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Enhancement of Drilling Fluid Properties Using Iron Oxide and Zinc Oxide Nanoparticles

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Abstract

Drilling fluids play a critical role in the success of oil and gas drilling operations, with rheological and filtration properties being key factors influencing performance. Nanoparticles (NPs), due to their high surface-to-volume ratios, have shown potential in enhancing these properties. This study aims to investigate the effects of iron oxide (Fe_2O_3) and zinc oxide (ZnO) nanoparticles on the rheological and filtration properties of water-based mud (WBM) to meet API Standard specifications. Water-based muds were prepared with Fe_2O_3 and ZnO nanoparticles at varying concentrations. The drilling fluid properties, such as mud weight, viscosity, and pH, were tested to evaluate the impact of the nanoparticles. The addition of nanoparticles improved mud weight from 8.5 ppg to 8.7 ppg, aligning with API standards. Carboxymethyl cellulose (CMC) at concentrations of 1 – 3g improved performance, while higher concentrations (7 – 9g) exceeded device capacity (>300 rpm). Fe_2O_3 enhanced the rheological properties, achieving the API standard minimum of 30 cP at 600 rpm, but negatively affected the pH. The study demonstrates that Fe_2O_3 and ZnO nanoparticles significantly improve drilling fluid properties, particularly rheological behavior and filtration, adhering to API standards at ambient temperature. However, Fe_2O_3 adversely impacts pH levels, which needs further optimization. Nanoparticles, especially Fe_2O_3 and ZnO, effectively enhance the density, rheological, and filtration properties of drilling fluids. This study confirms the potential of Fe_2O_3 and ZnO nanoparticles to meet API standards, providing a sustainable solution to drilling fluid performance issues.

Keywords: *Rheological properties; Filtration properties; Water-based mud; API standards; Mud weight.*

1. Introduction

In petroleum engineering, drilling mud is a dense, viscous fluid mixture used in oil and gas drilling operations. Its primary functions are to transport rock cuttings to the surface and to lubricate and cool the drill bit [1-2]. The hydrostatic pressure exerted by drilling mud prevents the collapse of unstable geological formations into the borehole and blocks the intrusion of water from water-bearing strata that may be encountered during drilling [3-4].

Drilling fluids are traditionally composed of water, which can include fresh water, seawater, natural brines, or engineered brines [5]. Some drilling fluids are also oil-based, using products derived directly from petroleum refining, such as diesel oil or mineral oil, as the fluid matrix [6]. In addition, synthetic-based drilling fluids are formulated with highly refined fluid compounds that meet stricter property specifications compared to traditional petroleum-based oils [7].

Generally, water-based drilling fluids are suitable for less demanding drilling operations, such as conventional vertical wells at moderate depths. In contrast, oil-based drilling fluids are more suitable for deeper wells or for directional and horizontal drilling, which exert greater stress on drilling equipment [8]. Synthetic-based drilling fluids were developed to address environmental concerns associated with oil-based fluids, and all types of drilling fluids are subject to strict regulatory oversight regarding their composition [9]. In certain cases, specific combinations of fluids are prohibited in particular environments.

The inclusion of nanoparticles in existing material systems used in the construction and production of oil and gas wells has been shown to significantly enhance material performance [10]. Research in petroleum well drilling, design, stimulation, and reservoir production management has demonstrated that nanoparticles can make industrial materials tougher, improve well completion and production processes, and enable real-time sensing of a well's structural health and productivity [11]. Nanoparticles are highly valued in the industry because they impart favorable physical properties to materials through their high surface area-to-volume ratios. These properties include high surface activity, high aspect ratios (such as those found in nanotubes), enhanced surface-dependent properties (like thermal and electrical conductivities), and superparamagnetic properties in some nanoparticles, such as sub-20 nm iron oxides [12]. Nanoparticles used in enhanced oil recovery (EOR) have been observed to exhibit a structural disjoining pressure effect, which is a key mechanism in surface spreading for chemical EOR applications. This effect is believed to increase the efficiency of oil displacement in oil-wet reservoir rocks [13].

