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Comparative Investigation of the Effect of EggshellPowder and Calcium Carbonate as Additivesin Eco-Friendly Polymer Drilling Fluids

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Abstract: Drilling fluid systems have seen the addition of new natural additives in recent years in order to replace traditional additives, improve their rheological properties, and ensure the functionality of the drilling fluid taking into account health and environmental factors. This paper aims to study and compare the effect of the addition of eggshell powder (ESP) as a native and local additive and calcium carbonate (CC) as a traditional and conventional additive on the rheological and filtration properties of the drilling fluid system based on Na-bentonite of the region of Meghnia (Algeria). The test results of 10, 20, and 30 g of CCwerecompared to the same concentrations of ESP.The findings showed that the CC with various concentrations (10, 20, and 30 g) increases the rheological properties and the mud density while it reduces the filter cake and the fluid loss values which are desirable, calcium carbonate had aslightly higher effect on the pH. The obtained results following the addition of ESP with different ratios revealed that the latter has a considerable impact on the plastic viscosity, the yield point, the gel strength, and the cake thickness. Additionally, the effect of the presence of eggshell as an additive in pH, fluid loss, and mud density was studied; we observed a slight increase in the pH, while the fluid loss values decreased. However, the mud density values increased. Beyond 20 g of eggshell, the properties of the mud becomeundesirable. Moreover, this study contributes tonewfindings and suggests that the utilization of waste food and local goods in drilling mud mixtures has a bright future respecting the percentages of use.

Keywords: calcium carbonate; eggshell powder; rheology; filtration; eco-friendly polymer; water-based-drilling fluid

1. Introduction

Drilling fluid is one parameter of a successful drilling operation [1]. Previously, it was considered only as a vehicle for transporting debris to the surface, whereas old drilling fluid systems were used uniquely with water and clay [1,2], these systems had poor characteristics that may cause ineffective drilling operations [3]. However, many difficulties can confront this operation, such asthe fact thatsuperalloys' low thermal conductivity is a problem for machining properties because heat accumulation at the cutting zone leads to elevated temperatures, contributing to the diffusion mechanism and adhesive effect on cutting tools [4,5].

The current drilling fluid systems contain different chemicals, they are incorporated to enhance their functions and improve their properties, these compounds includebentonite as a viscosifier, polymers for filtration control, and calcium carbonate as a weighting agent. From an economic point of view, the cost of some of these are expensive; moreover, they are harmful to the environment and can pose a health risk; barite is a carcinogen, and may provoke eye and skin irritation [6,7].

Water and wastewater treatment have become increasingly important in recent years due to growing concerns about the environment and public health [8,9]. Effective treatment of wastewater is essential to ensure that contaminated water is safe for reuse or release into the environment. In response to these concerns, the field of wastewater treatment and pharmacology has seen the introductionof natural compounds, such as magnetite-decorated sulfate cellulose nanoparticles used as an efficient system for water remediation from amine pollutants [10–13], as well as the investigation of these additives in drilling fluid systems to minimize the cost of the drilling operation and to valorize the natural resources with increased global environmental awareness [14–19]. Many works have been published describing the use of natural additives to water-based drilling fluids such as grass powder, pomegranate peels, banana peels, mandarin peels, eggshells, and snail shells [6,20–23].

Hossain et al. [24] mentioned that the grass powder at various particle sizes improved the rheological properties while reducing the pH of the drilling fluid. Al-Hameedi et al. [6] concluded that the banana peel powder increases the chloride content and improves the filtration characteristics. Al-Hameedi et al. [22] suggested the possibility of using mandarin peel powder as a pH reducer, particularly at high concentrations. Olamigoke et al. [23] interpreted the effect of the addition of eggshell andsnail-shellpowders on the rheological and filtration properties of KCl polymer water-based drilling fluid. It was confirmed that both powders at low concentrations demonstrated a deflocculating effect.

Furthermore, extensive studies in the literature investigated the use of ESP as an additive in drilling fluids because it is considered an activated absorbent regarding pollution problems [25]. Nevertheless, in the literature, there are a few or rare studies that discussed the difference between the effects of ESP and CC. Indeed, Iqbal R. et al. [26] replaced primordial commercial CC with eggshell-derived CC, and they found that the latter was more efficient in terms of rheological properties. However, using heating the eggshells under a temperature ranging from 300 to 500 °C improved their efficiency and dissipated the unpleasant smell. On the other hand, Al-Hameedi et al. [27] demonstrated that drilling fluid blends containing ESP outperformed the drilling fluid blends including the barite $BaSO_4$ and $CaCO_3$ in terms of mud weight improvement at all concentrations. Al-Hameedi et al. [28] revealed that the ESP can be investigated as a weighting agent, viscosity elevator, and fluid loss control material. Additionally, the others showed that adding a 0.75% (5.25 gm) concentration of ESP to spud mud using standard API mud tests had no significant impact on the alkalinity and slightly lowered the pH at a 1.5% (10.5 gm) concentration.

The aim of this study focused on the effect of adding both a conventional additive (CC) and a natural waste additive (ESP) as weighting agents in the water-based mudon the rheological and filtration properties. Furthermore, we investigated of the feasibility of substituting ESP as a cost-effective and environmentally friendly component in the biopolymer/Algerian Na-bentonite water-based drilling fluid.

2. Materials and Methods

2.1. Chemicals and Materials

Seven water-based drilling fluid samples were prepared using Na-bentonite from the region of Meghnia as a viscosifier, sodium hydroxide for alkalinity control, potassium chloride as an inhibitor, carboxymethyl cellulose (CMC) as a viscosifier, and potato starch as fluid loss control, and we varied concentration of CC and ESP as a weighting agent as shown in Table 1. Viscometer FANN35, mud balance, pH meter, and filter press (LPLT) were used to realize the experimental work.

Table 1. Composition of water-based drilling fluid samples.

Component	Amount	Function
Water	330 mL	Base fluid
Na-Bentonite	22.4 g	Viscosifier
NaOH	1 g	Alkalinity control
KCl	1 g	Inhibitor
CMC	1 g	Viscosifier
Potato starch	6.6 g	Filtration control
CC	(10, 20, and 30 g)	Weighting agent
ESP	(10, 20, and 30 g)	Weighting agent

2.2. Preparation of Additives

2.2.1. Potato Starch

The potatoes were washed thoroughly with fresh water, peeled, and cut into pieces. Subsequently, water was added to the pieces of potato; thereafter, the mixture wasfiltrated through iron and fabric strainers. After 30 min, a precipitate of potato starch wasobtained and the water excess was eliminated. The potato starch was then dried in the air, blended again to get a uniform particle size, and stored in amber glass bottles protected from light. A similar protocol has been applied to potato waste [29,30]. The obtained yield reached 280 g of starch for 2 kg of potatoes.

2.2.2. EggshellPowder

Eggs were boiledto extract the shells. Theywere then broken down into smaller pieces after extraction to give a large surface area for optimal drying. Because eggshells have small water content, theywere dried in the sun for 2 days. Then, theywere ground using a mechanical grinder and sieved to a size of 250 mm before being stored in a clean Petri dish [23]. The obtained yield reached 69 g from 10 eggs.

2.2.3. Preparation of Na-Bentonite

In a 1 L Erlenmeyer flask, 30 g of raw bentonite was mixed with 800 mL of distilled water and swirled at room temperature for 2 h. The above mixture wasthen given 600 mL of a sodium chloride solution (1 M) and stirred for 48 h at room temperature. After that, the product wascentrifuged and rinsed with distilled water until the Cl^-ions were entirely removed. The silver nitrate test was used to confirm the absence of Cl^-ions. After drying in the oven at 105 °C, the resultingNa-bentonitewasground to obtain a homogenous particle size [31].

2.3. Characterization

The prepared materials were characterized by Fourier infrared (FTIR) spectra using a Shimadzu 1240 FTIR spectrometer; the analysis was performed in the range of 4000–400 cm^{-1}. The samples were ground into thin disc pellets after being dissolved in KBr. A Bruker D8 diffractometer with CuK radiation operating at 40 kV and 30 mA was used to perform the X-ray diffraction (XRD) experiment to examine the crystalline structure aspect and crystallinity level of the samples. The XRD patterns were taken with a 5°/min scanning rate in the ranges of 3–60° and 10–80°.

2.4. Experimental Procedure

The drilling fluid formulations were prepared using different concentrations of CC and ESP. The suspensions were prepared using 330 mL of distilled water containing 22.4 g of Na-bentonite and 1 g of caustic soda, 1 g of potassium chloride, 1 g of carboxymethylcellulose(CMC), and 6.6 g of potato starch as a base reference fluid while varying the amount of CC and ESP (10, 20, and 30 g). The as-obtained suspensions were agitated mechanically for 4 h, rested for 24 h, and then agitated slowly for 1 h before taking measurements (to achieve a relatively unstructured state and a homogenous mixture). The rheological properties such as plastic viscosity (PV), apparent viscosity (AP), yield point (YP), and initial and final gel strength were determined with viscometer FANN 35 with (3–600 rpm) speeds at ambient conditions (25 °C). The density of the drilling mud was measured by a balance model 140 and the pH values were measured with pH/ORP while the filtration properties were measured by the LPLT filter press. Table 2 shows the properties of the formulations before adding CC or ESP.

