Comparative Rheological Performance of Cassava Starch and Carboxymethyl Cellulose in Recycled and Freshwater Media for Sustainable Gravel Packing Operations

NDUBUISI, ELIZABETH CHINYEREM[1], KIKA OZIOMA AUGUSTINE[2], OKOGBE, BOLAJI BARTHOLOMEW[3]
[1, 2, 3]University of Port Harcourt, Faculty of Engineering, Department of Petroleum and Gas Engineering, East-West Road, Choba, Port Harcourt, Nigeria, Choba.

Abstract- The growing emphasis on sustainability in industrial operations has prompted increased exploration of alternative water sources, notably recycled water. Concurrently, the environmental risks associated with sludge disposal stemming from its complex composition of organic and inorganic contaminants remain a significant concern, contributing to soil and water pollution, greenhouse gas emissions, and broader ecosystem degradation. While several sustainable sludge management strategies exist, such as biological treatment, phytoremediation, and energy recovery through incineration, these approaches are often capital-intensive. This study evaluates the viability of using recycled water in gravel packing during well completion operations, with a focus on its impact on the rheological behavior of two key polymers: cassava starch and carboxymethyl cellulose (CMC). A comparative analysis of freshwater and recycled water was conducted to assess polymer hydration and viscosity characteristics using detailed rheological profiling. Results indicate that CMC solutions exhibited comparable hydration rates and viscosity profiles in both water types, suggesting minimal impact from water quality. In contrast, cassava starch showed significantly reduced hydration efficiency and viscosity development in recycled water, with peak viscosity at 60 minutes measuring 4 cP, compared to 13 cP in freshwater. Similarly, plastic viscosity (PV) and yield point (YP) values for starch in recycled water (2 cP and 2 lb/100 ft²) were lower than those in freshwater (7 cP and 5 lb/100 ft²). These discrepancies are attributed to the presence of impurities and salts in recycled water, which hinder the swelling and gelatinization of starch granules. Overall, while recycled water presents a sustainable alternative to freshwater, its compatibility with starch-based systems requires careful consideration to ensure optimal performance in completion fluid applications.

Indexed Terms- Gelatinization, Phytoremediation, Carboxymethyl Cellulose, Recycled Water, Cassava Starch

I. INTRODUCTION

The pursuit of sustainability in industrial operations has intensified interest in the reuse of water, particularly within the oil and gas industry, where significant volumes are consumed during drilling and completion activities. One such completion technique gravel packing is employed to control sand production in unconsolidated formations and depends heavily on the rheological behavior of polymer-based fluids for effective gravel placement within the wellbore (Ahmed and McKinney, 2005). The success of gravel packing operations relies on the ability of these fluids to maintain optimal viscosity and hydration properties, which are largely influenced by the type of polymer and the quality of water used in their formulation.

Natural and modified polymers, such as cassava starch and carboxymethyl cellulose (CMC), are commonly employed as viscosifiers in drilling and completion fluids due to their thickening, stabilizing, and water-retention capabilities. Cassava starch, derived from *Manihot esculenta*, is a biodegradable, cost-effective biopolymer that is particularly prevalent in tropical regions, offering favorable rheological characteristics (Olayemi, 2021). In contrast, CMC a chemically modified, water-soluble cellulose derivative demonstrates broad compatibility across a wide range of aqueous systems, including those with high salinity and variable pH, making it a versatile choice in complex environments (Yang, 2019).

However, the performance of these polymers is significantly affected by the quality of water used. While freshwater typically supports optimal hydration and viscosity, its increasing scarcity and associated environmental impacts have prompted the exploration of recycled water as a viable alternative. Recycled water, often obtained from industrial sludge or produced water, can contain dissolved salts, organic matter, and residual treatment chemicals that may impair polymer hydration and reduce solution viscosity (Kavitha, 2020).

II. LITERATURE REVIEW

Recent investigations have highlighted the sensitivity of cassava starch to the ionic strength and chemical composition of the surrounding medium. Impurities in recycled water can interfere with the swelling and gelatinization of starch granules, resulting in lower viscosity and prolonged hydration times compared to freshwater-based systems (Afolayan, 2022). For example, cassava starch solutions prepared in saline or recycled water often exhibit reduced plastic viscosity (PV) and yield point (YP), which can compromise their efficiency in suspension and transport applications.

On the other hand, CMC tends to maintain stable rheological properties regardless of moderate variations in water quality. Its chemically altered structure enhances interaction with dissolved ions, enabling it to retain functionality even in the presence of calcium, magnesium, and other divalent cations commonly found in recycled water sources (Gohil and Ray, 2009). Yang et al. (2019) reported that CMC solutions retained effective thickening behavior in both low and high salinity media, supporting its potential for use in operations where water reuse is prioritized.