The unique properties of nanoparticles, such as their small particle sizes, high specific surface area, mechanical strength, and thermal stability, make them suitable for use in drilling fluids [14]. The cost of the drilling fluid system often represents a significant portion of the capital expenditure in drilling a new well, and these costs can escalate rapidly when drilling deep holes, in complex formations, or in remote locations. The success of drilling operations in reaching oil and gas targets heavily depends on the effectiveness of the drilling fluids [15]. Nanoparticles are utilized to minimize shale permeability in drilling mud, thereby promoting well stability. This research aims to address challenges related to the rheological and filtration properties of drilling mud by using nanoparticle additives. The goal of this study is to investigate the impact of nanoparticles on the rheological and filtration properties of drilling fluids and to compare the results with API Standard specifications in drilling fluid analysis.

2. Study area

The study area for this project is Effurun, Delta State, Nigeria as shown in Figure 1. The nanoparticles used in the research were purchased from a chemical store in Effurun, Delta State. These nanoparticles were then taken to the Petroleum Training Institute, PMB 20 Effurun, Delta State, Nigeria, specifically to the Production Laboratory 2 in the Petroleum Engineering and Geosciences Department. In this laboratory, the nanoparticles were used to prepare drilling fluids, and the properties of these fluids were tested and analyzed.

Nanoparticles are small objects that behave as a single unit in terms of their transport and properties. As their size approaches the atomic scale, their material properties change. This change is due to the increase in the surface area-to-volume ratio, which causes the surface atoms to dominate the material's performance. Because of their very small size, nanoparticles have a much larger surface area-to-volume ratio compared to bulk materials like powders, plates, or sheets [16]. This characteristic gives nanoparticles unique optical, physical, and chemical properties, as they are small enough to confine their electrons and produce quantum effects. Nanoparticles typically range in size from 1 to 100 nanometers and are undetectable by the human eye. They can exhibit significantly different physical and chemical properties compared to their larger material counterparts.

Nanoparticles can enhance the rheological properties of drilling fluids through various mechanisms, which depend mainly on the continuous phase of the drilling fluids and the characteristics of the nanoparticles. Silica nanoparticles can enhance the apparent viscosity of water-based drilling fluids [17]. Nanoparticles are also known to reduce permeability, fluid loss, and bulk shrinkage in cement. Their incorporation into drilling fluids can improve wellbore stability, and the inclusion of nanomaterials in drill bits can enhance durability and wear resistance.

