

Effects of Modified Natural Polymers in the Effectiveness of Drilling Fluid Performance.

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Abstract

This study investigated the effects of chemical modification of cassava starch (TME 419) and its synergistic interaction with xanthan gum on the rheological and filtration properties of water-based drilling mud, with emphasis on viscosity enhancement and fluid loss control. Baseline characterization of native cassava starch showed moderate swelling power, low solubility, and a near-neutral pH (6.0–6.8), while carboxymethylation introduced carboxymethyl functional groups (DS 0.10–0.30), improved hydrophilicity, and increased alkalinity (pH 8.0–10.0). Mud samples were formulated using unmodified starch, modified starch, and their blends with xanthan gum, after which plastic viscosity, apparent viscosity, yield point, and filtrate volume were evaluated. Results showed that unmodified cassava starch reduced mud viscosity, with plastic viscosity decreasing to 15 cp and yield point to 18 lb/100 ft², indicating limited structural development. Chemical modification significantly improved rheology, increasing plastic viscosity to 20 cp and yield point to 30 lb/100 ft² due to enhanced hydration and molecular interaction. The most pronounced improvement occurred in the modified starch–xanthan gum blend, which achieved the highest rheological performance with 26 cp plastic viscosity, 43 cp apparent viscosity, and 34 lb/100 ft² yield point. Filtration tests revealed progressively lower filtrate volumes with increasing starch modification, decreasing from 9.60 ml for unmodified starch to 9.40 ml for modified starch, while the modified starch–xanthan gum blend recorded the lowest filtrate loss of 6.70 ml, approaching the control value of 6.00 ml. These findings demonstrate that carboxymethylation and polymer blending strongly influence the functional behavior of cassava starch in drilling mud, improving viscosity development, structural stability, and fluid loss reduction. The study revealed that modified cassava starch, especially when combined with xanthan gum, offers a cost-effective and environmentally friendly alternative for enhancing the performance of water-based drilling fluids, and provides a framework for further optimization, scale-up, and application in drilling operations.

Keywords: Carboxymethylated Cassava Starch, Modified Natural Water based Drilling fluids, Natural Polymers, Fluid Loss Control, Sustainable Drilling.

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I. INTRODUCTION

The production and exploration of hydrocarbons, particularly crude oil and natural gas, remain fundamental to global energy supply and economic development. Drilling operations are the primary method through which these resources are accessed from the earth's subsurface. However, drilling activities are technically demanding, capital intensive, and require highly controlled operational conditions to ensure efficiency and safety. A critical component that determines the success of drilling operations is the drilling fluid, commonly referred to as drilling mud. Drilling fluids play an indispensable role in drilling systems, influencing the rate of penetration, wellbore stability, and overall drilling efficiency (Reis et al., 2021). Properly formulated drilling fluids help prevent major operational challenges such as wellbore collapse, formation damage, and uncontrolled influxes of formation fluids that may lead to blowouts.

Fink et al., (2022), Drilling fluids are often described as the “lifeblood” of drilling operations because they circulate continuously through the wellbore and perform several essential functions simultaneously. These functions include cooling and lubricating the drill bit, transporting drilled cuttings to the surface, controlling subsurface formation pressure through hydrostatic balance, sealing permeable formations, and maintaining wellbore stability. In addition, drilling fluids facilitate the transmission of hydraulic energy to downhole tools and provide important geological information through the analysis of cuttings brought to the surface. Consequently, the formulation, selection, and performance of drilling fluids significantly affect the technical success and economic efficiency of oil and gas drilling operations.

Darley & Gray (1988), traditionally, drilling fluids are broadly classified into three main categories: water-based muds (WBMs), oil-based muds (OBMs), and synthetic-based muds (SBMs) Among these, water-based muds are the most widely used due to their relatively low cost, ease of handling, and lower environmental impact

compared to oil-based alternatives. However, the performance of water-based mud systems largely depends on the type and quality of additives incorporated into the fluid formulation. These additives are used to modify rheological properties, enhance suspension capacity, reduce fluid loss, and improve the overall stability of the drilling fluid system.

