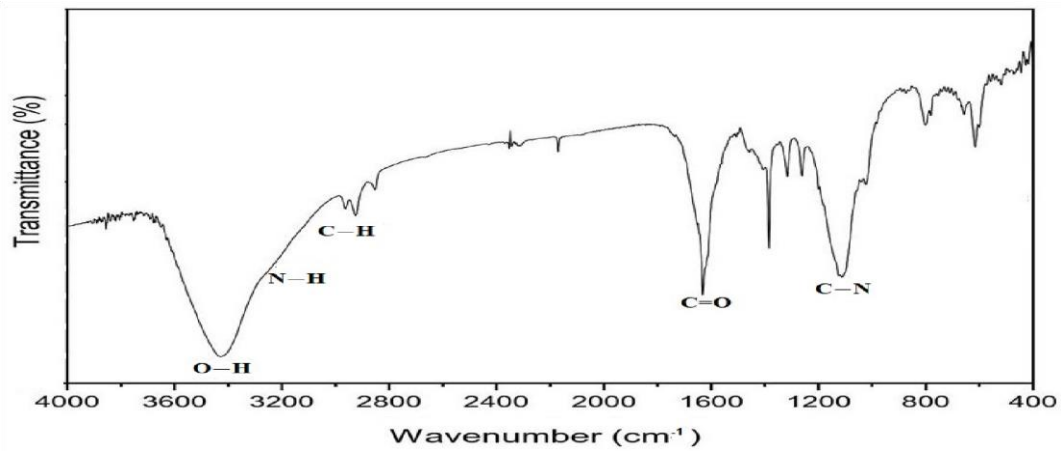

Fig. 7: IR spectrum of solution (**Source:** Sid et al., 2023)

Comparing the formulated hybrid biopolymer (starch) to the HPAM polymer

The formulated biopolymer has some similar properties to HPAM such as the -OH (hydroxyl) group, which are relevant properties needed for interfacial tension (IFT) reduction in core flooding operations. Also, the formulated biopolymer has a simple organic compound while that of HPAM has a complex organic compound which makes the formulated biopolymer more user-friendly and eco-friendlier. The acrylamide structure present in HPAM makes this synthetic polymer to be toxic to humans (Al-Kindi et al., 2022). From the results obtained after

FTIR analysis, there is the presence of amide groups R-C(O)-NH-R (C=O stretching vibrations) and R-C(O)-NH2 (N-H symmetric). These functional groups contribute to the acrylamide's properties and reactivity in the synthetic polymer HPAM. This polymer is harmful to the environment due to its synthetic nature (Agi et al., 2018). It is significant to note that in high permeability zone, HPAM channeling can take place leading to premature loss of polymer from the wellbore, as a result affect oil phase displacement (Lopez et al., 2017). The amide functional group is not present in the formulated hybrid biopolymer (starch) indicating that it is non-toxic (biocompatible) to humans.

Brine Preparation/ Experimental Set up/Design

A synthetic brine solution of 30,000 ppm salinity was meticulously prepared by dissolving 30 grams of sodium chloride in 1000 mL of distilled water. This concentration was selected to simulate conditions characteristic of high-salinity petroleum reservoirs. From this stock solution, precisely 200 mL was allocated using a calibrated beaker and transferred into five sealed, airtight containers. Additional brine, prepared at the same salinity concentration (30,000 ppm), was evenly distributed into the remaining airtight vessels to ensure uniformity across all samples. Seven distinct quantities—ranging from 0.3 g to 2.1 g—of both purple yam and sweet potato starches were individually weighed using precision electronic balances. These starches were introduced separately into 200 mL portions of the brine solution, yielding a total of fourteen monocomponent experimental samples for preliminary evaluation. Subsequently, hybrid formulations were prepared by blending purple yam and sweet potato starch in a 1:1 mass ratio. Specifically, 0.3, 0.6, 0.9, 1.2, 1.5, 1.8, and 2.1 grams of each starch type were measured and incorporated into seven individual containers, each containing 400 mL of the brine solution (see Table 1). This process produced composite biopolymer solutions with total starch concentrations of 0.6, 1.2, 1.8, 2.4, 3.0, 3.6, and 4.2 grams per 400 mL, respectively.