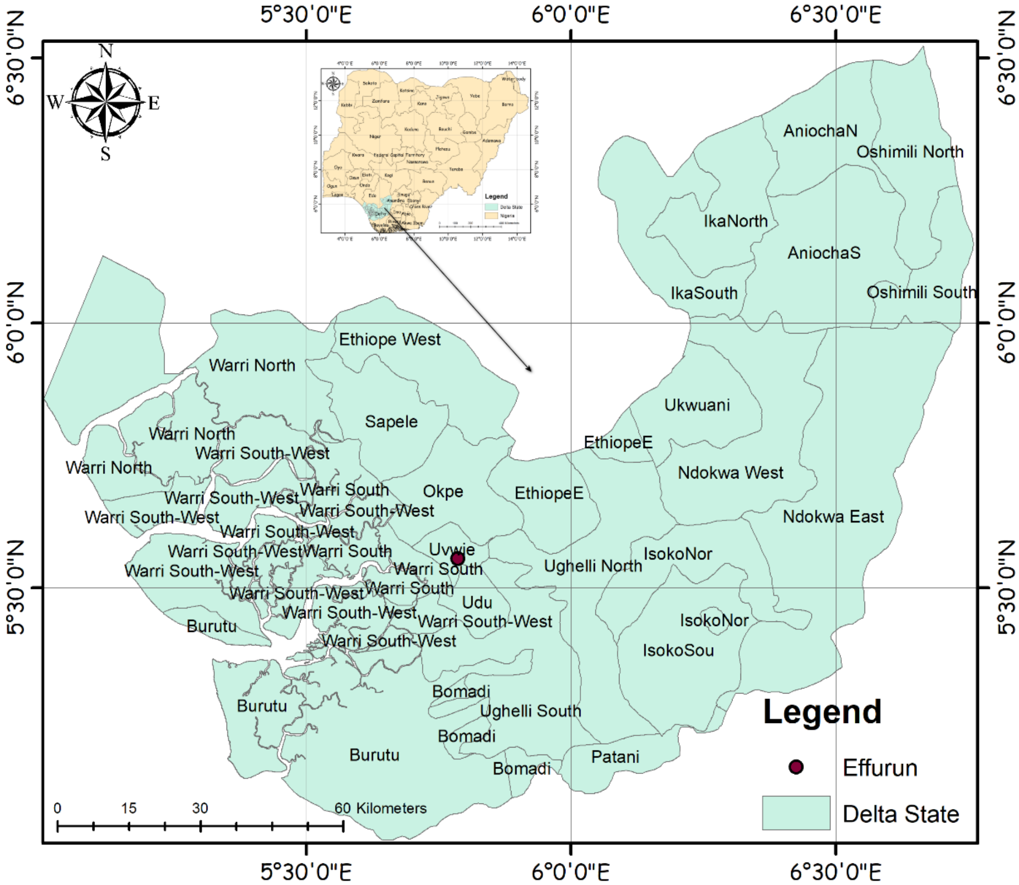

Figure 1. Map showing the location of PTI, Effurun Delta State in Nigeria.

In this research, iron oxide nanoparticles were used. These are iron oxide particles with diameters ranging from about 1 to 100 nanometers. The two main forms of iron oxide nanoparticles are magnetite (Fe_3O_4) and its oxidized form, maghemite (γ-Fe_2O_3). These nanoparticles have attracted significant interest due to their superparamagnetic properties and potential applications in various fields. When applied to drilling fluids, iron oxide nanoparticles showed a substantial improvement in rheological properties, thermal stability, fluid loss reduction, and wellbore stability. The iron oxide nanoparticles were mixed with drilling fluid at different ratios and concentrations to assess their effects.

3. Materials and method

Materials refer to the items used in conducting the experiment, while the method encompasses the overall experimental procedure undertaken to analyze the research. This includes the preparation of mud samples and the investigation of a physical phenomenon under specific conditions.

3.1. Materials and equipment

The materials and equipment utilized in this research include clay, iron oxide nanoparticles, zinc oxide nanoparticles, water, a weighing balance, measuring cylinder, high-speed mixer, mud balance, rheometer (viscometer), sand content kit, pH paper with color chart, and a filter press [18]. Each material and equipment item plays a specific role in the preparation and analysis of drilling fluids, as applied to the oil and gas industry.

3.1.1. Composition of samples

Various samples were prepared to assess the effects of different concentrations of nanoparticles and additives on the properties of the drilling fluid. Sample compositions are as follows:

Control (A): 22g of clay without additives.

Samples with Fe_2O_3: A1 (22g clay + 7g Fe_2O_3), A2 (22g clay + 8g Fe_2O_3), A3 (22g clay + 9g Fe_2O_3).

Samples with ZnO: B1 (22g clay + 7g ZnO), B2 (22g clay + 8g ZnO), B3 (22g clay + 9g ZnO).

Samples with CMC at low concentrations: C1 (22g clay + 1g CMC), C2 (22g clay + 2g CMC), C3 (22g clay + 3g CMC).

Samples with CMC at higher concentrations: D1 (22g clay + 7g CMC), D2 (22g clay + 8g CMC), D3 (22g clay + 9g CMC).

These compositions were systematically tested to analyze the impact of various nanoparticles and additives on the rheological and filtration properties of the drilling fluids.

3.2 Research design

Research design refers to the overall strategy employed to integrate the various components of a study in a coherent and logical manner to effectively address the research problem. This study was conducted using laboratory analysis at the Petroleum Training Institute. Drilling and the experimental design for the preparation of drilling fluid with Fe_3O_4 additives is outlined in Table 1. The table details the composition of the mud preparation, including specific quantities of clay, water, Fe_3O_4, CMC, and ZnO used in different ratios.

Table 1. Mud preparation with Fe_3O_4 additive.

Clay (g)	Water (mL)	Fe_3O_4 (g), CMC (g), and ZnO (g)
22	350	1-3 & 7-9 ratios

3.2.1. Mud preparation with Fe_3O_4 and ZnO

To prepare the drilling mud with Fe_3O_4 and ZnO, the weighing balance was connected to a power source and turned on. A plain filter paper was placed on the balance and zeroed. Various amounts of bentonite clay were measured and recorded. A volume of 350 mL of fresh water was measured using a measuring cylinder. The blender was connected to a power source and switched on. While the blender was on low speed, water was added, and the clay was gradually poured into the blender over 5 seconds. The blender was then switched to high speed for 35 seconds to achieve a homogeneous mixture. The results of the mixtures were tabulated.

