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Potential Use of Kepok Banana Peel Waste as Raw Material for Carboxymethyl Cellulose for Oil and Gas Drilling Fluid Applications

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ABSTRACT - This research aims to evaluate the potential of kepok banana peel as a raw material for carboxymethyl cellulose synthesis and to assess its effects on the rheological properties and filtration behavior of bentonite-based drilling mud. The CMC synthesis process involves the stages of delignification, bleaching, alkalization, and carboxymethylation. CMC characterization includes alpha cellulose content, degree of substitution, purity, pH, FTIR, SEM, and EDS. CMC concentrations of 3 g, 6 g, and 9 g are being added to the drilling mud samples to test mud rheology and filtrate volume. The results show that the alpha-cellulose content is 91.60%, the degree of substitution is 1.0, and the purity is 88.17%, meeting the SNI CMC grade II standard. The application of CMC increases plastic viscosity (12–14 cP), yield point (19–21 lb/100 ft²), and gel strength (8–13 lb/100 ft² for 10 seconds; 12–17 lb/100 ft² for 10 minutes) as the concentration increases. The filtrate volume decreases from 15 ml to 13 ml over 30 minutes, and the mud cake thickness decreases from 0.5 mm to 0.3 mm. The pH value is stable at 9. CMC from kepok banana peel meets the SNI grade II standard, increases plastic viscosity, yield point, and gel strength of drilling mud, and decreases filtrate volume and mud cake thickness. With its stable pH and environmentally friendly properties, this CMC has the potential to serve as an effective drilling mud additive.

Keywords: kepok banana peels, carboxymethyl cellulose, drilling mud, rheology, filtration loss.

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INTRODUCTION

In an era of global concern about natural resource conservation and mitigating environmental degradation, researchers and practitioners in the oil and gas industry are increasingly adopting sustainable approaches that prioritize environmentally friendly practices. Strict government regulations, such as US EPA (Environmental Protection Agency) standards, are forcing the industry to optimize drilling efficiency, particularly through innovations in drill cuttings management and disposal that minimize soil and groundwater contamination. Scientifically, this is crucial because conventional drilling fluids often produce toxins and heavy metals that damage ecosystems. Therefore, the transition to biodegradable drilling fluids, such as those enriched with natural polymers (e.g., CMC from agricultural waste), is essential to reduce the overall carbon footprint and ecological impact of drilling operations (Gu et al., 2017; Hossain & Wajheeuddin 2016; Kumar et al., 2021).

In well drilling operations, drilling fluid is a complex colloidal suspension that usually consists of water as the continuous phase and bentonite as the main thickening agent, known as drilling mud. In the drilling process, drilling fluid functions like blood in the human body, with the pump as the heart and rock fragments (cuttings) as waste (Skalle 2011). The mud cleaning system, which includes filters and shale shakers, acts like the kidneys and lungs in removing cuttings from the fluid (Meng et al., 2012; Skalle, 2011). The purpose of drilling fluid is to maintain the efficiency and safety of the drilling process. Some of its critical functions are: 1). Carrying rock debris particles to the surface; 2). Providing the right density to control formation pressure; 3).Cooling and lubricating the drill bit to prevent it from wearing out quickly; and 4). Forming a dense mud cake on the hole wall to prevent formation collapse and maintain well integrity. Oil and gas industry waste, such as used drilling mud, production water, and drill cuttings, poses a continuous threat to the environment. Many chemical additives in conventional water-based mud systems, chosen for their low cost, are hazardous and difficult to break down. Ignoring this problem can pose risks to the environment, health, and safety. Common additives such as potassium chloride, sodium hydroxide, and chromium-based substances are not only expensive but also polluting. In response to strict regulations from the US Environmental Protection Agency (EPA) on waste disposal, researchers are now developing environmentally friendly, easily biodegradable, and affordable additives to support nature conservation (Al-Hameedi et al., 2020; Borah & Das 2022).

The main characteristics of drilling mud are detailed in the ANSI/API 13B-1 recommended practice for field testing of water-based mud. These properties may vary from well to well (Kartini, 2014). Some critical properties include rheological properties (such as plastic viscosity, yield point and gel strength) that support the fulfillment of hydraulic requirements, cuttings transportation, and solid particle suspension when circulation stops; filtration properties to prevent mud infiltration into the formation; density to maintain hydrostatic balance in the well; inhibition properties to increase drilling rate and borehole stability; and lubrication properties to prevent pipe stucking (Quintero, 2002).

The use of persistent additives to control drilling mud properties poses environmental hazards and human safety risks (Satiyawira et al., 2025). This has led to the need for alternative additives that can minimize the disposal of persistent waste. Most traditional chemicals consist of persistent compounds that pose a risk if released into the environment (Samura et al., 2025). Examples include potassium chloride and polyamines, which have adverse environmental effects. Therefore, there is a need for environmentally friendly additive innovations that can manage drilling mud properties, improve their effectiveness, and reduce environmental impact. In this case, bio-products and various waste materials have proven very useful (Le et al., 2025). They offer a range of properties comparable to those of certain commercial additives, are readily available, and are cost-effective. Thus, choosing to use them can be a wise decision to save money, energy, and time (Borah & Das 2022).

In addition to biological products and waste materials, various chemical additives and polymers are equally superior. Substances such as carboxymethyl cellulose, polyionic cellulose, and xanthan gum are highly effective drilling mud additives that are also environmentally friendly (Borah & Das 2022).

According to the Environmental Protection Agency (EPA), the drilling process contributes the second-largest volume of waste discharged into the environment (Onwukwe & Nwakaudu 2012). The selection of drilling mud additives also affects the level of environmental pollution (Miranti et al., 2014). As science advances, innovations in the field of drilling mud have been made by utilizing environmentally friendly natural materials. The advantages of using natural materials, apart from their ability to reduce household waste, include their capacity to prevent pollution during drilling operations and their easy availability in the surrounding environment. One of the materials used is kepok banana peel, the contents of which have been researched.

Figure 1. Kepok banana peel

Banana peel contains 35% to 51.05% cellulose, suggesting its potential as a drilling mud additive (Abdullah et al., 2013; Bilba et al., 2007; Kurniawan & Haryanto 2017; Nur 2018; Quintana et al., 2009). Cellulose compounds, as linear polymers with hydroxyl (-OH) groups, can increase viscosity by forming hydrogen bonds that create a three-dimensional network, thereby inhibiting fluid flow (Hubbe et al., 2017). Derivatives such as CMC can form gel structures with shear-thinning properties, increasing viscosity, yield point, and gel strength. This supports the ability to transport cuttings and to form a dense mud cake to reducing filtration. Based on research by (Li et al., 2015), cellulose has been shown to improve rheological stability and reduce filtration. Thus, the cellulose content in Kepok banana peel has the potential to be developed as a biopolymer additive to improve the viscosity and rheological properties of drilling mud.

In contrast to previous studies that primarily focus on conventional chemical and commercial polymer additives, this research investigates the use of kepok banana peel waste as an eco-friendly natural polymer additive in a water-based mud system through laboratory evaluation. The expected outcome of this study is to evaluate the feasibility and performance of the kepok banana peel additive in improving the rheological properties and filtration characteristics of water-based mud.

METHODOLOGY

The research was conducted on a laboratory scale to determine the potential of the Kepok banana peel sample. In the initial stage, a literature review was conducted to gather information on the potential use of Kepok banana peel as a polymer additive in drilling fluid. Based on Figure 2, this research was conducted in two main process series: the synthesis and characterization of polymer additives from biomass waste, and the formulation and performance evaluation of drilling mud.

The first stage focuses on converting agro-industrial waste, namely Kepok banana peel, into carboxymethyl cellulose (CMC). The process begins with material preparation, which involves drying the Kepok banana peel and preparing the bentonite. The Kepok banana peel is sun-dried for 2 days to ensure the remaining water content in the banana peel is eliminated. The dried banana peel is ground to expand the surface area before undergoing a gradual purification and chemical modification process. The delignification stage

