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Original Article

The Innovative Green Drilling Application of Water-Based Drilling Mud Containing Pectin Biopolymer Extracted from Lemon Peels

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Abstract *- The quest for sustainable practices in the oil and gas industry has led to significant advancements in drilling technologies, focusing on green drilling operations, particularly in developing environmentally friendly drilling fluids. This study explores the innovative use of pectin biopolymer as an eco-friendly additive or viscosity builder for fluid loss control in water-based drilling mud. The work proceeds with the pectin extraction from dried lemon peels, pectin modification, drilling mud formulation and experiments to characterize the mud density, specific gravity, plastic viscosity, pH value, and Filtration Properties using filter loss method at temperatures of 25℃ and 250℃, and compared to a standard mud prepared with Carboxymethyl Starch (CMS). From the results, Pectin Mud (PEM) provides superior performance over CMS.*

***Keywords* -** *Drilling mud, Filtration properties, Green drilling, Lemon peels, Pectin biopolymer.*

1. Introduction

Drilling mud comprises a blend of the base fluid and various additives mixed in precise proportions to clean a drilled well, transport cuttings, lubrication and cool the drill string, wellbore wall consolidation, and formation pressure regulation (Agwu et al., 2021). However, for drilling mud to perform the abovementioned functions, the fluid properties must fall within international standards (Oneill et al. 2017). Two properties are mud rheology and filtration behaviour (ISO, 2008). Examining the rheological and fluid loss behaviour of drilling mud in down hole settings is pivotal for the success or failure of wellbore drilling operations. This significance stems from the deviations these properties experience from their original values when subjected to variations in temperature and pressure in subsurface conditions (Shah et al., 2010). Despite the higher performance of some traditional mud (Oil and synthetic based mud) in drilling operations, these muds contaminate water and soil, causing environmental harm (Laine et al., 2022). Water Based Drilling Muds (WBDM) are not associated with environmental issues (Prakash et al., 2021) but, in some cases, have existing limitations and efficiency problems (Bayat et al., 2021; Aftab et Al., 2020). As environmental protection requirements are becoming increasingly strict at drilling sites, the development of WBDM maintaining its optimal environmental friendliness with improved filtration and rheological behaviour is crucial for sustainable and efficient drilling operations (Wajheeuddin and Hossain, 2017). Non-toxic and degradable biopolymers have attracted the scientific community's attention to enhance sustainable drilling and improve the swelling control, rheology, and fluid loss control of WBDM (Murtaza et al., 2024). Currently, pectin biopolymers have been studied and successfully applied in WBDM by scholars like (Chike et al., 2020 and Prem et al., 2022). The result shows its ability to improve rheology and filtration control through chemical modifications compared to existing mud, making them attractive candidates for green drilling technologies.

To optimize the performance of pectin as an additive in mud formulation, it has to be modified. The modification of pectin aims at tailoring the properties to meet the specific requirements of drilling muds (Li et al., 2015; Chike-Onyegbula et al., 2012). However, it is important to note that modifications should be made carefully to maintain pectin's eco-friendliness and biodegradability, ensuring it remains a sustainable drilling mud additive (Tatongjai and Lumdubwong, 2010). In this study, biodegradable drilling mud was prepared using modified pectin polymer (PEM) extracted from dried lemon peels. Evaluation tests like mud density, plastic viscosity, pH, specific gravity, yield point, and fluid loss characterization were conducted and compared to existing mud containing Chemically Modified Starch (CMS).

2. Materials and Methods

2.1. Materials

Lemon peels were obtained from a local market of Imo state in Nigeria. Carboxymethyl starch, Hydrochloric acid, distilled water isopropanol, Calcium phosphate, Bentonite clay, Soda ash, Caustic soda, Borax, Potassium chloride, Barite & Bentonite and Xanthan gum, were got from Nigeria.

2.2. Methods of Preparing Samples

2.2.1. Extraction of Pectin

In this research, pectin was extracted from dried lemon peel using acid extraction method. The dried grounded lemon peels were digested and boiled in 0.01mol of HCl for a period of 60minutes at 95°C. The mixture was then stirred while been heated maintaining the above conditions. After 60minutes, the heated mixture was pressed and filtered through cloth to recover the extract which was further filtered through Whatman No 3 filter paper with the aid of a funnel to obtain a light brown viscous filtrate. The viscous extract (pectin) was coagulated by adding absolute isopropanol. The coagulated pectin was collected and stored for further analysis.