Table 2. The reference fluid's properties.

Property	Plastic Viscosity (cP)	Yield Point (cP)	Gel_0 (lb/100 ft^2)	Gel_{10} (lb/100 ft^2)	Fluid Loss (mL)	Filter Cake (mm)	Mud Density (ppg)	pH
Value	11.3	28.1	15	21	6.5	1.7	7.7	9.16

The following equations have been used to determine the plastic viscosity (PV), the apparent viscosity (AV), and the yield point (YP), respectively:

$$PV = \theta_{600} - \theta_{300} \text{ (in cP)} \tag{1}$$

$$AV = \theta_{600}/2 \text{ (in cP)} \tag{2}$$

$$YP = \theta_{300} - PV \text{ (in lb/100ft}^2) \tag{3}$$

where

AV: apparent viscosity (cP = mPa·s);
PV: plastic viscosity (cP = mPa·s);
YP: yield point (lb/100 ft^2);
θ_{600}: shear stress at 600 rpm;
θ_{300}: shear stress at 300 rpm.

3. Results and Discussions

3.1. XRD Analysis

The XRD patterns of the as-prepared materials are illustrated in Figure 1a showing that the raw and Na-bentonite clay reveals several peaks corresponding to the montmorillonite and quartz phases, which is consistent with JCPDS card No. 00-046-1045 [32]. Table 3 lists the corresponding structural parameters. This technique can be used to identify the crystallographic structure c and to determine the sheet-to-sheet distance after the thickness of the sheet has been subtracted. Similar peaks to those of raw bentonite can be seen in the XRD of the treated clay with Na^+ with changes in the position and broadening, this can be due to the chemical modification treatment. The peak position is clearly shifted towards lower than 2 theta from 6.77 to 5.64 2θ (°), indicating an expansion of the unit cell lattice and confirming the intercalation of Na^+ within the parent phase of montmorillonite clay. The interlayer distances have been determined and listed in Table 3 from the perspective of quantification. It should be noted that for raw and treated bentonite, the interlayer distance d(001) has been increased significantly by almost 15.37%, i.e., from 13.07 to 15.68 Å. This finding can be explained by the sodium ions replacement of inter-lamellar cations in bentonite with a relatively larger diameter.

Figure 1b depicts the crystallinity of the extracted starch from the potato indicating the presence of both amorphous and crystalline phases; the XRD pattern of starch exhibits a halo with few diffraction peaks, demonstrating its semi-crystalline nature. The diffraction peaks at 15.11°, 15.43°, 17.10°, 19.15°, 22.23°, and 23.91° revealed a typical type B and A structure model and they are indexed as (021), (120), (012), (220), (131), and (041) [33–36].

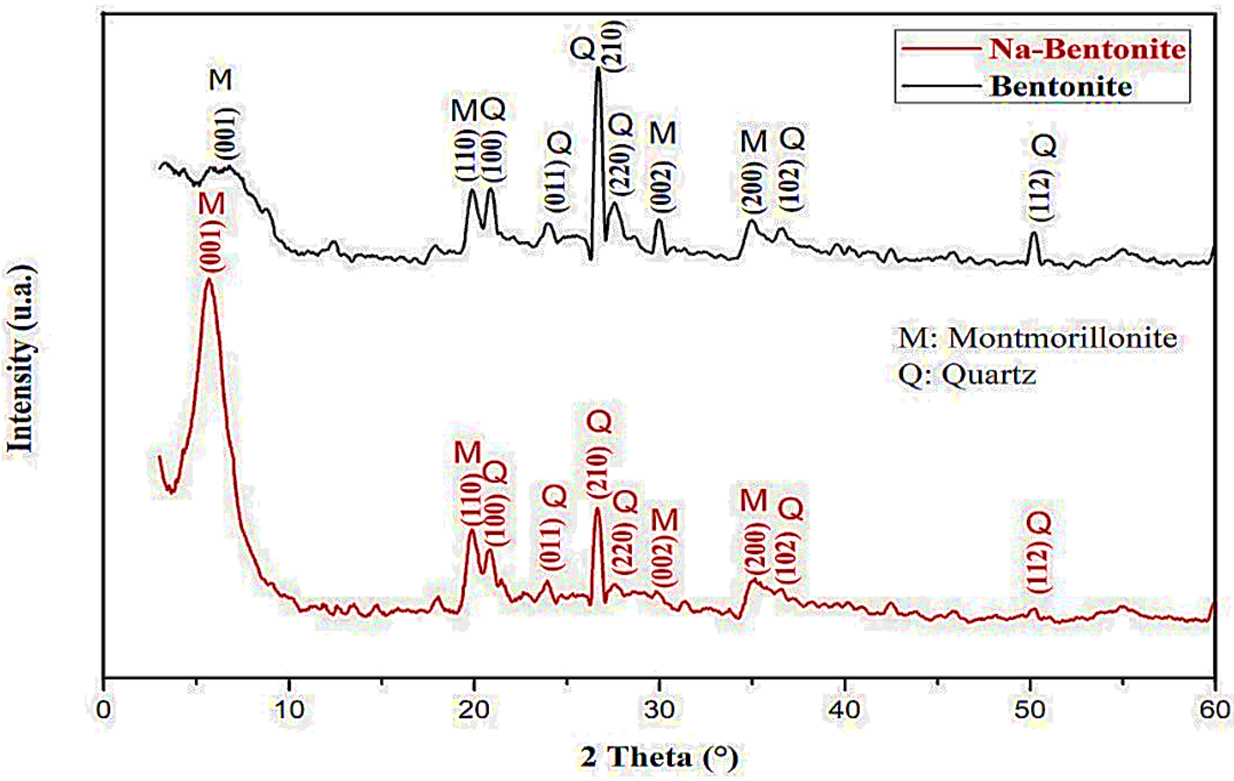
The crystallite size (D) was determined using the renowned Scherrer equation [37], and the related results are shown in Table 3:

$$D = \frac{0.9\,\lambda}{\beta \cos\theta} \quad (4)$$

where λ is the X-ray wavelength (1.5418 Å), β is the full width at half maximum of the diffraction peak, θ is the diffraction angle of the peak, and 0.9 represents a constant depending on the particles' shape.

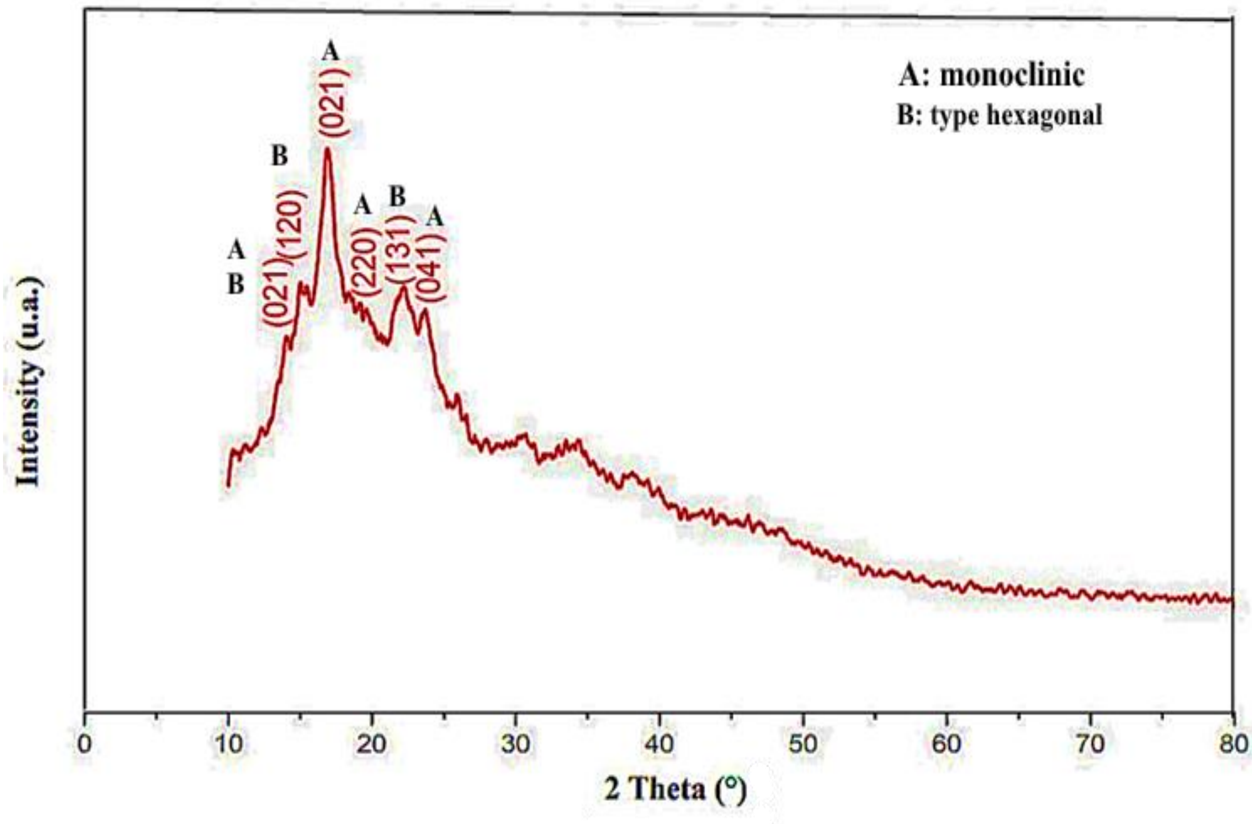
From the obtained mean size value, it can be highlighted that after treatment, the mean crystallite size ($\overline{D}$) of bentonite decreased by 2.86%. This behavior can be due to the chemical content of the bentonite layers, which were altered with Na+ activation. Further, quartzwas more resistant to Na^+ treatment, as evidenced by the fact that quartz crystal size remained stable.