The implications of water quality extend beyond polymer hydration. Variability in pH, ionic strength, and organic content in recycled water may pose operational challenges if not properly accounted for in fluid design. Kavitha et al. (2020) emphasized that water reuse strategies must consider these parameters to ensure polymer performance and avoid process inefficiencies.

Additionally, sludge management from drilling and completion operations presents significant environmental and economic burdens. The use of recycled water not only minimizes freshwater consumption but also offers a pathway for reducing sludge generation and associated disposal issues. By selecting polymers that can perform effectively in recycled water, operators can enhance environmental stewardship and support broader waste minimization goals (Sivapullaiah and Sridharan, 2005).

Given the critical role of fluid rheology in gravel packing and the growing need to utilize sustainable water sources, a comparative analysis of cassava starch and CMC in recycled versus freshwater environments is warranted. While previous studies have addressed polymer behavior in brines and synthetic media, limited attention has been paid to performance in actual recycled water derived from sludge. This study addresses this gap by directly evaluating hydration kinetics and rheological profiles of cassava starch and CMC in both water types, thereby informing material selection for environmentally responsible gravel packing operations.

III. METHODOLOGY

This study employed a laboratory-based experimental approach to evaluate the rheological performance of cassava starch and carboxymethyl cellulose (CMC) in both freshwater and recycled water media. The materials selected for the investigation include polymers with distinct chemical properties and water sources representative of typical industrial conditions. Rheological measurements were conducted to assess viscosity and hydration behavior under controlled conditions, enabling a comparative analysis of polymer performance in sustainable gravel packing applications.

3.1 Materials

Table 1: List of Materials

Material	Description
Carboxymethyl Cellulose (CMC)	A chemically modified cellulose derivative widely used for its high water solubility and viscosity control properties.
Cassava Starch	A natural, biodegradable polymer obtained from *Manihot esculenta*, selected for its rheological potential in aqueous systems.
Freshwater	Laboratory-grade distilled water used as the control medium.
Recycled Water	Water reclaimed from sludge generated during industrial operations, filtered and tested prior to experimental use.

3.2 Equipment

The following laboratory equipment was used in conducting the experiments:

Table 2: List of Equipment

S/N	Equipment	Function
1	Measuring Cylinder	Used to measure accurate volumes of liquids.
2	Glass Beaker	Used for mixing and holding liquid samples.
3	Weighing Balance	Used to accurately measure the mass of polymers.
4	Spatula	Used to transfer solid samples during preparation.
5	pH Meter	Used to measure the acidity or alkalinity of water samples.
6	Electric Stirrer	Used to ensure uniform dispersion of polymers in water samples.
7	Viscometer	Used to measure fluid viscosity at different time intervals.
8	Stopwatch	Used for tracking hydration time during testing.
9	Rheometer	Used to measure rheological properties under controlled shear and temperature.

3.3 Experimental Procedure

A series of controlled experiments were conducted to evaluate the hydration rate and rheological behavior of cassava starch and CMC in both freshwater and recycled water environments.

3.3.1 Procedure for Starch Solution Preparation and Testing

To assess the rheological behavior of cassava starch in different water media, a systematic procedure was followed under controlled laboratory conditions:

Weighing and Mixing
A total of 1.08 grams of cassava starch was accurately measured using a calibrated digital weighing balance. This quantity was selected based on preliminary optimization to ensure effective dispersion and measurable viscosity changes.

Water Preparation and pH Measurement
Two types of water were used for this experiment: distilled freshwater and recycled water sourced from treated industrial sludge. For each sample, 150 milliliters of water were measured using a graduated measuring cylinder. The pH of the freshwater sample was recorded as 4.30, while the recycled water sample exhibited a pH of 7.48, indicating a more alkaline

nature likely due to the presence of dissolved salts and other residual substances.

Polymer Dispersion
Each water sample was placed in a clean glass beaker and stirred using an electric stirrer to simulate mixing conditions found in field operations. The weighed cassava starch was gradually introduced into the stirring liquid in order to prevent clumping and to ensure homogeneous dispersion of the polymer particles.

Hydration Monitoring and Viscosity Measurement
Once dispersion was complete, viscosity readings were taken using a viscometer at 5-minute intervals over the first 30 minutes to capture the initial hydration phase. These measurements allowed for the assessment of the rate and extent of viscosity development, which is critical for understanding the polymer's thickening behavior. Following the stirring period, the starch solutions were allowed to stand undisturbed for an additional 30 minutes to observe further hydration and potential structural stabilization.

This procedure was performed separately for both the freshwater and recycled water systems, enabling a direct comparison of their effects on starch hydration and rheological performance.