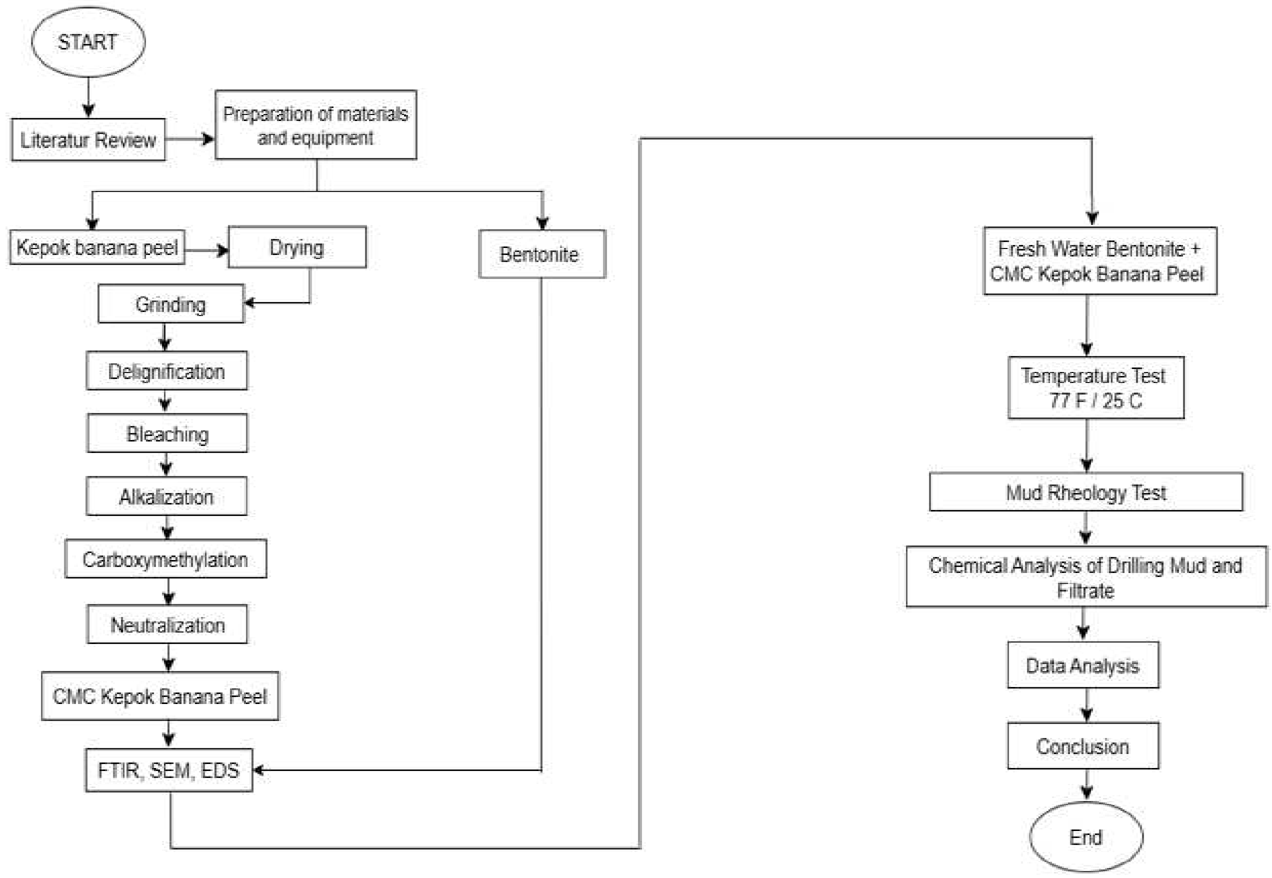

Figure 2. Flowchart of research

aims to remove lignin by dissolving it with 15% NaOH, followed by bleaching to whiten and further purify the cellulose. After the delignification stage, an alpha-cellulose test will be conducted to determine the pure alpha-cellulose content contained in the Kepok banana peel. The purified cellulose fibers are then alkalized to activate the hydroxyl groups, a prerequisite for the carboxymethylation reaction. In the carboxymethylation stage, carboxymethyl groups are introduced into the cellulose structure using sodium monochloroacetate, thereby producing CMC. This water-soluble polymer functions as a thickening and rheology-control agent. The reaction is concluded by neutralization to stabilize the product's pH. After the CMC manufacturing stages are completed, testing in accordance with SNI 06-3736-1995, CMC grade 2, is conducted to assess the quality of the Kepok banana peel CMC. These tests include the analysis of the degree of substitution, purity, and pH. Following completion of this process, the resulting CMC material and bentonite will be characterized using Fourier Transform Infrared Spectroscopy (FTIR) to identify functional groups, Scanning Electron Microscopy (SEM) to observe surface morphology, and Energy Dispersive X-ray Spectroscopy (EDS) to determine elemental composition. The test was conducted at the Nanoscience and Nanotechnology Laboratory of ITB.

The second stage of the research involves formulating and testing drilling mud. The composition of the materials used consists of distilled water (aquadest) and bentonite (fresh water bentonite) mixed with the CMC synthesized from Kepok banana peel to form a test mud. This formulation is then conditioned at a standard room temperature of 77°F (25°C) to simulate initial conditions. The performance evaluation of the mud is carried out through a series of tests. The Mud Rheology Test measures the flow properties and stability of the mud, such as viscosity, yield point, and gel strength, which are crucial for the ability to carry drill cuttings and suspend particles. Chemical Analysis of the Drilling Mud and Filtrate is conducted to determine the chemical composition of the mud and its filtrate, including pH and fluid loss, to assess chemical stability and filtration control capability. The data from all these tests are then comprehensively analyzed to evaluate the effectiveness of Kepok banana peel CMC as an environmentally friendly additive in bentonite-based drilling mud, ultimately leading to a conclusion on its potential application in the drilling industry.

RESULT AND DISCUSSION

Analysis of celulose alpha

In the synthesis of CMC from kepok banana peel, there are two initial stages: delignification and bleaching. These processes are carried out to remove soluble non-cellulose components from the kepok banana peel sample and to produce pure cellulose components before the carboxymethylation and alkalization processes are carried out. To determine the value of pure cellulose components, alpha-cellulose testing can be performed on samples that have undergone delignification and bleaching. In this study, alpha-cellulose testing was conducted at the Center for Standardization and Industrial Services for Cellulose.

Table 1. Alpha celulose test result

No	Sample	Alpha selulose
1	CMC pisang kepok	91.60%

Based on Table 1 on the Kepok banana CMC sample with 15% NaOH content, the delignification process in Kepok banana peel occurs through the attack of hydroxide ions on the ester and ether bonds that connect lignin and hemicellulose to the cellulose matrix so that more lignin and hemicellulose fractions are released and dissolved in the liquid phase, as can be seen in Figure 3, which shows a black solution in the delignification process.

Figure 3. Delignification process on banana peel CMC samples

In the bleaching process, the alkaline conditions cause the fibers to swell and open the cell wall structure, enabling the 6% NaOCl bleaching solution to work more effectively on lignin and produce brighter, relatively purer cellulose, as shown in Figure 4. At a higher NaOH concentration of 15% compared to the previous concentration, the base degradation mechanism, such as the peeling reactions and glycosidic bond cleavage, begins to occur significantly, causing some of the high-polymer cellulose chains to be cut and converted into beta/gamma cellulose fractions or even solutions, which operationally reduces the alpha cellulose content to 91.60%.

Analysis of substitution degree

The degree of substitution (DS) is defined as the average number of carboxymethyl groups bound to each anhydroglucose unit in the cellulose chain. The DS value plays a role in controlling the hydrophilic-hydrophobic balance of CMC, which in turn affects the solubility and rheological behavior of the material in an aqueous medium. According to SNI 06-3736-1995, CMC grade II requires a DS value between 0.4 and 1.0, which meets the standards for technical applications such as drilling fluids. Test results show a DS value of 1.0, which meets the criteria set in the standard.

This high DS value indicates an increase in negative charge and hydrophilic properties in the polymer chain, which contributes to increased solubility in water, viscosity-forming ability, system stability, and salt resistance (Rahman et al., 2021; Wijayani et al., 2010).

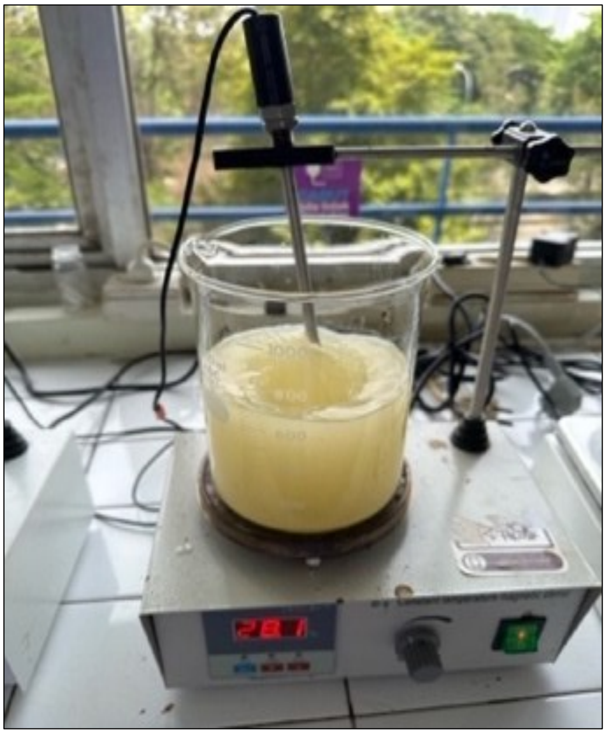

Figure 4. Bleaching process on CMC banana peel samples

Analysis of CMC purity

The purity of carboxymethyl cellulose (CMC) is one of the main parameters determining its quality and performance consistency as an additive in various industrial applications, including the petroleum sector. According to SNI 06-3736-1995, Type II CMC requires a minimum purity of 65%, which meets the standard for technical applications such as drilling fluids. The test results showed that the CMC purity was 88.17%, exceeding the minimum threshold set by the standard. This high purity value indicates a larger fraction of active Na-CMC, which plays a role in viscosity development, suspension stability, and control of filtrate loss, along with a correspondingly smaller fraction of impurities such as NaCl, unreacted organic compounds, residual lignin and hemicellulose, and ash content.

Analysis of pH CMC

pH is an important parameter that determines the quality and performance consistency of carboxymethyl cellulose (CMC) as an additive in various industrial applications, including the petroleum sector. Based on SNI 06-3736-1995, Type II CMC requires a pH range of 6.0 to 8.5. The test results showed that the pH of CMC derived from kepok banana peel was 8.95, indicating a weakly basic character. This value is slightly above the upper threshold specified in the standard. However, this value falls within the general characteristic range of technical CMC and drilling-grade CMC, which have been widely reported to have pH values between 7.0 and 9.5 (Inteq, 1995). Therefore, although the pH value of kepok banana peel CMC slightly exceeds the maximum limit of Type II SNI, this material still has functional potential to be applied as an additive in drilling fluids, provided that standard conditioning is carried out to adjust the pH to comply with the quality standards applicable in the petroleum industry.

