

Causticized Application of Low-Carbon Lignite for PH And Fluid Loss Control in An Aqueous Mud System

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Abstract

Lignite, a low-carbon coal variety, is prevalent in numerous global locations. Its application in the oil and gas drilling industry, particularly for controlling pH and fluid loss in aqueous mud systems, has garnered significant attention. Through causticization, lignite can be modified to enhance its performance in these systems. The present study undertakes an assessment of the efficacy of Nigerian lignite in mitigating fluid loss within water-based mud systems. Laboratory analyses were executed in accordance with American Petroleum Institute standards to ascertain the rheological attributes and filtration properties of the developed drilling muds, which contained varying levels of lignite. Furthermore, the performance of the lignite was juxtaposed with that of carboxymethylcellulose (CMC), a traditional fluid loss reduction agent, to elucidate its potential advantages. It was noted that as the lignite concentration escalated from 0.5g to 5g, there was a corresponding reduction in fluid loss, ranging from 0.3ml to 7ml, in contrast to the conventional additive (CMC). Nigerian lignite emerges as an exceptional fluid loss control agent, effectively diminishing the thickness of the mud cake. The integration of Nigerian lignite into water-based drilling fluids led to a significant reduction in both filtrate loss volume and mud cake thickness during drilling activities. The mud cake generated within the water-based mud system incorporating the Nigerian lignite sample was characterized by its thinness and smoothness. Progressive gelation was observed in the mud formulations. Additionally, it is inferred that causticized lignite functions as mud thinner. With increasing lignite concentration, mud viscosities exhibited a decline. Lignite also contributed to the stabilization of the drilling muds' pH across various concentrations. The mud's pH remained constant at 13. Therefore, it is affirmed that Nigerian lignite possesses the potential to serve as a pH modifier for water-based mud. This research underscores the viability of utilizing locally sourced lignite, fostering sustainable methodologies within the oil and gas sector and potentially diminishing operational expenditures.

Introduction

Drilling fluids cool and lubricate the drill bit, carry and float cuttings from the hole to the surface, release the cuttings at the shale shaker, minimize formation damage, and wall the wellbore with an impermeable filter cake. Drilling fluid loss is the most notable technical challenge in drilling, and static and dynamic filtration are regulated by the permeability of the filter cake and should be managed for efficient drilling (Herzraft et al. 2001; Oleas et al. 2008). Fluid loss control is the process of preventing or minimizing the loss of drilling or completion fluids to the formation during well operations. Fluid loss can cause various problems, such as formation damage, reduced productivity, increased operational costs, and compromised well control (Bourgoyne et al. 1991; Caenn et al. 2011). Various forms of materials are used as fluid loss control additives. They include polymers or gels, particles

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or fibers (Uwaezuoke et al. 2022), nanoparticles (Uwaezuoke 2022; Al-Awadhi 2019), and biopolymers (Uwaezuoke et al. 2017) both in water-based and oil-based muds. But they must conform to standards such as the American Petroleum Institute specifications. However, Nigerian lignite is a type of coal that has been proposed as a potential fluid loss control additive in water-based drilling mud. Lignite is the lowest coal grade and has the least concentration of carbon. It can control fluid loss, stabilize shale, and improve hole cleaning. Its application in drilling muds can be done in a variety of techniques. In dry application, lignite is added directly to the drilling mud formulation. It can also be pre-solubilized; where it is dissolved in another solution before addition to the mud formulation. Also, in a causticized form of application, the addition of caustic soda or any alkaline solution to lignite to maintain consistent pH is achieved. Causticization releases the humic acid content in lignite to serve better as fluid loss control agents (Apostolidou 2020). In causticized lignite, impurities are removed, and reactivity is improved. This technique yields a lignite that can function as thinner. Research findings have been presented on the suitability of Nigerian lignite and other alternatives as fluid loss control materials in drilling fluid formulations. Al-Hameedi et al. (2019) examined the effect of adding lignite nanoparticles to water-based drilling fluid. They showed that lignite nanoparticles can significantly reduce fluid loss and increase the temperature stability of the drilling fluid. They also suggested that lignite nanoparticles can be used as a cost-effective and environmentally friendly additive. A comparison of Nigerian lignite as a fluid loss control additive in water-based drilling mud to conventional additives has been presented. Okon et al. (2020) compared the performance of Nigerian lignite with CMC, an organic polymer. The fluid loss was reduced by Nigerian lignite by 64.89% at 20g per 350ml mud concentration. Nigerian lignite had a lower filter cake thickness, higher resistance to water penetration, and good thermal stability. They concluded that Nigerian lignite could be a viable and environmentally friendly alternative to CMC in aqueous mud systems. Onuh, et al. (2017), compared Nigerian lignite with coconut shell and corn cob biowastes. It was observed that the mixture of Nigerian lignite and corn cobs had a lower fluid loss than the corn cobs and lignite considered separately. It was also more effective than coconut shells.