3.3.2 Procedure for CMC Solution Preparation and Testing

The preparation and testing of carboxymethyl cellulose (CMC) solutions followed the same methodology as outlined for cassava starch, ensuring consistency and enabling direct comparative analysis.

Weighing and Dispersion
A measured quantity of 1.08 grams of CMC was weighed using a calibrated digital balance. This mass was selected to match the concentration used in the starch experiments, maintaining consistency in polymer loading for comparative evaluation.

Water Preparation and pH Measurement
Two sets of solutions were prepared using 150 ml each of distilled freshwater and recycled water obtained from industrial sludge treatment. Prior to polymer addition, the pH values of both water samples were confirmed to match those recorded in the starch tests (pH 4.30 for freshwater and pH 7.48 for recycled water), ensuring comparability in experimental conditions.

Polymer Introduction and Mixing
Each water sample was stirred using an electric stirrer to create a uniform vortex, and the CMC powder was slowly added to avoid agglomeration. Continuous stirring ensured the polymer was evenly dispersed throughout the liquid medium.

Hydration and Viscosity Monitoring
Following polymer addition, viscosity readings were recorded at 5-minute intervals for 30 minutes using a viscometer to monitor the hydration kinetics and viscosity development of CMC in both water types. After the stirring phase, the solutions were left to stand for an additional 30 minutes to allow for further hydration under static conditions.

This standardized procedure facilitated a detailed comparison of the hydration efficiency and rheological performance of CMC in freshwater and recycled water media, thereby contributing to an informed assessment of its suitability for use in sustainable gravel packing operations.

3.3.3 Rheological Testing

The rheological behavior of each polymer solution prepared in both freshwater and recycled water media was evaluated using a rotational rheometer. The instrument was calibrated and set to operate at a constant shear rate of 511 s^{-1} and a controlled temperature of 80°F (approximately 27°C), simulating typical downhole conditions during gravel packing operations.

Rheological measurements were taken at multiple rotational speeds: 3, 6, 100, 200, 300, and 600 revolutions per minute (RPM). This range allowed for a thorough characterization of the flow behavior and shear-thinning properties of each polymer solution. The resulting data provided insights into viscosity changes under varying shear rates, which is critical for understanding the fluid’s performance during both injection and packing phases.

Plastic Viscosity (PV) and Yield Point (YP) were determined based on the Bingham Plastic Model, which is widely used in drilling and completion fluid analysis. The calculations were performed as follows:

Plastic Viscosity (PV) was computed as the difference between the readings at 600 RPM and 300 RPM, representing the fluid's internal resistance to flow caused by interparticle friction.

Yield Point (YP) was derived by subtracting the PV value from the 300 RPM reading, reflecting the initial stress required to initiate fluid movement an important indicator of the fluid's ability to suspend gravel and cuttings.

All readings and calculated values were documented for each sample to facilitate comparative analysis across different test conditions.

3.4 Data Analysis

Following the completion of all experimental procedures, the collected data were analyzed to evaluate the impact of water type on polymer hydration and rheological performance.

Viscosity measurements taken at five-minute intervals were plotted as time-series graphs to illustrate the hydration kinetics of each polymer in freshwater and recycled water media. These plots allowed for the visualization of initial hydration rates, peak viscosity development, and equilibrium behavior over time.

In addition to viscosity trends, key rheological parameters—including plastic viscosity, yield point, and gel strength were compared to assess the structural integrity and carrying capacity of the fluid systems. The influence of water quality, particularly the presence of salts and other impurities in recycled water, was analyzed to determine its effect on polymer performance.

This comparative analysis enabled the identification of performance disparities between cassava starch and CMC under varying water conditions, offering valuable insights into their respective suitability for sustainable gravel packing operations.

IV. RESULTS AND DISCUSSION

This section presents and interprets the experimental findings on the rheological performance of cassava starch and carboxymethyl cellulose (CMC) when hydrated in both freshwater and recycled water media. The data are analyzed to assess the impact of water quality on polymer hydration behavior, viscosity development, and overall rheological properties, including plastic viscosity (PV) and yield point (YP). These parameters are critical in evaluating the suitability of each polymer system for use in gravel packing operations where fluid performance directly influences the success of sand control and formation stability.