The XRD analysis in Figure 1c displays the qualitative phase of ESP. The analysis of the powder showed that the sample's main component was the thermodynamically stable calcite $CaCO_3$ phase. The characteristic peaks in Figure 1c appeared to be all well-fitted with $CaCO_3$, demonstrating the eggshell's significant hardness. Through this work, one can conclude that it is possible to produce $CaCO_3$ with a rhombohedral structure above 90%, despite being consistent with some earlier works [38–41].



(**a**)

Figure 1. *Cont*.



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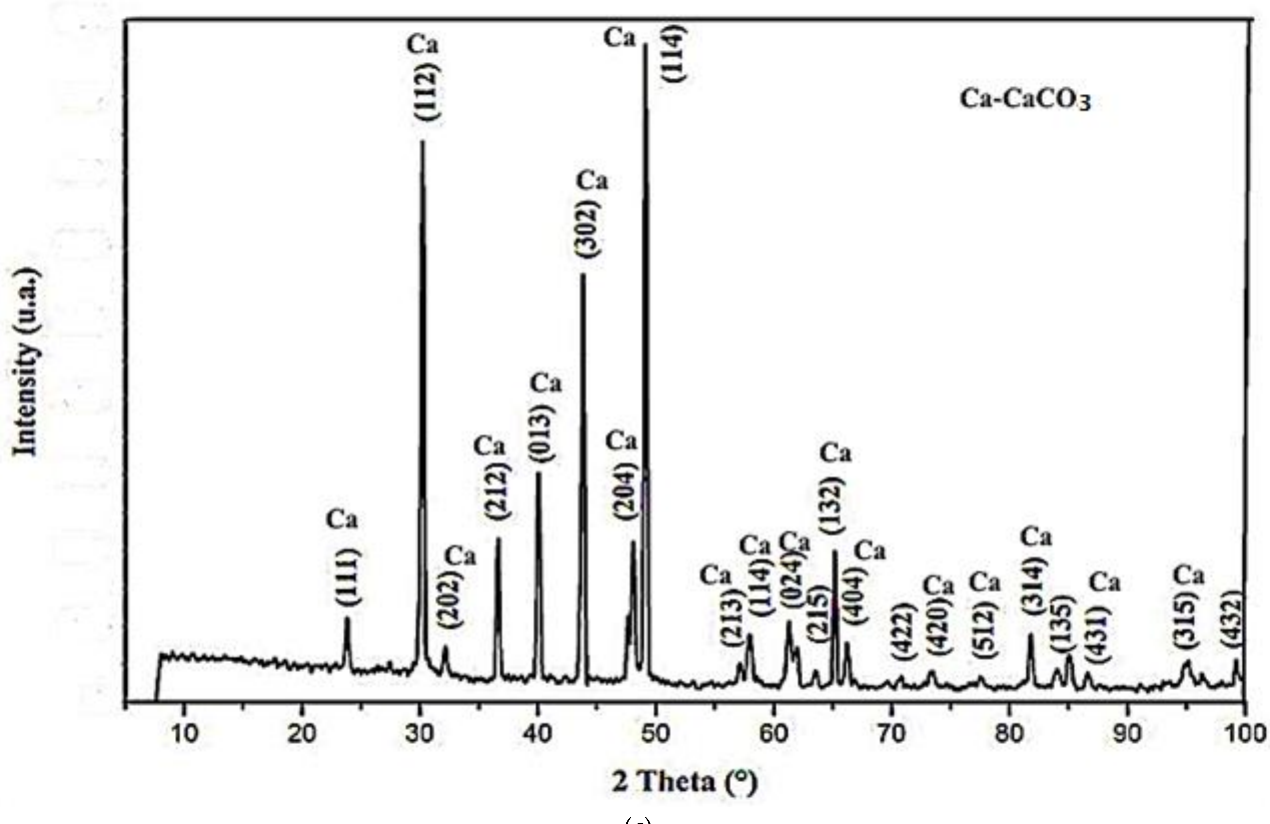


(**c**)

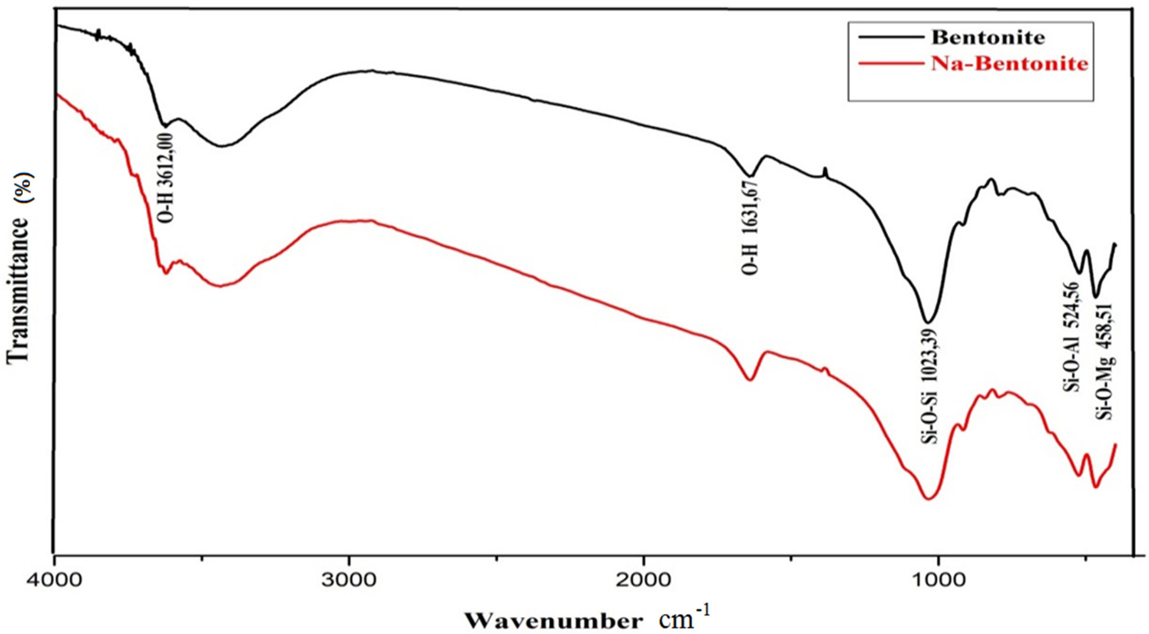
Figure 1. XRD patterns of (**a**) raw bentonite and Na-bentonite treated with NaCl, (**b**) extractedstarch, and (**c**) eggshell powder.

Table 3. Structural and parameters of bentonite and Na-bentonite.