FTIR analysis

The FTIR spectrum of the bentonite sample, as shown in Figure 5, indicates the presence of several clay minerals. At peaks of 3603.03 and 3448.72 cm^{-1}, stretching vibrations of O–H groups from bound water and structural hydroxyl groups within the silicate layers are observed, indicating the presence of hydrated clay minerals. The band at 1637.56 cm^{-1} corresponds to the H–O–H bending vibrations of water molecules adsorbed in the interlayer spaces of bentonite, further supporting bentonite's characteristic hygroscopic behavior. At peaks of 1109.07 and 1039.63 cm^{-1}, stretching vibrations of Si–O–Si or Si–O–Al are present in the tetrahedral and octahedral frameworks, which are key features of the layered silicate structure of montmorillonite. The bands between 916.19 and 692.44 cm^{-1} indicate a combination of Al–Al–OH and Al–Mg–OH bending vibrations, as well as silicate framework deformations, confirming the octahedral cation composition within the bentonite structure. The low-wavenumber bands at 526.57 and 424.34 cm^{-1} correspond to Si–O and Al–O bending vibrations within the aluminosilicate

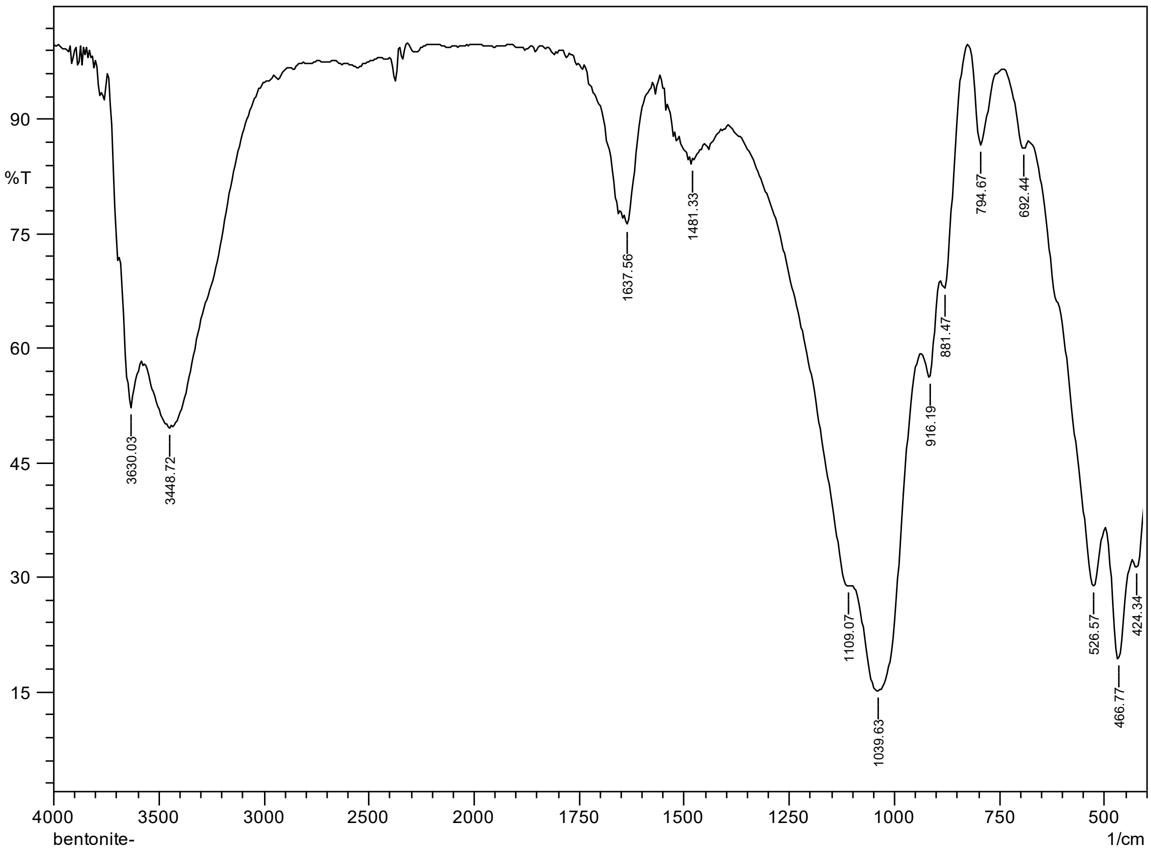

Figure 5. FTIR results for bentonite samples

network. Overall, the spectrum indicates that the sample is bentonite with an intact montmorillonite structure, containing bound water and hydroxyl groups typical of clay minerals.

The FTIR spectrum confirms that the sample is bentonite with an intact montmorillonite structure, characterized by the presence of O–H groups from bound water and structural hydroxyls, interlayer water molecules, Si–O–Si/Si–O–Al frameworks, and octahedral cation compositions of Al and Mg. This demonstrates the characteristic properties of montmorillonite clay minerals, namely their hygroscopicity and well-hydrated state.

Based on Figure 6, the FTIR spectrum of the Kepok banana peel CMC sample shows an O–H peak at around 3448.72 cm^{-1} with lower intensity (smaller %T value), indicating that more –OH groups are involved in the formation of carboxymethyl groups or internal hydrogen bonds, resulting in a more organized polymer network. The carboxylate peaks at 1562.34 cm^{-1} and 1413.82 cm^{-1} appear sharper and more intense, indicating an increased number of $–COO^-$ groups, which confirms the CMC's ability to absorb water, form gels, and interact with ions in the mud. The bands at 1155.36 cm^{-1}, 1066.64 cm^{-1}, and 1020.34 cm^{-1} (C–O–C and C–O) appear stronger, indicating that the ether/ester structure of CMC is more dominant and continuous, which is highly favorable for forming dense polymer films in the mud cake. The combined enhancement of $–COO^-$ and C–O–C/C–O groups in this sample indicates a higher yet still controlled degree of substitution, ideal for a biopolymer intended to reduce filtration loss without making the mud too stiff or over-gelled.

The FTIR spectrum of the Kepok banana peel CMC shows an O–H peak with lower intensity (indicating the involvement of –OH groups in internal hydrogen bonds), as well as sharper and stronger carboxylate ($–COO^-$) and C–O–C/C–O peaks. This indicates a high but controlled degree of substitution, making this CMC ideal for reducing mud filtration loss without causing excessive stiffness or over-gelling.