4.1.1 Hydration Rate with Time for Starch and CMC in Freshwater and Recycled Water

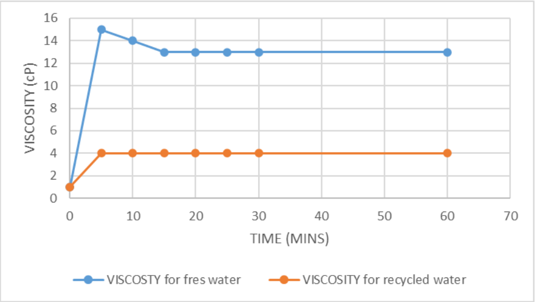

Figure 1: Viscosity-Time Profile for Cassava Starch Hydration in Freshwater and Recycled Water

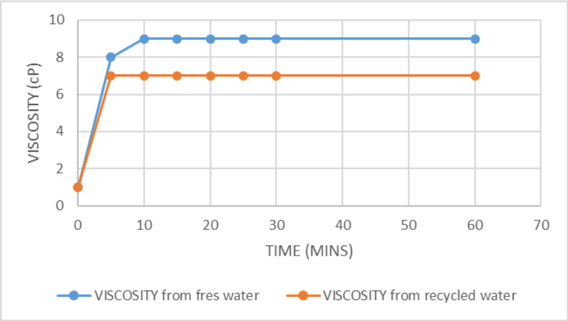

Figure 2: Viscosity-Time Profile for Carboxymethyl Cellulose (CMC) Hydration in Freshwater and Recycled Water

Figures 1 and 2 depict the hydration kinetics of cassava starch and carboxymethyl cellulose (CMC) in both freshwater and recycled water media. The results reveal distinct hydration behaviors influenced by the water source and the intrinsic properties of each polymer.

Hydration in Freshwater

Cassava starch demonstrated a rapid hydration response in freshwater, with viscosity increasing sharply within the first 5 minutes and reaching a peak of 13 cP by the 10-minute mark. This behavior is characteristic of native starch granules, which swell and gelatinize quickly in neutral to mildly acidic aqueous environments due to their amylose and amylopectin content (Hoover, 2001; Olayemi et al., 2021). The relatively low ionic strength of freshwater facilitates efficient water-polymer interactions, enhancing granule swelling and viscosity development.

CMC, in contrast, showed a slower hydration response under the same conditions, with viscosity increasing more gradually to a peak of 9 cP at 10 minutes. This can be attributed to the higher molecular weight and structured configuration of CMC, which delays water penetration and dissolution. Moreover, CMC's hydration involves not only water absorption but also molecular disentanglement, which takes longer than starch gelatinization (Yang et al., 2019).

Hydration in Recycled Water

Both starch and CMC exhibited markedly reduced hydration rates in recycled water, reflecting the influence of water composition on polymer performance. Starch only reached 4 cP after 10 minutes less than one-third of its viscosity in freshwater indicating impaired gelatinization. This is likely due to the presence of dissolved salts and metal ions (e.g., Ca^{2+}, Fe^{3+}, and Mg^{2+}), which can disrupt hydrogen bonding between water molecules and hydroxyl groups on starch granules (Afolayan et al., 2022; Chukwu and Ogbonna, 2020). These ions also promote retrogradation and reduce granule swelling by creating ionic bridges that inhibit full hydration.

CMC, although also affected, showed a slightly better response, achieving 7 cP at 5 minutes before plateauing. This relative resilience is consistent with findings that CMC, due to its carboxymethyl substitution, can remain soluble and maintain partial viscosity even in saline or alkaline environments (Gohil and Ray, 2009). The anionic groups on CMC chains may also chelate with divalent ions, reducing their disruptive effects.

Starch demonstrates a markedly higher sensitivity to water quality compared to carboxymethyl cellulose (CMC), rendering it less reliable in recycled or brackish water environments. In scenarios where freshwater availability is limited and the use of recycled water is necessary, CMC exhibits more robust and consistent rheological properties. This stability is critical for maintaining gravel pack integrity and ensuring effective sand control. The reduced viscosity observed in starch-based solutions under recycled water conditions may impair gravel suspension and placement, thereby potentially compromising wellbore stability and filtration control (Caenn et al., 2011).

4.1.2 Rheology Test of Starch and CMC in Freshwater and Recycled Water

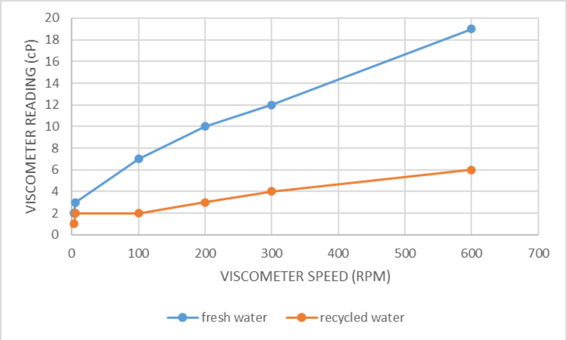

Figure 3: Rheological Properties of Cassava Starch Solutions in Freshwater and Recycled Water