Materials and Methods

Sample Collection. The lignite was obtained from Kaduna State, Northern Nigeria, and stored in a clean and airtight glass container to avoid moisture and contamination. The lignite sample was further processed by crushing with glass mortar, ground using a Hamilton Beach blender and sieved with a no. 200 mesh to get the fine grain size of 74 μm . It was stored in an airtight glass bottle for use. The materials and laboratory apparatus used are presented in **Tables 1** and **2**.

Table 1—Mud composition and function(s).

Product	Density (g/cc)	Function(s)
Water	1	Base fluid
Bentonite	2.6	Mud Viscosifier
NaOH	2.13	pH control
CMC	1.6	Fluid loss control
PAC-R	1.5	Viscosifier and mild fluid loss control
Lignite	1.5	Fluid loss and pH control
CaCO ₃	2.5	Densifier
Barite	4.48	Densifier

Table 2—Laboratory apparatus/equipment used.

Laboratory apparatus/equipment	Function(s)
Baroid mud balance	Measurement of mud density
Meter rule	Measurement of filter cake thickness
Hamilton Beach blender	Blending of the lignite
Hamilton Beach mixer	Mixing of the mud compositions
Fann V-G meter	Measurement of viscosity and gel strength
API LT/LP filter press with 2.7 μ m pore size API filter paper	Fluid loss control test
pH meter	pH measurement
SEM-EDS	Surface morphology and elemental composition
TGA/DTA	Measures weight changes due to temperature change

Characterization of the Lignite. The lignite was characterized to obtain the elemental composition, surface morphology, and weight changes due to temperature variation.

SEM/EDS. The Scanning Electron Microscope – Energy Dispersion Spectroscopy (SEM) Phenom Prox (by Phenom-World Eindhoven) was used to carry out the morphology and elemental analyses. With sticky carbon tape, the sample was placed in the Aluminium stub. The sample was insulated using gold and then grounded electrically. Each sample was then labeled on its stub and then dried in the oven at 140 °F for 3 hours. The nitrogen line was opened at 50 psi and the vent button was pressed to fill the area with nitrogen for proper purging of the chamber. The sample holder stub was then placed in the sample chamber holes, the door was shut, and the rotary pump was picked. At about 35 minutes, the vacuum of 5×10^{-5} Pa was created. The filament light was switched on and the monitor automatically switched on. At this stage, the peak accelerator voltage read 15kV and the filament burned out. Specific wavelengths of X-rays are emitted when electron beams excite surface atoms which characterize the element's atomic structures. A dispersive energy detector analyzes the emissions, assigning elements, which yields atomic composition. The lowest scan mode of 10x was picked and the TV scan clicked. The magnification was then taken to 1000x at a slow scan, 2000, 3000 to 10,000. The image was then saved. This is known as energy-dispersive X-ray spectroscopy (EDS), and it is used for specimen surface composition analyses.

TGA/DTA Analyzer. TGA of the biomass residues was performed using a TG analyzer (TGA-Q500 series, TA instruments) at standard pressure. The sample was first dried to a constant weight at 103°C to remove all moisture present then pulverized and silver to 50 microns size before the analysis. About 10.0 mg of each sample was placed in platinum crucibles in the furnace chamber of the TGA and heated linearly at given heating rates, (5, 10, 15, 20, 25, or 30 °C/min) from ambient room temperature to 950 °C. Nitrogen gas was opened and allowed to flow throughout the chamber of the furnace at a flow rate of 30 mL/min. This was used to purge the system and provide an inert atmosphere for the experiments. The Thermogravimetric analysis then produced a curve, that shows the effect of temperature (or time), presented on the x-axis, on the weight of the sample (the y-axis). The weight is usually expressed in terms of the percentage of the sample that remains, versus the weight at the start of the experiment, at a given temperature/time. The results also include a second y-axis on the graph which presents the data for the first derivative of the TGA curve. This is known as the Derivative Thermogravimetric Analysis (DTA) curve and represents the rate of change of mass concerning temperature. The DTA curve often allows for easier visual interpretation of the data, as periods of large mass change can be seen with more clarity.