In conventional drilling operations, synthetic polymers and chemical additives such as polyacrylamides, polyanionic cellulose (PAC), and polyvinyl alcohol are commonly used to enhance drilling fluid performance. These materials effectively improve viscosity, filtration control, and thermal stability. Despite their technical advantages, synthetic additives present several challenges including high cost, limited biodegradability, and potential environmental hazards when disposed of as drilling waste. As environmental regulations become stricter and the petroleum industry faces increasing pressure to adopt sustainable practices, the development of environmentally friendly drilling fluid additives has become an important research focus.

Das et al., (2016), natural polymers derived from renewable biological sources have emerged as promising alternatives to synthetic drilling fluid additives. Examples of such biopolymers include starch, cellulose derivatives, xanthan gum, and guar gum. These materials are attractive due to their biodegradability, low toxicity, availability, and relatively low cost. In drilling fluid systems, starch and cellulose derivatives are commonly used as fluid-loss control agents, xanthan gum functions as an effective viscosifier, and guar gum improves suspension characteristics and rheological stability

Kelessidis et al., (2007) Despite these advantages, natural polymers in their raw form exhibit several limitations when used in drilling environments. They often suffer from poor thermal stability, limited resistance to high salinity conditions, susceptibility to microbial degradation, and weak shear resistance under drilling conditions. These limitations restrict their application in deep wells and high-pressure high-temperature (HPHT) drilling environments.

To overcome these challenges, researchers have explored various chemical and physical modification techniques aimed at improving the performance of natural polymers. Chemical modification processes such as carboxymethylation, graft copolymerization, cross-linking, and etherification alter the molecular structure of natural polymers, thereby enhancing their solubility, thermal stability, and mechanical strength. For example, carboxymethyl starch (CMS) and carboxymethyl cellulose (CMC) have been widely applied in water-based drilling fluids to improve filtration control and enhance filter cake quality.

Similarly, graft copolymerization techniques involve attaching synthetic monomers such as acrylamide onto natural polymer backbones to enhance rheological properties and filtration performance. Cross-linking methods create three-dimensional polymer networks that significantly improve viscosity retention and thermal stability under harsh drilling conditions. These modified polymers represent a new generation of sustainable drilling fluid additives that combine the environmental benefits of natural polymers with the performance advantages of synthetic materials.

Although considerable progress has been made in the development of modified natural polymers for drilling fluids, several research gaps still exist. The performance of these modified polymers under varying conditions of temperature, salinity, and pH requires further investigation. Additionally, the synergistic effects of combining different modified biopolymers within hybrid drilling fluid formulations remain relatively unexplored. In many cases, promising results have been reported at laboratory scale, but large-scale industrial implementation is limited due to variability in raw material sources and lack of standardized modification techniques.

Therefore, this research is motivated by the need to investigate the effectiveness of modified natural polymers in improving the performance of drilling fluids, particularly in water-based mud systems. The study focuses on evaluating how chemical modification enhances key drilling fluid properties such as viscosity, gel strength, fluid loss control, and thermal stability. Furthermore, the study seeks to assess the environmental and economic implications of replacing conventional synthetic additives with modified natural polymer alternatives. The outcome of this research is expected to contribute to the development of more sustainable, efficient, and environmentally responsible drilling fluid technologies for the oil and gas industry.

Wang et al., 2022, Carboxymethylated cassava starch, on the other hand, undergoes significant structural and functional enhancement through chemical modification, primarily by introducing carboxymethyl (-CH₂-COO⁻) groups onto the starch backbone. This modification increases the hydrophilicity of the starch, leading to improved solubility, higher swelling power, and enhanced hydration characteristics

Chamorro et al., 2025, Cassava starch is a naturally occurring polysaccharide composed primarily of amylose and amylopectin. In its native form, it typically exhibits limited solubility in cold water, moderate swelling capacity, and relatively low viscosity development at lower temperatures. The granules remain largely intact during hydration, resulting in restricted interaction with water molecules. Native cassava starch also possesses minimal functional groups that can influence electrochemical interactions, which makes its performance in drilling fluid applications somewhat limited. These limitations include poor thermal stability, weak gel-forming tendencies, and a moderate ability to build viscosity or control fluid loss under demanding drilling condition.