3.2.2. pH determination

The pH of the mud was determined using pH paper with a standard color chart. The freshly prepared mud was poured into a beaker, and a pH paper strip was immersed in the fluid. After allowing sufficient time for the strip to absorb the fluid, it was removed, and the color change was compared with the standard pH color chart to determine the pH value. The results were recorded.

3.2.3. Mud weight determination

Mud weight was determined using a mud balance. The balance was first calibrated with fresh water. Fresh water was poured into the mud balance cup to the brim, and the lid was securely placed and dried. The cup was then set on the knife edge of the balance, and the rider was adjusted to 1 specific gravity [19]. When the spirit level indicated a balanced condition, the equipment was confirmed to be in good working order. The water was then discarded, and the process was repeated with the drilling fluid. The rider was adjusted until the spirit level was balanced, and the mud weight was read and recorded.

3.2.4. Sand content determination in mud

The sand content in the mud was determined using a sand content kit. The reblended mud was poured into the sand content tube up to the "mud to here" mark. Water was added to the "water to here" mark using a wash bottle. The mixture was then poured through a 74-micron (200-mesh) screen [20]. The wash bottle was used to rinse the screen until only sand remained on the screen, with no foreign matter. The funnel and screen were inverted into the sand content tube, and water was used to wash the retained sand back into the tube. The sand was allowed to settle, and the value was read and recorded.

3.2.5. Determination of mud rheological properties

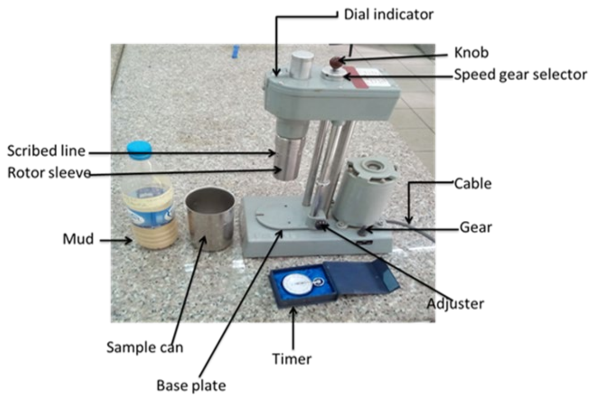

Figure 2. Mud rheological properties equipment set-up.

The rheological properties of the mud were determined using a rheometer (viscometer) as shown in Figure 2. The reblended drilling fluid was poured into the rheometer cup up to the marked line. The cup was tilted and securely fitted onto the base plate of the rheometer. The cup was adjusted until the mud touched the scribed line. Using the knob at the base of the rotor sleeve, the gear was adjusted to high for readings at 600 rpm and low for 300 rpm. Similarly, using the knob at the top, the gear was adjusted to high for readings at 200 rpm and low for 100 rpm. Finally, with the center knob, the gear was adjusted to high for readings at 6 rpm and low for 3 rpm.

3.2.6. Determination of mud filtration properties

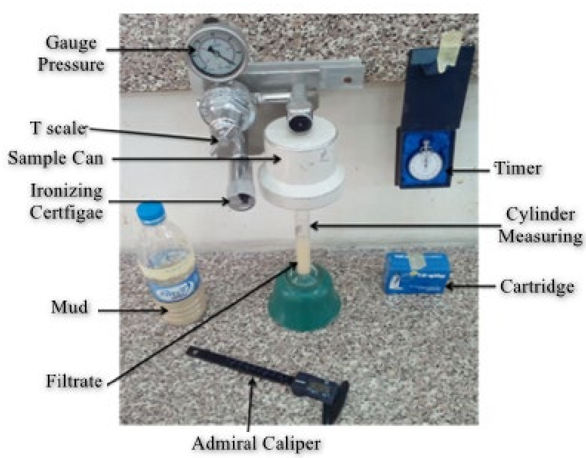

Figure 3. Mud filtration properties equipment set-up.

The equipment for determining mud filtration properties is called Filter (Figure 3) and the procedure is as bellow: CO_2 cartridge was loaded into the filter press and the pressure gauge was adjusted to read 100psi. The freshly prepared mud was poured into the sample cup to about 70% of the overall volume and the rubber "O ring" was placed on it [21]. Filter paper was placed on top of the "O ring" and the lid was placed and locked. The cup with sample was inverted and fixed into the filter press and measuring cylinder was positioned directly under the orifice of the sample cup to receive the filtrate. The timer started simultaneously as soon as the first drop was observed and the filtrate was collected and recorded after 30 minutes..