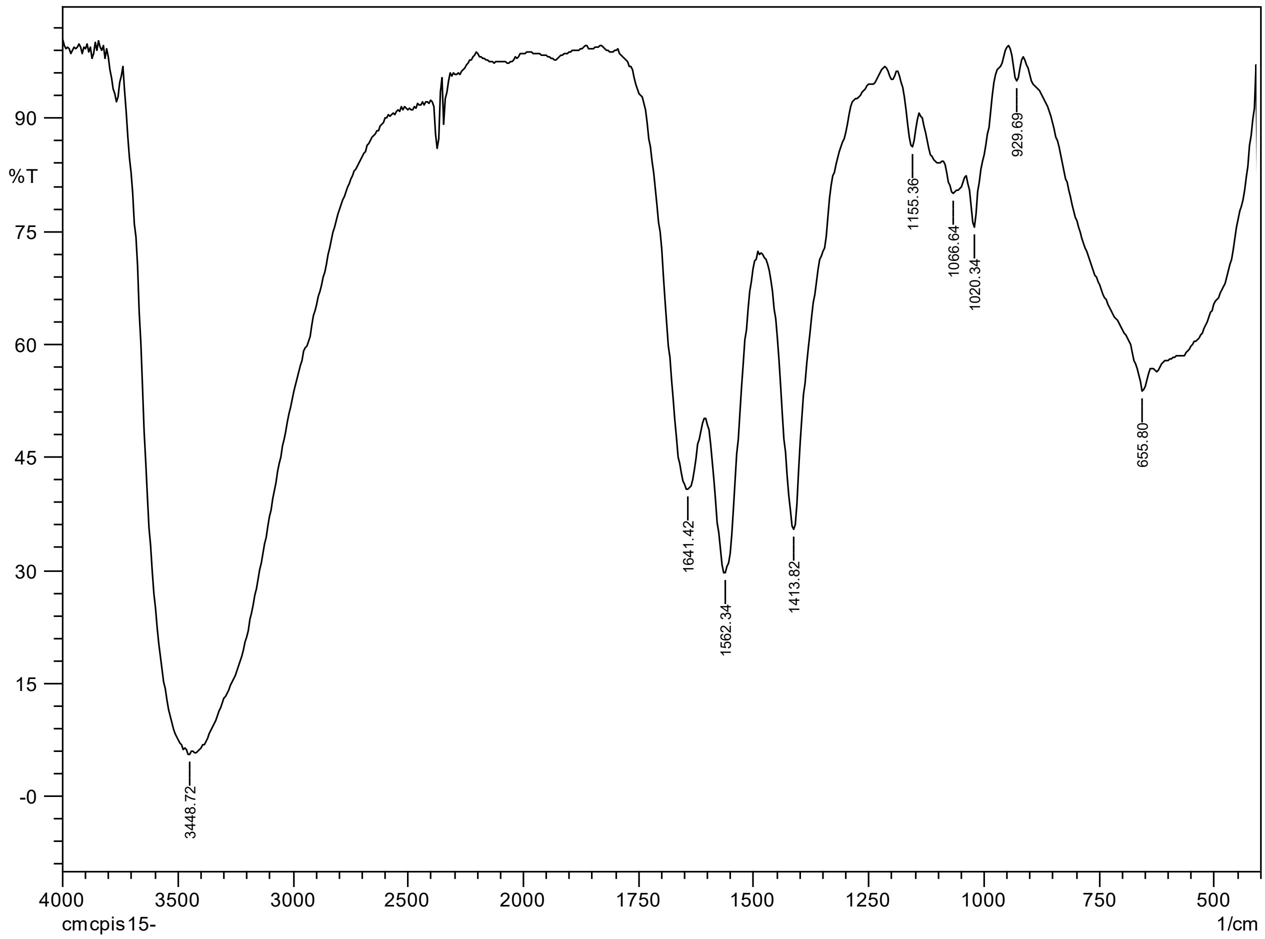

Figure 6. FTIR results for CMC kepok banana peel sample

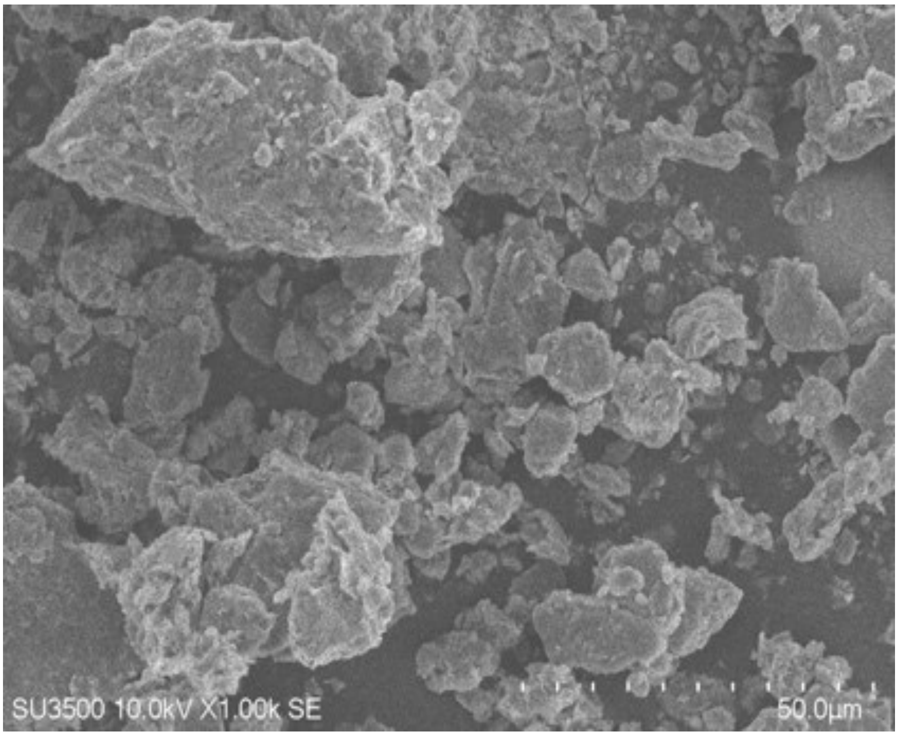

Figure 7. SEM result for bentonite samples

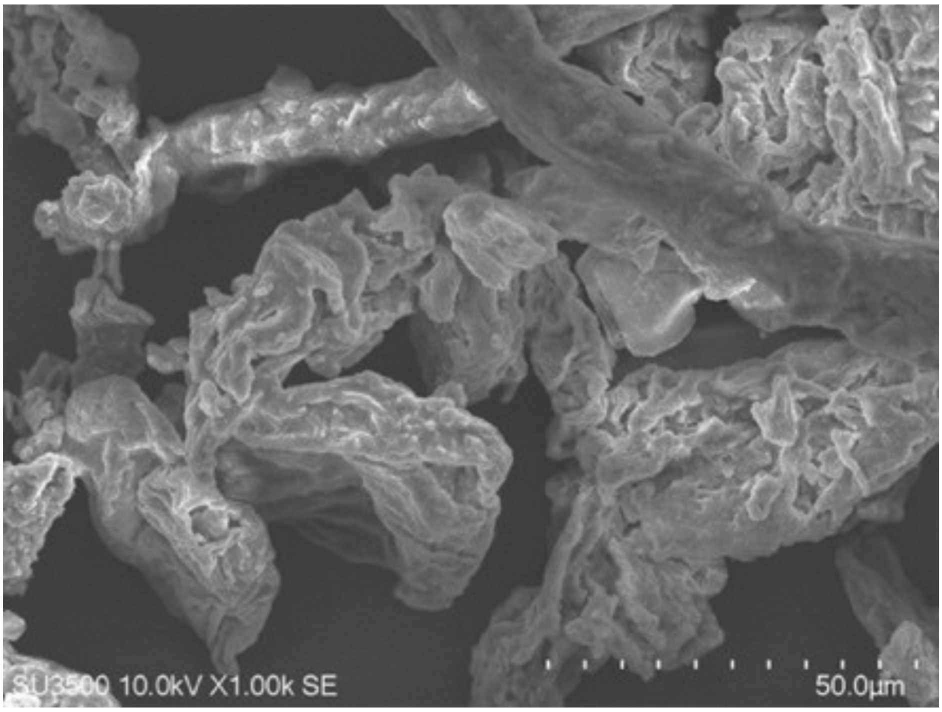

Figure 8. SEM result for CMC Kepok banana peel samples

SEM analysis

The morphology of bentonite in the SEM image in Figure 7 shows that the particles are thin plates that stack and aggregate, forming irregular clumps with rough, porous surfaces (Zhang et al., 2022). These montmorillonite plates are densely arranged in some areas, forming a compact layered mass. In contrast, in other areas, the aggregates appear looser with visible gaps and voids between plates, reflecting a porous structure and providing a high surface area. The aggregate surfaces appear covered with small protrusions, depressions, and micro-cracks, indicating numerous active sites on the particle surfaces, which are important for bentonite's ability to absorb water and swell (Zhang et al., 2022). The combination of laminar-layered morphology, aggregation into flocs, and the presence of interplate pores strongly supports the behavior of bentonite in drilling fluids, namely its ease of dispersion to form viscous suspensions and its ability to build a thin yet sufficiently dense filter cake on the borehole wall, while also providing good filtration control through fine and tortuous pore pathways.

The morphology of bentonite consists of thin plates that are arranged and aggregated into irregular clumps with rough and porous surfaces. This structure provides a high surface area and numerous active sites, which support bentonite's ability to absorb water and swell. These characteristics make bentonite easy to disperse, forming a viscous suspension that can build a thin yet dense filter cake and provide good filtration control in drilling fluids.

The morphology of the CMC sample from the kepok banana peel, based on the SEM image in Figure 8, exhibits a relatively smoother surface with particles that appear to adhere to one another, indicating an increased degree of substitution. The pore structure appears finer and more homogeneous, accompanied by a surface morphology resembling a flaked layer. This pattern is a characteristic feature of modified CMC, in which the original fiber structure gradually disappears and is replaced by a more continuous polymer matrix.

EDS analysis

Based on Table 2, the bentonite sample has a dominant composition of C, O, and Si, with lesser amounts of Al, Na, and Mg, reflecting the presence of aluminosilicate clay minerals. The relatively high carbon content generally originates from carbon coating or surface organic contamination.

Table 2. EDS test result for bentonite samples an CMC kepok banana peel samples

NO	Samples	Element	Weight (%)
1	Bentonite	C	30.25
		O	40.1
		Na	0.81
		Mg	0.39
		Al	7.52
		Si	20.93
2	*CMC kepok banana peel*	C	46.15
		O	32.75
		Na	15.21
		Cl	5.89

The combination of Si–Al–O with Na and Mg indicates a layered silicate framework with charge-balancing cations between the layers, which is highly relevant to bentonite's swelling properties, cation exchange capacity, and dispersion in drilling fluids. Na and Mg, as cations, play a role in the swelling and rheological properties of the mud, as the presence of Na-montmorillonite typically provides better viscosity and yield point compared to Ca-montmorillonite. Thus, even a small amount of sodium contributes to the formation of a favorable gel structure in the mud.

In the Kepok banana peel CMC sample, EDS analysis shows that it is still dominated by C (46.15%) and O (32.75%), confirming that the organic polymer structure remains dominant after carboxymethylation. The increase in the Na (15.21%) and Cl (5.89%) fractions indicates the formation of sodium carboxymethyl salt groups and the remaining chloride ions from the NaOH/ monochloroacetate reagents; thus, the CMC tends to be in the form of a sodium salt that is compatible with NaCl brine-based mud systems. The presence of NaCl within the CMC structure/surface can influence the interaction of CMC with the saline aqueous phase in drilling fluids: at moderate salt concentrations, NaCl can help stabilize viscosity and reduce filtration loss in certain brine muds. However, at excessively high concentrations, it can disrupt polymer hydration and diminish the effectiveness filtration control.

Density analysis

Density is the mass per unit volume of a substance. Driling fluid density is achieved by adding weighting materials that dissolve and are suspended in the drilling fluid, which controls the formation pressure. Moreover, in helps combat shale sloughing (Borah & Das 2022). Below are the results of the density test.

Based on Figure 9, drilling mud testing using CMC derived from banana peel shows density data indicating a significant effect from its addition. The test was conducted with three CMC weight variations: 3 grams, 6 grams, and 9 grams, with the same base composition: fresh water (SG 1.0) and bentonite (SG 2.6), each at 19 grams. The test was carried out using a mud balance. With the addition of 3 grams of CMC, the mixture weighed 363 grams and had a volume of 350 ml, resulting in a density of 8.7 ppg. When the CMC was increased to 6 grams, the total weight rose to 364 grams with the same volume, increasing the density to 8.8 ppg. Furthermore, with the addition of 9 grams of CMC, the total weight reached 365 grams, and the volume remained 350 ml, yielding a density of 8.9 ppg. These data show an increasing trend in density with higher concentrations of banana peel CMC. This increase in density is caused by the CMC's ability to bind water, increasing the viscosity of the mud and allowing solid particles to be more evenly dispersed, thereby increasing the weight per unit volume. These results indicate that CMC from banana peel has potential as an additive in drilling mud to control density, although the increase is relatively small.