Sample	2θ (°)	(hkl)	d_{hkl} (Å)	D (nm)
Bentonite	6.77	(001)	13.07	4.30
	19.85	(110)	4.45	13.93
	20.81	(100)	4.33	4.28
	24.02	(011)	3.78	5.14
	26.70	(210)	3.43	11.36
	27.59	(220)	3.32	14.05
	30.00	(002)	3.08	7.15
	34.91	(200)	2.69	6.07
	36.60	(102)	2.58	14.36
	50.25	(112)	2.00	10.79
				$\overline{D}$ = 9.14
Na-Bentonite	5.64	(001)	15.68	5.23
	19.85	(110)	4.45	10.59
	20.81	(100)	4.33	4.28
	24.02	(011)	3.78	5.14
	26.70	(210)	3.43	11.34
	27.59	(220)	3.32	12.35
	30.00	(002)	3.08	8.75
	34.91	(200)	2.69	5.10
	36.60	(102)	2.58	14.26
	50.25	(112)	2.00	11.39
				$\overline{D}$ = 8.84

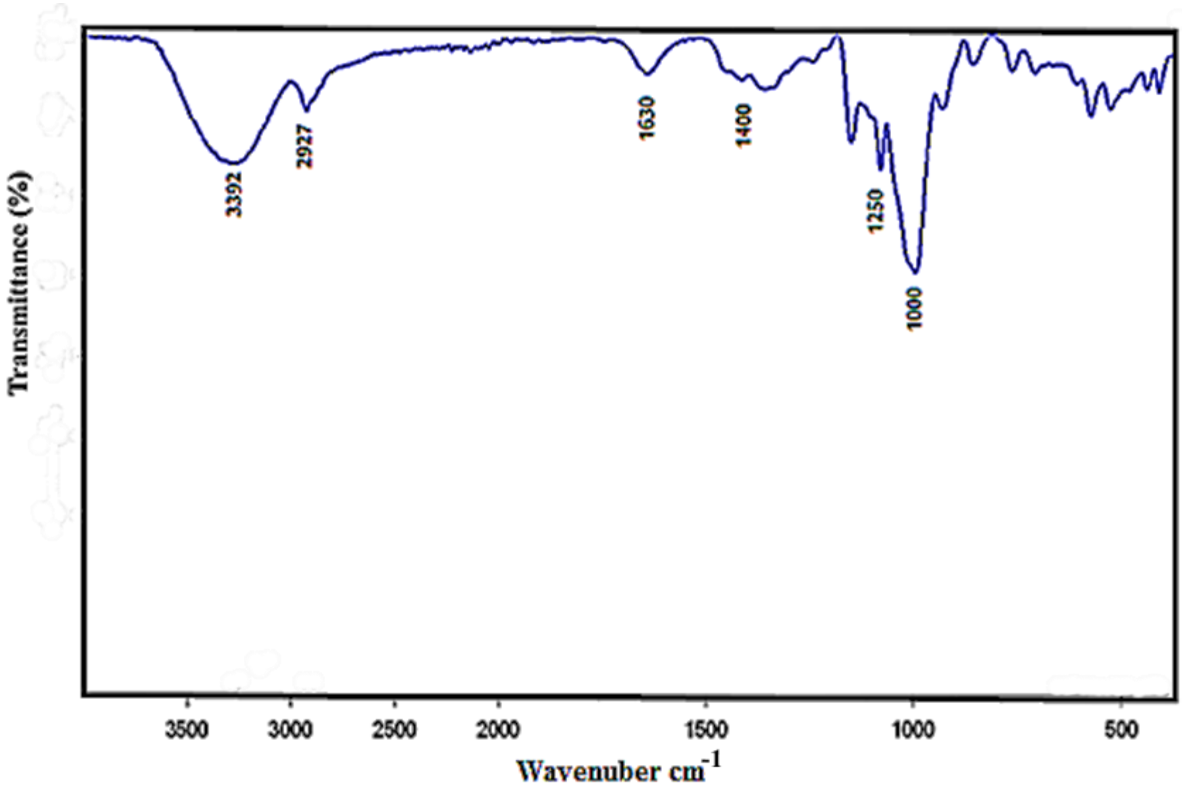
3.2. FTIR Analysis

The structure of montmorillonite is confirmed by FTIR spectroscopy of Na-bentonite. Figure 2a showed a broad absorption band around 3200 and 3600 cm^{-1}, whichis characteristic of the OH group bonded to octahedral aluminum. The stretching vibration at 1631 cm^{-1} belongs to the OH of the H_2O group. The band Si-O-Si stretching vibration in the tetrahedral layer is also observed in the FT-IR spectrum as a strong peak at 1023 cm^{-1}. Si-O-Al and Si-O-Mg are the group's characteristic bands detected at 524 and 458 cm^{-1}, respectively [31].



(**a**)

Figure 2. *Cont.*



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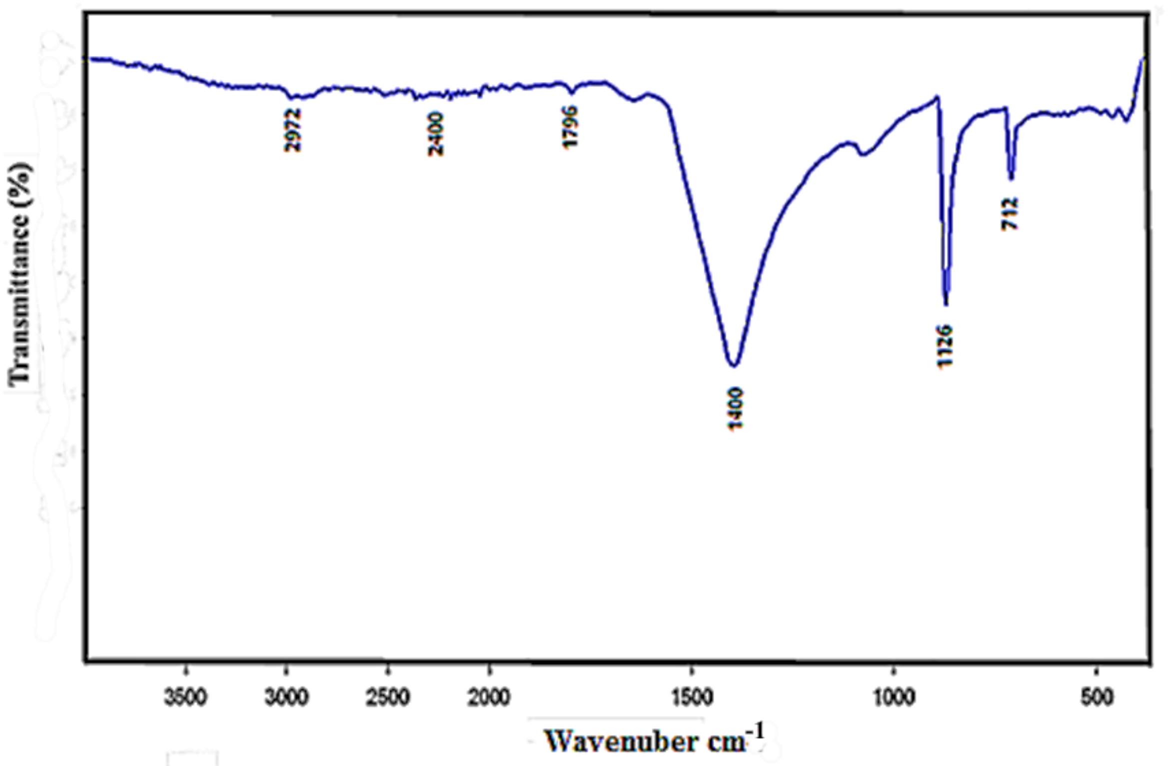


(**c**)

Figure 2. (**a**) FTIR spectra of bentonite and Na-bentonite; (**b**) FTIR spectra of starch extracted from potatoand (**c**) eggshell powder.

The FTIR spectrum of starch extracted from potatoesis shown in Figure 2b, with two distinguishingfeatures:

O-H and C-H groups are the characteristics of starch located in the regions between 1600 and 1700 cm^{-1} and between 3000 and 3500 cm^{-1}. The band thatspreads out between 1600 and 1700 cm^{-1} is centered around 1630 cm^{-1} corresponding to the valence vibrations of the OH groups of the water present in the starch [42]. The band extended from 3000 to 3500 cm^{-1} with an intense peak at 3392 cm^{-1},characterizing the complex structure of starch and correspondingto the stretching vibrations of the OH groups in the glucose units of the amylose and amylopectin chains [43].

The intense peak located around 1000 cm^{-1} is attributed to the stretching vibrations of the C-O bond in the C-O-C [43,44]. The characteristic peak located at 1000 cm^{-1} corresponds to the stretching vibrations of the C-O bond of C-O-H [45].

The peak located at 2927 cm^{-1} corresponds to an asymmetric stretching vibration of the C-H bond of the $–CH_2–$ group [39]. The peak located at 1400 cm^{-1} corresponds to the deformation vibrations of the C-H bond of CH_2 [46]. The peak located at 1250 cm^{-1} corresponds to the symmetrical deformation vibrations of the C-H bond of CH_3 [38]. A chelation peak is around 2376 cm^{-1} due to the hydrogen bonds present between the hydroxyl groups [41].

The FTIR spectrum of eggshell powder is shown in Figure 2c, illustrating the presence of several peaks. The characteristic absorption peak at 712 cm^{-1} is attributed to the symmetric band vibrations of Ca-O [47,48]. The intense peak observed at 876 cm^{-1} can be associated with the out-plane deformation mode.

The band vibrations at 1296 cm^{-1} may be assigned to the bending and stretching band vibrations of C-N stretching of secondary aromatic amines. The absorption peaks at 876 cm^{-1}, 1424 cm^{-1}, and 1638 cm^{-1} correspond to the asymmetric stretching vibration band of the $CO_3{}^{-2}$ of the calcium carbonate minerals [49,50]. The vibration band at 1077 cm^{-1} represents the asymmetric stretching vibration of the asymmetric O-C-O of $CO_3{}^{-2}$ [49]. The vibration peaks at 1126 cm^{-1} suggestthe S-O band due to the presence of sulfur in the eggshell membrane [49]. On the other hand, the band at 1564 cm^{-1} designatesthe C=O band vibration of $CaCO_3$, while the vibration peaks that appeared at 1796 cm^{-1}, 2400 cm^{-1}, and 2972 cm^{-1} suggest the presence of amines and amides functions in the eggshell membrane. The vibration peak at 3434 cm^{-1} is assigned to the H-O-H bending vibration in the egg membrane. Furthermore, the low vibration band at 3642 cm^{-1} revealed that the stretching vibration of calcium-bound O-H groups is unique to the water absorber during the eggshell preparation.