Table 1. Hybrid Polymer Concentration Table (1:1 Purple Yam : Sweet Potato Blend)

Run	Concentration (w/v%)	Total Starch Mass (g)	Purple Yam (g)	Sweet Potato (g)
1	0.15	0.6	0.3	0.3
2	0.30	1.2	0.6	0.6
3	0.45	1.8	0.9	0.9
4	0.60	2.4	1.2	1.2
5	0.75	3.0	1.5	1.5
6	0.90	3.6	1.8	1.8
7	1.05	4.2	2.1	2.1

Each mixture was homogenized using a magnetic stirrer to ensure uniform distribution of starch granules within the saline medium. A sterile, white cotton handkerchief served as a filtration medium to remove undissolved particulates from each formulation. Some hybrid mixtures, comprising equal contributions from both starch sources, are shown in Plate 1. The pH values of the prepared suspensions were determined across varying thermal conditions using a calibrated digital pH meter. For rheological characterization of the individual starch solutions, a viscometer set at two rotor (2) and operated at twelve revolutions per minute (12RPM) was

employed. The same viscometer was set at two rotor (2) and operated at sixty (60) revolutions per minute (60RPM) for the hybrid starch solution. Apparent viscosity was recorded meticulously for each starch-brine matrix. Concurrently, density measurements were acquired using a density bottle method, supported by a digital weighing balance for precise mass determination.

Plate 1: Some samples of blended starches/biopolymer at different concentration in 400ml brine.

To explore thermal influence, all starch-brine formulations were subjected to controlled heating using a thermostatically regulated water bath. Temperature intervals included 30°C, 45°C, 70°C, and 90°C to reflect a range of reservoir-relevant conditions. At each specified temperature, pH, mass, and viscosity parameters were re-measured and documented. These measurements facilitated the evaluation of thermo-rheological behavior and pH stability of the biopolymer-infused solutions. The study thereby assessed the adaptability of native starches under saline and thermal stress, providing crucial insights into their potential for enhanced oil recovery applications. The comprehensive data generated supports further investigation into the physicochemical resilience and functional capacity of these natural polymers.

RESULTS AND DISCUSSIONS

The present study assessed the physicochemical properties of purple yam starch, sweet potato peel starch, and their 1:1 hybrid blend in aqueous solutions to determine their viability as biopolymeric candidates for Chemical Enhanced Oil Recovery (CEOR) applications. CEOR requires polymers that can withstand subsurface reservoir conditions, particularly elevated temperatures, varying pH levels, and mechanical shear, while maintaining sufficient viscosity to improve the mobility ratio of displacing fluids. As shown in Table 2, purple yam starch solutions exhibited a moderate increase in viscosity with rising concentration, reaching 27.50 centipoise at 1.05% and 30°C. However, viscosity dropped to 20.00 cp at 90°C, indicating sensitivity to thermal degradation. pH values declined from neutral to mildly acidic with increasing temperature, while weight values remained stable, suggesting minimal thermal decomposition. These results highlight purple yam starch's modest thermal stability and intermediate rheological behavior, indicating that while it may not fully withstand the thermal stress of deep reservoirs, it offers some potential for moderate-temperature CEOR settings.

Table 2: Effect of Concentration and Temperature on the Physicochemical Properties of Purple Yam Starch Solution.

Run	Conc. (%)	30°C			45°C			70°C			90 °C		
		W (g)	pH	η (cp)	W (g)	pH	η (cp)	W (g)	pH	η (cp)	W (g)	pH	η (cp)
1	0.15	53.91	6.9	12.80	51.47	5.0	12.03	51.23	4.7	11.50	51.00	6.0	10.00
2	0.30	54.04	6.8	15.00	51.65	4.8	13.50	51.41	4.5	13.00	51.31	5.7	12.00
3	0.45	54.17	6.6	18.50	51.86	4.6	17.30	51.54	4.3	15.50	51.39	5.4	13.50
4	0.60	54.30	6.5	20.00	52.89	4.3	17.80	51.67	4.1	16.00	51.44	5.1	15.66
5	0.75	54.43	6.4	22.50	53.01	4.1	21.00	51.84	3.9	18.00	51.60	4.8	16.90
6	0.90	54.56	6.2	25.00	53.37	3.8	23.50	52.13	3.7	20.00	51.73	4.4	19.00
7	1.05	54.69	5.9	27.50	53.67	3.5	25.00	52.30	3.4	24.50	51.96	4.1	20.00

Sweet potato peel starch outperformed purple yam starch in terms of viscosity and structural resilience, as reflected in Table 3. At 1.05% concentration and 30°C, the viscosity reached 35.00 cp—significantly higher than that of purple yam and even at 90°C, it retained a strong viscosity of 26.22 cp. This robust viscosity profile under increasing thermal conditions is essential in CEOR, where viscosity retention is directly linked to effective oil displacement. The consistently low pH values, decreasing with temperature, may suggest potential limitations in alkaline reservoir environments. Nonetheless, the weight of the solution remained largely unaffected, indicating excellent thermal stability and molecular integrity. These results position sweet potato starch as a strong biopolymer candidate for CEOR, especially in thermally active reservoirs that demand persistent viscoelastic performance.