Funnel viscosity analysis

Funnel viscosity is a method of measuring the viscosity of a fluid, particularly drilling mud, using a simple device known as a Marsh funnel. This measurement is performed by timing the time required for a specific volume of fluid to flow from the funnel. In the standards commonly used in the oil and gas industry, funnel viscosity values are expressed in seconds, for example, for a volume of one quart (946 ml) or one liter (1,000 cc) of mud. It is important to understand that the value generated by this test is not the fluid's true (absolute) viscosity, but rather a relative viscosity that serves as a qualitative indication of how viscous or "thick" the mud is. Below are the results of the funnel viscosity test.

Based on Figure 10, testing of drilling mud using CMC extracted from kepok banana peel showed marsh funnel viscosity data indicating a

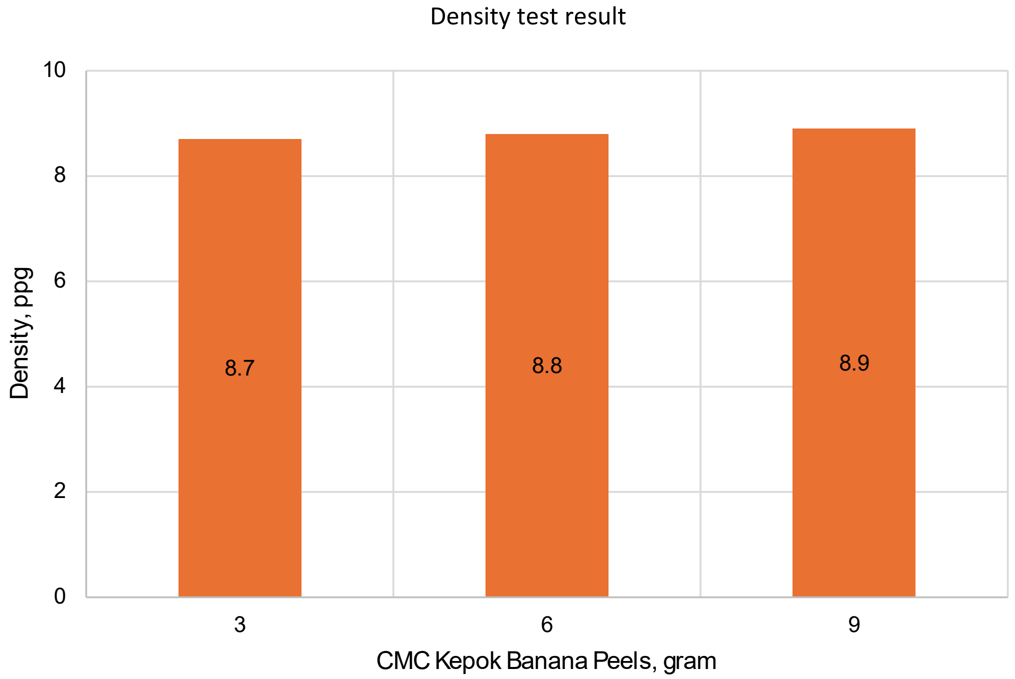

Figure 9. Density test result

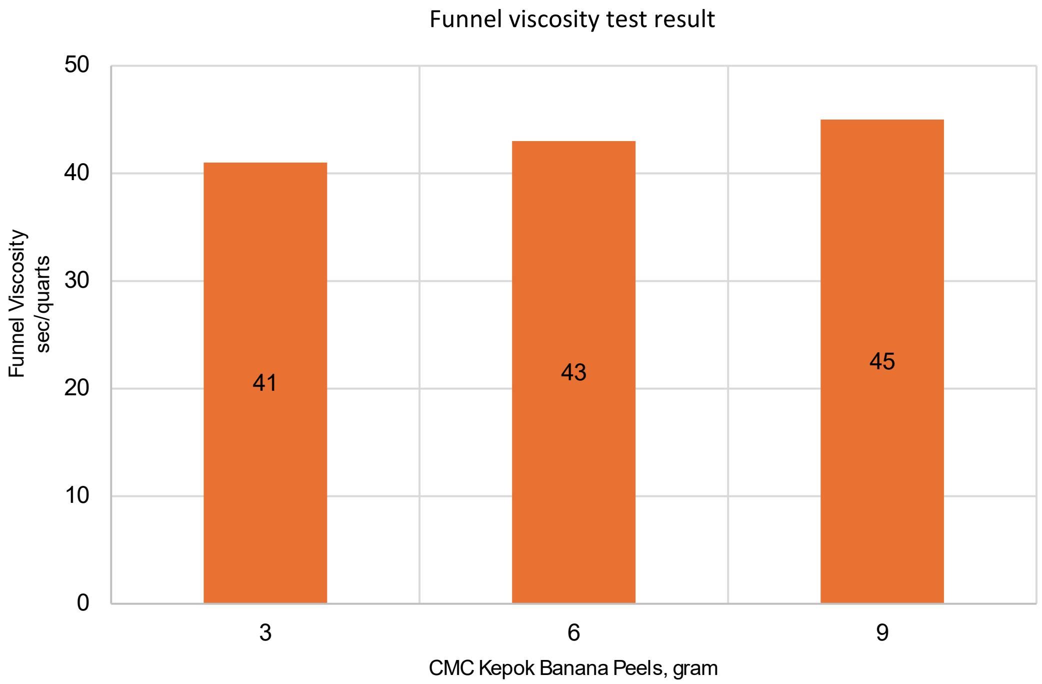

Figure 10. Funnel viscosity test result

significant effect of CMC concentration on mud viscosity. The test was conducted with three CMC weight variations: 3 grams, 6 grams, and 9 grams, each mixed into a mud formulation consisting of fresh water and bentonite. The measurement results showed that with the addition of 3 grams of CMC from kepok banana peel, the recorded Marsh funnel viscosity was 41 seconds per quart. Furthermore, with the addition of 6 grams of CMC, the viscosity increased to 43 seconds per quart. Moreover, at the highest CMC concentration of 9 grams, the marsh funnel viscosity increased again to 45 seconds per quart. This increase in viscosity correlates with the amount of CMC added to the mud system, indicating that CMC derived from kepok banana peel effectively functions as a thickener, increasing the drilling mud's viscosity. This occurs due to the presence of linear polymers rich in hydroxyl groups, which can form hydrogen bonds between chains and with water molecules. These interactions create a three-dimensional network that slows the movement of solvent molecules, thereby increasing viscosity (Hubbe et al., 2017; Klemm et al., 2005). This property is crucial in drilling operations because controlled viscosity helps lift drilling cuttings to the surface and maintain borehole stability.

CMC extracted from the kepok banana peel is an effective thickener for drilling mud. The higher the concentration of CMC added, the higher the viscosity of the resulting mud. This increase in viscosity occurs because the hydroxyl groups on the CMC polymer form hydrogen bonds and a three-dimensional network that hinders the movement of solvent molecules. Therefore, CMC derived from kepok banana peel has the potential to serve as an environmentally friendly and economical additive for drilling mud.

Plastic viscosity analysis

Plastic viscosity is a measure of the fluid's resistance to frictional forces between the phases in the drilling mud, such as the solid and liquid phases (Inteq 1995; Rabia 2002). To measure the Plastic Viscosity value, a Fann VG meter can be used by recording the dial readings at 600 rpm and 300 rpm. The Plastic Viscosity value is then obtained by subtracting the 300 rpm dial reading from the 600 rpm dial reading, resulting in a value expressed in centipoise units. Figure 10 shows the results of the plastic viscosity test.

Based on Figure 11, drilling mud testing using CMC derived from kepok banana peel as an