The sample cup was then opened and the filter cake was collected, rinsed, and was measured and recorded

3.3. Data collection and analysis

The clay and water were sourced from the Petroleum Training Institute (PTI) drilling and production laboratory in Effurun-Warri, Delta State, Nigeria. The nanoparticles were purchased from a chemical store on Effurun Sapele Road, Effurun-Warri, Delta State, Nigeria.

The clay and water were utilized to prepare the mud, to which the nanoparticles were added at varying concentrations and ratios. The resulting mixtures were tested to evaluate the impact of the nanoparticles on the rheological and filtration properties of the drilling fluid.
Zinc oxide (ZnO) nanoparticles have garnered considerable interest in the oil and gas industry due to their distinctive characteristics, such as high surface area, catalytic activity, and antimicrobial properties. These nanoparticles find applications in enhanced oil recovery (EOR), drilling fluids, and corrosion inhibition.

4. Result and discussion

4.1. Result of the experiment

This research examines the impact of nanoparticle additives on the rheological and filtration properties of drilling mud, with the goal of optimizing these properties to meet API Standard specifications. The results presented in Table 2 provide insights into how nanoparticles such as CTRI, Fe_2O_3, and ZnO, along with different concentrations of CMC, influence key mud properties.

Table 2. Results of the nanoparticles in the mud.

Mud theses	CTRI	Fe_2O_3	ZnO	CMC (1 – 3) g	CMC (7 – 9) g
	7g	8g	9g	7g	8g
A	A1	A2	A3	B1	B2
pH	10.000	8.000	8.000	8.000	10.000
Density (ppg)	8.500	8.700	8.700	8.700	8.700
600 rpm (cP)	12.000	17.000	17.000	19.000	17.000
300 rpm (cP)	7.000	10.000	11.000	13.000	11.000
200 rpm (cP)	5.000	8.000	8.000	10.000	9.000
100 rpm (cP)	2.000	4.000	5.000	7.000	6.000
6 rpm (cP)	1.000	2.000	4.000	5.000	4.000
3 rpm (cP)	0.000	2.000	3.000	4.000	4.000
10 Sec. G.S. (Ib/100ft^2)	3.000	5.000	5.000	6.000	5.000
10 Min. G.S. (Ib/100ft^2)	7.000	8.000	8.000	9.000	13.000
P.V (cP)	5.000	7.000	6.000	6.000	6.000
A.V (cP)	6.000	8.500	8.500	9.500	8.500
Y.P (Ib/100ft^2)	2.000	3.000	5.000	7.000	5.000
Y.S	-1.000	2.000	2.000	3.000	4.000
N	0.770	0.770	0.630	0.550	0.630
K	0.280	0.430	1.120	2.190	1.120
Sand content (%)	0.300	1.000	1.000	1.000	0.700
Fluid loss (mL)	21.000	23.000	24.000	24.000	26.000
Filter cake (mm)	1.500	1.500	1.600	1.600	1.800

The viscosity measurements at various rotational speeds (600 rpm, 300 rpm, 200 rpm, 100 rpm, 6 rpm, and 3 rpm) show a clear trend: increasing CMC concentrations generally lead to higher viscosities across all rpm settings. At 600 rpm, mud samples with 9g CMC exhibit a viscosity greater than 300 cp, compared to 12 cp for samples with lower CMC concentrations. This significant increase in viscosity with higher CMC concentrations aligns with the expected behavior of CMC as a viscosifier, which enhances the mud's ability to suspend and carry cuttings.

The plastic viscosity (P.V.) and apparent viscosity (A.V.) measurements also demonstrate this trend. Higher CMC concentrations lead to increased P.V. and A.V., indicating greater internal friction and resistance to flow. These changes are crucial for controlling the mud's flow behavior and ensuring proper wellbore stability during drilling. The results suggest that nanoparticles and CMC can be effectively used to tailor the mud's rheological properties to meet specific operational needs.

Gel strength values at 10 seconds and 10 minutes further illustrate the influence of CMC on the mud's performance. Higher gel strengths observed with increased CMC concentrations indicate improved suspension properties, which are vital for preventing the settling of solid particles and ensuring effective cuttings removal. The gel strength at 10 minutes increases from 35 Ib/100ft² to >300 Ib/100ft² with higher CMC concentrations. This enhancement supports the mud’s ability to maintain a stable column and prevent issues like hole instability or stuck pipe.