2.2.2. Modification of Pectin

The modification was done so as to pre-gelatinize the extracted pectin. During the modification, **s**ome calcium water was firstly prepared by missing the calcium phosphate and water in the ratio 1:5, and this meant that 100g of calcium phosphate was added to 500ml of distilled water, and was well stirred. The stirring was done at interval of 10 minutes for about 40 minutes. The extracted pectin of weight 250g was added to the mixture and the whole solution was stirred in a mixer at intervals for about 12 hours. At this point, there was formation of a gel, which was allowed to dry and solidify under atmospheric temperature. The solidified gel was transformed into powdered form by grinding.

2.2.3. Preparation of Drilling Mud

The pectin polymer in powered form was used to prepare water-based drilling mud. The water based polymer drilling mud tagged PEM in this work was prepared by mixing 4.0g, 8.0g, 15.0g, 20.0g and 25.0g of the powdered pectin polymer respectively in 520ml of water to obtain 0.01-0.05g/ml concentrations of pectin in water for the PEM mud sample. Firstly, the mud (PEM) was prepared by mixing bentonite clay, water, and then the pectin polymer was added slowly to avoid formation of limps, while stirring takes place. Soda ash, caustic soda and borax were included. Also, for comparison, chemically modified Carboxymethyl starch was used to prepare standard water-based drilling mud of the same concentrations and more additives, and the standard mud is tagged CMS in this work.

2.3. Experimental Methods

Experimental methods refer to the specific techniques and procedures used in this experiment to gather data and test hypotheses. This method aims to establish data such as mud density, specific gravity, pH values, plastic viscosity, yield point, and filter loss method for filtration properties of the pectin mud.

2.3.1. Mud Density Experiment

The mud density of each concentration of the mud samples CMS and PEM was determined using a mud balance (scale) consisting of a fixed-volume mud cup with a lid on one end of a graduated beam and a counterweight on the other. A slider weight was moved along the beam, and there was an indication of a bubble when the beam was level. The density was read at the point where the slider weight sat on the beam level.

2.3.2. Specific Gravity Test using Mud Weight Method

The Specific Gravity (SG) was determined using the mud weight in kilograms per cubic meter (Kg/m^3) method to determine mud density. Here, the density was determined by a weighing balance (mud balance) and graduated beam (graduated cylinder). Then, the specific gravity of each concentration of mud samples was determined using equation (1) (Okumo & Isehunwa, 2007).

$$\text{Specific Gravity} = \text{Mud Density (kg/m}^3) \div 1000 \qquad [1]$$

2.3.3. pH Values

The pH values of the mud samples were determined using a pH meter scale based on API **s**pecifications. The pH meter had a glass membrane measuring electrode and **r**eference electrode, which read from 0 to 14. The pH also compensates for the temperature automatically. Each mud sample containing a particular additive concentration was subjected **t**o the pH measurement after shaking for about an hour (Ukachukwu et al., 2010).

2.3.4. Plastic Viscosity

A brook-field viscometer was used to measure the plastic viscosity. Each mud sample of each **c**oncentration was subjected to two different shear stresses in revolution per minute, that is, 3000rpm shear stress (R300) and 600rpm shear stress (R600).

The plastic viscosity was determined by subtracting the value obtained under the 300rpm shear stress from that of the 600rpm shear stress. This was performed for each mud sample’s concentrations (Sulaimon et al., 2017; Ukachukwu et al., 2010).

2.3.5. Yield Point

The yield point of the drilling mud was calculated by subtracting the plastic viscosity (PV) from **t**he R300 reading of each mud of each concentration. Then, to change the units to reciprocal **s**econds, the rpm was multiplied by 1.7 values (Sulaimon et al., 2017).

Table 1. Formulation for PEM mud (New mud with Pectin Polymer

S/N	Materials	Quantity/Weight	Functions
1	Water	520ml	Base fluid
2	Bentonite	30.0g	Weighting agent
3	Caustic soda	0.3g	pH adjustment
4	Soda ash	0.3g	Hardness control
5	Borax	2.0g	Preservative
6	Pectin polymer (PEM)	4.0g, 8.0g, 15.0g, 20.0g, 25.0g	Filtration/Fluid loss control, Viscosity agent, and inhibitor.