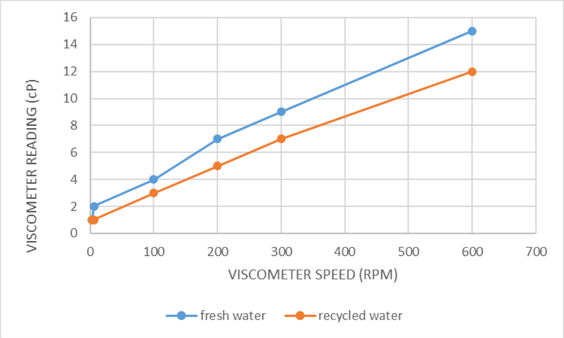

Figure 4: Rheological Properties of Carboxymethyl Cellulose (CMC) Solutions in Freshwater and Recycled Water

Figures 3 and 4 illustrate the rheological properties of cassava starch and carboxymethyl cellulose (CMC) solutions in both freshwater and recycled water, highlighting the significant impact of water quality on polymer performance.

Starch Rheology

In freshwater, starch exhibited higher plastic viscosity (PV) and yield point (YP), with values of 7 cP and 5 lb/100ft², respectively. These elevated rheological parameters indicate that starch solutions in freshwater possess greater resistance to flow and enhanced ability to suspend cuttings, which is crucial for effective drilling operations. The superior performance in freshwater can be attributed to the optimal hydration and swelling of starch granules, leading to increased viscosity and gel strength (Hoover, 2001).

Conversely, in recycled water, starch solutions demonstrated reduced PV and YP, with values of 2 cP and 2 lb/100ft², respectively. This decline in rheological properties suggests that the presence of dissolved ions and contaminants in recycled water interferes with the hydration and swelling of starch granules, resulting in lower viscosity and reduced suspension capabilities (Afolayan et al., 2022).

CMC Rheology

CMC solutions in freshwater exhibited a PV of 6 cP and a YP of 3 lb/100ft², indicating a strong shear-thinning behavior and good cuttings suspension properties. The anionic nature of CMC allows for better interaction with water molecules, leading to enhanced hydration and viscosity development (Gohil and Ray, 2009).

In recycled water, CMC solutions showed a slight decrease in PV and YP, with values of 5 cP and 2 lb/100ft², respectively. While CMC's performance remained relatively stable compared to starch, the presence of divalent ions in recycled water can lead to ionic cross-linking, which may slightly reduce the polymer's ability to hydrate fully and form a viscous network (Yang et al., 2019).

Starch exhibits greater sensitivity to variations in water quality, with pronounced reductions in rheological properties observed when using recycled water. This sensitivity may limit its effectiveness in drilling operations where water quality is variable or uncontrollable. In contrast, carboxymethyl cellulose (CMC) displays more consistent rheological performance across diverse water qualities, making it a more dependable option for applications involving recycled or brackish water. The higher plastic viscosity (PV) and yield point (YP) values exhibited by starch in freshwater indicate superior capabilities in suspending cuttings and facilitating their transport to the surface, which are critical factors in maintaining wellbore stability and minimizing the risk of stuck pipe incidents.

4.1.3 Plastic Viscosity and Yield Point of Starch and CMC

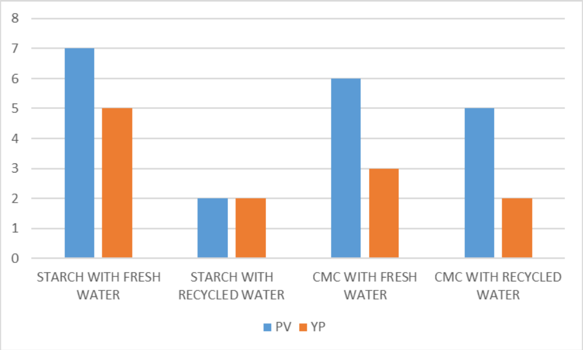

Figure 5: Plastic Viscosity and Yield Point Values for Starch and CMC Solutions

Plastic viscosity (PV) and yield point (YP) are critical rheological parameters that influence the performance of drilling fluids. PV represents the internal friction within the fluid, dictating its flow resistance, while YP indicates the minimum stress required to initiate fluid movement. These properties are essential for efficient cuttings transport and wellbore stability during drilling operations.

Impact of Water Type on PV and YP

The rheological properties of both starch and CMC solutions were significantly affected by the type of water used. In freshwater, starch exhibited higher PV and YP values, with measurements of 7 cP and 5 lb/100ft², respectively. In contrast, in recycled water, these values decreased to 2 cP and 2 lb/100ft². Similarly, CMC solutions demonstrated higher PV and YP in freshwater (6 cP and 3 lb/100ft²) compared to recycled water (5 cP and 2 lb/100ft²). These variations can be attributed to the differences in water chemistry, which influence the hydration and dispersion of polymer molecules.

