

Synergistic Rheological Characterisation of a Novel Cassava-Yam Hybrid Biopolymer for Chemical Enhanced Oil Recovery

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Abstract

This study elucidates the formulation, rheological behaviour, and chemical characterisation of a novel hybrid biopolymer synthesised from agro-waste—specifically *Manihot esculenta* (cassava) and *Dioscorea alata* (yam) peels—for potential deployment in Enhanced Oil Recovery (EOR). Conventional synthetic polymers, notably partially hydrolysed polyacrylamide (HPAM), suffer from severe thermal degradation and shear-induced mechanical breakdown in high-salinity reservoir environments. To address these limitations, a hybrid biopolymer was formulated and evaluated across a concentration gradient (0.3% to 2.1% w/v) and a rigorous thermal spectrum (30°C to 90°C) in a 30,000 ppm NaCl brine. Rheological analyses demonstrated that the hybrid biopolymer solutions exhibit pronounced non-Newtonian, pseudoplastic behaviour, maintaining a viscosity range of 1.5 to 8.5 mPa·s and exceptional thermal stability even at elevated temperatures. Fourier Transform Infrared Spectroscopy (FTIR) confirmed the presence of critical active functional groups, notably O-H and C-H stretching vibrations, indicative of polysaccharide structural stability and high reservoir compatibility. The findings substantiate this hybrid biopolymer as a highly viable, thermo-chemically stable, and environmentally benign alternative to conventional synthetic flooding agents in mature fields.

Keywords: Enhanced Oil Recovery (EOR); Agro-waste Biopolymers; Rheological Characterisation; Pseudoplastic Fluid; FTIR Spectroscopy; Niger Delta Marginal Fields.

1 Introduction

The continuous depletion of easily recoverable hydrocarbon reserves necessitates the advancement of tertiary recovery mechanisms, primarily Chemical Enhanced Oil Recovery (CEOR). Polymer flooding remains a cornerstone of CEOR, conventionally relying on high-molecular-weight water-soluble polymers like HPAM to increase the displacing phase viscosity, thereby lowering the mobility ratio and mitigating viscous fingering.

However, the operational efficacy of HPAM is severely compromised in high-temperature, high-salinity (HTHS) environments, such as those found in many mature Niger Delta reservoirs. Multivalent cation interactions and elevated reservoir temperatures precipitate premature macromolecular chain scission, resulting in a significant reduction in hydrodynamic volume and viscosity. Consequently, contemporary petroleum research has pivoted towards sustainable, agro-waste-derived biopolymers.

While individual agro-waste derivatives like banana peel and mango kernel polymers have been explored, the synergistic blending of multiple botanical sources remains largely uncharted. This research pioneers the synthesis of a synergistic hybrid biopolymer from cassava and yam peels, characterising its rheological limits and chemical phase composition to assess its viability for EOR operations.

2 Materials and Methods

2.1 Biopolymer Extraction

The extraction protocol involved the mechanical comminution and aqueous dissolution of fresh cassava and yam peels. The extracted starch-rich solutions were allowed to settle for 8 hours, followed by decantation. The resultant solute was sun-dried for 24 hours to yield fine, distinct biopolymeric precursor powders.

2.2 Fluid Formulation and Salinity

To simulate standard reservoir brine conditions, a base saline solution of 30,000 ppm was prepared by dissolving 30g of analytical-grade Sodium Chloride (NaCl) in 1000 mL of distilled water. Aqueous polymeric solutions were subsequently formulated by dissolving varying masses of the hybrid powders into 200 mL aliquots of the brine. For the hybrid biopolymer, concentrations ranging from 0.6g to 4.2g per 200 mL were utilised, equating to a true concentration gradient of 0.30% to 2.10% w/v.

2.3 Rheological and Chemical Characterisation

Rheological parameters were quantified using an NDJ-8S rotational viscometer at an operational speed of 60 RPM. Measurements were taken across a thermal spectrum of 30°C, 45°C, 70°C, and 90°C using a thermostatic water bath. Chemical functional groups were identified using Fourier Transform Infrared Spectroscopy (FTIR).

3 Results and Discussion

3.1 Rheological Behaviour and Thermal Stability

The formulated biopolymers exhibited characteristic non-Newtonian, shear-thinning (pseudoplastic) fluid dynamics. Viscosimetric profiling indicated that viscosity increased proportionally with polymer concentration due to enhanced macromolecular chain entanglement. Table 1 illustrates the consolidated performance of the hybrid biopolymer across all tested thermal profiles.

Table 1: Rheological Profile of Hybrid Biopolymer in 30,000 ppm NaCl Brine.

True Conc. (% w/v)	Viscosity (mPa·s) at Specified Temperatures			
	30°C	45°C	70°C	90°C
0.30	1.50	4.00	3.00	4.00
0.60	1.50	4.00	3.00	4.00
0.90	3.00	4.50	3.00	4.50
1.20	3.00	4.50	4.00	4.50
1.50	5.00	5.00	4.50	5.00
1.80	5.00	5.00	5.00	5.00
2.10	8.50	5.50	5.50	5.50

Notably, while elevated temperatures (up to 90°C) induced expected thermal thinning—reducing intermolecular friction and viscosity—the hybrid cassava-yam blend demonstrated a synergistic resistance to thermal degradation. At peak thermal stress (90°C), the highest concentration (2.10% w/v) hybrid maintained a functional viscosity of 5.50 mPa·s. Furthermore, the pH profile of the hybrid solution remained highly alkaline (7.0 to 10.9), effectively mitigating the risk of acidic degradation within complex reservoir matrices.

3.2 FTIR Spectroscopic Characterisation

FTIR analysis of the hybrid biopolymer verified its organic simplicity, dominated by polysaccharide structures, compared to the complex, degradation-susceptible amide linkages found in synthetic HPAM. The critical absorption bands are detailed in Table 2.

The absence of complex triple bonds or highly reactive ketone components highlights its structural stability. This simplicity in functional grouping enhances its predictability and compatibility within heterogeneous, high-salinity brines, shielding the polymer backbone from thermal degradation.

Table 2: Main Infrared Bands Observed in the Hybrid Biopolymer.

Wavenumber (cm ⁻¹)	Chemical Bond / Functional Group	Significance in EOR Performance
~ 3339	O-H (Hydroxyl) stretching vibrations	Indicative of extensive inter- and intra-molecular hydrogen bonding typical in starch and cellulose matrices; responsible for high thermal stability.
~ 2922	C-H stretching vibrations	Confirms the presence of robust aliphatic groups forming the polymer backbone.
~ 1636	O-H bending / Bound interstitial water	Common in highly hydrophilic biopolymers; ensures excellent compatibility and hydration within high-salinity brines.

4 Conclusion

The novel cassava-yam hybrid biopolymer represents a highly promising paradigm shift in sustainable CEOR chemical design. Its inherent pseudoplastic rheology, coupled with robust thermochemical stability up to 90°C and excellent brine compatibility, positions it as a superior, cost-effective substitute for conventional synthetic polymers like HPAM.

Recommendations for Future Work: Future investigations should focus on the polymerisation of this hybrid extract into bio-polymeric nanoparticles. Nanoparticle synthesis would exponentially increase the surface-area-to-volume ratio, allowing for advanced mobility control, enhanced profile modification, and highly efficient deep-reservoir thief zone plugging.

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