Table 2. Formulation for CMS mud (Standard mud with Carboxymethyl starch)

S/N	Materials	Quantity/Weight	Functions
1	Water	520ml	Base fluid
2	Xanthan gum	2.4g	Viscosity agent
3	Potassium chloride	20g	Inhibitor
4	Barite	48.4g	Weighting agent
5	Bentonite	30.0g	Weighing agent
6	Caustic soda	0.3g	pH adjustment
7	Borax	2.0g	Preservative
8	Soda ash	0.3g	Hardness control
9	Carboxymethyl starch (CMS)	4.0g, 8.0g, 15.0g, 20.0g, 25.0g	Filtration/fluid loss control

2.3.6. Filter Loss Method for Filtration Properties

The filtration properties were determined by the filter loss method. The experiment was done at room temperature 25℃and a higher temperature 250℃. Each mud sample of 500ml of 0.04g/ml polymer concentration was poured into the chamber of the standard filter press under a constant pressure of 100psi at room temperature. The filtrate volume (fluid loss) was collected in a graduated cylinder. In a further experiment, the same quantity or volume of mud was subjected to heating at a higher temperature of 250℃ in an oven, and a filtration test was carried out after re-mixing. The volume of fluid loss or filter loss (filtrate volume) was collected, read and recorded. Each experiment was carried out at different time intervals in minutes. According to the American Petroleum Institute, the Filter Loss method was based on these models in Equations 2 and 3 (Chike et al., 2020; Sulaimon et al., 2017; Ukachukwu et al., 2010).

$$V = St^{½} \qquad [2]$$

Where V is the filtrate volume or fluid loss or filter loss, S is the sorptivity of fluid, and t is the filtration time in minutes. The filtration rate was analyzed based on the theoretical mode below.

$$\Phi(R) = \Phi_o \exp^{-Dt} \qquad [3]$$

Where Φ_o and Φ are initial and final filtration rates, respectively, D is fluid diffusivity, and t is time in minutes.

3. Results and Discussion

3.1. The Results of Mud Density, Specific Gravity (SG) and pH Values

Figure 1 is a bar chart showing the comparison between the mud densities of CMS and PEM over concentration. It was observed that the mud density of PEM is higher than the mud density of CMS at any given concentration. Higher mud density helps control formation pressure & enhances wellbore stability. This proves that PEM has a better control of hydrostatic pressure and wound give a better hole cleaning result than CMS mud.

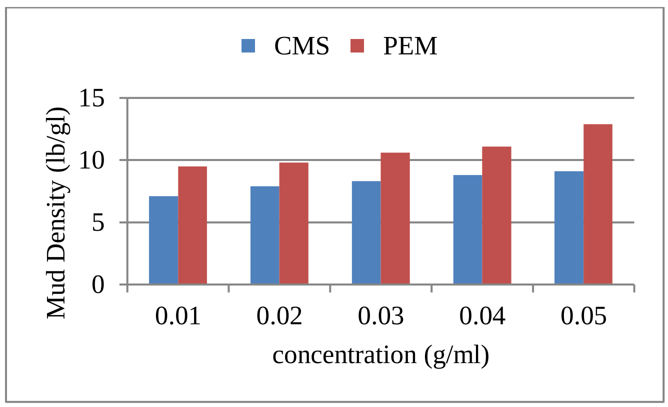

Fig. 1 A plot of mud density versus concentration for the mud samples, CMS and PEM

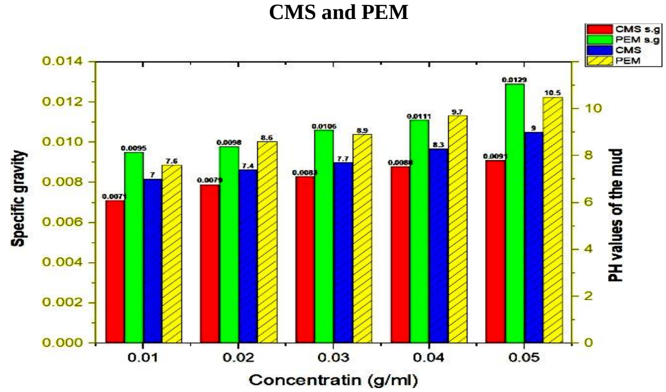

Fig. 2 Plot of Specific Gravity (SG) and pH value versus concentrations of CMS and PEM mud samples