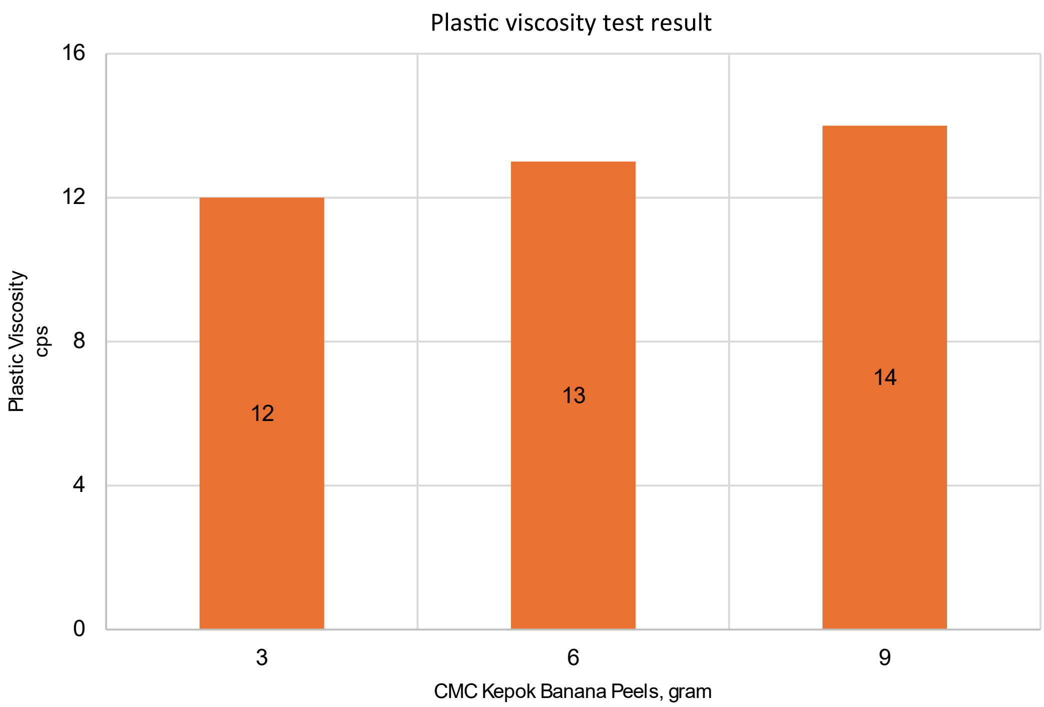

Figure 11. Plastic viscosity test result

additive yielded plastic viscosity data indicating an increase in mud viscosity with increasing concentration. This test employed three CMC weight variations: 3 grams, 6 grams, and 9 grams, each mixed into the mud system with a composition of fresh water and bentonite. In each sample, the volume of fresh water used tended to decrease as the CMC weight increased, from 341 ml in the 3gram sample to 339 ml in the 6gram sample and 337 ml in the 9gram sample. Meanwhile, the bentonite weight was kept constant at 19 grams in all samples. The plastic viscosity measurements showed a consistent increase with increasing CMC concentration from the kepok banana peel. In the sample containing 3 grams of CMC, the plastic viscosity was measured at 12 cP. When the CMC weight was increased to 6 grams, the plastic viscosity rose to 13 cP. A further increase was observed in the sample containing 9 grams of CMC, where the plastic viscosity reached 14 cP. The significant increase in plastic viscosity in drilling mud upon the addition of CMC derived from kepok banana peel is attributed to the polymer hydration mechanism that occurs when the hydrophilic CMC is added to a mixture of water and bentonite. The CMC molecules absorb water and swell, forming a network structure that hinders fluid flow, thereby increasing mud viscosity. As the CMC concentration increases from 3 grams to 9 grams, the amount of dispersed solids in the mud also rises, enhancing internal friction between particles. Furthermore, at higher concentrations, polymer chains begin to entangle and interact, forming a more complex three-dimensional structure that requires greater energy to flow through. . Another contributing factor is the reduction in free water volume, as most of the water is bound by CMC molecules, which diminishes the lubricating effect between particles and further amplifies viscosity. The combination of hydration mechanisms, increased solid concentration, polymer chain interactions, and reduced free water consistently drives the rise in plastic viscosity.

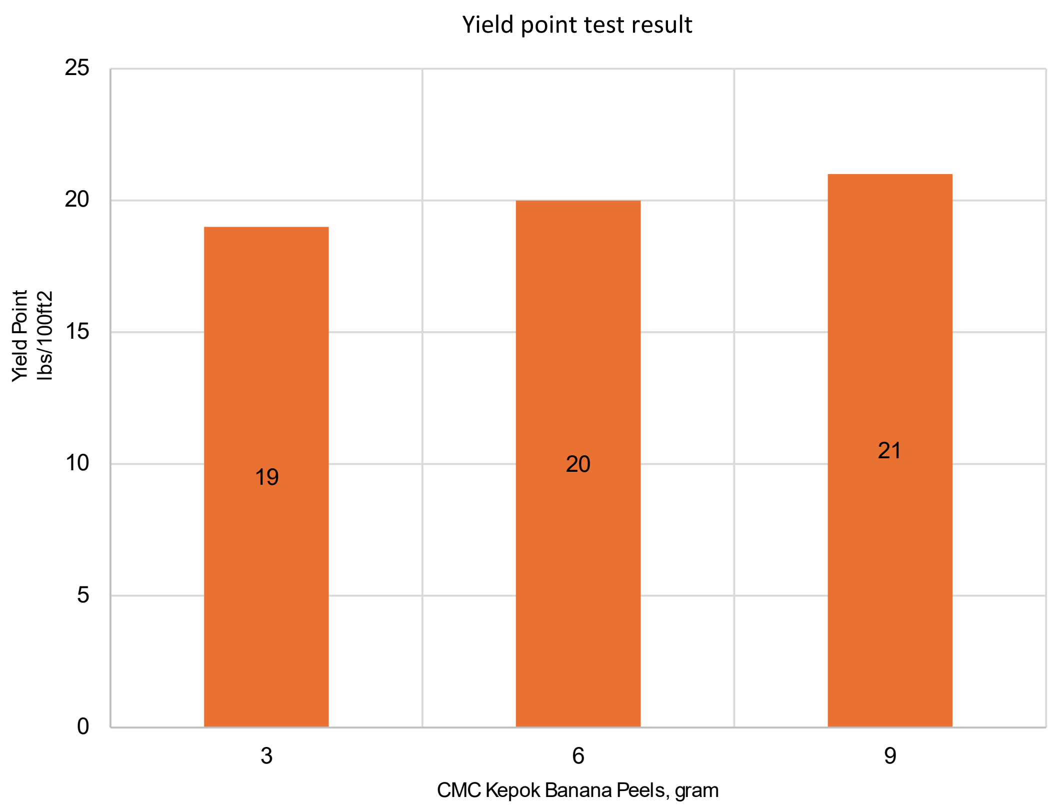

Figure 12. Yield point test result

Yield point analysis

Yield Point is a measure of the electrochemical forces occurring between fluids and between solids and fluids. Yield Point is directly related to subsurface cleaning; the higher the yield point value, the better the wellbore cleaning by the drilling mud. Yield Point can be measured using a Fann VG meter by subtracting the Plastic Viscosity value from the dial reading at 300, yielding a result in units of lb/100 ft². Below are the results of the yield point test.

Based on Figure 12, the drilling mud test results using a CMC additive derived from Kepok banana peel showed varying yield points at different concentrations. With the addition of 3 grams of CMC from kepok banana peel, the recorded yield point was 19 lb/100 sq.ft. When the concentration was increased to 6 grams, the yield point rose to 20 lb/100 sq.ft. Furthermore, with the addition of 9 grams of CMC from kepok banana peel, the yield point increased again to 21 lb/100 sq.ft.

This increase in yield point indicates that CMC from kepok banana peel effectively functions as a viscosifier in the drilling mud system. The yield point itself is a rheological parameter that indicates the mud's ability to carry drill cuttings to the surface. The higher the yield point, the better the mud's capability to clean the borehole, especially under static circulation conditions. This occurs because the yield point is closely related to the attractive forces between particles in the mud, which increase along with the concentration of the CMC polymer.

Based on the test results, the addition of CMC from kepok banana peels was shown to increase the yield point of drilling mud and to increase concentration (from 19 to 21 lb/100 sq. ft). This indicates that CMC is an effective thickener that improves the mud's ability to transport drill cuttings, potentially making it an environmentally friendly and economical alternative additive in the drilling industry.

Gel strength analysis

Gel strength is a value that indicates the extent to which drilling mud can suspend solid particles when circulation is stopped, serving to hold cuttings in the annulus column so they do not fall

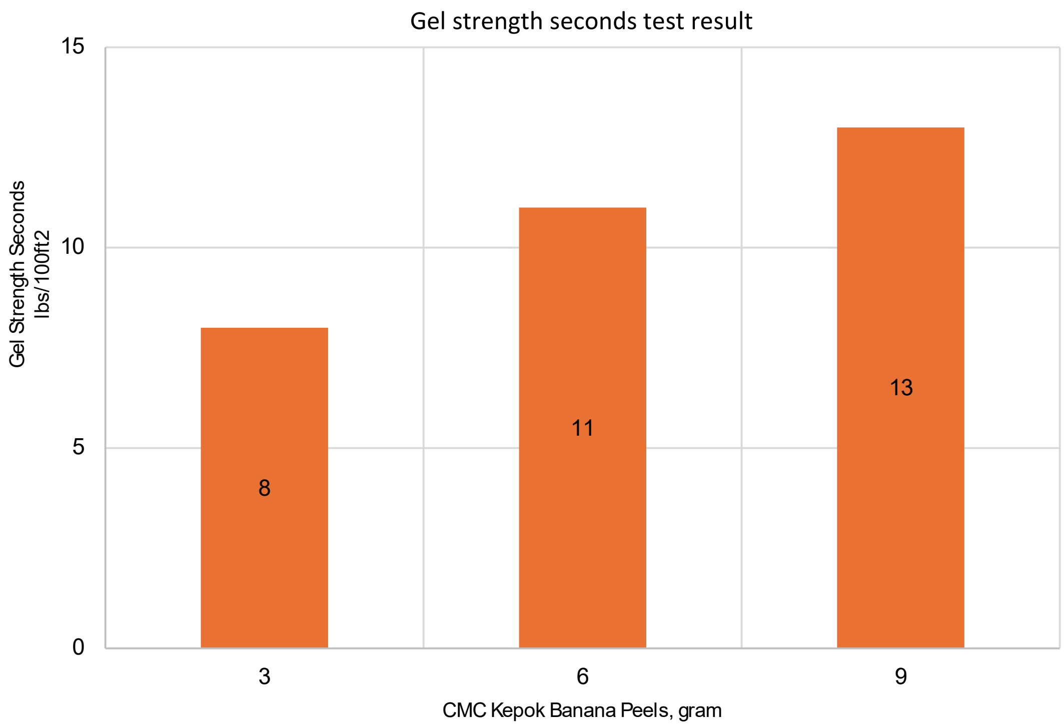

Figure 13. Second gel strength test Result

back into the wellbore. To determine the gel strength value, testing can be conducted using a Fann VG meter. Gel strength measurements are divided into two types: the 10-second gel strength measurement and the 10-minute gel strength measurement. Below are the results of the 10-second gel strength.

Based on the drilling mud test results presented in Figure 13, the use of CMC derived from kepok banana peel as an additive significantly affected gel strength values. The test was carried out with three concentrations: 3 grams, 6 grams, and 9 grams of CMC from kepok banana peel. The gel strength measurements, expressed in seconds, indicated that at a concentration of 3 grams, the gel strength value was 8 seconds. When the concentration was increased to 6 grams, the gel strength rose to 11 seconds. The most substantial increase occurred at the 9-gram concentration, which produced a gel strength value of 13 seconds.