3.3. Rheological Properties of Different Samples

The effect on the rheological properties such as the plastic viscosity (PV), the yield point (Yp), and the gel strength (Gel_0, Gel_{10}) by the addition of ESP and CC with various amounts (10, 20, and 30 g) to thesamples of water drilling fluid have been examined and the obtained results are illustrated in Figure 3a–d.

From a mechanical strength value, and as the name implies, shear stress refers to the action of a force applied to a material, as indicated by Equation (4).

$$\tau = F/A \tag{5}$$

where τ is the shear stress, F is the applied force, and A is the cross-sectional area parallel to the direction of the applied force.

The above equation gives the average shear stress per unit area. From Newton, for fluids we have:

$$\tau = \mu \cdot x \cdot \frac{d\mu}{dy} \tag{6}$$

where μ is the viscosity and $d\mu/dy$ is the shear rate.

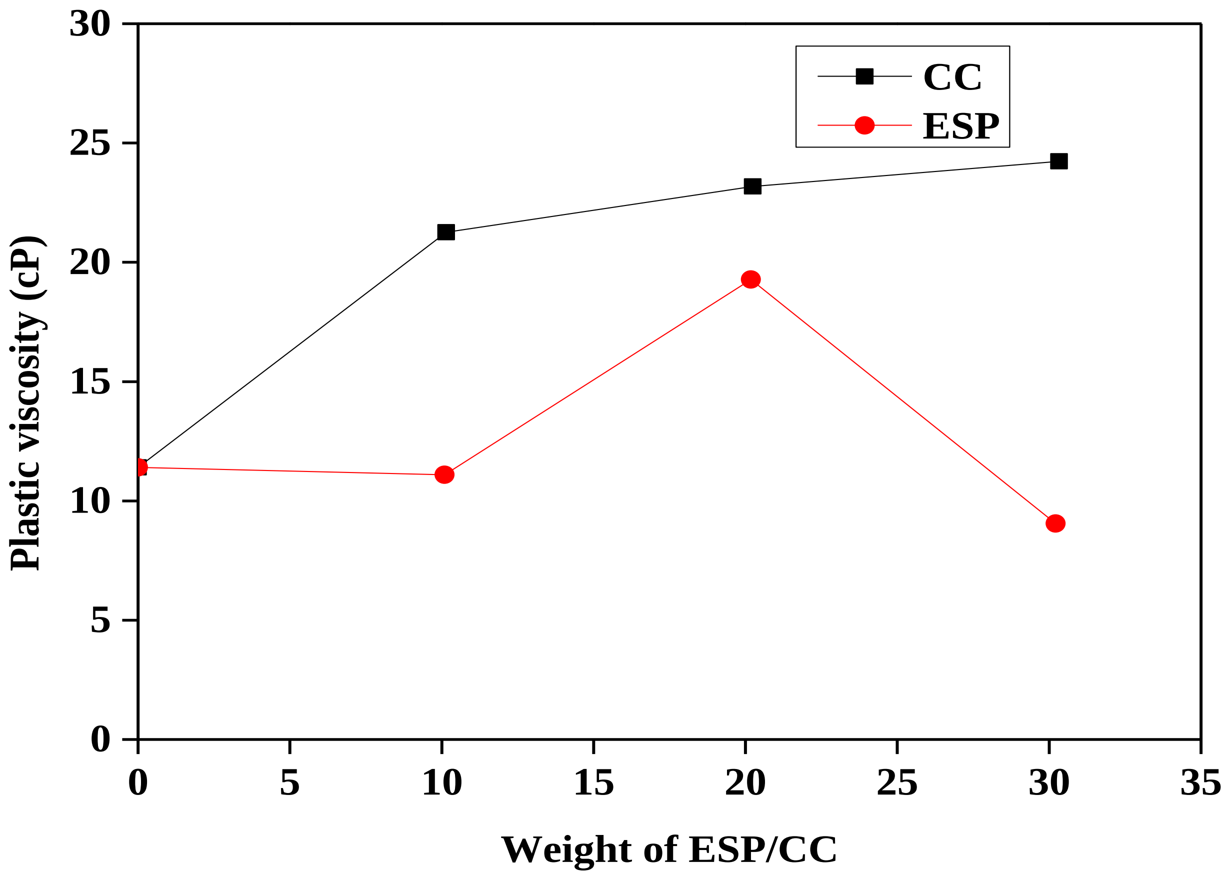
The shear stress of a fluid can be defined as a unit area amount of force acting on the fluid parallel to a very small element of the surface. For the most accurate calculation, the elements should be infinitesimal. The greatest source of stress is fluid viscosity.

Similar to Newton's laws for classical motion, when a force is applied to a fluid, the result is motion. For fluids, this is called fluid flow, which does not occur without resistance.

From Equation (5), we see that if the shear rate is constant, then the shear stress is zero, even under changing viscosity. It is also true that there are fluids where the viscosity remains constant irrespective of the shear force for constant temperature. These fluids, which include gasoline, alcohol, mineral oil, and water, are known as Newtonian fluids. There are, of course, non-Newtonian fluids, where the viscosity changes with the application of shear force. These are classified as follows:

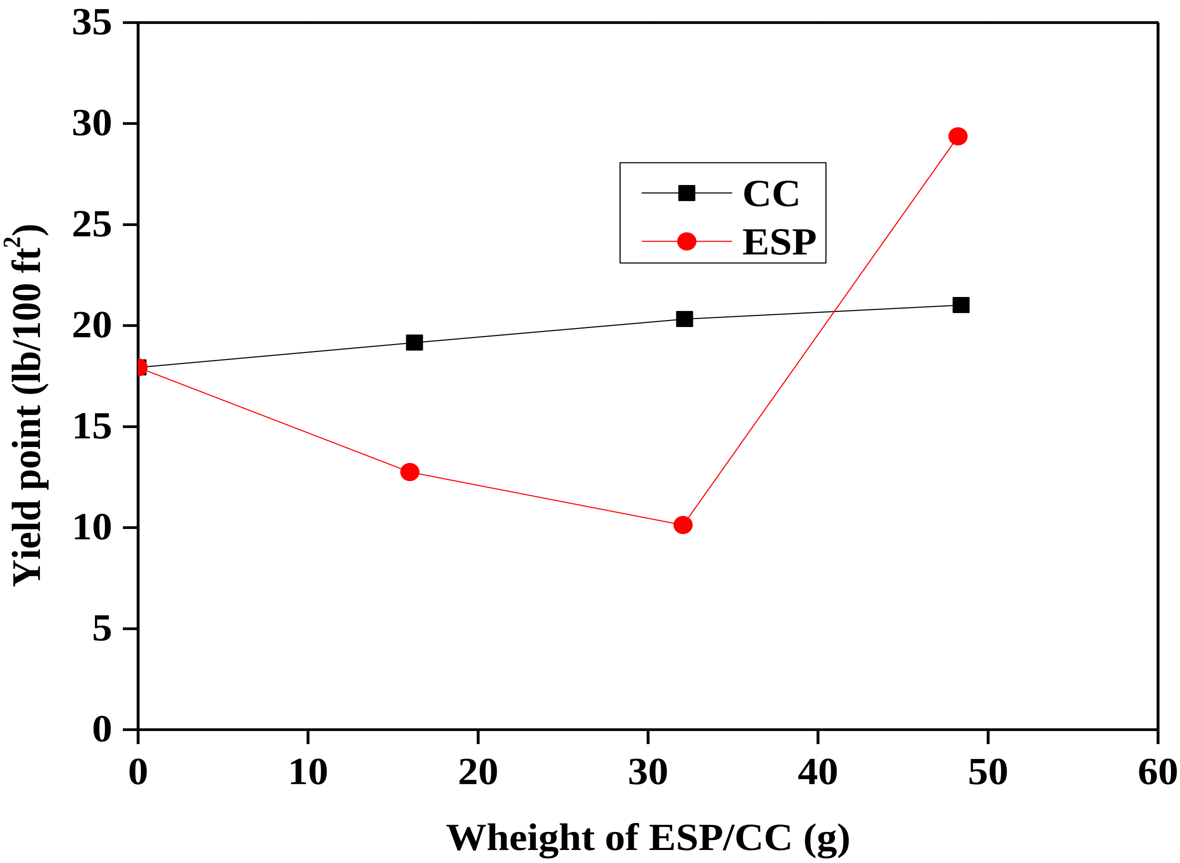
Pseudoplastic—decrease in viscosity.
Thixotropic—time-dependent decrease in viscosity.
Dilatant—increase in viscosity.
Rheopectic—time-dependent increase in viscosity.