Effect of Water Chemistry on Polymer Behavior

The presence of dissolved ions and contaminants in recycled water can interfere with the hydration and dispersion of polymer molecules, leading to reduced viscosity and stability of the drilling fluid. For instance, the addition of high-viscosity carboxymethyl cellulose (CMC) can increase the viscosity of the system by interacting with starch during the gelatinization process, forming a complex dispersed in the starch gel (Chen et al., 2014; Chen et al., 2015). Conversely, in recycled water, the presence of divalent ions can lead to ionic cross-linking, which may slightly reduce the polymer's ability to hydrate fully and form a viscous network (Yang et al., 2019).

Molecular Structure and Rheological Performance

The differences in PV and YP values between starch and CMC can be attributed to their distinct molecular structures. Starch, with its larger and more complex molecular structure, tends to form more viscous solutions compared to CMC, which has a smaller and simpler molecular structure. The amylopectin outer shell of starch must be ruptured in a process known as pre-gelatinization, releasing the water-swellable amylose, which then further modifies to decrease viscosity and crosslink to increase temperature stability (Drilling Fluids Technology, 2020). This structural complexity allows starch to form a more robust network in freshwater, leading to higher PV and YP values.

Implications for Drilling Operations

The higher PV and YP values observed in starch solutions in freshwater suggest that these fluids have a greater ability to suspend and transport cuttings, which is crucial for maintaining wellbore stability and preventing issues such as stuck pipe incidents. On the other hand, the lower PV and YP values in recycled water indicate a reduced capacity for cuttings suspension, which may compromise drilling efficiency and safety. Therefore, understanding the impact of water chemistry on polymer behavior is essential for optimizing drilling fluid formulations and ensuring effective drilling operations.

4.1.4 Comparison between Hydration Rate of Starch and CMC in Freshwater and Recycled Water

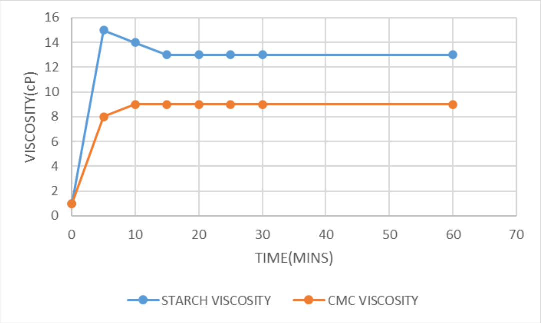

Figure 6: Comparative Hydration Rate of Cassava Starch and Carboxymethyl Cellulose (CMC) in Freshwater

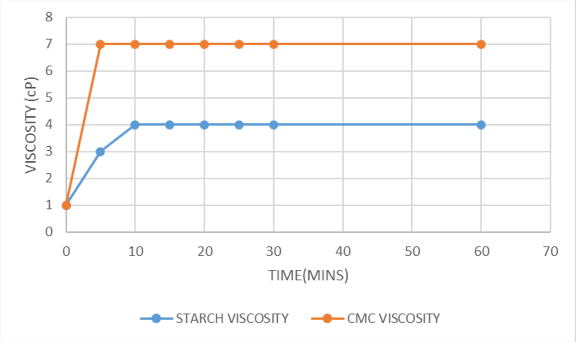

Figure 7: Comparative Hydration Rate of Starch and Carboxymethyl Cellulose (CMC) in Recycled Water

Figures 6 and 7 illustrate the differential hydration behaviors of cassava starch and carboxymethyl cellulose (CMC) in both freshwater and recycled water. The data reveal that starch exhibits a faster hydration rate than CMC in freshwater, while CMC shows a slightly accelerated hydration rate compared to starch in recycled water.

Hydration in Freshwater

In freshwater, cassava starch demonstrates rapid hydration due to its granular morphology and its inherent capacity to absorb and retain water. The hydration process primarily involves the swelling of starch granules and the leaching of amylose, leading to the formation of a gel-like network (Hoover, 2001). The dual presence of amylose and amylopectin allows for rapid viscosity development, making starch effective for applications requiring quick thickening or fluid-loss control.

Conversely, CMC, a chemically modified, anionic cellulose derivative, exhibits a slower and more controlled hydration profile. The hydration of CMC depends on the gradual solvation of polymer chains and electrostatic repulsion between the negatively charged carboxymethyl groups, which facilitates chain dispersion (Yang et al., 2019). This slower rate may be advantageous in applications where a progressive increase in viscosity is required, such as in controlled-release or temperature-sensitive operations.