The filtration properties, as indicated by fluid loss and filter cake thickness, are also affected by the addition of nanoparticles and CMC. Fluid loss decreases with higher CMC concentrations, which is beneficial for reducing formation damage and improving the efficiency of the drilling process. Fluid loss reduces from 21 mL to 5.2 mL as CMC concentration increases. Filter cake thickness shows a similar trend, with higher CMC concentrations leading to thicker filter cakes. A thicker filter cake can enhance the mud's ability to form a more effective barrier, preventing the invasion of mud into the formation.

When comparing these results to API Standard specifications, it is evident that the optimized mud formulations with nanoparticle additives and higher CMC concentrations can meet or exceed standard requirements. The API standards for drilling mud typically specify acceptable ranges for viscosity, gel strength, fluid loss, and filter cake thickness. The results of this study suggest that by adjusting nanoparticle types and CMC concentrations, it is possible to tailor the mud properties to achieve compliance with these standards while addressing specific challenges encountered during drilling.

4.2. Analysis of the result of the experiment

In this analysis of the result of the experiment, the reaction of the Fe_3O_2 and that of ZnO shall be discussed in details for each of the theses of the mud parameters carried out in the practical operation.

4.2.1. Analysis of the mud pH

The baseline pH of the pure mud sample (A) without any additives was measured at 10. Figure 4 illustrates the impact of various nanoadditives on the pH of drilling mud. When Fe_2O_3 was introduced to the mud, a notable decrease in pH was observed. For samples A1, A2, and A3, which included Fe_2O_3 at different concentrations, the pH dropped to 8. This reduction suggests that Fe_2O3 exhibits acidic properties, as it lowers the pH of the mud. The consistent drop in pH across all Fe_2O_3 samples indicates that this additive consistently affects the acidity of the drilling fluid.

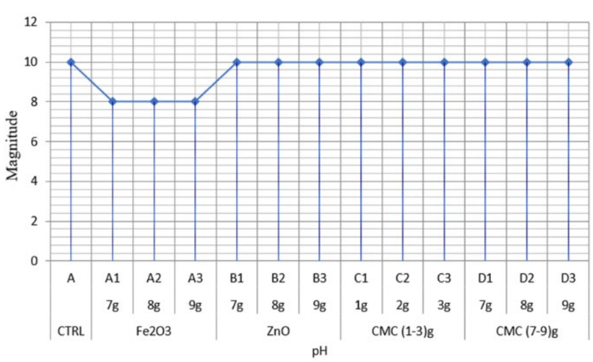

Figure 4. pH Values of mud with nanoadditives.

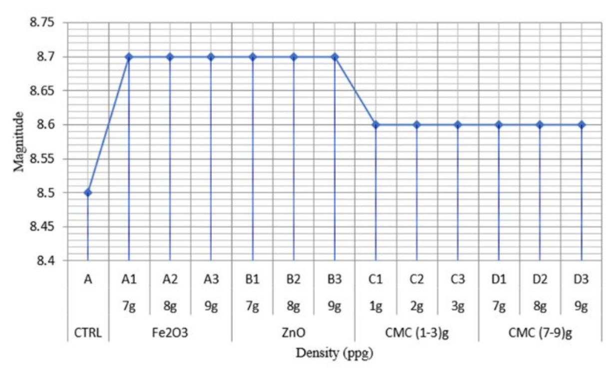

Figure 5. Mud weight (density) with nanoadditives.

In contrast, the addition of ZnO (samples B1, B2, B3) and varying concentrations of CMC (samples C1, C2, C3 with 1 – 3g CMC, and samples D1, D2, D3 with 7 – 9g CMC) did not alter the pH of the mud. The pH values for these samples remained constant at 10, consistent with the pure mud sample. This stability in pH suggests that both ZnO and CMC do not significantly affect the acidity or alkalinity of the mud.

The findings underscore that ZnO and CMC are neutral with respect to their impact on pH, unlike Fe_2O_3 which has a distinct acidic effect. This information is critical for controlling the chemical stability of drilling fluids, ensuring that the pH remains within the desired range for optimal drilling performance and to prevent any adverse reactions with the formation or equipment.

