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Synthesis and Comparative Evaluation of an Eco-Friendly Viscosifier from Empty *Elaeis guineensis* Bunches for Water-Based Drilling Fluid

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ABSTRACT

A viscosifier for water-based drilling fluid (WBDF) was developed from empty *Elaeis guineensis* (Oil palm fruit) bunches. The process of development requires the conversion of cellulose from the oil palm empty fruit bunches (OPEFB) into carboxymethyl cellulose (CMC) polymer and comparing its effectiveness as a viscosifier against a commercial CMC. The Fourier Transform Infrared (FTIR) spectroscopy results of both viscosifiers, showed the presence of the same functional groups, as indicated by the similar wavenumbers for hydroxyl, carboxyl, methylene, and glycosidic groups present in both. The rheological properties such as plastic viscosity, apparent viscosity, and yield point of the water-based drilling fluids produced from the developed viscosifier and the commercial CMC, exhibited similar trends in their variation with changes in rotational speed and percentage loading. Both water-based drilling fluids showed a steady reduction in apparent viscosity values, as temperatures increased from 40°C to 100°C at 0.5%, 1% and 1.5% loading respectively. However, at 2% loading, there was a large deviation from this trend. Their yield points also showed a steady reduction with increase in temperature for samples of WBDF prepared with OPEFB-based CMC and those prepared with commercial CMC, at all the percentage loading considered. These comparisons, to some extent is an indication of the potential of producing a bio-based viscosifier from empty *Elaeis guineensis* bunches, which can serve as an alternative to the commercial CMC, for drilling activities in the Nigerian oil and gas industry.

Keywords: Cellulose, Rheological, biomass, alkalization, fiber

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INTRODUCTION

The process of extracting hydrocarbons from deep down the earth's crust, starts with drilling operations, that employs various drilling fluids for specific functions, such as cleaning of wellbore, cooling of drill bit, managing formation pressure, etc. Water-Based Drilling Fluids (WBDFs), for instance, are the most commonly used drilling fluid type worldwide. They have the advantage of high stability, environmental compatibility and controlling low circulation pressure losses. The WBDF is usually a homogeneous blend of water as a lubricant or base fluid, and chemicals such as emulsifiers, corrosion inhibitors, pH control agents, viscosifiers, fluid loss control agents, weighing agents, and salts [1] to enhance its performance. Viscosifiers are mostly imported products, even though it is common knowledge that they can be produced from various high cellulose-containing waste biomass. This necessitated this research of developing a cellulose-based viscosifier from OPEFB for WBDF, evaluating its rheological properties and comparing it with the imported counterparts. Good enough, the Nigerian palm oil industry generates significant quantities of oil palm empty fruit bunches (OPEFB), from which cellulose can be extracted; offering a sustainable viscosifier source. Carboxymethyl cellulose (CMC) is a type of polymer generated from cellulose that is insoluble in water, but becomes water-soluble when transformed into a polyelectrolyte. There are two steps in the synthesis of CMC; carboxymethylation and alkalization. The hydroxyl groups of cellulose are activated during the alkalization step, by reacting cellulose with NaOH solution (which also serves as a swelling agent) and monochloroacetic acid. The quantity of dissolved monochloroacetic acid will depend on the alkali and solvent mixture amount; in large quantities, this will promote and speed up the diffusion of monochloroacetic salts to react with the hydroxyl group of cellulose.

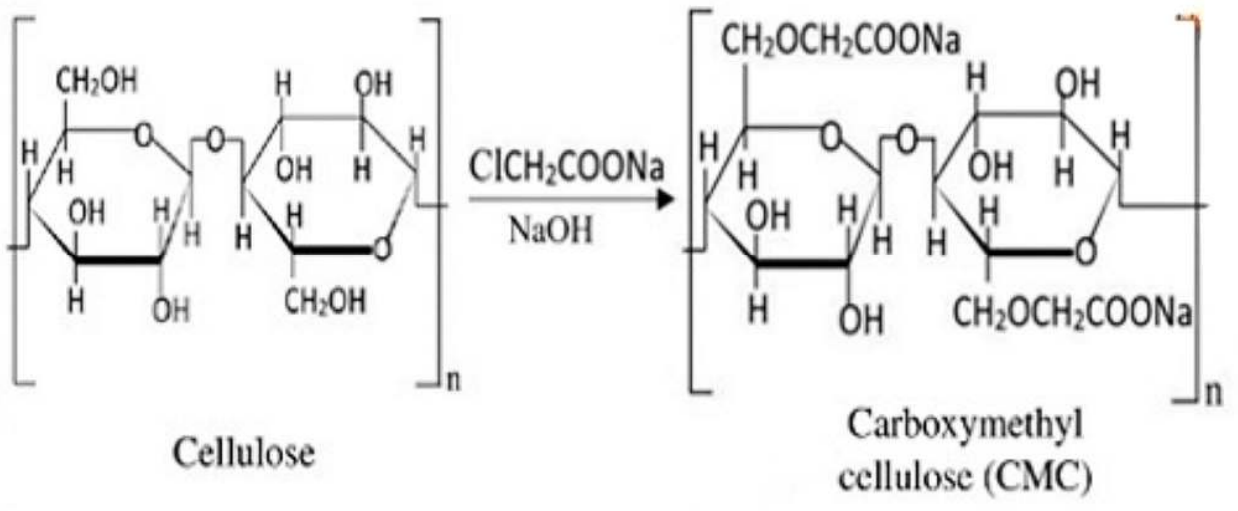


Fig. 1: Conversion of Cellulose to CMC [2]