Hydration in Recycled Water

In recycled water, the presence of dissolved ions, such as calcium and magnesium, and contaminants such as organic matter and suspended solids, can hinder the hydration process. For starch, these ions can form complexes with hydroxyl groups on the starch molecules, disrupting the swelling and gelatinization processes (Water Absorption Behavior of Starch, 2024). Consequently, a marked reduction in viscosity and hydration rate is observed, limiting starch's effectiveness in low-quality water environments.

CMC, however, maintains relatively better hydration performance in recycled water. Its chemically stable structure and polyelectrolytic behavior enable it to maintain hydration capacity despite ionic interferences. The carboxymethyl groups enhance its interaction with water even in the presence of divalent ions, contributing to a more stable viscosity profile (Chen et al., 2014). Although some viscosity loss still occurs due to ion shielding, the effect is less severe than with starch.

Starch exhibits a high sensitivity to the ionic composition and impurity levels commonly found in recycled water, significantly reducing its effectiveness under variable or uncontrolled water quality conditions. This sensitivity limits its practical application in drilling operations conducted in water-scarce regions or under stringent environmental regulations (Hamed and Jaber, 2015). In contrast, carboxymethyl cellulose (CMC) demonstrates stable hydration behavior across a wide range of water qualities. Its resistance to ionic interference and chemical contaminants enhances its reliability as a viscosifier and fluid-loss control agent in systems utilizing recycled or brackish water (Yang et al., 2019).

From an operational standpoint, the rapid hydration and viscosity build-up of starch in freshwater make it particularly advantageous in scenarios requiring quick fluid development, such as gravel packing in high-efficiency completions. Conversely, the more gradual and controlled hydration of CMC allows for sustained rheological properties, making it better suited for long-duration pumping operations where fluid stability over time is critical (Chen et al., 2014).

4.1.5 Comparison between Rheology of Starch and CMC in Fresh Water and Recycled Water

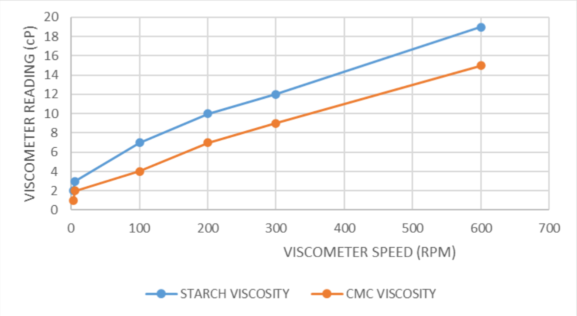

Figure 8: Comparative Rheological Properties of Starch and Carboxymethyl Cellulose (CMC) in Freshwater

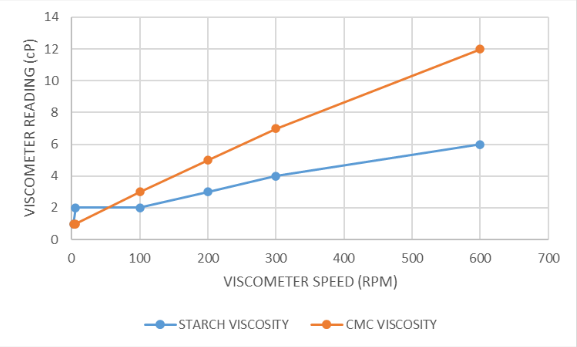

Figure 9: Comparative Rheological Properties of Starch and Carboxymethyl Cellulose (CMC) in Recycled Water

Figures 8 and 9 illustrate the differential rheological behaviors of cassava starch and carboxymethyl cellulose (CMC) in both freshwater and recycled water. The data reveal that starch consistently exhibited higher plastic viscosity (PV) and yield point (YP) compared to CMC in both water types. This indicates that starch solutions had a higher resistance to flow and better suspension properties compared to CMC solutions, regardless of the water type.

Impact of Water Quality on Rheological Properties

The rheological properties of drilling fluids are significantly influenced by the quality of water used. Freshwater, with its low ionic content, facilitates better hydration of polymers, leading to higher PV and YP values. In contrast, recycled water contains dissolved ions and contaminants that can interfere with polymer hydration, resulting in lower rheological values. This underscores the importance of water quality in formulating effective drilling fluids (Chukwu and Ogbonna, 2020).

Polymer-Specific Rheological Behavior

Starch and CMC exhibit distinct rheological behaviors due to their molecular structures. Starch, being a polysaccharide with a granular structure, swells upon hydration, leading to a significant increase in viscosity. The presence of amylose and amylopectin contributes to the gel-like consistency observed in starch solutions (Hoover, 2001). On the other hand, CMC, a cellulose derivative, forms a more stable and uniform gel upon hydration, resulting in a moderate increase in viscosity (Yang et al., 2019).