At this stage and from the literature, we can deduce that the drilling fluid exhibits a non-Newtonian fluid. Unlike CC, the addition of ESP has a considerable impact on the plastic viscosity, the yield point, and the gel strength, which could be explained by the elastic properties, which resistmechanical deformations better than the CC additive [29].



(a)

Figure 3. *Cont.*



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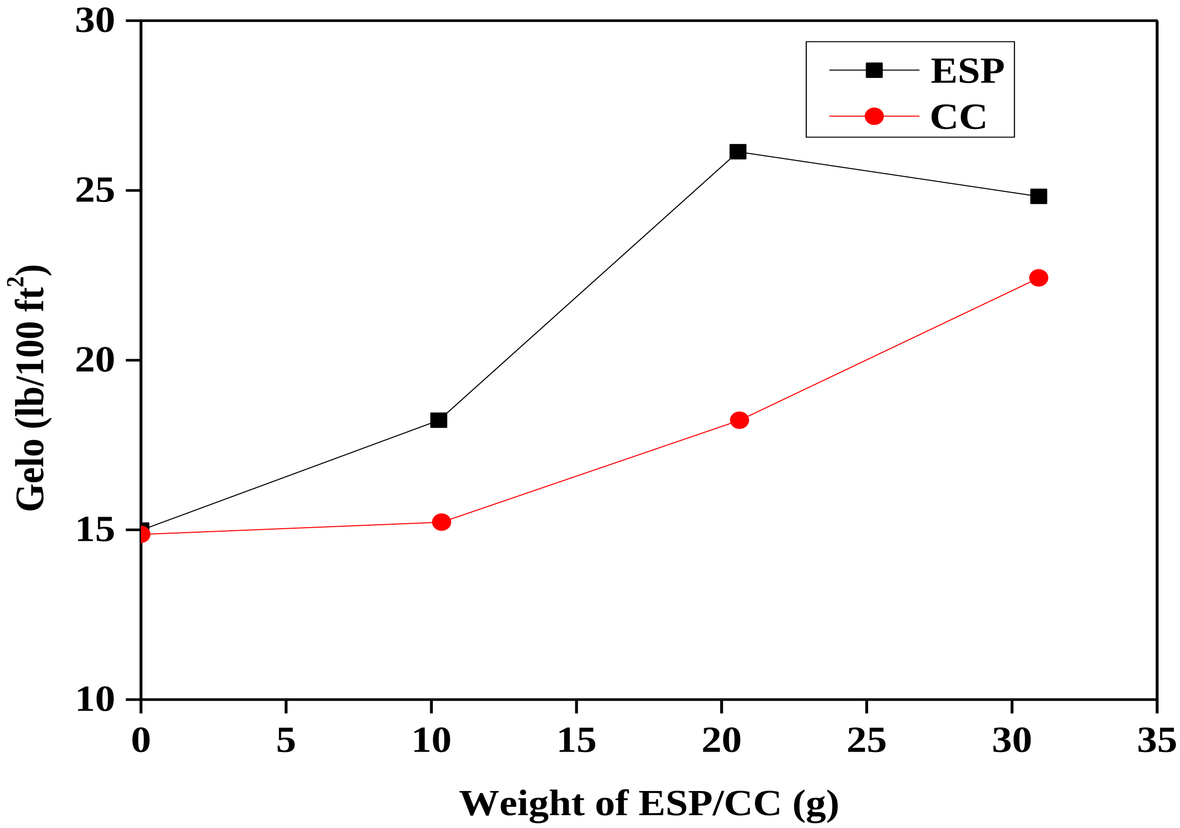

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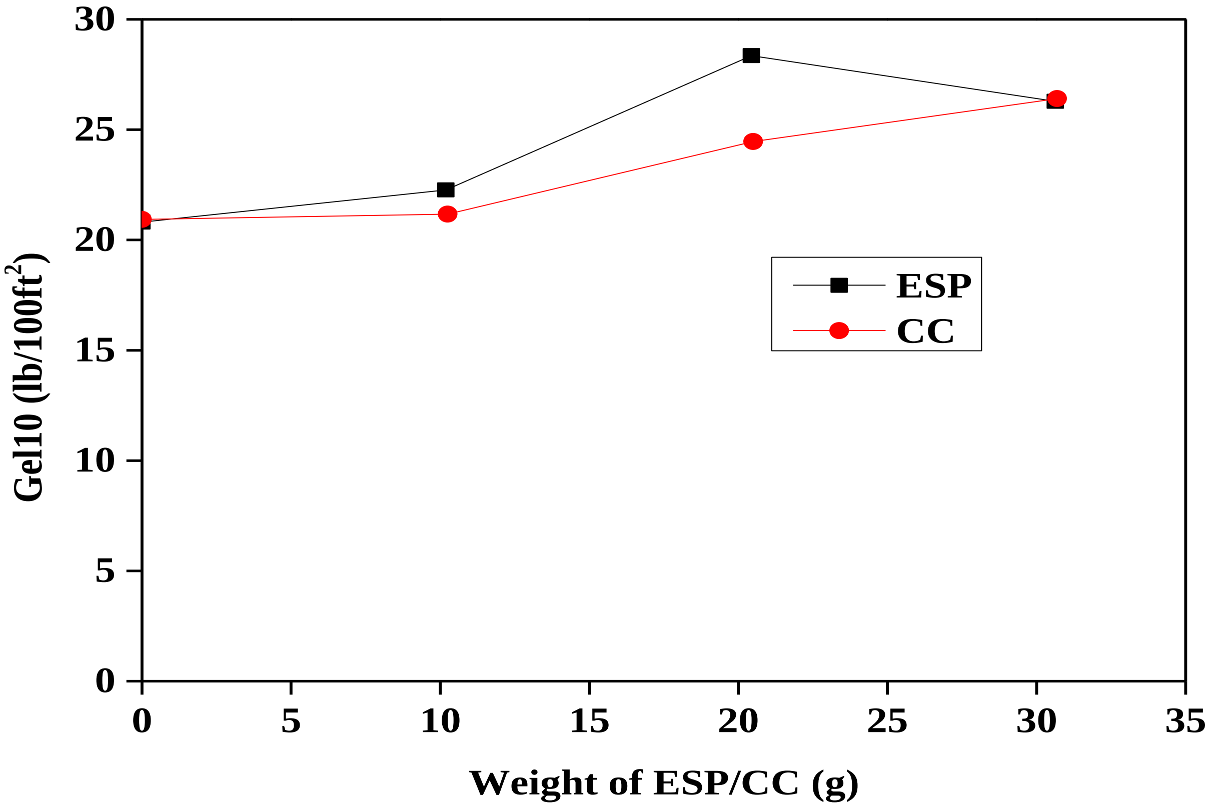

(**d**)

Figure 3. (**a**) Plastic viscosity vs. additive concentration; (**b**) yield point vs. additive concentration; (**c**) Gel_0 vs. additive concentration; (**d**) Gel_{10} vs. additive concentration.

For the CC additive, it is noteworthy that the main rheological parameters (PV, YP, Gel_0, and Gel_{10}) increase substantially with the increase of the CC concentration, i.e., 86, 103, and 112% 10, 20, and 30 g, respectively, as compared to the reference fluid. Similarly, the value of YP increases only by 7, 14, and 17% (the percentages are calculated from the values obtained, see Table 4). In addition, the initial gel strength increases by 3, 22, and 51%, respectively, while the final gel strength increases by 2, 17, and 27%, respectively. These data couldbe due to the presence of solid particles in the fluid, the solid content in the mud system causes trouble for the drilling operation and affects the PV, and high PV values increase surge and swab pressure, reduce rates of penetration, and increase the probability of differential sticking. In this study, the obtained rheological parameter values are acceptable based on the values of mud density [25].

Table 4. Measurement values for Ref, CC, and ESP.

	PV (cp)	YP (lb/100 ft^2)	Gel0 (lb/100 ft^2)	Gel10 (lb/100 ft^2)	Fluid Loss (mL)	Mud Density (ppg)	Cake Thickness (mm)	pH
References	11.3	28.1	15	21	6.5	7.7	1.7	9.16
	21	30	15.4	21.3	6.1	8.4	1.5	9.17
CC	23	32	18.3	24.6	5.8	9.1	1.1	9.18
	24	33	22.6	26.6	5.4	11.6	0.9	9.21
	11	20	18.2	22.3	6.3	7.9	1.5	9.16
ESP	19	16	26.4	28.4	6	8.2	1.3	9.17
	9	46	24.8	26.2	6.5	8.7	1.4	9.2

For the ESP additives, the findings show that the plastic viscosity values varied from −2.65%, 68.14%, and −20.35% for 10 g, 20 g, and 30 g, respectively, as compared to reference fluid, while the YP values varied from −28.82%, −43.06%, and 63.7% for 10 g, 20 g, and 30 g, respectively. In addition, the initial gel strength values increased by 21.33%, 76%, and 65.33% for 10 g, 20 g, and 30 g, respectively, while the final gel strength increased by 6.19%, 35.23%, and 24.76% for 10 g, 20 g, and 30 g, respectively, compared to the reference fluid.It should be pointed out that for 30 g of ESP, the values dropped.