On the other hand, carboxymethylation is the incorporation of carboxymethyl groups to a polysaccharide chain, through an acid-catalyzed reaction process. Carboxymethyl celluloses are categorized into four (4) types, based on their level of purity; the technical grade (<75% CMC), semi-purified grade (75-85% CMC), purified grade (>98% CMC), and extra purified food grade (>99.5% CMC). The technical grade is for detergent production, the semi-purified grade is for oil and gas drilling, the purified grade is for paper coating and textile sizing, and the extra purified

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grade is for food, pharmaceuticals, cosmetics etc. This study selected oil Palm Empty Fruit Bunch (OPEFB) as the starting material for CMC production. The lignocellulosic components that make up the extractive-free fiber of OPEFB range from 17–33% hemicelluloses, 43–65% cellulose, to 13–37% lignin [3]. FTIR analysis was carried out on the OPEFB-based CMC and the commercial CMC, in order to compare their chemical structures. The variations in the rheological properties of the WBDF prepared with different weight percents of CMC were also studied. Rheology is the study of the flow and deformation properties of a fluid [4]. It encompasses crucial properties like apparent viscosity, plastic viscosity, and yield point, which evolve under subsurface conditions due to pressure and temperature fluctuations. Monitoring these rheological properties is essential for mitigating wellbore issues such as loss circulation and pipe stuck, in order to ensure seamless drilling operations. The primary tool for assessing drilling fluid rheology is a viscometer. Apparent viscosity, is the ratio of shear stress to shear rate, while plastic viscosity is a fluid's resistance to flow [5]. A high plastic viscosity can result in adverse effects such as increased pump pressures and reduced penetration rates. The yield point is the resistance to initial flow and represents the stress required to start the fluid movement [6]. Yield point influences strain recovery and frictional pressure losses.

A lot of related studies have been carried out, such as in Okon *et al.* [7], which entail an investigation into the use of rice husk as an environmentally friendly filtration control additive. The outcome showed that, in comparison to the performance of 10 ppb of carboxymethyl cellulose (CMC), a 20-ppb concentration of rice husk decreased fluid loss by 65%. However, the high concentration of rice husk might potentially harm sensitive Measurement While Drilling (MWD) instruments and have an unfavorable impact on the plastic viscosity [7]. Iranwan *et al.,* [8] investigated the application of sugar cane and corncob as viscosifying agents. When the concentration of the viscosifying agents was raised from 6 ppb to 10 ppb, the plastic viscosity increased, while the yield point and the gel strength decreased. Similarly, Nmegbu and Bari-Agara [9] examined the potential of corncob cellulose to enhance the rheological characteristics of water-based mud. According to the experimental findings, corncob reduced fluid loss more effectively than polyanionic cellulose (PAC). Jarni *et al*. [10] conducted a rheological study of Oil Palm Trunk Waste as a Viscosifier Agent for Water-Based Mud. The results from this study showed that the cellulose extracted through the method of Dewaxed-Alkaline-Delignification of oil palm trunk waste, has the potential of being commercialized as a viscosifier agent for water-based drilling fluid. Elrayah *et al.* [11], also researched on drilling fluid additive, Sodium Carboxymethyl Cellulose (CMC), where CMC was produced from palm fronds and compared with commercial CMC. Thus, this study is unique, in being concerned with using a waste product of the oil palm industry, OPEFB, in the synthesis of a CMC viscosifier for WBDF and comparing it with an imported CMC viscosifier. This study is therefore very significant since it amounts to waste reduction, local content value addition, green technology, and cost-effective and efficient drilling fluid preparation.

MATERIALS AND METHODS

Materials

OPEFB was collected from Ubogo market in Udu Local Government Area of Delta State. The reagents used were sodium hydroxide, sodium chlorite ($NaClO_2$), glacial acetic acid, distilled water, isopropyl alcohol, monochloroacetic acid, ethanol, CMC polymer (purified grade); which were all bought from a local chemical store. Freshwater and bentonite clay were used to produce the WBDF. The instrument and apparatus used were Electric Grinder, Oven, Hamilton Beach

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Mixer, weighing balance, spatula, filter cloth, sieving mesh, heating mantle, mechanical stirrer, Rotational Couette Viscometer, Perkin Elmer Fourier Transform Infrared (FTIR) Spectrometer.

Methods

Pre-treatment of OPEFB

The raw OPEFB was washed with a 1% dish detergent solution to remove any visible impurities like mud and sand. Once cleansed, it was rinsed with tap water until the dark brown water became colourless. After that, the washed OPEFB was sun-dried for several days until it was completely dried. The dried sample was then finely ground using the electric grinder.

Alkaline treatment

First, 50.0 g of ground OPEFB was treated with 4% (w/v) NaOH solution at 80˚C for 9 hours under mechanical stirring. Subsequently, the OPEFB fiber was filtered, repeatedly rinsed with distilled water until it reached a neutral state, and allowed to dry for 4 hours at 60˚C in the oven.