4.2.2. Analysis of the mud weight (ppg)

Initially, the pure mud sample (A), which did not contain any additives, had a density of 8.5 ppg. Figure 5 presents the effect of different nanoadditives on the density of drilling mud. This value is below the API standard specification range of 8.65 to 9.60 ppg, indicating that the base mud falls short of meeting the required density standards for effective drilling operations.

Upon adding Fe_2O_3 (samples B1 to B3) at various concentrations, the density of the mud increased to 8.7 ppg. This change reflects the role of Fe_2O_3 as a densifier, effectively raising the mud density to within the API standard range. The consistent increase in density across different concentrations of Fe_2O_3 suggests that this additive effectively enhances the mud weight, aligning it with industry specifications.

Similarly, the addition of ZnO (samples C1, C2, C3) also resulted in a density of 8.7 ppg, identical to that achieved with Fe_2O_3. This indicates that ZnO functions as another effective densifier for drilling fluids, maintaining the density within the acceptable API range. The stable graph for ZnO across its different concentrations further supports its reliability as a densifying agent.

However, the results differed with the addition of CMC (samples D1 to D3). Although CMC improved the density slightly, the values remained at 8.6 ppg, which is still below the API standard specification. This implies that while CMC can marginally enhance the density of drilling fluids, it does not achieve the necessary density levels required by the API standards.

4.2.3. Analysis of the mud sand content

Initially, the pure mud sample (A) without any additives had a sand content of 0.3%. Figure 6 illustrates the impact of different nano additives on the sand content of drilling mud, as depicted in Table 2. This value is well within the API standard specification range of 1-2%, indicating that the base mud has a relatively low sand content. The addition of Fe_2O_3 to the mud (samples A1 – A3) caused an increase in sand content to 1%. This rise suggests that the iron particles in Fe_2O_3 may contribute additional sand-like material to the mud, which is reflected in the increased sand content.

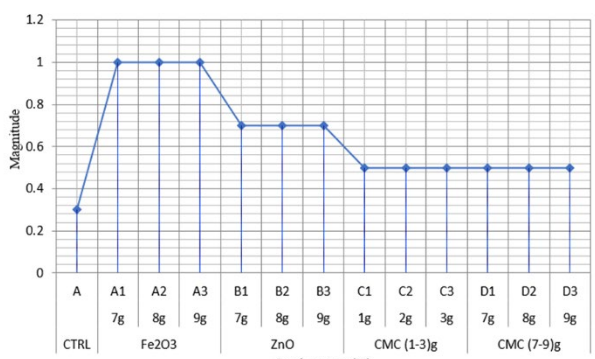

Figure 6. Sand content of mud with nano additives.

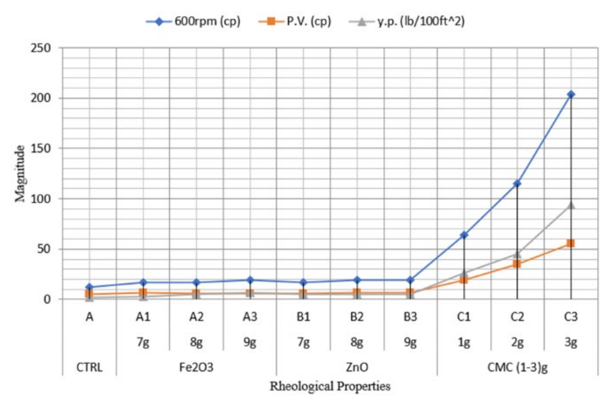

Figure 7. Rheological properties of mud with nano additives.

Conversely, the incorporation of ZnO (samples B1 – B3) resulted in a decrease in sand content to 0.7%. This reduction indicates that ZnO might help in minimizing the presence of sand or its equivalent in the mud, potentially due to its finer particle size or different chemical interactions. Similarly, CMC additives (samples C1 – C3) further decreased the sand content to 0.5%. This suggests that CMC, which is primarily used for its rheological properties, also contributes to reducing the sand content in the mud.

Overall, both the nano additives (Fe_2O_3 and ZnO) and CMC, as well as the control (blank) mud, fall within the API standard specification for sand content, which is 1-2%. This implies that the tested additives, including Fe_2O_3, ZnO, and CMC, are suitable for use in drilling fluids with respect to sand content. They all meet industry standards, ensuring that the drilling fluid's sand content remains within acceptable limits for effective and efficient drilling operations.