A critical look at Table 3 and Figure 2 indicates an increase in specific gravity and pH value of the mud samples at an increase in concentration. At any given concentration, the specific gravity and pH value of PEM are higher than those of CMS. Therefore, PEM shows a more favorable pH value, which can be considered more suitable for preventing corrosion and maintaining clay and shale stability than C.

Table 3. Results for Mud Density, Specific Gravity (SG) values and pH values

Concentration (g/ml)	Mud Density		Specific Gravity		pH Values	
	CMS	PEM	CMS	PEM	CMS	PEM
0.01	7.1	9.5	0.0071	0.0095	7.0	7.6
0.02	7.9	9.8	0.0079	0.0098	7.4	8.6
0.03	8.3	10.6	0.0083	0.0106	7.7	8.9
0.04	8.8	11.1	0.0088	0.0111	8.3	9.7
0.05	9.1	12.9	0.0091	0.0129	9.0	10.5

3.2. Plastic Viscosity and Yield Points Results

Table 4. Result of the experiment on plastic viscosity and yield points of the mud

Concentration (g/ml)	Plastic Viscosity		Yield Point	
	CMS	PEM	CMS	PEM
0.01	40.15	78.27	63.00	132.00
0.02	45.81	80.11	70.00	143.02
0.03	52.55	87.65	81.00	150.04
0.04	58.00	91.99	85.01	159.13
0.05	61.33	98.06	92.31	165.00

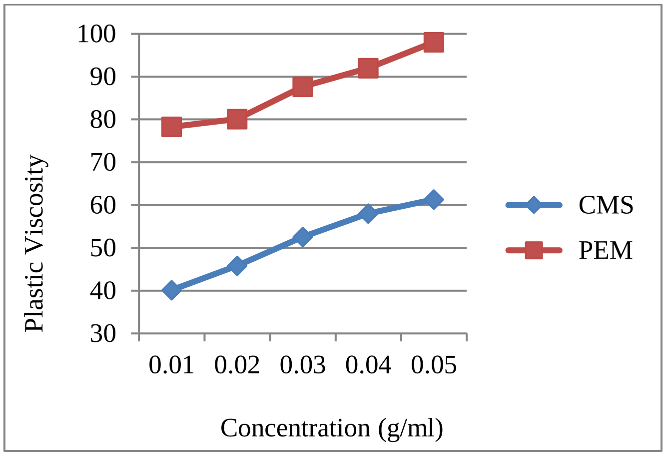

Fig. 3 A plot of plastic viscosity versus concentrations of the mud, MS and PEM

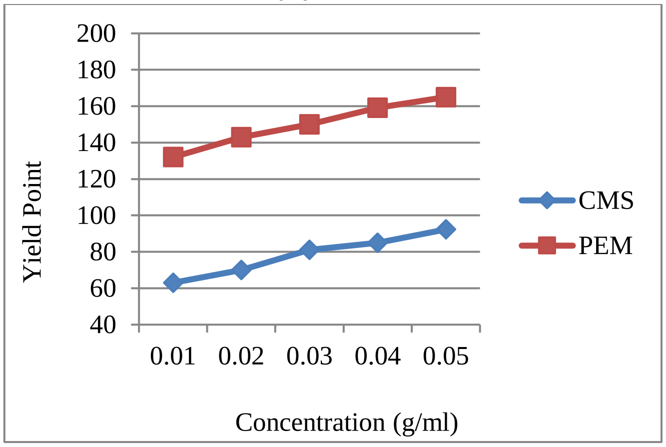

Fig. 4 A plot of yield point versus concentrations of the mud, CMS and PEM

Figure 3 shows that at any given concentration, the plastic viscosity of PEM is far higher than that of CMS at any given concentration. This shows that pectin is a better viscosifying additive than Carboxymethyl starch.

Figure 4 shows that the yield point of PEM & CMS increases with concentration. At any concentration point, the yield point of PEM is greater in value than that of CMS mud. It is clear that the higher the yield point value, the more stable the drilling mud is, as it could suspend cuttings effectively.