II. MATERIALS AND METHOD

2.1 Materials Used

The materials used in this study include laboratory equipment, chemical reagents, and drilling fluid additives required for the preparation, modification, formulation, and evaluation of cassava starch-based drilling fluids. Fresh cassava tubers (TME 419 variety) were obtained from Ogoni farmland due to their high starch content. Chemical reagents such as sodium hydroxide (NaOH), monochloroacetic acid, ethanol, and isopropanol were used for the modification of cassava starch through the carboxymethylation process.

Other materials utilized during the drilling fluid formulation include xanthan gum, barite, bentonite, potassium chloride (KCl), polyanionic cellulose (PAC), borax, soda ash, and caustic soda. Laboratory equipment employed during the experimental procedures include a mechanical grater for starch extraction, drying oven, desiccator, muffle furnace, pH paper, API mud mixer, mud balance, filter press, and a Fan V-G rheometer used for rheological measurements.

2.2 Method

The experimental procedures adopted in this research involve starch extraction from cassava, chemical modification of the starch, drilling fluid formulation, and laboratory evaluation of the resulting mud samples. Various analytical tests were carried out to determine the physicochemical and rheological properties of the formulated drilling fluids.

2.2.1 Cassava Starch Collection and Preparation

Fresh cassava tubers (TME 419) were collected from Ogoni farmland because of their high starch content. The cassava roots were thoroughly washed with clean water to remove soil and other contaminants. The tubers were then peeled to remove the outer skin and cortex containing fibers and impurities.

After peeling, the cassava was grated into a fine pulp using a mechanical grater in order to increase the surface area for starch extraction. The resulting pulp was mixed with clean water to form a slurry which was subsequently filtered through cloth filters to separate fibrous materials from the starch suspension.

The filtrate obtained was allowed to stand undisturbed for several hours to enable the starch granules settle by gravity at the bottom of the container. The supernatant liquid was carefully decanted while the sedimented starch was retained. The starch sediment was washed repeatedly with clean water to remove residual impurities and cyanogenic compounds.

The wet starch was then spread in thin layers and dried either under sunlight or in a mechanical dryer at controlled temperature. After drying, the starch was milled into fine powder, sieved to obtain uniform particle size, and stored in moisture-proof containers prior to use.

2.2.2 Modification of Cassava Starch (Carboxymethylation)

The cassava starch was chemically modified using the carboxymethylation method. A measured quantity of 100 g of dried cassava starch was suspended in 150 mL of isopropanol in a beaker. Subsequently, 20 g of sodium hydroxide (NaOH) was added to the mixture and stirred continuously for 30 minutes in order to alkalize the starch. After alkalization, 15 g of monochloroacetic acid was introduced into the mixture to initiate the carboxymethylation reaction. The reaction mixture was then maintained at a temperature of 60 °C and stirred continuously for approximately 3 hours.

Upon completion of the reaction, the resulting product was filtered and washed with ethanol several times to remove unreacted chemicals and impurities. The modified starch was then dried in an oven at 50 °C for 24 hours before being stored for further experimental analysis.



Fig. 1 Modified cassava starch after being dried at 50°C for 24 hours.

2.2.3 Determination of Moisture Content

The moisture content of the cassava starch sample was determined using the oven-drying method. A known weight of 5 g of the wet sample was measured and placed in a hot-air oven maintained at a temperature of 105 °C. The sample was dried until a constant weight was achieved.

After drying, the sample was cooled in a desiccator to prevent moisture absorption from the atmosphere and subsequently reweighed. The moisture content was calculated from the weight difference using the relation:

$$\text{Moisture Content (\%)} = \frac{W_i - W_f}{W_i} \times 100 \quad (1)$$

Where:

W_i = Initial weight of the sample before drying

W_f = Final weight of the sample after drying

2.2.4 Determination of Ash Content

The ash content of the cassava starch sample was determined through incineration in a muffle furnace. A pre-weighed portion of the sample was placed in a crucible and heated in a furnace at a temperature range of 550–600 °C to ensure complete combustion of all organic matter.