3.3.1. Filtration Properties of Different Samples

In this section, the effects of adding calcium carbonate (CC) and eggshell powder (ESP) to thesamples of water drilling fluid in various amounts (10 g, 20 g, and 30 g) on the fluid loss and the cake thickness have been studied.

For the CC additives, it is noteworthythat there exists a linear relationship between the CC concentration and the fluid loss and cake thickness, whereas, with the increase of the CC concentration, both fluid loss and cake thickness decreased, where the fluid loss was estimated to be reduced by −6.15%, −10.76%, and −16.92%, respectively, when compared to the reference fluid, which minimizes solid invasion and filters the pore spaces of rock [21]. This finding is a very important indicator to save the integrity of the drilling fluid, and the cake thickness decreased by an average of −31.36%. A similar approach was observed for 10 g and 20 g of ESP where the fluid loss decreased by −3.07% and −7.69%; however, beyond 20 g it returns to the same value as the reference fluid. For the cake thickness test, it was observed that there is a decrease for 10 g, 20 g, and 30 g of ESP by −11.76%, −23.52%, and −17.64%, respectively (see Figures 4 and 5).

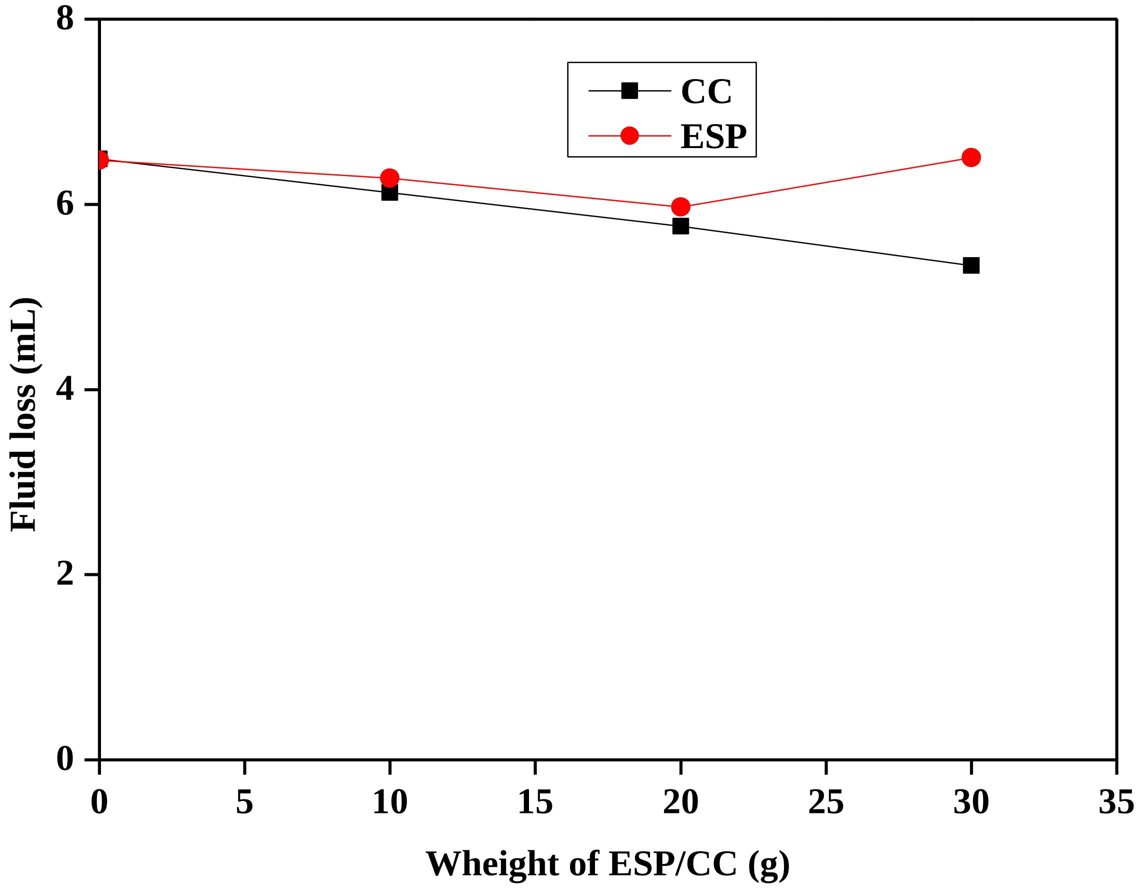

Figure 4. Fluid loss vs. additiveconcentration.

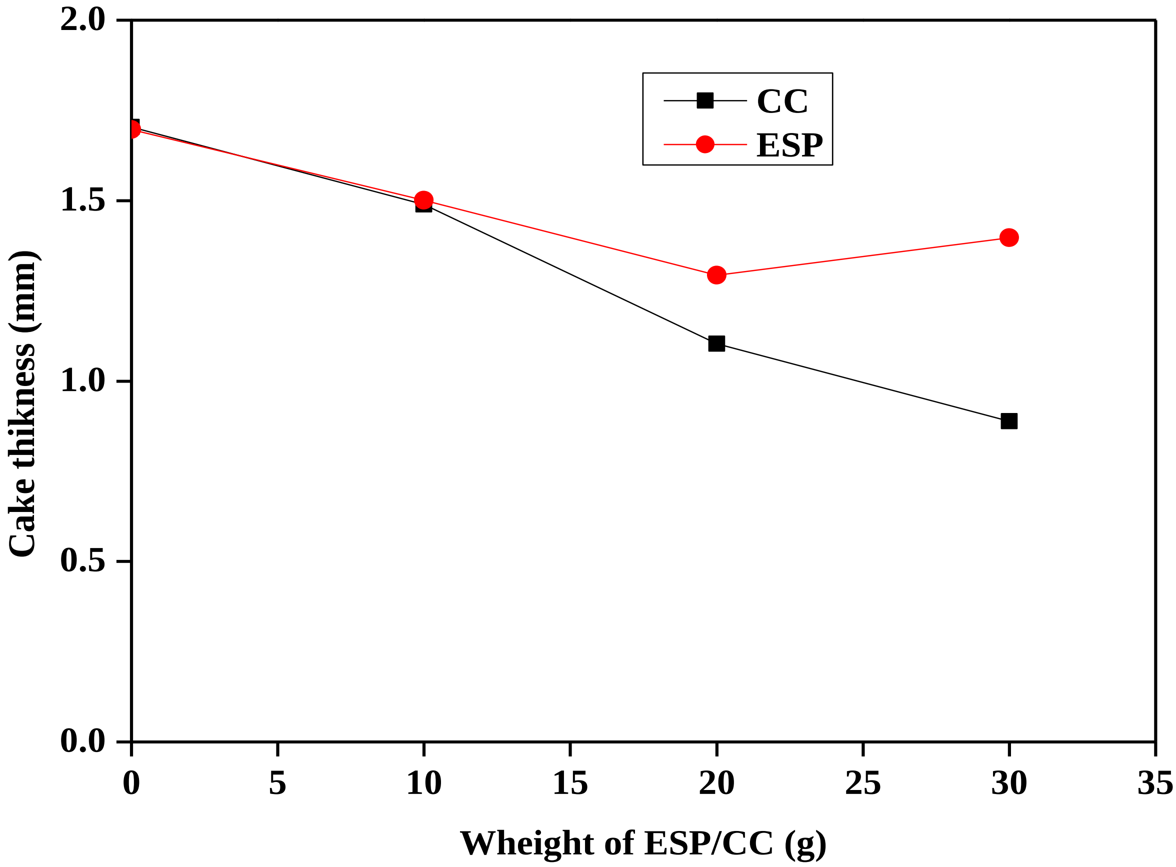

Figure 5. Cake thickness vs. additive concentration.

3.3.2. Effect of Additives on the Mud Density and the pH

In this section, the effect of adding calcium source from calcium carbonate (CC) and eggshell powder (ESP) at various amounts (10 g, 20 g, and 30 g) to thesamples of water drilling fluid on the fluid loss and the cake thickness have been studied.

The result demonstrated that the addition of CC or ESP is beneficialand while an observed increase average of 25.97% in the mud density of the fluid by adding C samples (the highest efficiency of 50.64% has been achieved by adding 30 g of CC), whereas the mud density with ESP increases by an average of 7.35% (the highest efficiency of 12.98% has been achieved by adding 30 g of ESP) (see Figure 6).

In addition, for the pH tests, no significant enhancement in the pH values was observed whenadding both CC and ESP to the samples, where a slightly greater change is noticed than the pH of the reference fluid (an average of 0.28% for CC samples and 0.17% for ESP samples) (see Figure 7). Results compared to the same work from the literature are summarized in Table 5.