Bleaching process

To further remove the lignin from the OPEFB, 20.0 g of the treated fiber was soaked in an equal part of acetate buffer (27 g NaOH; 75 ml glacial acetic acid and diluted with distilled water to 1 litre), 1.7% (w/v) of aqueous sodium chlorite, and distilled water at 90˚C for 12 hours while being continuously stirred. Subsequently, the obtained OPEFB cellulose fiber was filtered, rinsed thoroughly with distilled water, and dried at 80˚C until a consistent weight was reached [12].

Production of CMC

A mixture of 15.0 g of cellulose powder, 50 ml of 50% (w/v) NaOH solution and 450 ml of isopropyl alcohol was prepared in a 500 ml beaker. The mixture was stirred using a magnetic stirrer for 30 minutes. The carboxymethylation reaction was initiated by introducing 18.0g of monochloroacetic acid (MCA) into the mixture, which was then constantly agitated for 4.0 hours while being heated at a temperature of 55ºC. Subsequently, the mixture underwent phase separation, resulting in the formation of two distinct phases. The liquid phase was extracted and the solid phase was dispersed in 100ml of methanol, then rinsed repeatedly with water, until a pH of 7 was achieved, and then filtered using a Buchner funnel. The finished product was dissolved in 300 ml of 70% (v/v) ethanol and allowed to stand for 10 minutes to eliminate unwanted by-products and subsequently rinsed with 300 ml of 100% (v/v) methanol. The filtrate was subjected to drying at a temperature of 75°C in an oven for 5 hours, and packed as the CMC [13].

Characterization of the viscosifier

Characterization was done using Fourier Transform Infrared (FTIR) Analysis. The chemical structure of the OPEFB-derived CMC and the commercial CMC were determined using a Perkin Elmer FTIR Spectrometer.

Preparation of WBDF samples and rheological analyses

Nine (9) samples of drilling fluid were prepared using 350ml of water, and 22.5g bentonite clay. One was kept as a control sample. Four samples were then mixed with 4g, 6g, 8g, and 10g of OPEFB-derived CMC respectively, and the remaining four samples were mixed with 4g, 6g, 8g, and 10g of CMC Polymer respectively. The drilling fluid's rheological properties were measured using a Rotational Couette Viscometer according to the procedure outlined in the API RP 13B-1 - Recommended Practice for Field Testing Water-Based Drilling Fluids [14].

RESULTS AND DISCUSSION

The following colour changes were observed that when producing OPEFB-derived cellulose; after reacting with the NaOH solution, the colour of the OPEFB fibers changed from light brown to dark brown, after the treatment with the acetate buffer solution, the colour became light yellow.

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Finally, after bleaching with sodium chlorite, the colour became off-white; which is the colour of the OPEFB-derived CMC.

Percentage Yield of OPEFB-Derived CMC

The reaction of cellulose with monochloroacetic acid under these alkaline conditions caused the substitution of the hydroxyl group of the cellulose with the carboxymethyl group, which has a higher molecular weight. Hence, the huge percentage yield of OPEFB-derived CMC or synthesized CMC depicted in Table 1, may have resulted from the high NaOH concentration, which is consistent with previous research, such as was carried out by El-Sakhawy *et al.* [15].

Table 1: Table Showing the Percentage Yield of OPEFB-derived CMC

Parameters	Values
Weight of dried cellulose (g)	15
Weight of obtained CMC (g)	21.7
Yield of CMC (%)	144.67

Graphical Illustrations of Rheological Properties

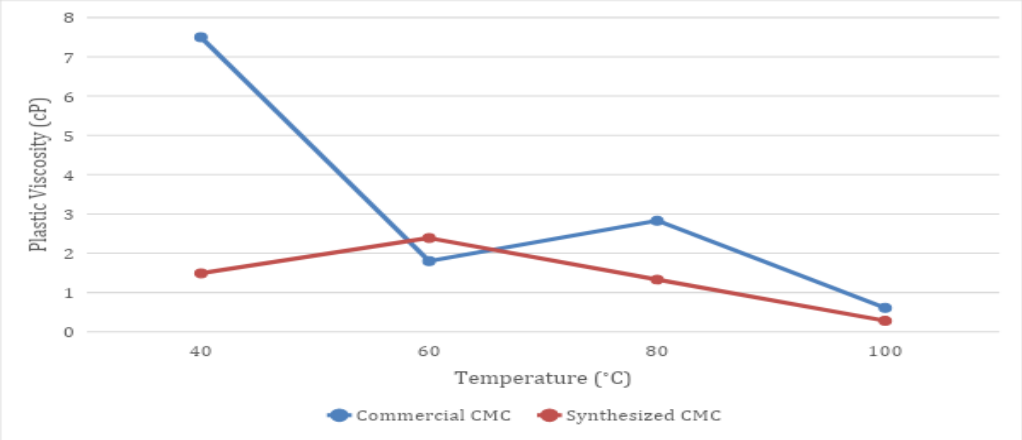


Figure 2: Comparison between Plastic Viscosity of Commercial CMC and Synthesized CMC at 0.5% Loading