Table 3: Effect of Concentration and Temperature on the Physicochemical Properties of Sweet Potato Peel Starch Solution

Run	Conc. (%)	30°C			45°C			70°C			90 °C		
		W (g)	pH	η (cp)	W (g)	pH	η (cp)	W (g)	pH	η (cp)	W (g)	pH	η (cp)
1	0.15	53.45	4.6	20.00	53.28	4.5	19.50	52.28	4.4	17.60	52.00	5.0	17.00
2	0.30	53.55	4.4	22.00	53.31	4.3	20.50	52.41	4.2	19.00	52.23	4.8	17.33
3	0.45	53.65	4.3	23.40	53.52	4.2	21.68	52.54	4.1	20.00	52.38	4.5	18.40
4	0.60	53.66	4.2	25.00	53.59	4.1	23.00	52.58	4.0	22.00	52.41	4.2	20.00
5	0.75	53.69	4.1	27.00	53.62	4.0	25.54	52.63	3.9	24.00	52.48	4.1	22.40
6	0.90	53.77	4.0	30.50	53.68	3.8	28.30	52.71	3.5	25.00	52.60	4.0	24.00
7	1.05	53.93	4.6	35.00	53.71	3.6	31.03	52.91	3.2	27.00	53.85	3.9	26.22

The hybrid starch system, prepared by blending purple yam and sweet potato starches in a 1:1 ratio, yielded a unique performance profile. As presented in Table 4, this system showed comparatively lower viscosity values, reaching only 6.50 cp at 1.05% and 30°C, and declining further under thermal stress. While its rheological profile may fall below CEOR thresholds for mobility control for high permeable reservoirs, the starch blend exhibited a highly unusual and favorable pH response: an upward shift in pH with temperature, peaking at 13.9 at 90°C and 0.15% concentration. This suggests the potential formation or activation of alkaline components, which could be advantageous in alkaline-polymer flooding, a CEOR method where elevated pH assists in reducing interfacial tension and enhancing oil displacement.

Additionally, the hybrid maintained strong mass retention under heat, indicating excellent thermal and compositional stability despite its lower viscosity.

Table 4: Effect of Concentration and Temperature on the Physicochemical Properties 1:1 Purple Yam: Sweet Potato Blend to form a hybrid polymer solution.

Run	Conc. (%)	**30°C**			**45°C**			**70°C**			**90 °C**		
		W (g)	pH	η (cp)	W (g)	pH	η (cp)	W (g)	pH	η (cp)	W (g)	pH	η (cp)
1	0.15	53.49	9.1	3.00	52.43	11.1	2.90	51.2	13.1	2.60	50.92	13.9	2.50
2	0.30	53.54	8.8	3.80	52.48	10.9	3.60	51.3	12.8	3.20	51.18	13.8	3.00
3	0.45	53.61	8.7	4.00	52.54	10.8	3.89	51.41	12.5	3.57	51.29	13.7	3.00
4	0.60	53.66	8.5	4.50	52.6	10.7	4.00	51.57	12.3	4.88	51.34	13.6	3.50
5	0.75	53.70	8.2	5.00	52.65	10.5	4.50	51.64	12.1	4.00	51.50	13.4	3.70
6	0.90	53.75	7.7	5.50	52.71	10.3	5.00	51.68	10.6	4.50	51.58	13.3	4.00
7	1.05	53.78	7.4	6.50	52.77	10.1	5.00	51.74	10.0	4.60	51.66	13.0	4.50