Implications for Drilling Operations

The higher PV and YP values of starch solutions in both freshwater and recycled water suggest that starch-based drilling fluids offer superior cuttings suspension and hole cleaning capabilities. However, the performance of starch-based fluids may be compromised in recycled water due to reduced hydration rates. CMC-based fluids, while exhibiting lower PV and YP values, demonstrate more consistent performance across different water qualities, making them suitable for applications where water quality is variable (Afolayan et al., 2022).

The comparative analysis of starch and CMC rheology in freshwater and recycled water highlights the significant impact of water quality on the performance of drilling fluids. While starch-based fluids offer higher viscosity and better suspension properties, their performance may be adversely affected in recycled water. CMC-based fluids provide a more stable alternative, ensuring consistent performance across varying water qualities.

Acknowledgement
We wish to acknowledge University of Port Harcourt for their support in the during the laboratory stage of study.

Funding

No funding was obtained from any organization or entities.

REFERENCES

[1] Afolayan, M., Ogunbanjo, R. O. and Eze, C. I. (2022). Effects of water salinity on polymer hydration for drilling applications. *Petroleum Science and Technology, 40*(8), 903–910. https://doi.org/10.1080/10916466.2021.1999793

[2] Ahmed, T., and McKinney, P. D. (2005). *Advanced reservoir engineering*. Gulf Professional Publishing.

[3] Caenn, R., Darley, H. C. H., and Gray, G. R. (2011). *Composition and properties of drilling and completion fluids* (6th ed.). Gulf Professional Publishing.

[4] Chen, H., Zhang, Y., and Zhang, X. (2015). Effect of carboxymethyl cellulose and/or wheat gluten on the pasting, rheological and quality properties of wheat starch-based batter for deep-fried products. *Food Hydrocolloids, 50*, 1–9. https://doi.org/10.1016/j.foodhyd.2015.04.015

[5] Chukwu, O., and Ogbonna, I. (2020). Water chemistry impacts on starch-based drilling fluid additives. *Journal of Environmental Engineering and Geoscience, 26*(3), 209–216. https://doi.org/10.2113/JEnvEngGeosci.26.3.209

[6] Drilling Fluids Technology. (2020). *Drilling Fluids Technology*. Retrieved from https://studylib.net/doc/8770130/drilling-fluids-technology

[7] Gohil, J. M., and Ray, P. (2009). Studies on the performance of CMC in various water qualities. *Carbohydrate Polymers, 77*(2), 181–186. https://doi.org/10.1016/j.carbpol.2008.12.018

[8] Hamed, Y. K., and Jaber F'Hamed, M. (2015). Superabsorbent polymers: Classification, synthesis, and applications. *Polymer Science and Technology, 28*(3), 123–135. https://doi.org/10.1016/j.polymer.2015.02.001

[9] Hoover, R. (2001). Composition, molecular structure, and physicochemical properties of tuber and root starches: A review. *Carbohydrate Polymers, 45*(3), 253–267. https://doi.org/10.1016/S0144-8617(00)00260-5

[10] Kavitha, S., Ramesh, S., and Varghese, S. (2020). Recycled water quality and its impact on polymer hydration in industrial applications. *Journal of Environmental Chemical Engineering, 8*(5), 104178. https://doi.org/10.1016/j.jece.2020.104178

[11] Olayemi, J. B., Ajiboye, T. K., and Osho, A. A. (2021). Rheological behavior of cassava starch in oilfield drilling applications. *International Journal of Applied Science and Engineering Research*, *10*(3), 101–110.

[12] Sivapullaiah, P. V., and Sridharan, A. (2005). Experimental study on impact of chemical composition of water on drilling fluid parameters. *Journal of Petroleum Science and Technology, 23*(9), 1107–1115.

[13] Water absorption behavior of starch: A review of its determination methods, influencing factors, directional modification, and food applications. (2024). *Trends in Food Science & Technology, 144*, 104321. https://doi.org/10.1016/j.tifs.2023.104321

[14] Yang, J., He, S., and Li, Q. (2019). Rheological behavior of carboxymethyl cellulose in various ionic environments. *Journal of Applied Polymer Science, 136*(16), 47388. https://doi.org/10.1002/app.47388

[15] Yang, L., He, J., and Li, D. (2019). Rheological characteristics and thickening performance of carboxymethyl cellulose in brine solutions. *Polymer Bulletin, 76*(8), 3973–3984. https://doi.org/10.1007/s00289-018-2532-x