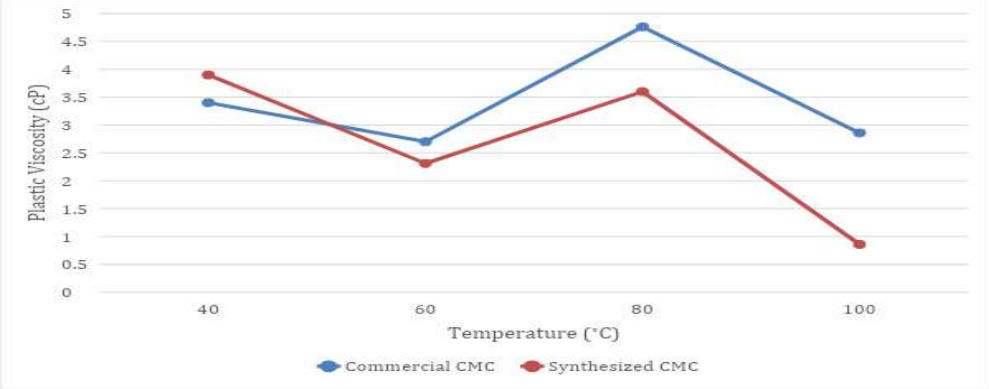


Figure 3: Comparison between Plastic Viscosity of Commercial CMC and Synthesized CMC at 1% Loading

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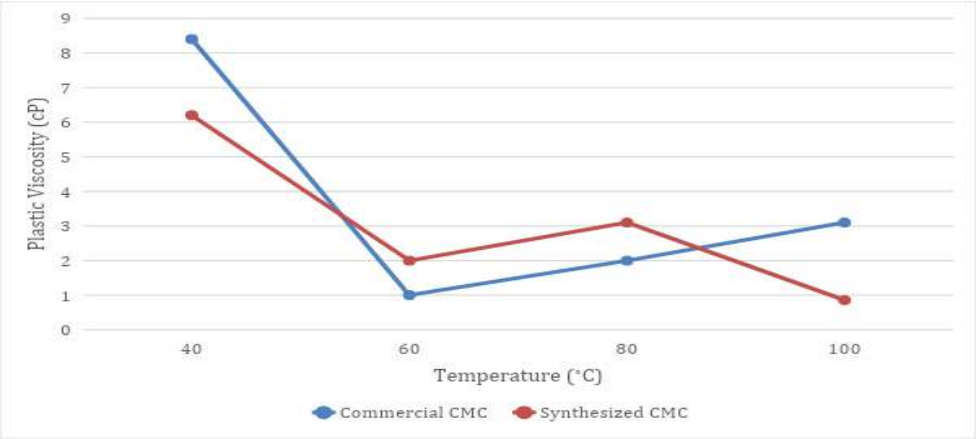


Figure 4: Comparison between Plastic Viscosity of Commercial CMC and Synthesized CMC at 1.5% Loading

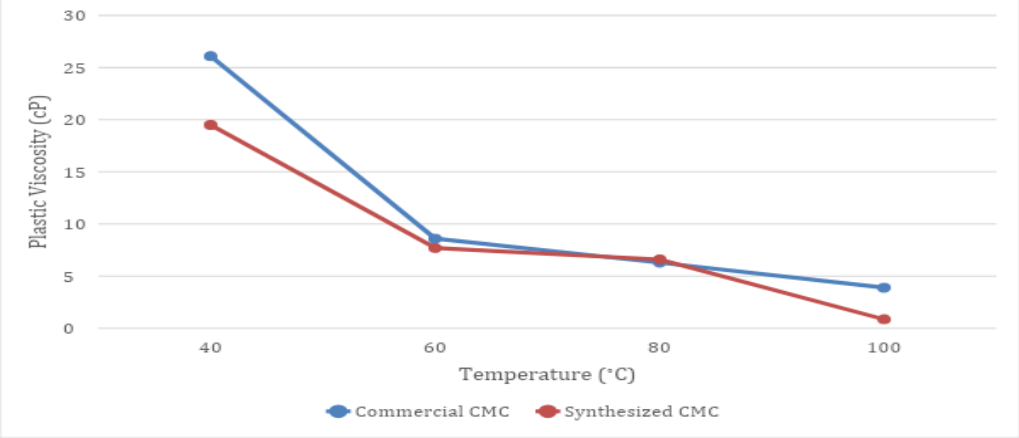


Figure 5: Comparison between Plastic Viscosity of Commercial CMC and Synthesized CMC at 2% Loading

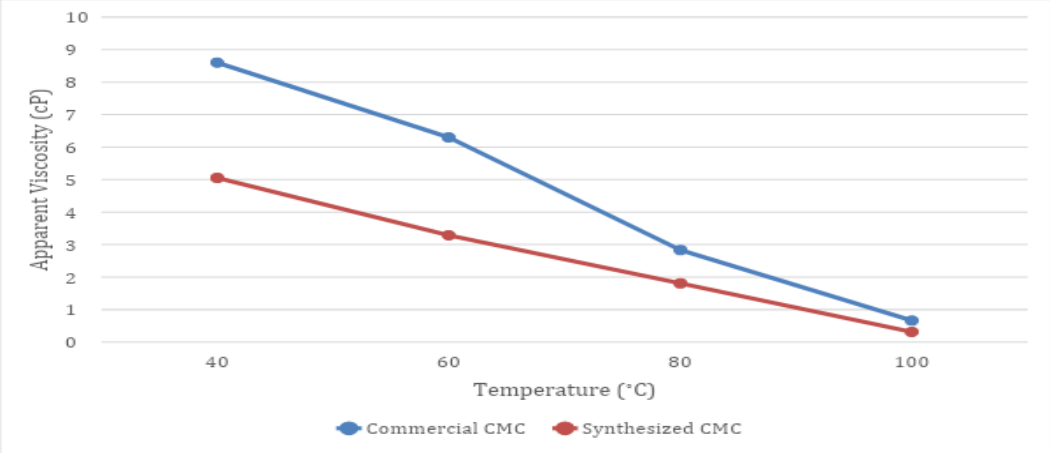


Figure 6: Comparison between Apparent Viscosity of Commercial CMC and Synthesized CMC at 0.5% Loading