Table 5 and Figure 5 show that CMS's fluid loss volumes are slightly higher than that of PPM at 25°C, and the fluid loss volume of the mud increases with an increase in the square root of time. It should be noted that lower fluid loss minimizes filtrate invasion, thereby reducing the risk of formation damage and preserving formation integrity during operations.

The plot in Figure 6 shows that the rate of filtration of PEM is lightly lower than CMS as both decrease with time.

This proves that pectin polymer mud (PEM) gives a better filtration control than the standard mud produced with chemically modified carboxyl methyl starch From Table 6 and Figure 7, it was observed that at high temperatures (250°C), the fluid loss volume of the mud samples increases with an increase in square root of time, and fluid loss volume is higher in CMS when compared to PEM.

3.3. Filter Loss Results

Table 5. Results from the Filter Loss Experiment for Muds at Room Temperature, 25°C

Time (Mins)	Square Root of Time $T^{1/2}$ (Mins)	PEM		CMS	
		Fluid Loss volume V (ml)	Rate of Filtration dv/dt (volume/time)	Fluid Loss volume V (ml)	Rate of Filtration dv/dt (volume/time)
5	2.23	111.00	22.2	123.00	24.60
10	3.16	128.00	12.8	144.00	14.40
15	3.87	147.00	9.80	161.00	10.73
20	4.47	159.00	7.95	174.00	8.70
25	5.00	178.00	7.12	186.00	7.44
30	5.47	189.00	6.30	201.00	6.70
35	5.91	199.00	5.69	219.00	6.26
40	6.32	210.00	5.25	224.00	5.60
45	6.70	216.00	4.80	233.00	5.83
50	7.07	220.00	4.40	241.00	4.82

Table 6. Results from the filter loss equipment for the mud at a high temperature, 250°C

Time (Mins)	Square Root of Time $T^{1/2}$ (Mins)	PEM		CMS	
		Fluid Loss volume V (ml)	Rate of Filtration dv/dt (volume/time)	Fluid Loss volume V (ml)	Rate of Filtration dv/dt (volume/time)
5	2.23	133.00	26.6	156.00	31.20
10	3.16	154.00	15.40	178.00	17.80
15	3.87	174.00	11.60	194.00	12.93
20	4.47	191.00	9.55	216.00	10.80
25	5.00	211.00	8.44	230.00	9.20
30	5.47	223.00	7.43	242.00	8.07
35	5.91	237.00	6.77	253.00	7.23
40	6.32	249.00	6.23	264.00	6.60
45	6.70	255.00	5.67	269.00	5.78
50	7.07	261.00	5.22	274.00	5.48