In comparative terms, sweet potato peel starch emerges as the most promising candidate due to its superior viscosity retention and structural robustness under high temperatures—key attributes for polymers used in CEOR. As shown, the individual starch formulations reveal that increasing the concentration of starches increases the weight and apparent viscosity while the pH decreases gradually as concentration of starch increases, maintaining a pH value below 7 (pH < 7). This shows that the individual starch formulations remain acidic at varying concentrations and temperatures. Also, at increased temperatures and concentrations, the viscosity of the formulation increased, indicating that these biopolymer/starch solutions exhibit good thermal behavior and is non-Newtonian in nature (Figures 3 through 5). High concentration of polymers is used to reduce the effect of salinity and sustain high viscosity in formation water. Purple yam starch offers moderate performance, with potential for formulation enhancement or use in milder reservoir conditions. The hybrid system demonstrates exceptional pH modulation and stability, making it a compelling additive for alkaline-polymer flood strategies or as a pH buffer in multi-chemical flooding systems. Viscosity of the starch blend (hybrid polymer) **showed a moderate** reduction from 6.50cp @ 30C to 4.50cp @ 90C displaying thermal stability. These findings support further investigation into biopolymer (starch) blending to optimize starch-based materials for eco-friendly, cost-effective CEOR technologies.

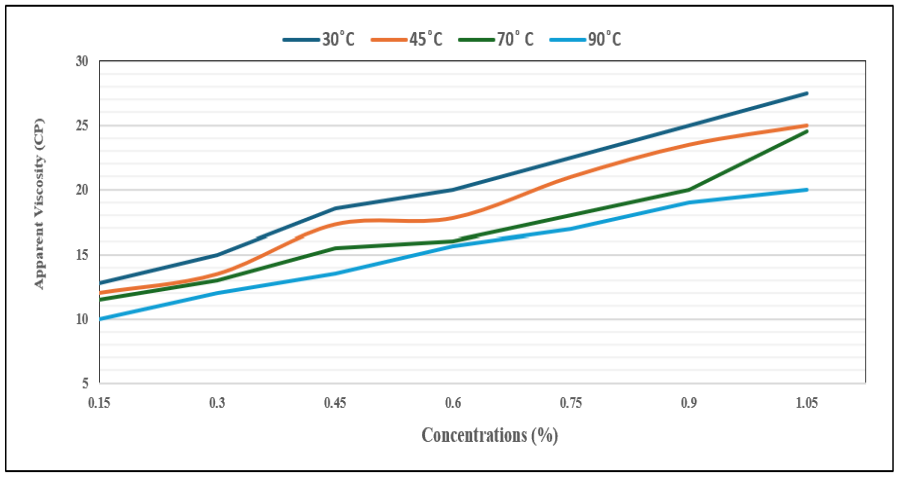

Fig. 3: The effect of concentration on the viscosity of purple yam starch at prescribed temperatures.

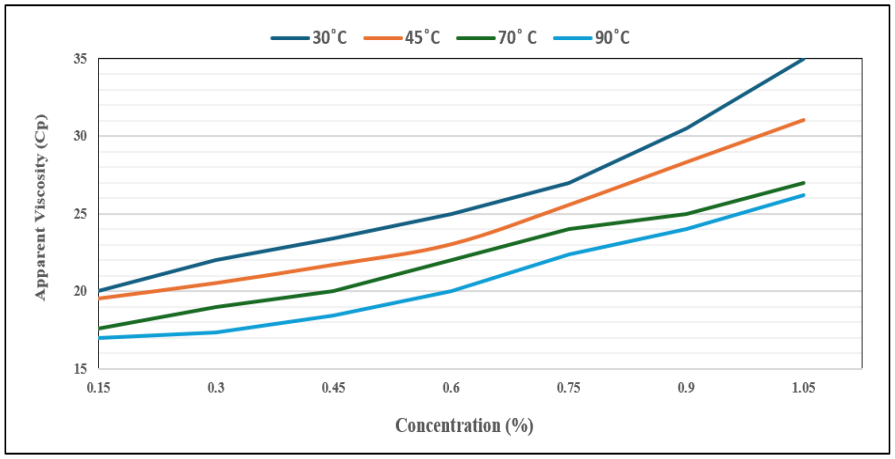

Fig. 4: The effect of concentration on the viscosity of Sweet Potato Peel Starch Solution at prescribed temperatures.