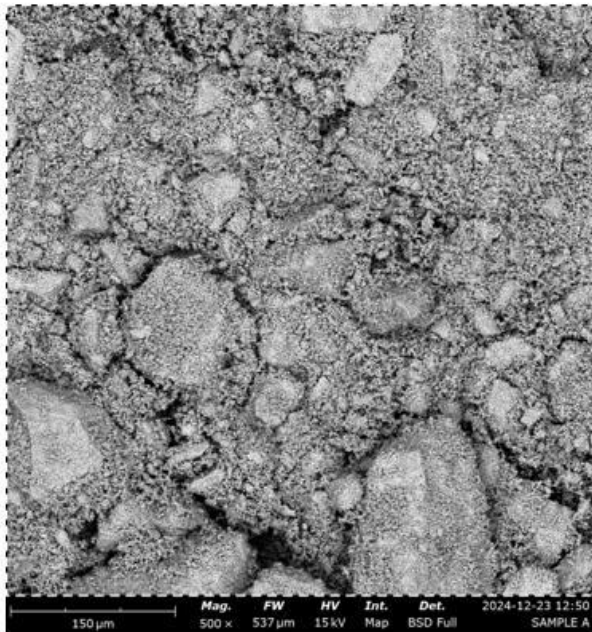
Causticizing of the Lignite. The purpose of the sieved and ground lignite was to expose the surface area. The sieved lignite was causticized using NaOH of about 11% concentration in water to facilitate the reaction. It was an allowed time of 45 minutes since NaOH was designed to be a composition of mud for pH control. A waiting time of 2-4 hours is normally allowed for other applications. It was not added directly in the formulation; so, impurities were also removed in the process. The reaction was done in a glass vessel by agitating the powder in a glass with NaOH solution using a magnetic stirrer, while ambient temperature was maintained. It was later filtered and allowed some time to dry at ambient temperature. Using the API specifications for water-based muds, the formulations were prepared by mixing with the Hamilton beach mixer using the mixing order (**Table 3**) for testing in the viscometer and the API LT/LP filter press.

Table 3—Mixing order and time.

Product	Density g/cc	Unit	Mixing order	Mixing time mins	Grams	Mls
Water	1	Bbl	1	4		341.51
Bentonite	2.6		2	5	15	5.769
NaOH	2.13		3	3	0.5	0.235
CMC	1.6		4	2	1.5	0.938
PAC-R	1.5		5	3	0.2	0.133
Lignite	1.5		6	2	0.5, 1, 3, 5	0.333
CaCO ₃	2.5		7	2	1.5	0.6
Barite	4.48		8	5	28	6.25
						350

Results

It has been noted through careful observation and analysis that lignite, as depicted in **Figures 1 and 2**, exhibits characteristics of a low-carbon fuel. Additionally, the particles of lignite are found to be highly inhomogeneous, displaying a tendency to clump together because of being wetted by moisture content. This agglomeration is further influenced by the particles' varying sizes, which contribute to bridging effects. These bridging tendencies are a direct consequence of the heterogeneous nature of the particle sizes present in lignite, leading to a complex structure that can pose challenges in handling and processing.



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
20	Ca	Calcium	55.39	63.19
15	P	Phosphorus	17.61	15.52
40	Zr	Zirconium	3.72	9.66
7	N	Nitrogen	14.29	5.70
11	Na	Sodium	2.87	1.88
38	Sr	Strontium	0.50	1.26
6	C	Carbon	3.39	1.16
12	Mg	Magnesium	1.17	0.81
13	Al	Aluminium	0.73	0.56
14	Si	Silicon	0.33	0.27
16	S	Sulfur	0.00	0.00
17	Cl	Chlorine	0.00	0.00
30	Zn	Zinc	0.00	0.00
47	Ag	Silver	0.00	0.00
26	Fe	Iron	0.00	0.00
22	Ti	Titanium	0.00	0.00
19	K	Potassium	0.00	0.00

Figure 1—SEM/EDS spectroscopy of the lignite showing the elemental composition.