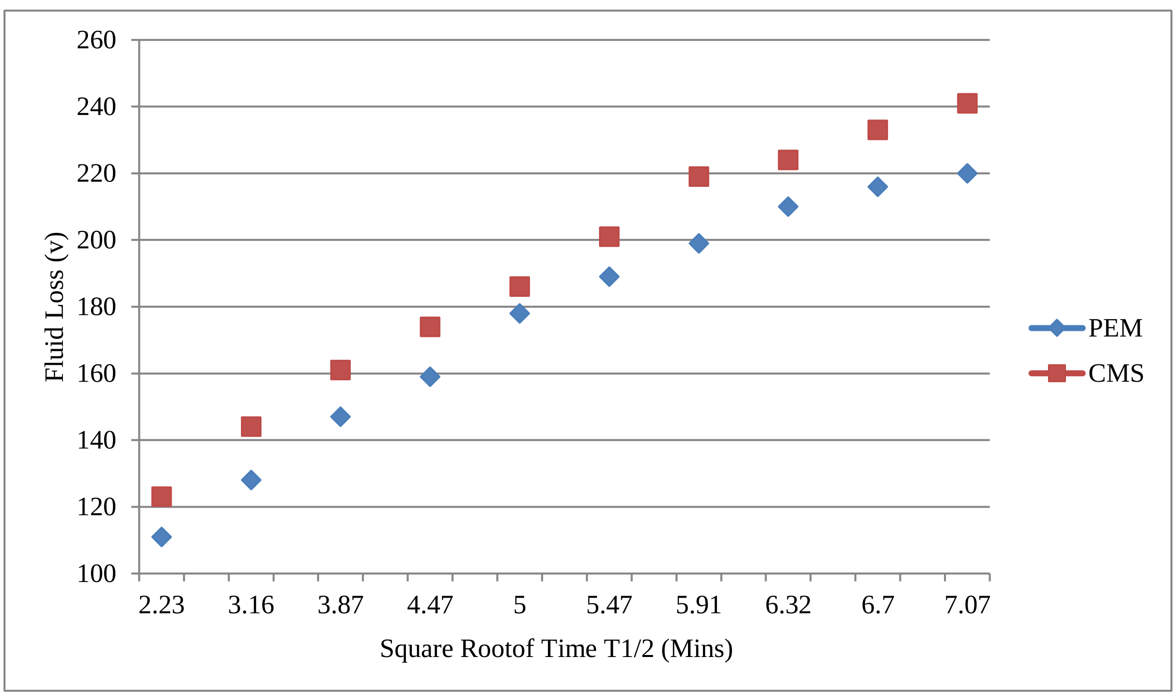

Fig. 5 Plot of fluid loss versus square root of time for the muds at room temperature, 25°C

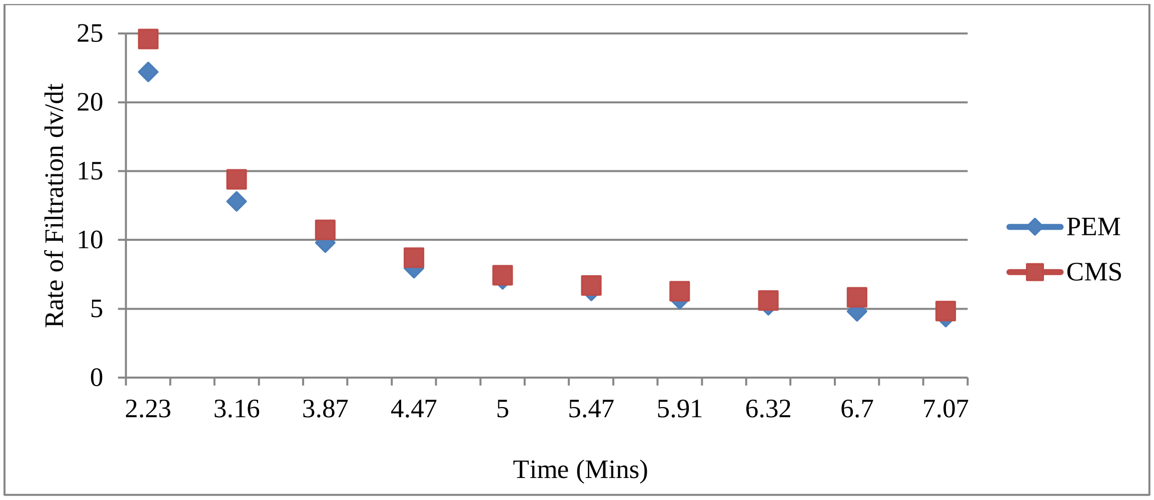

Fig. 6 Plot of the filtration rate versus time for the muds at room temperature, 25°C