This increase in gel strength suggests that the addition of CMC derived from kepok banana peel enhances drilling mud gel strength. Implies that the mud has a better ability to suspend solid particles and prevent them from settling when circulation is stopped. The higher the concentration of added CMC, the stronger the gel structure formed in the mud. Therefore, CMC derived from kepok banana peel has the potential to serve as an alternative thickening and viscosity-controlling agent in drilling mud systems.

Based on Figure 14, gel strength data were obtained for three concentrations of the banana peel CMC mud sample: 3 g, 6 g, and 9 g. From the test results, the gel strength values (in lb/100 sq.ft) were 12 for the 3-gram concentration, 14 for the 6-gram concentration, and 17 for the 9-gram concentration. This data indicates that an increase in banana peel CMC concentration is followed by an increase in gel strength values.

The effect of banana peel CMC on increasing gel strength is due to its nature as a polymer capable of forming intermolecular bonds within the liquid phase of the mud. The more CMC that is added, the more polymer chains interconnect, forming a stronger three-dimensional gel structure when the mud is in a static condition. This increases the viscosity and gel strength, preventing solid particles in the mud from settling easily. Thus, banana peel CMC is effective as a

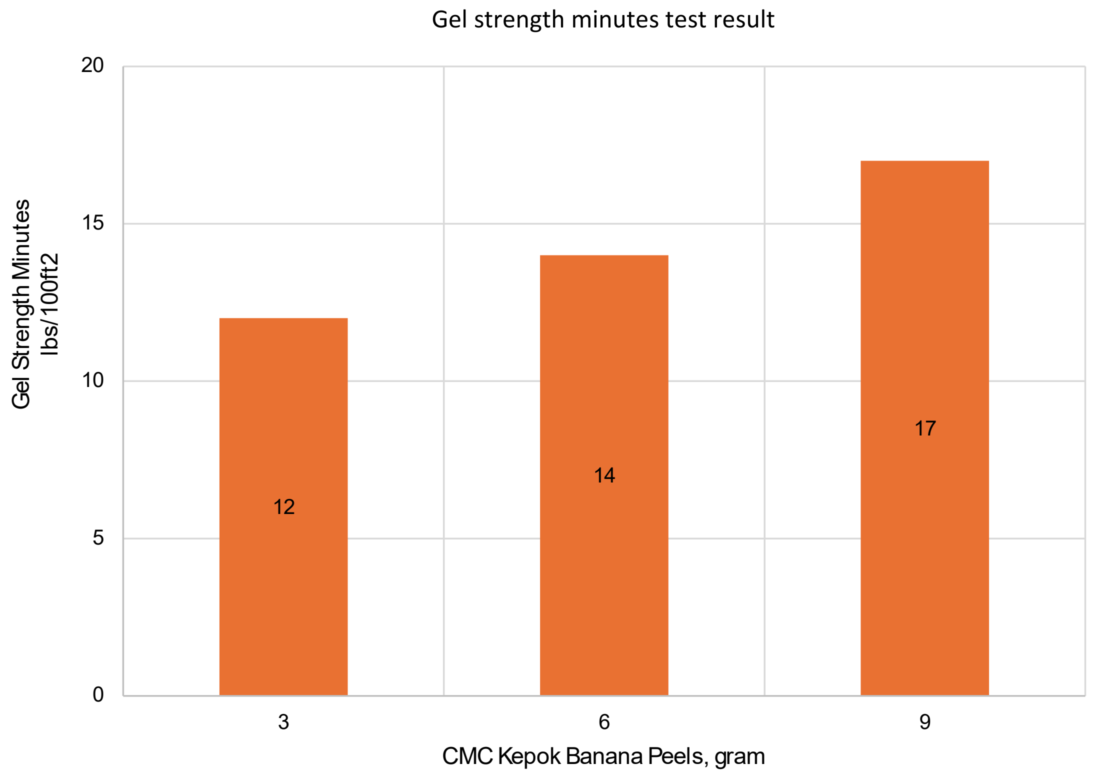

Figure 14. Minutes gel strength test result

rheology controller for drilling mud, particularly in enhancing gel strength, thereby improving drilling efficiency.

The presence of cellulose in banana peel CMC is one of the factors contributing to the increase in gel strength, both in seconds and in minutes. This is attributed to the nature of cellulose, which enhances the gel-forming ability of drilling fluids. The nanocellulose contained within plays a role in forming a dense three-dimensional structure through hydrogen bonds, both between cellulose chains and between cellulose chains and water molecules. It is this three-dimensional structure that generates viscoelastic properties in the fluid, thereby directly enhancing the resulting gel strength (Hubbe et al., 2017; Klemm et al., 2005).

Filtration and mud cake analysis

Filtration loss is the condition where the liquid phase of drilling fluid seeps into the formation, while mud cake is formed from solid particles that are left behind and deposited on the wellbore wall due to the loss of this filtrate. To measure filtration loss and mud cake thickness, an API filter press is used, operating at 100 psi for 30 minutes to determine the filtrate volume and the thickness of the solid layer (mud cake) formed. Below are the results of the filtration test.

Based on the results shown in Figure 15, the filtration loss test on drilling mud with the addition of a CMC additive derived from kepok banana peel showed a significant reduction in filtrate volume lost to the formation. The test was conducted using an API filter press at 100 psi for 30 minutes, with three CMC concentrations: 3 g, 6 g, and 9 g. The basic mud composition consisted of fresh water and bentonite, totaling approximately 350 ml. The test results showed that at a CMC concentration of 3 grams, the filtration loss volume was 15 cc in 30 minutes. Subsequently, at a concentration of 6 grams, the filtrate volume decreased to 14 cc/30 minutes, and at a concentration of 9 grams, it further decreased to 13 cc/30 minutes. These data show a downward trend in filtration loss with increasing CMC added to the drilling mud.

This reduced filtration loss can be explained by the role of CMC (carboxymethyl cellulose) as an additive that acts as a filtration control agent and viscosity enhancer. CMC is a water-soluble

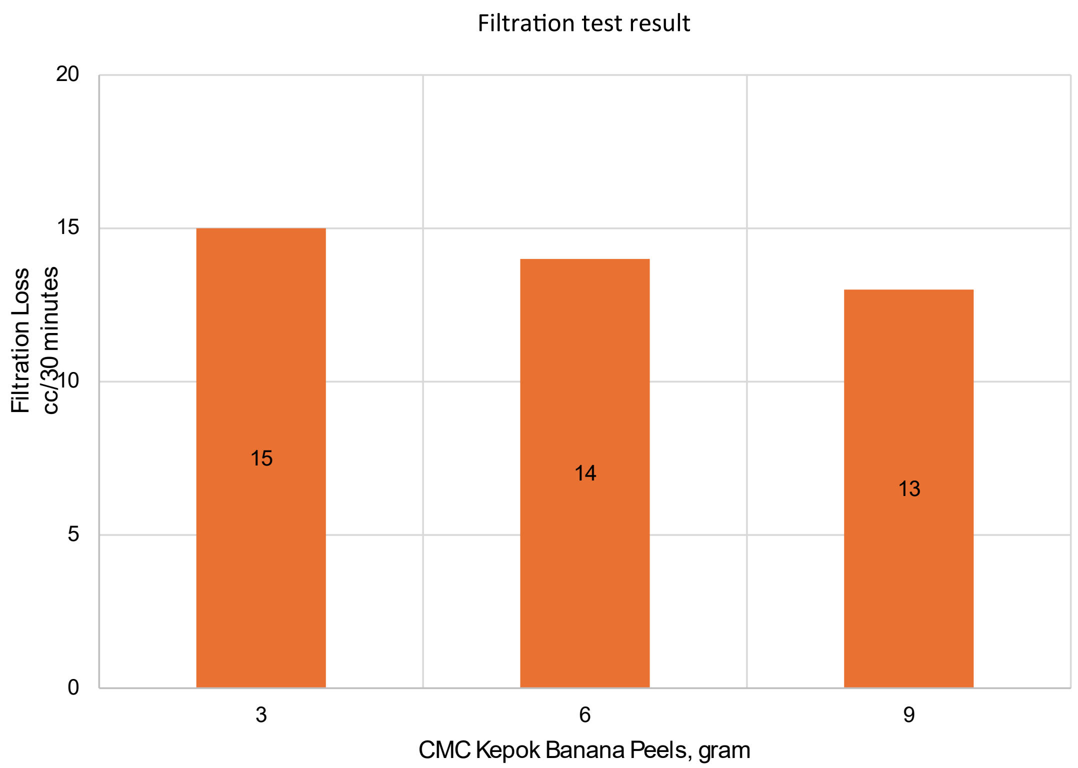

Figure 15. Filtration loss test result

polymer that forms a thin layer, called a mud cake, on the wellbore wall. When CMC is added to the mud, polymer molecules interact with bentonite particles and water, forming a more stable colloidal structure and reducing the fluid flow rate through porous media. The higher the CMC concentration, the more polymer is available to strengthen the bonds between solid particles, resulting in a denser, thinner, and more impermeable mud cake. Consequently, the filtrate or liquid phase capable of penetrating the formation is reduced.

Based on Figure 16, the measurement results indicate that higher CMC concentration results in a thinner mud cake. With the addition of 3 grams of CMC, the mud cake thickness was recorded at 0.5 mm. When the concentration was increased to 6 grams, the thickness decreased to 0.4 mm. At the highest concentration of 9 grams, the mud cake formed was only 0.3 mm thick.

This reduction in mud cake thickness indicates that CMC derived from Kepok banana peel effectively acts as a filtration-control agent or fluid -loss-control agent. CMC is an anionic polymer that is soluble in water and can increase mud viscosity and form a thin, tight, and impermeable filter cake. As the CMC concentration increases, the polymer molecules bind to bentonite particles and form a denser structure on the formation wall surface. This makes it difficult for the mud fluid to penetrate the formation, thereby reducing the volume of filtrate lost and resulting in a thinner mud cake.