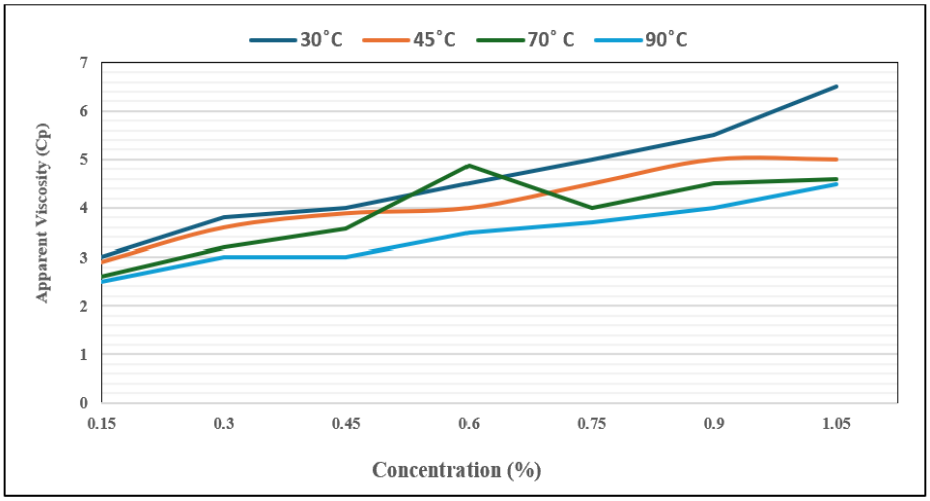

Fig. 5: The effect of concentration on the viscosity of 1:1 Purple Yam: Sweet Potato Blend to form a hybrid polymer solution at prescribed temperatures.

V. CONCLUSION AND RECOMMENDATION

Since the absorption peaks were less than 5, the hybrid biopolymer solution shows a simple organic compound compared to HPAM with its complex chemical compound. The formulated hybrid biopolymer solution is a non-Newtonian fluid having a pseudo plastic (shear thinning) characteristic. The formulated biopolymer's composition provides environmental advantages over HPAM, and both have -OH groups that are helpful in reducing interfacial tension (IFT). Additionally, blending starches to produce hybrid biopolymeric solutions will help the oil and gas industry to produce injectants that can further reduce fluid-rock interactions (contact angle) for wettability alteration in water wet reservoirs.

This research recommends strategically blending starches synthesized from purple yam and sweet potato peels to improve their physicochemical and functional properties such as pH, viscosity etc. for enhanced oil recovery processes. The increased pH of 13.0 @ 90C noticed from Table 4 may have resulted to the reduced viscosity value (4.50cp @ 90C). To meet the threshold for mobility control during EOR applications in high permeable reservoirs, the mixing ratio of the starches should be put into consideration when blending as this may have synergistic or antagonistic effect on the pH or viscosity. To enhance viscosity, pH and other physicochemical and functional properties of the hybrid starch solution, complimentary starches should be blended with appropriate ratios to improve performance especially for EOR applications. This hybrid (starch) blend can be recommended for tight formations. In many reservoirs, high salinity of formation′s water enforces a challenge on polymer flood applicability (Algharaib et al., 2014). Further research should be conducted on formulating hybrid biopolymeric (starch) fluids, and to ascertain the effectiveness and efficiency of these kind of fluids for enhanced oil recovery purposes. Since physical blending of starches has the potential from this study to improve physicochemical properties than when its used individually, there is need for further studies to investigate these type of starch blends for effective polymer flooding. These starch blends have proven to be stable at high temperature and salinity (HTHS) systems. Physical blending of starches will provide the oil industry with an eco-friendly (non-toxic) and low-cost approach rather than conventional chemical modifications. Characterization of starch blends using Zeta Potential Distribution, Differential Scanning Calorimetry (DSC), Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM) is highly recommended. Also, further research should be conducted to investigate the effect of shear rates and aging time on the viscosity of starch blends synthesized from agro-waste materials. While native starche blends show potential, further optimization via nanoparticle synthesis is needed to reduce starch granules, enhance stability, control viscosity, and performance during EOR applications. A reasonable amount of starch is found in agro-waste materials, utilizing these biomaterials will provide the oil and gas industry with an environmentally friendly, efficient and low cost injectant for enhanced oil recovery. Waste can be converted to wealth!

CONFLICT OF INTEREST

No conflict of interest

AUTHOR CONTRIBUTIONS

Imad B. Eseimokumoh conducted the research, analysed the data collected, and wrote this paper, Kuradoite G. Sagbe assisted in the experimental procedures and analysis of data collected, Jeffrey R. Gbonhinbor also assisted in conducting this research**,** all authors had approved the final version.

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