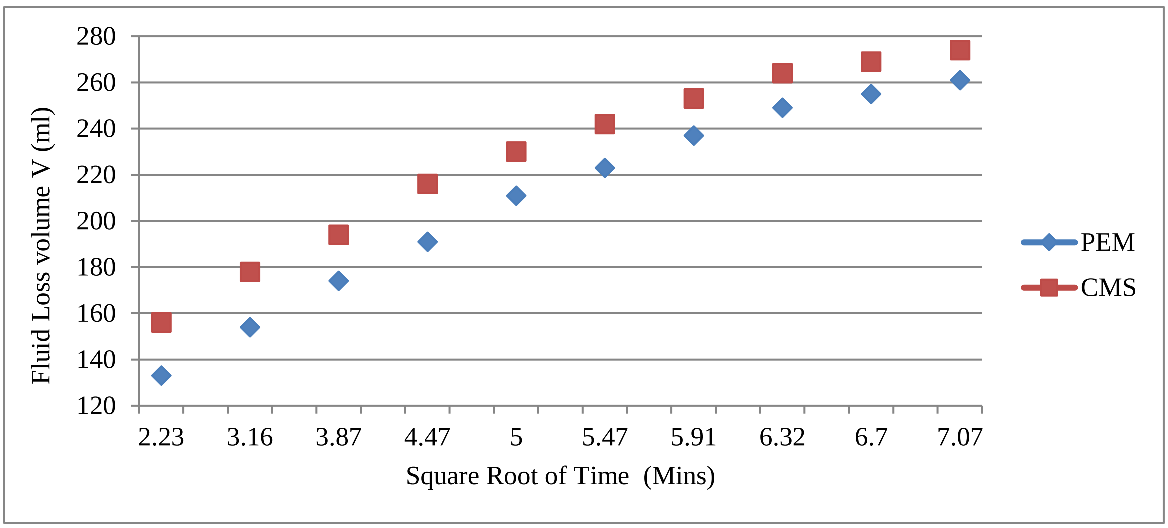

Fig. 7 Plot of fluid loss versus square root of time at high temperature, 250°C

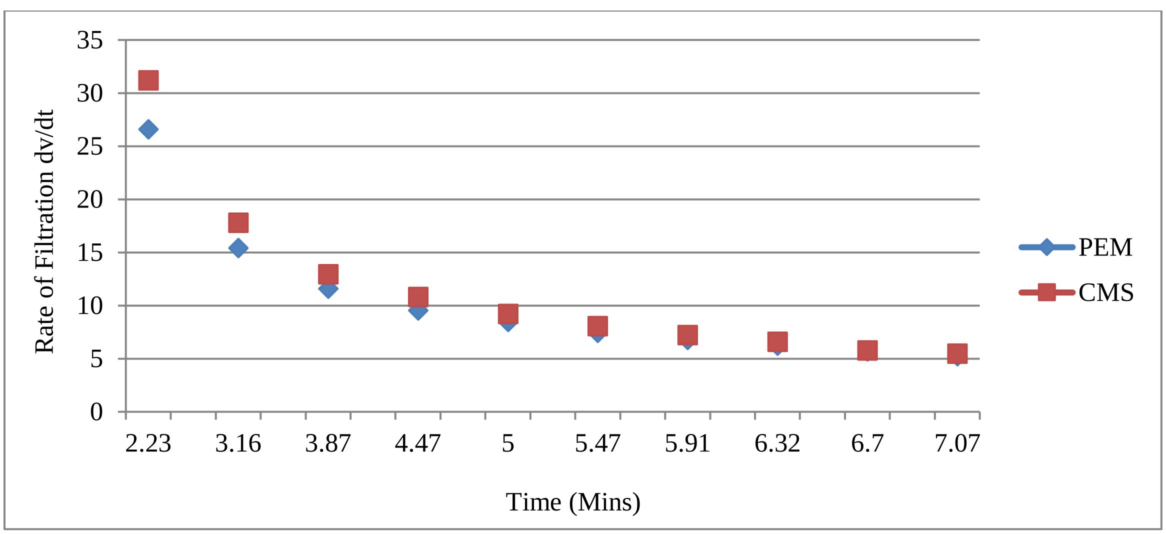

Fig. 8 Plot of rate of filtration versus time at high temperature, 250°C

This shows that PEM is a better fluid loss controlling additive, even at high temperatures, than CMS. Figure 8 shows that the filtration rate for both PEM and CMS samples decreases speedily initially within the first 15 minutes and then decreases slowly with an increase in time above 15 minutes. The rate at which filtration occurs in CMS is higher than that of PEM, indicating that filtration is better with PEM, even at higher temperatures.

4. Conclusion

Biodegradable water-based drilling mud prepared with pectin polymer (PEM) has shown better filtration behavior than mud prepared with chemically modified Carboxyl Methyl Starch (CMS). This implies that the PEM has more fluid loss control capacity and enhanced rheological influence at higher temperatures than the widely applied CMS mud. By leveraging the filtration behaviour and environmental footprint, integrating pectin biopolymer into drilling mud formulations represents a pivotal advancement towards sustainable drilling practices. Further studies, research and development efforts are crucial to optimize pectin performance across different drilling conditions, thereby expanding their adoption within the industry.

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