A thin mud cake is highly desirable in drilling operations because it can reduce the potential for problems such as differential sticking and maintain borehole stability. Furthermore, the thinner the mud cake, the better the protection of the productive formation, as mud fluid invasion is minimized. From these results, it is evident that Kepok banana peel CMC has the potential to be an alternative filtration control additive that is both environmentally friendly and economical. Increasing the CMC concentration to 9 grams yielded the best result, with the thinnest mud cake thickness of 0.3 mm. Overall, this data proves that utilizing Kepok banana peel waste as a raw material for CMC can make a positive contribution to the oil and gas drilling industry.

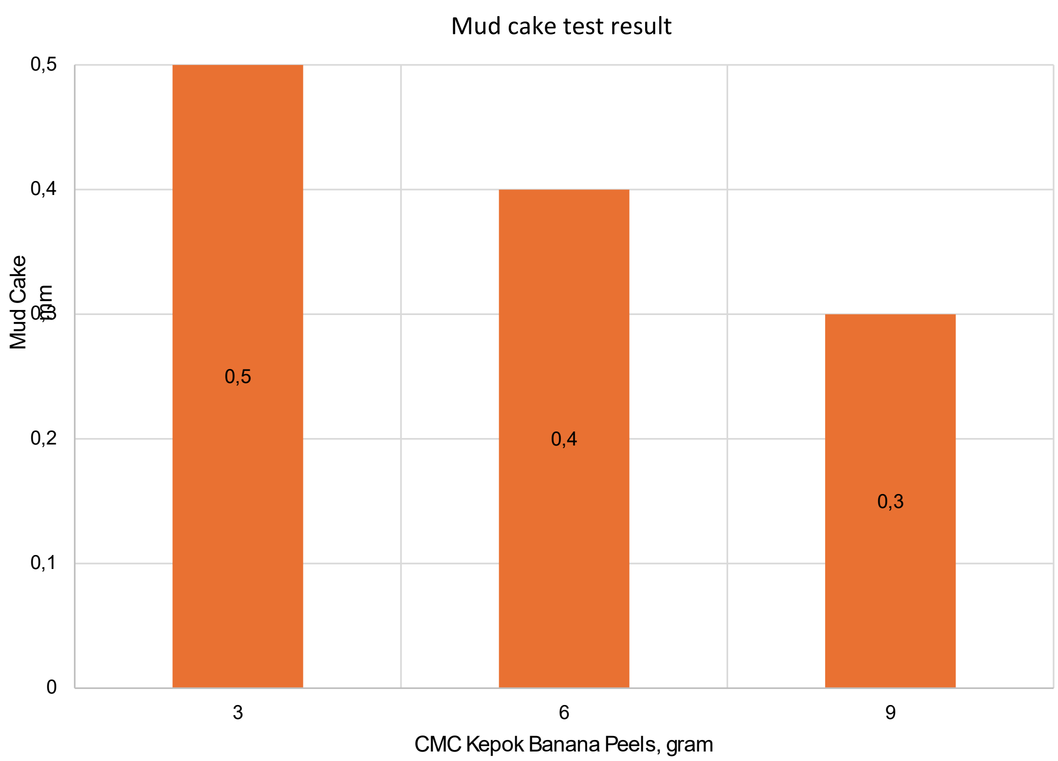

Figure 16. Mud cake test result

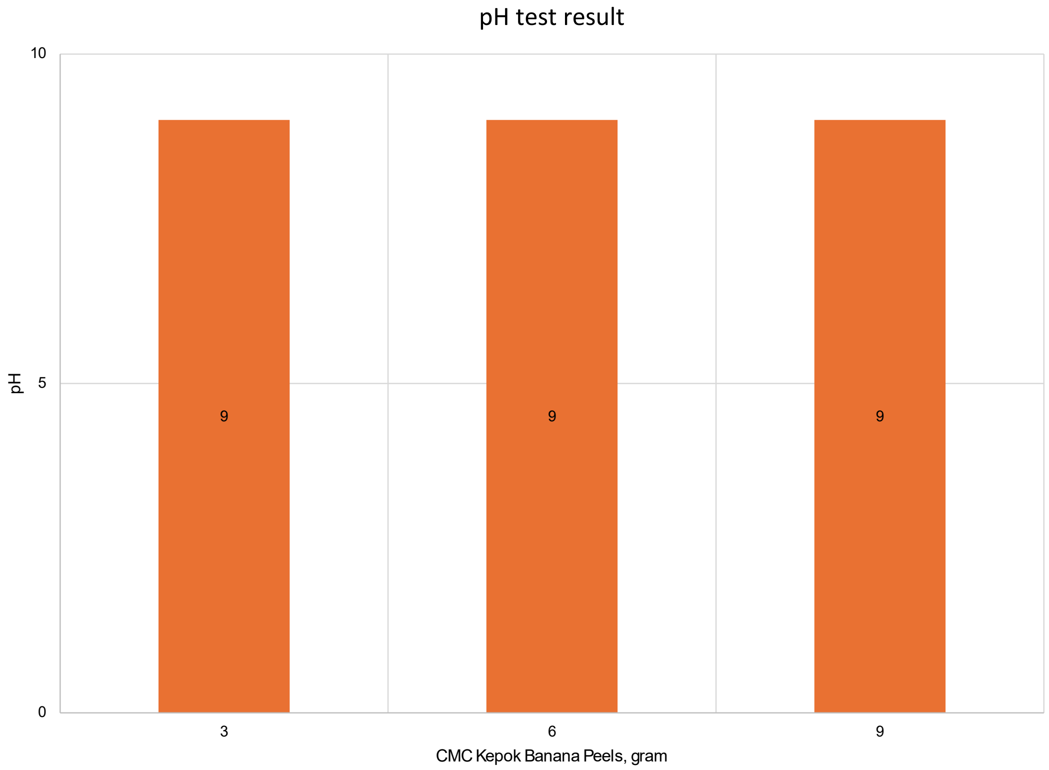

Figure 17. pH test result

pH analysis

pH is a chemical parameter that indicates the acidity or alkalinity level of a solution. In drilling mud, pH plays a crucial role in determining its characteristics and performance. The ideal pH range for drilling mud is generally in alkaline, specifically 8-10. Establishing this alkaline pH range serves critical technical objectives. First, alkaline conditions help maintain the solid form of cuttings (drill cuttings) during lifting to the surface, thereby facilitating their separation and disposal. Second, an alkaline environment also helps minimize corrosion risk to drilling equipment, thereby preserving its integrity and service life throughout the drilling operation.

Based on Figure 17, the pH values for the three samples were the same at 9. This indicates that although the amount of CMC added to the mud mixture (consisting of fresh water and bentonite) varied, there was no significant change in pH value. In other words, increasing the dose of CMC from banana peel kepok from 3 grams to 9 grams did not quantitatively affect the mud's acidity or alkalinity.

The stable pH condition at 9 indicates that CMC from banana peel kepok has a relatively neutral property and does not alter the ion balance in the mud. Most likely, this pH value of 9 is more influenced by the mud's basic components, namely, fresh water and bentonite. Bentonite itself is generally alkaline because it contains minerals such as sodium montmorillonite, which can increase pH when dispersed in water. Thus, the addition of CMC from banana peel kepok—derived from organic material—does not significantly affect pH, whether acidic or alkaline.

The effect of CMC from banana peel kepok on the pH of drilling mud in this test can be explained as follows. As an organic polymer extracted from banana peel, CMC generally possesses carboxymethyl functional groups that tend to be stable within a certain pH range in solution. In drilling mud formulation, CMC primarily acts as a thickener and a filtrate control agent, not as a pH regulator. Therefore, adding up to 9 grams of CMC does not shift the pH established by the other components (water and bentonite). This demonstrates that CMC from banana peel kepok is compatible with the mud system without disrupting its chemical characteristics, particularly in terms of pH.

This pH stability is important in drilling operations because pH fluctuations can trigger corrosion in drilling equipment, interfere with the performance of other additives, or damage rock formations. With a pH consistently maintained at 9, within the weak alkaline range, this mud is expected to maintain optimal rheological and filtration properties. These results also indicate that CMC from banana peel kepok can serve as an environmentally friendly alternative additive without drastically altering the chemical balance of the mud.

CONCLUSION

Based on the results of this study, carboxymethyl cellulose (CMC) synthesized from kepok banana peels has excellent potential as a drilling mud additive, particularly as a thickener and filtration control agent. CMC from kepok banana peel demonstrates performance in increasing funnel viscosity, plastic viscosity, yield point, and gel strength due to its fine morphology and semicrystalline cellulose domains. Banana peel CMC can reduce filtration loss and mud cake thickness because the anionic polymer structure in the CMC forms an absorption layer on the surface of bentonite particles, thereby reducing filtration loss and producing a thin mud cake. These findings indicate that CMC from kepok banana peel is a viable alternative additive for drilling fluids, contributing to the development of sustainable drilling fluids aligned to utilize environmental waste.

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DECLARATIONS

Author contribution

A.R.R. Wastu: conceptualization, methodology, investigation, data curation, formal analysis, software, visualization, writing original draft, writing review & editing. A.K. Permadi: Supervision (co), visualization, methodology, validation, writing review. D. Wahyuningrum: Supervision (co), methodology, validation, writing review & editing. A.Nugrahanti: Supervision (co), methodology, validation, writing review & editing.

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Competing interest

None

The use of AI or AI-assisted technologies

None

GLOSSARY OF TERMS NAD SYMBOLS

Terms & Symbols	Definition	Unit
CMC	Carboxymethyl cellulose	
PV	Plastic viscosity	cps
YP	Yield point	$Lbs/100ft^2$
DS	Degree of substitution	

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