After the incineration process, the remaining inorganic residue (ash) was allowed to cool in a desiccator and weighed. The ash content was then calculated as a percentage of the original sample weight using the relation:

$$\text{Ash Content (\%)} = \frac{W_a}{W_s} \times 100 \quad (2)$$

Where:

W_a = Weight of ash after incineration

W_s = Initial weight of the sample

2.2.5 Determination of Amylose Content

The amylose content of the starch sample was determined by gelatinizing starch in water followed by the addition of iodine solution to form a characteristic blue complex. The absorbance of the resulting solution was measured using a spectrophotometer at a wavelength of 620 nm.

The amylose concentration was obtained by comparing the absorbance values with a standard calibration curve prepared from known amylose concentrations.

2.2.6 Determination of Carboxymethyl Substitution

The degree of substitution (DS) of the carboxymethyl starch was determined by neutralizing a known quantity (10 g) of the modified starch with acid, followed by titration with standardized sodium hydroxide (NaOH) solution.

The degree of substitution represents the average number of hydroxyl groups replaced by carboxymethyl groups in the starch structure and was calculated using the standard substitution equation as described by Lemieux et al. (2010).

$$DS = \frac{162 \times A}{1000 \times W - (58 \times A)} \quad (3)$$

Where:

A is milliequivalents of sodium hydroxide (NaOH) consumed during titration

W is weight of the sample in grams

Molecular weight of the anhydro glucose unit in gram is 162

Molecular weight of the carboxymethyl substituent group in gram is 58

2.2.7 pH Measurement

The pH of the sample solution was determined using pH indicator paper. Approximately 10 mL of the prepared sample solution was collected in a clean container. A strip of pH paper was dipped into the solution and the resulting color change was compared with the standard pH color chart to determine the approximate pH value of the sample.

2.2.8 Formulation of Drilling Fluid Samples

The drilling fluid samples were formulated using the standard measurement of pounds per barrel (lb/bbl) commonly applied in water-based drilling fluid systems. In this study, cassava starch was investigated as a substitute for xanthan gum in freshwater drilling mud formulation.

Five different drilling mud samples were prepared as follows:

Sample A: Drilling mud formulated with xanthan gum (control sample)

Sample B: Drilling mud formulated with unmodified cassava starch

Sample C: Drilling mud formulated with modified cassava starch

Sample D: Drilling mud formulated with unmodified cassava starch and xanthan gum

Sample E: Drilling mud formulated with modified cassava starch and xanthan gum

Each sample contained water as the base fluid along with additives such as barite (weighting agent), borax (preservative), potassium chloride (inhibition control), polyanionic cellulose (filtration control), caustic soda (alkalinity control), soda ash (calcium ion removal), and bentonite (viscosifier).

Table 1: Table of mud composition for Sample A Drilling Mud

S/N	Additive	Concentration	Function
1	Water	350	Based fluid
2	Barite	78	Weighting agent
3	Borax	2.0	Preservative
4	Xanthan gum	2.8	Viscosifier
5	Cassava starch	0	Viscosifier
6	Potassium Chloride	18	Inhibition control
7	PAC	2.8	Filtration control
8	Caustic soda	0.2	Alkalinity control
9	Soda ash	0.2	Calcium ion removal
10	Bentonite	2.8	Viscosifier

III. RESULTS AND DISCUSSION

4.1 Baseline Properties of Cassava Starch

The cassava tuber (TME 419) obtained from *Ogoni* was first analyzed for its baseline physical properties before formulation of drilling fluid.