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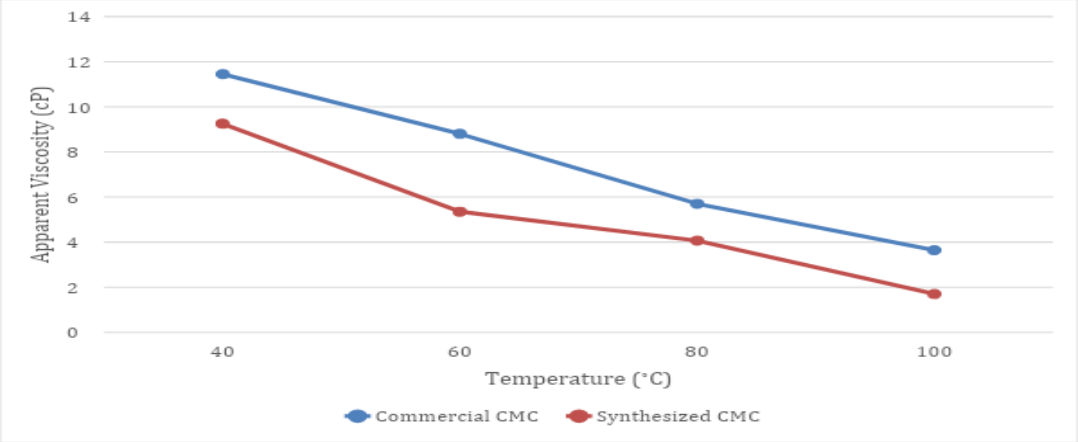


Figure 7: Comparison between Apparent Viscosity of Commercial CMC and Synthesized CMC at 1% Loading

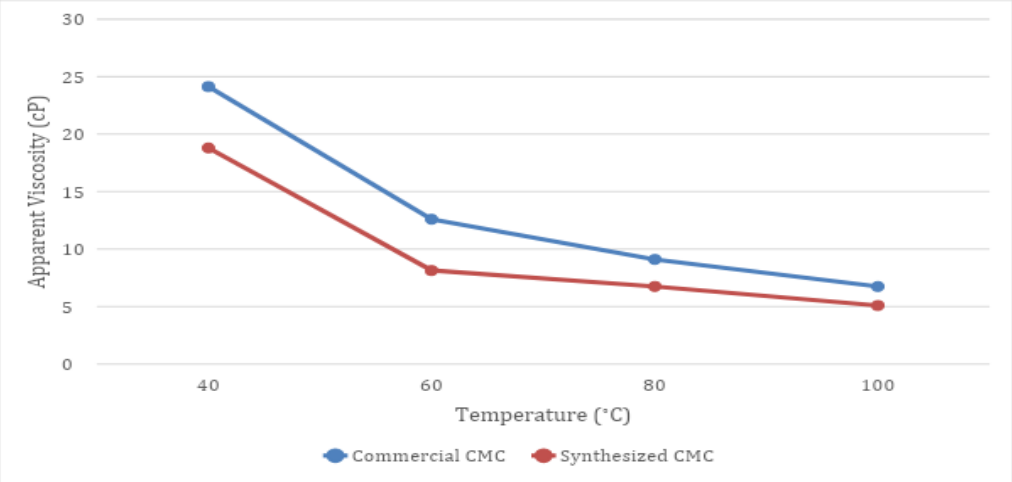


Figure 8: Comparison between Apparent Viscosity of Commercial CMC and Synthesized CMC at 1.5% Loading

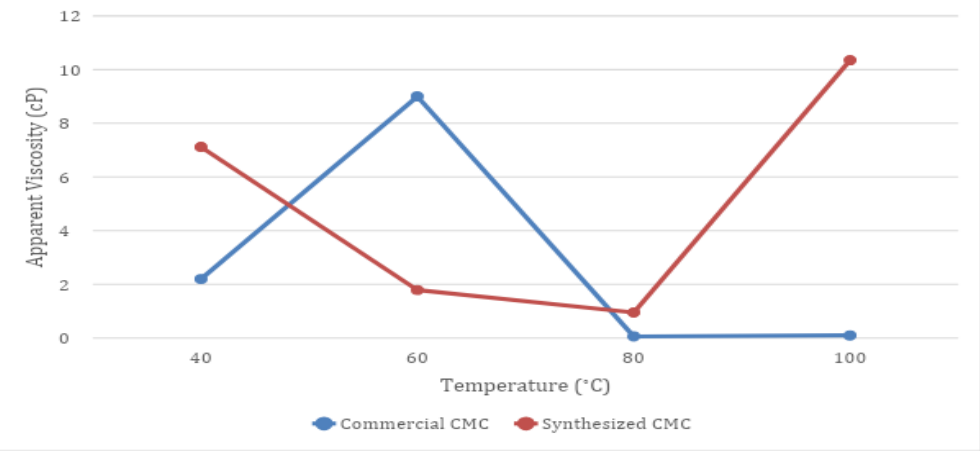


Figure 9: Comparison between Apparent Viscosity of Commercial CMC and Synthesized CMC at 2% Loading