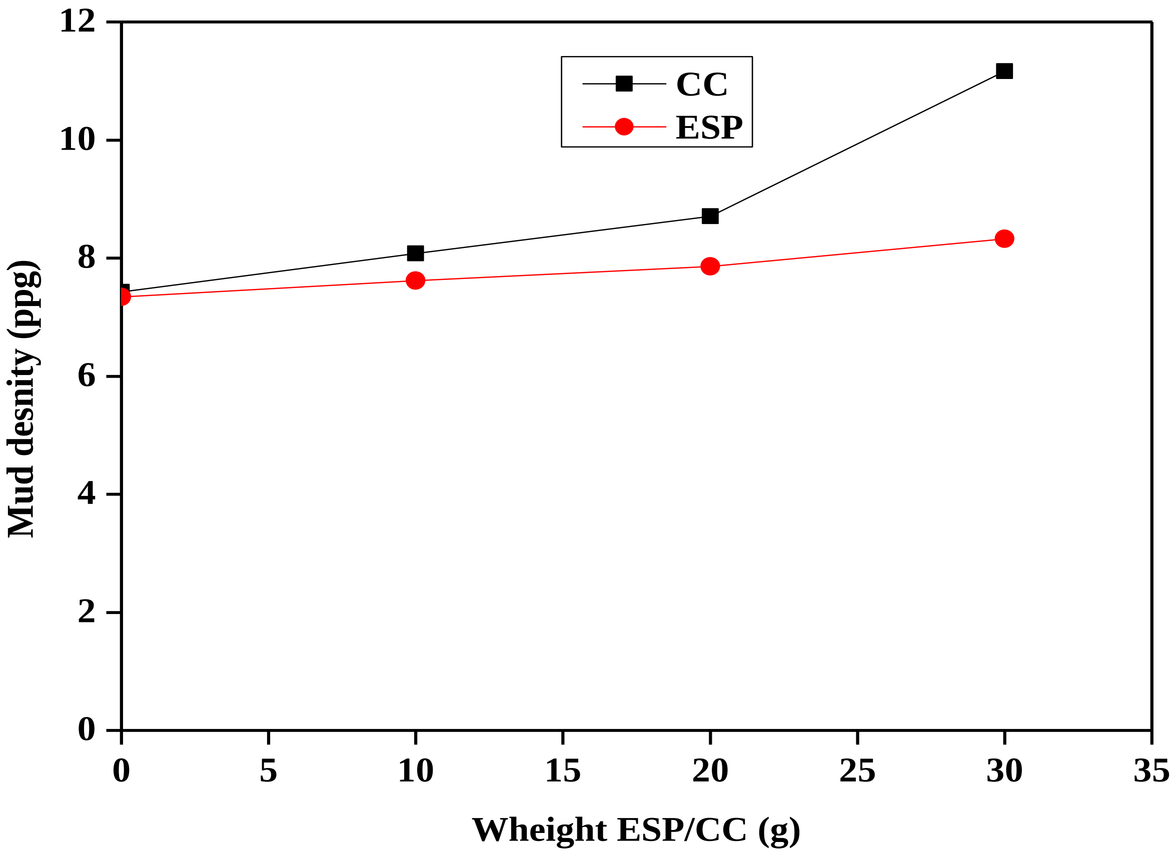

Figure 6. Mud density vs. additive concentration.

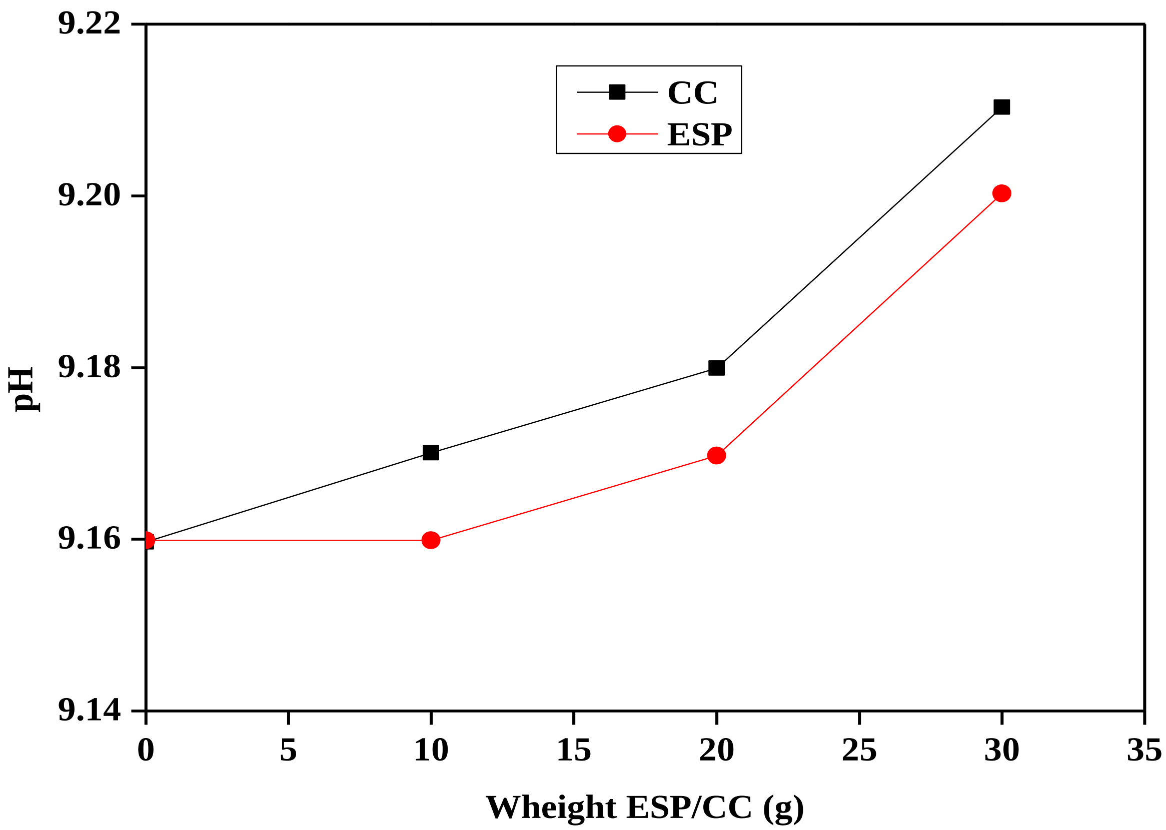

Figure 7. pH vs. additive concentration.

Table 5. Results compared to the same work from the literature.

Eco-Friendly Additive	PV (cp)	YP (cp)	Gels (lb/100 ft^2)	Range of Weight (g)	Mud Density (ppg)	pH
ESP (Rita U et al.) [51]	-	-	-	0–30	Increase with the increase of the weight of ESP	Increase with the increase of the weight of ESP
ESP (Olamigoke et al.) [23]	Effective at low concentration (2 g)	Effective at low concentration (2 g)	Effective at low concentration (2 g)	0–20	-	-
ESP (Alhameedi et al.) [28]	Increase with both 0.75% and 1.5% of ESP	Increase with both 0.75% and 1.5% of ESP	Increase with both 0.75% and 1.5% of ESP	0–1.5%	Increase with both 0.75% and 1.5% of ESP	Slight decrease
ESP (Iqbal et al.) [26]	Increase	increase	Increase	275 g–410 g	Increase	Same values of $CaCO_3$
ESP (current work)	Effective for 10 g and 20 g	Effective for 10 g and 20 g	Effective for 10 g and 20 g	10 g–30 g	Increase	Slight increase

4. Conclusions

This work aimed to study and compare the effect of adding two different sources of calcium, the first one from natural eggshell powder and the second from calcium carbonate, on the rheological and filtration characteristics of water-based drilling fluid formulated by Na-bentonite/potato starch at various concentrations.

Based on the results of our study we concluded that:

1. The addition of ESP and CC significantly improves the rheological properties of Na-bentonite/starch-based drilling fluids; this observation was confirmed by the increase in the plastic viscosity, the yield point, and the gel strength.
2. The addition of ESP and CC has a positive impact on the filtration properties of both Na-bentonite and starch-based drilling fluids and their effect was observed in the increase in the fluid loss and cake thickness.
3. A 30 g ratio of eggshell powder produces unfavorable outcomes.
4. The pH levels are slightly influenced by the eggshell powder.
5. The mud density is improved by the presence of both ESP and CC.
6. The rheological and filtration properties were proportionally adjusted by the addition of both ESP and CC, and they are changed by increasing the concentration.
7. The major goal behind this study is to develop drilling fluid additives that are environmentally eco-friendly and locally accessible.
8. The ESP concentrations ranging from 10 to 20 g aremore effective to improve both rheological and filtration properties. It was demonstrated that $CaCO_3$ has greater potential and an alternative uses to improve water-based drilling fluid mud density in comparison to eggshell powder. Finally, the addition of CC or ESP had a slight influence on the pH of the drilling fluids. This means that ESP is feasible to generate waste and study local products that represent an alternative to the use of chemicals.

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