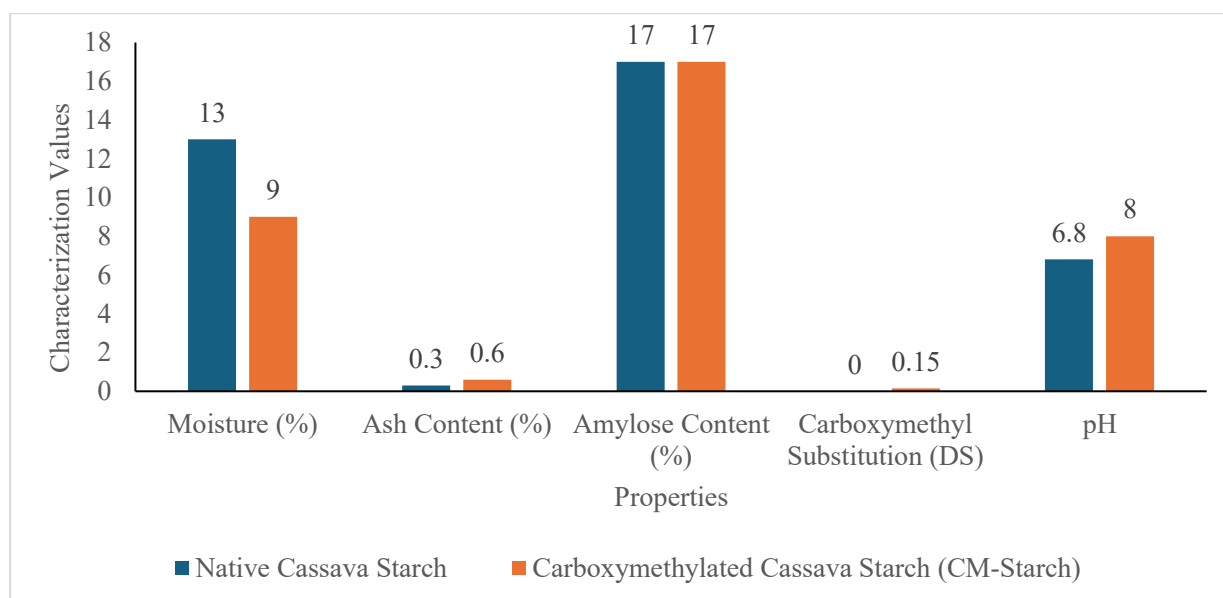


Fig. 2: Key Properties of Starch

The chemical composition of cassava starch as shown in Figure 4.1 changed noticeably after carboxymethylation, reflecting the introduction of functional carboxymethyl groups into the starch granule. Native cassava starch generally contained moderate moisture (10–13%) and very low levels of ash, consistent with its naturally high purity. Following modification, the moisture content slightly decreased while the ash content increased significantly, indicating the presence of residual sodium salts from the etherification reaction and the incorporation of $-\text{CH}_2\text{COO}^-$ groups.

Meanwhile, the amylose and amylopectin contents remained unchanged, confirming that the modification did not disrupt the primary polysaccharide structure but instead altered surface functional groups. A major distinguishing feature of the CM-starch is the measurable degree of substitution (DS 0.10–0.30), which is absent in the native sample and directly reflects the extent of carboxymethyl group incorporation.

Davoodi *et al.*, (2022b) & Gautam *et al.*, (2022) stated that modified-natural polymer has its performance which rely on the degree of substitution or the type of chemical modification. This substitution increased the pH

of the starch from near-neutral levels (6.0–6.8) to a distinctly alkaline range (8.0–10.0), consistent with the presence of sodium carboxylate ions. Functionally, CM-starch exhibited higher solubility in cold water, greater swelling power, and substantially enhanced hydrophilicity compared to the native starch, owing to the introduction of negatively charged groups that improve water–polymer interactions. Overall, these differences confirm that carboxymethylation effectively transforms cassava starch from a relatively inert, hydrophilic-limited polymer into a more reactive and water-compatible derivative with improved functional characteristics. These observations are validated by the works of El-Hamshary *et al.*, 2014 & Xu *et al.*, 2017a.