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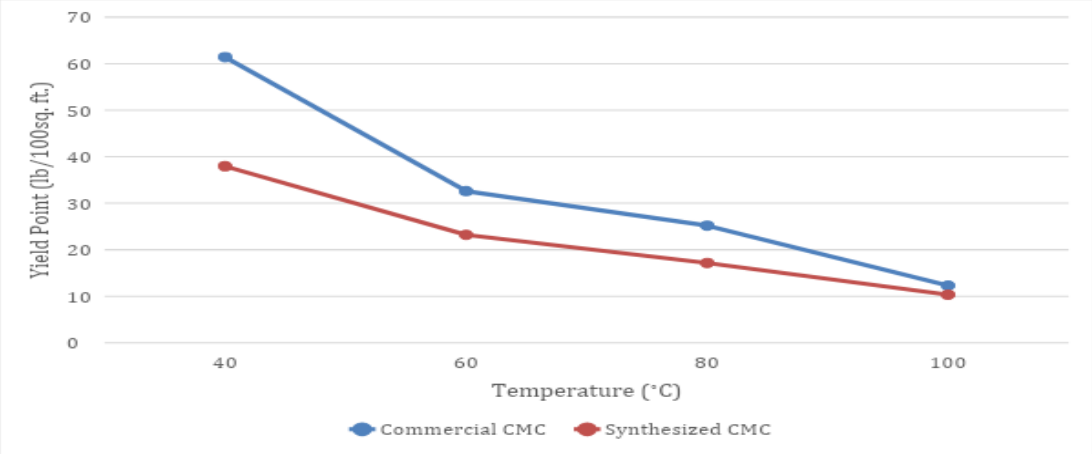


Figure 10: Comparison between Yield Point of Commercial CMC and Synthesized CMC at 0.5% Loading

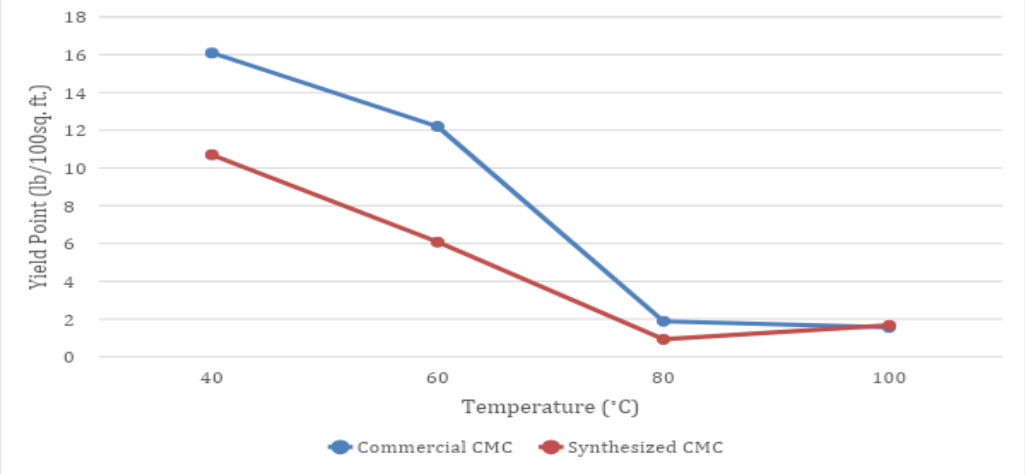


Figure 11: Comparison between Yield Point of Commercial CMC and Synthesized CMC at 1% Loading

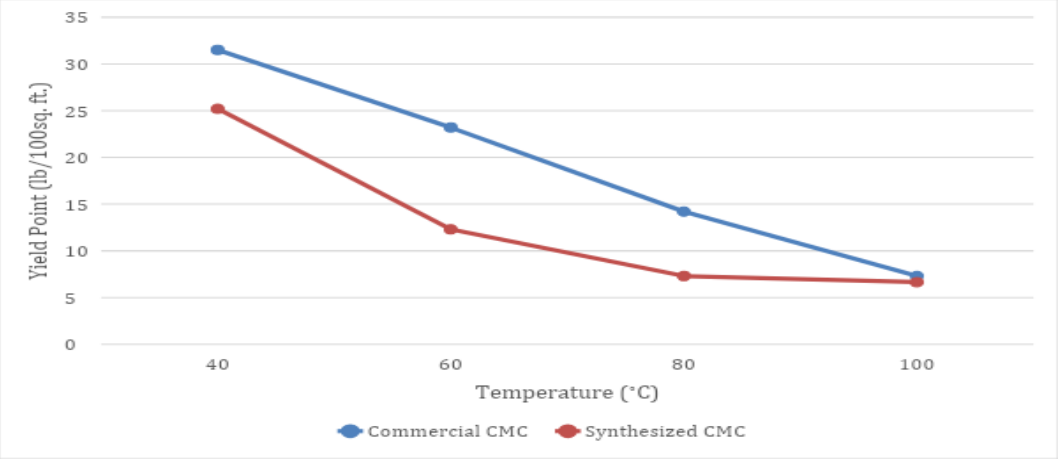


Figure 12: Comparison between Yield Point of Commercial CMC and Synthesized CMC at 1.5% Loading