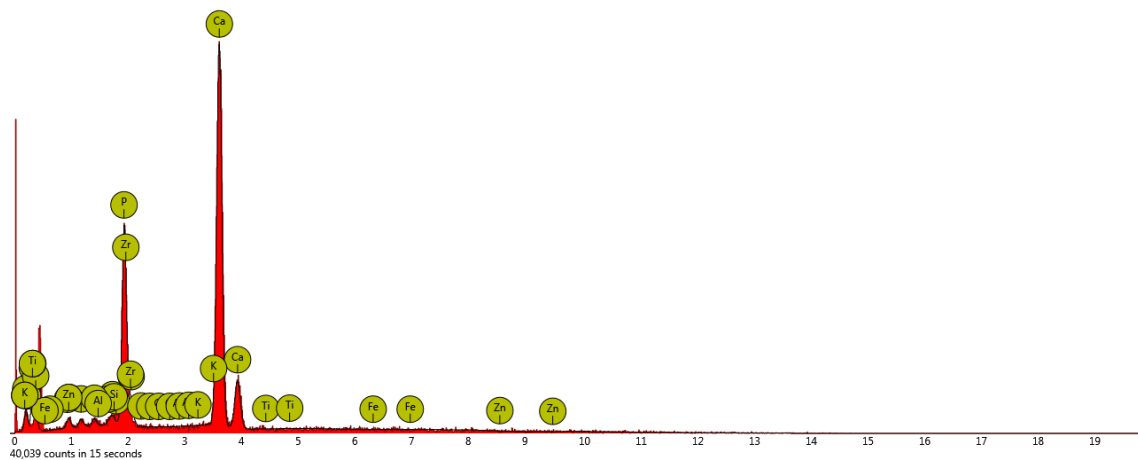


Figure 2—SEM/EDS result showing dominant elements.

There are three weight loss steps due to moisture, volatiles, and fixed carbon respectively (**Figure 3**). The first observable weight change occurred between 25.56°C to 100°C. That represents a change due to the evaporation of moisture in the lignite. The second stage of weight change is due to the material decomposition of the volatile components due to temperature from around 200°C to about 350°C. The third stage occurred from about 400°C to a peak value of around 470°C. All impurities would have decomposed as well. It is deduced that the lignite can withstand a temperature of up to 200°C while in use as a mud additive, with the volatile components being retained. Hence, it can also be used in high-pressure high-temperature (HPHT) wells.

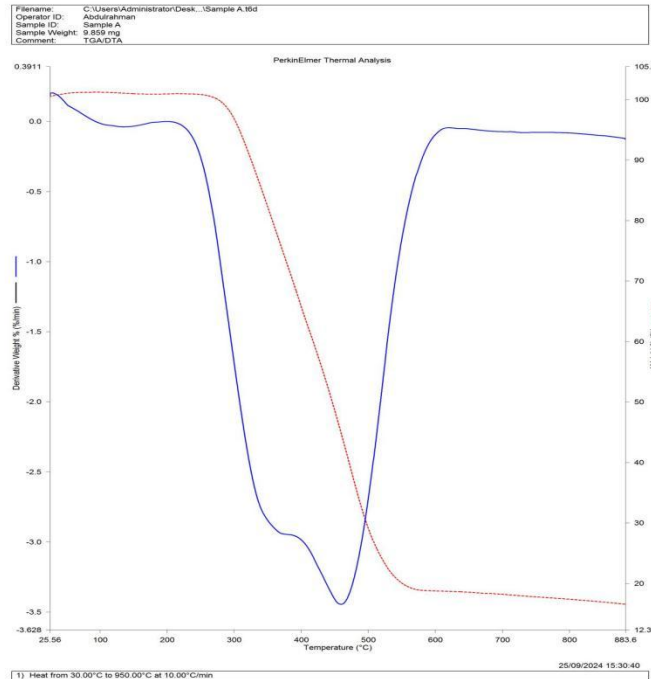


Figure 3—TGA/DTA test result.