4.2 Rheological Analysis on the Drilling Samples:

4.2.1 Plastic Viscosity (PV)

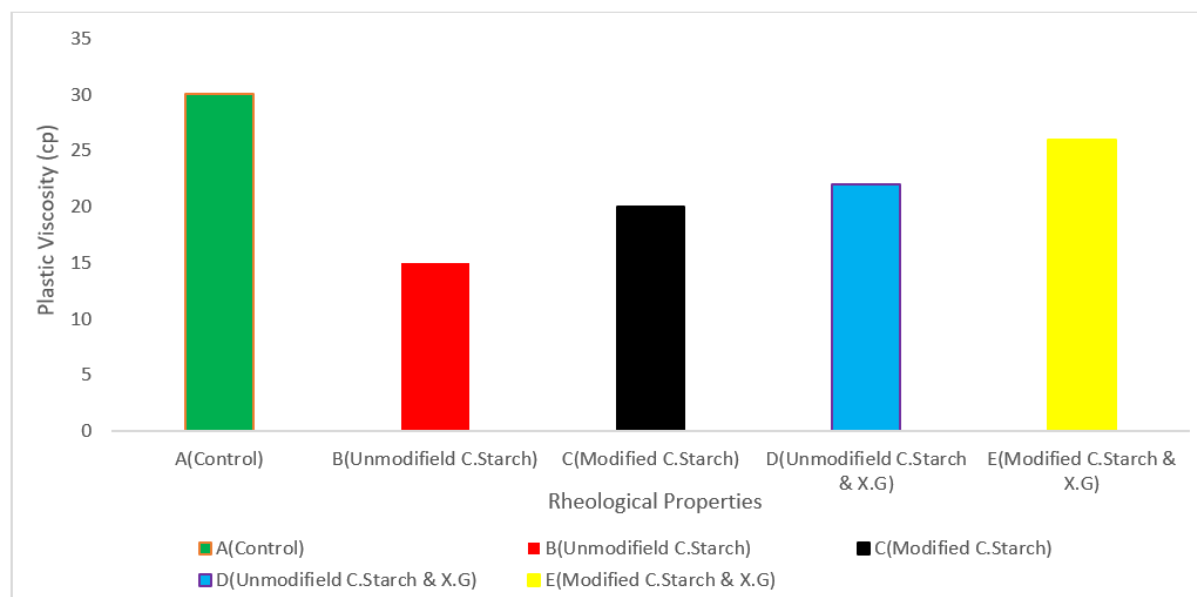


Figure 3 Effect on Plastic Viscosity of the drilling Samples

Figure 4.2 shows the rheological properties (plastic viscosity) of the five drilling mud samples.

The plastic viscosity of the control sample in the figure 4.2 above was 30cp, establishing the baseline resistance to flow caused by internal fluid friction. The introduction of unmodified cassava starch significantly reduced PV to 15cp, indicating a much thinner fluid due to the weak viscosity-building capability of native starch. Modification of the starch improved this performance, raising PV to 20cp as a result of enhanced molecular hydration and increased interaction within the fluid matrix. When unmodified starch was blended with xanthan gum, PV increased further to 22cp, reflecting the strong thickening ability of xanthan gum even when paired with a weaker starch variant. The combination of modified starch and xanthan gum produced the highest PV among the treated samples at 26cp, approaching the control value and demonstrating a strong synergistic effect between the two additives.

Meanwhile, Agbasimalo *et al.*, (2014) states that the ability of drilling fluids to perform their fundamental functions is measured by certain desirable performance characteristic standards especially the rheological properties which include desirable penetration enhancement characteristics that wet the drill string and keep the cutting surfaces of the drill bit clean, a high degree of lubricity, and ability to prevent the solids of the formation (such as shales and clays) from swelling. These findings validate the observations.

Overall, unmodified starch thins the fluid considerably, whereas modification and xanthan gum progressively rebuild viscosity, with the modified starch–xanthan gum blend showing the strongest resistance to flow. All these findings are in agreement with Patel *et al.*, (2012) who also observed that modified polymer has improved rheological properties under varying shear rates

IV. CONCLUSION

This study investigated the effects of cassava starch modification and xanthan gum addition on the rheological, filtration, and chemical properties of water-based drilling mud. From the experimental study, the following conclusions were drawn:

Native cassava starch contained moderate moisture (10–13%) and very low levels of ash 0.3%, consistent with its naturally high purity. The amylose contents were 17%. There was no degree of substitution because the

cassava starch was in its pure state, hence no modification. The pH value was 6.8 which was a near neutral value. These results showed that the natural cassava starch was a relatively inert and hydrophilic-limited polymer.

Modification of cassava starch improved all rheological properties, with plastic viscosity increasing from 15–20cp and yield point increasing from 18–30 lb/100 ft², demonstrating enhanced molecular interaction and hydration capacity.

This research contributes to knowledge in several important ways.

- i. This study contributes to knowledge by providing a comprehensive evaluation of cassava starch modification and polymer blending for water-based drilling mud enhancement.
- ii. It demonstrates that chemical modification via carboxymethylation significantly improves hydration, solubility, and structural properties of starch, while xanthan gum addition synergistically enhances rheological performance and filtration control.

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