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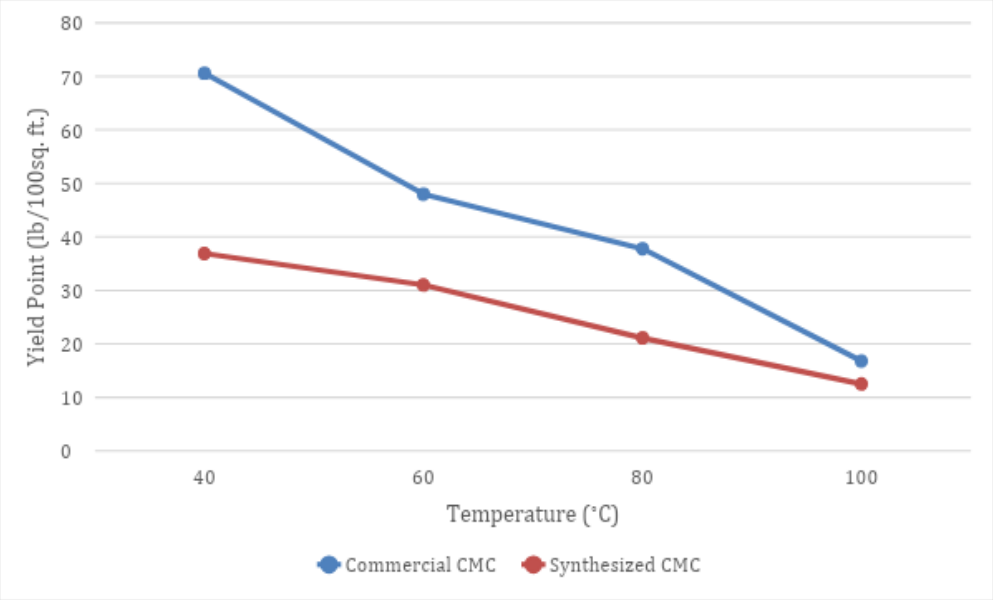


Figure 13: Comparison between Yield Point of Commercial CMC and Synthesized CMC at 2% Loading

Rheological Properties at Various Temperatures

The rheological properties; plastic viscosity, apparent viscosity, and yield point varied with changes in rotational speed and percentage loading.

From Fig. 2 to 6, the plastic viscosities of both the synthesized and commercial CMC showed a general decrease with an increase in temperature from 40°C to 100°C. There were a few outliers, though; like the observed increase in the plastic viscosity of both samples at 80°C in Fig. 3. When compared, the plastic viscosities of the drilling fluids made with the synthesized and commercial CMC were considerably similar at all temperatures and percentage loadings. The only two exceptions were the values at 40°C in Fig. 2 and at 100°C in Fig. 3.

Figures 6 to 9 describe the trend of the apparent viscosities of the drilling fluid samples made with synthesized and commercial CMC at different percentage loadings. There was a steady reduction in apparent viscosity values of the drilling fluid samples made with synthesized and commercial CMC as temperatures increased from 40°C to 100°C at 0.5%, 1% and 1.5% loading. However, at 2% loading, there was a large deviation from this trend. At this percentage loading, the fluid with commercial CMC started off with a low apparent viscosity value of 2.2cP at 40°C and was greatly increased to 9cP at 60°C. At higher temperatures of 80°C and 100°C, the apparent viscosity dropped down to approximately 0cP. The drilling fluid with the 2% loading of synthesized CMC, however, maintained a steady decrease until 100°C where it increased suddenly to 10.35cP. On the overall, the apparent viscosities of the drilling fluid samples made with synthesized and commercial CMC were similar at the various temperatures at 0.5%, 1%, and 1.5% loading.

From Fig. 10 to 13, the yield point showed a steady reduction with increase in temperature of both drilling fluid samples at all the percentage loading considered. These yield point values were comparable, especially at higher temperatures.