4.2.4. Analysis of the mud rheological properties

The baseline viscosity of the pure mud sample (without additives) at 600 rpm is 12 cP, which is significantly below the API standard minimum value of 30 cP. Figure 7 illustrates the effect of different nano additives on the rheological properties of drilling mud, focusing on viscosity, which is crucial for maintaining wellbore stability and effective cuttings transport. This indicates that, in its natural state, the mud has inadequate rheological properties for optimal drilling performance.

Upon adding Fe_2O_3 and ZnO at varying concentrations (7g and 8g), a slight improvement in viscosity is observed, increasing from 12 cp to 17 cP at 600 rpm. However, this enhancement is still insufficient to meet the API standard, indicating that these additives have a minimal impact on the rheology of the mud. Increasing the concentration to 9g of either Fe_2O_3 or ZnO results in a further increase in viscosity to 19 cp at 600 rpm. Although there is a gradual improvement, the mud's rheological properties remain below the API standard.

In contrast, the addition of CMC significantly boosts the mud's viscosity. When CMC is added at concentrations of 1 – 3g, the viscosity at 600 rpm rises dramatically to 64 cp, 115 cP, and 204 cP, respectively. These values far exceed the API minimum requirement, indicating that CMC is an effective viscosifier for drilling fluids. Further increasing the concentration of CMC to 7 – 9g results in viscosities exceeding 300 cP, beyond the measurement capacity of the rheometer used in this study. This demonstrates CMC's strong impact on mud viscosity and its potential to enhance the rheological properties of drilling fluids significantly.

4.2.5. Analysis of the mud filtration properties

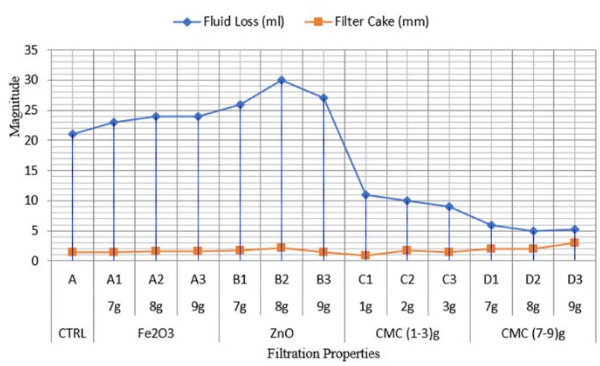

Figure 8. Rheological properties of mud with nanoadditives.

The baseline viscosity of the pure mud sample (without additives) at 600 rpm is 12 cP, which is significantly below the API standard minimum value of 30 cP. Figure 8 illustrates the effect of different nano additives on the rheological properties of drilling mud, focusing on viscosity, which is crucial for maintaining wellbore stability and effective cuttings transport. This indicates that, in its natural state, the mud has inadequate rheological properties for optimal drilling performance.

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5. Conclusion

Fe_3O_2 nanoparticles were found to negatively affect the pH of the drilling fluid, lowering it to 8 compared to the control value of 10. In contrast, ZnO and CMC at various concentrations had no significant impact on the mud's pH, maintaining a pH value of 10, similar to the control. The inclusion of nanoparticles positively affected mud weight, raising it from 8.5 ppg to 8.7 ppg, which falls within the acceptable API standard range. CMC had a minor impact on mud weight, increasing it slightly to 8.6 ppg across different concentrations. However, all additives—Fe_3O_2, ZnO, and CMC—showed limited effectiveness in modifying the sand content of the mud, performing worse than the control. The control mud exhibited a sand content of 0.3%, whereas Fe_3O_2 increased it significantly to 1%. Both the control and the nanoadditives had minimal effects on the rheological properties of the mud, although CMC performed well at concentrations of 1-3 g. At higher concentrations (7-9 g), however, CMC exceeded the measurement capacity of the device, with readings reaching a magnitude of >300 rpm. CMC was the only additive that showed a significant positive impact on filtration properties according to API standards, while the control and other nanoadditives were less effective.

The study concludes that Fe_3O_2 and ZnO nanoparticles have the potential to improve mud weight but have a limited effect on the rheological and filtration properties of drilling fluids. With proper optimization, these local nanoparticles could become viable alternatives to imported additives. Therefore, it is recommended that local Fe_3O_2 and ZnO nanoparticles undergo further modification to replace costly foreign additives. This could have economic benefits for Nigeria by creating jobs and providing employment opportunities for local communities.

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