Physical Properties. The fundamental fluid characteristics are explicitly presented in **Table 4**. It is evident that the addition of lignite played a significant role in maintaining the pH stability of the drilling mud across a range of different concentrations, as detailed in **Table 5**. From the data presented, one can infer that the causticized lignite functioned effectively as a mud thinner, as indicated in **Table 6**. As the concentration levels of the lignite were elevated, a corresponding reduction in mud viscosities was observed. This phenomenon was analogous to the behavior exhibited by the control mud sample. Nevertheless, it was noted that at the higher concentration of 5 grams, the effect was less pronounced compared to the results obtained at 0.5 grams, 1 gram, and 3 grams, respectively. Consequently, this could necessitate an increase in pump pressure to facilitate the circulation of the mud that was formulated using lignite, as outlined in **Table 7**. To manage this behavior, it might be essential to incorporate additional thinning agents into the mixture.

Table 4—Properties of the control mud.

Physical properties	Value	API specifications
pH	13	9.1-12
Mud Density (ppg)	9	-
Filtrate Volume (ml)	6.9	<12
Mud Cake Thickness (mm)	0.0625	<2mm
Temperature (°C)	28	-

Table 5—Properties of the formulations with lignite.

Physical Properties	Concentration of lignite				API specifications
	0.5g	1g	3g	5g	
pH	13	13	13	13	9.1-12
Mud Density (ppg)	9.1	9.1	9.1	9.1	-
Filtrate Volume (ml)	9.3	8.9	8.8	7	<12
Mud Cake Thickness (mm)	0.0625	0.0625	0.0625	0.0625	<2mm
Temperature (°C)	28	28	28	28	-

Table 6—Rheological behavior of the formulations at LT/LP.

RPM	Concentration of lignite				
	Control	0.5g	1g	3g	5g
3	2.5	4	6.5	3.5	2.5
6	3.5	4	7	3.5	4
30	7.5	6	9.5	6.5	5
60	11	8.5	10	7.5	6.5
100	15	10	12	10	8
200	24	13.5	17.5	15	12
300	31.5	15.5	21	19	15
600	49.5	24	30	29.5	24.5

Table 7—Gel strength measurement.

Time	Concentration of lignite sample				
	Control	0.5g	1g	3g	5g
@10secs.	5	7	10	7	7
@10mins.	13	12	21	14	10

Conclusions

This study has brought out different perspectives on the behavior of Nigerian lignite in drilling fluids. The data generated from the different experiments highlights the physical properties of mud samples with the lignite as a fluid loss agent. The pH obtained and maintained in the formulations closely matches the acceptable range of API limits for drilling fluids between 9.1 to 12. Knowing the pH of the mud is critical because it affects the solubility of the organic materials like thinners and the dispersion of clays present in the drilling fluid. An increase from 0.5g to 5g of the lignite sample shows a decrease in the fluid loss volume respectively. The fluid loss volumes are also within the API specifications. The thickness of the mud cake and its integrity can reveal that the lignite sample deposited on the cake with optimum concentration established an effective seal with all values within far less than the API specifications. The lignite did not inhibit the gelling of the mud. However, the progressive gel, which is the situation where the 10secs gel strength and the 10mins gel strength have dissimilar values might not be favorable to the circulating system. The reason is that the pressure of the pump might be increasingly altered to be able to push the mud. This might require changing the piston to a smaller area for an increase in pressure to

be achieved. This might happen at the expense of the adequate flow rate requirements which are achieved with larger pistons. Hence, alternative thinners might be incorporated in the mud as a requirement.

Nomenclature

ANSI	=	American National Standards Institute
API	=	American Petroleum Institute
CMC	=	Carboxymethyl cellulose
HPHT	=	High-Pressure High-Temperature
LT/LP	=	Low-Temperature Low-Pressure
SEM-EDS	=	Scanning Electron Microscopy/Energy Dispersive Spectroscopy
TGA/DTA	=	Thermogravimetric Analysis and Differential Thermal Analysis

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Conflict of Interest

The author(s) declare that they have no Conflicting interests.

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