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Result of FTIR Analysis

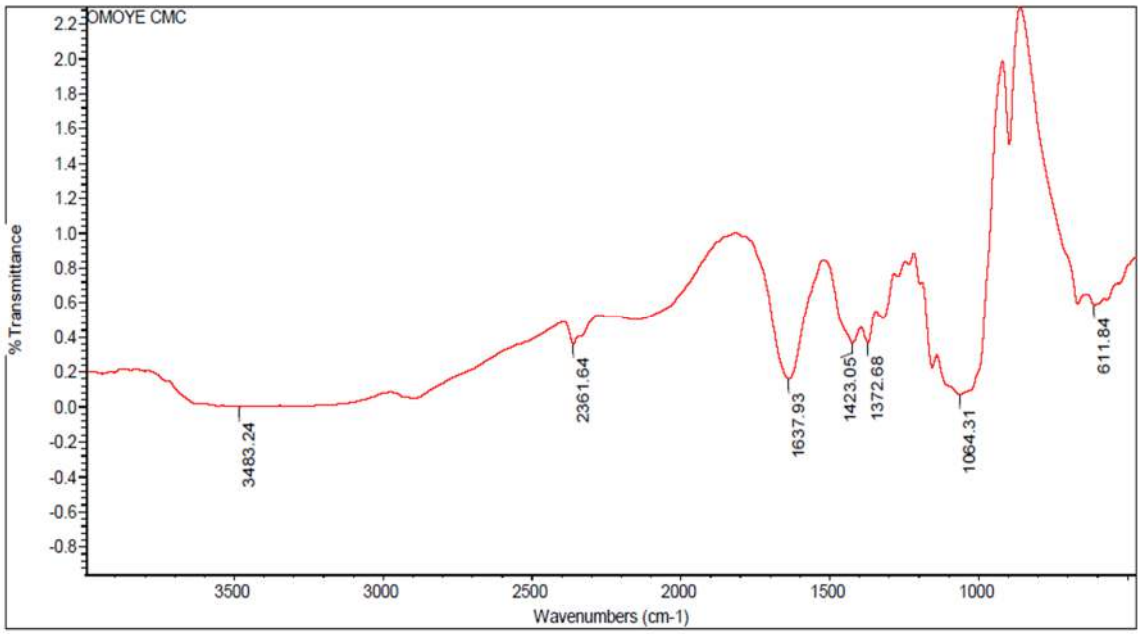


Figure 14: FTIR Spectroscopy Result for OPEFB-derived CMC sample

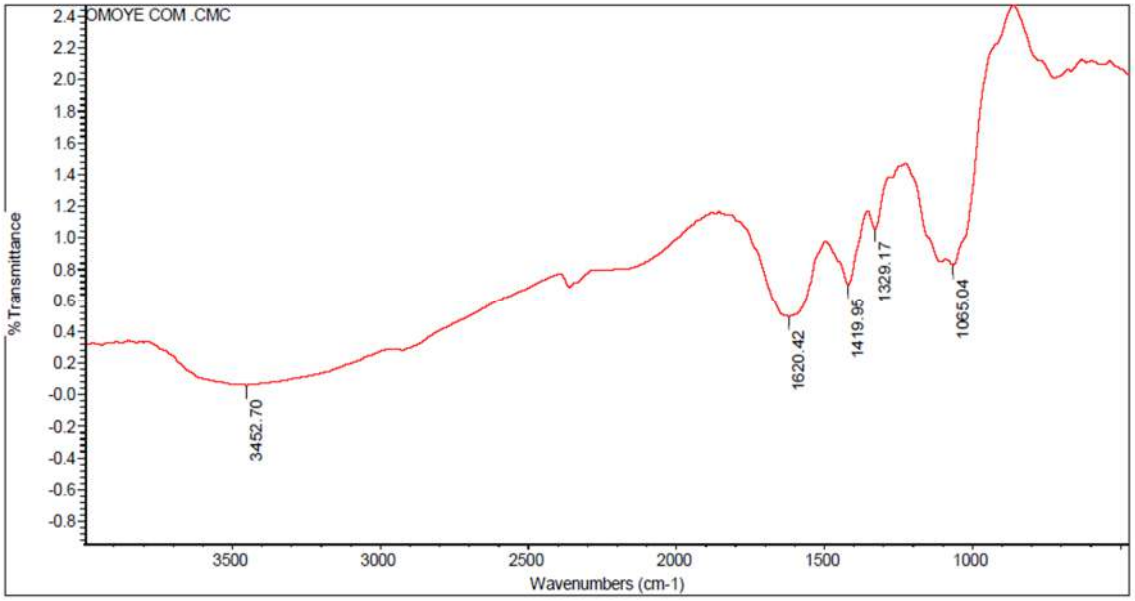


Figure 15: FTIR Spectroscopy Result for Commercial CMC sample

Both Fig. 14 and 15 shows the presence of the same functional groups as indicated by the peaks in the FTIR spectroscopy result chart. This result is in harmony with the work of Adel *et al.* [16] which reported that the FTIR analysis of CMC compounds for OH bands was seen in wave number 3400cm^{1}, CH_2 vibrations were seen in wave numbers 2900 and 1424cm^{-1}, and absorption of carboxyl group seen in wave number 1720cm^{-1}. It is further supported by the work of Suryadi *et al.* [17] which stated similar wavenumbers for hydroxyl (-OH), carboxyl (C=O), methylene (-CH_2-), and glycosidic (C-O-C) groups present in CMC standard.

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Table 2: Interpretation of Functional Group Corresponding to the FTIR Spectral Peak Values

Functional Groups	Wavenumber (cm^3)	
	OPEFB-derived CMC	**Commercial CMC**
-OH	3483.24	3452.70
C=O carboxyl	1637.93	1620.42
$-CH_2-$	1423.05	1419.95
C-O-C glycosidic	1064.31	1065.04

CONCLUSION

The successful synthesis and characterization of Carboxymethylcellulose (CMC) from OPEFB fibers, along with its comparison with commercial CMC, revealed striking similarities in both rheological properties and functional groups. These findings suggest that the OPEFB-derived CMC can serve as a viable substitute for the relatively expensive commercial CMC in water-based drilling fluid applications within the oil and gas industry. Further research avenues, should include comparing the OPEFB-synthesized CMC with semi-purified commercial CMC, exploring the degree of substitution, and evaluating gel strength as an additional rheological property.

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