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Impact of Bentonite Clay Addition on Rheological Properties and Corrosion Characteristics of Water-Based Drilling Mud

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Abstract

Drilling muds represent sophisticated fluid systems filled with several additives targeted at boosting and managing their rheological properties, including density, viscosity, yield point, and gel strength. This inquiry digs into the impact of bentonite clay addition on the rheological features of water-based drilling mud, conforming to the American Petroleum Institute (API) standard for mud composition. The research scrutinizes the influence of different bentonite clay additions, ranging from 2 to 15g, on mud characteristics, with regular additions of 5g each of starch, caustic soda, and gypsum, supplemented with 10g of barite. The data demonstrate a clear association between greater bentonite addition and improvements across many rheological parameters, including density, apparent viscosity, plastic viscosity, gel strength, and yield point. Although the effects of aging on the trials remain ambiguous, results imply a general loss in rheological characteristics at ambient temperature during age. Hence, maintaining an appropriate mud concentration appears as important for managing the rheological behavior of drilling mud. Notably, considerable differences in mud density, plastic viscosity, yield point, and gel strength are detected corresponding to modifications in the concentration of bentonite addition.

Keywords: *API standard; Bentonite clay; Mud composition; Mud concentration; Water-based drilling mud.*

1. Introduction

Additives to drilling mud are essential for improving drilling operations' effectiveness and performance in the oil and gas sector. Drilling rate optimization and wellbore stability depend on rheological characteristics like viscosity and fluid loss management [1]. Maintaining the lifetime and integrity of drilling infrastructure and equipment requires a thorough knowledge of the corrosion behavior of these additives [2]. Drilling mud technology has come a long way, but in order to meet the difficulties presented by a variety of geological formations and operating factors, thorough assessments of additive performance are still required [3].

Jinsheng *et al.* [4] present a complete analysis of the ingredients constituting drilling fluid, emphasizing its complicated makeup consisting of a base liquid, active materials, and inert solids. The liquid phase comprises water, which may express as brackish or fresh water, in addition to oil. The active solids, affected by the presence of clays and polymers, form suspended colloids inside the continuous liquid phase [5]. These suspended materials, dubbed inert solids, are key contributors to the rheological behavior of drilling fluid [6].

The control of drilling fluid's rheological characteristics is a complicated task that involves precise supervision of both the mud itself and its linked systems. A crucial part of this management rests in guaranteeing effective hole cleaning, accomplished via careful design of mud viscosity [7]. This design seeks to enable the removal of cuttings out of the hole during circulation, while also efficiently suspending these cuttings after circulation stops. The density of the drilling fluid must be modified in response to different formation pressures. In high-pressure formations, the insertion of weighted elements is important to improve fluid density, whereas in low-pressure formations, lighter mud designs assist minimize lost circulation [8].

Formations characterized by extreme temperatures create particular obstacles in drilling operations. Solids injected into the mud from such formations tend to hold more water, resulting to viscosity rise owing to water loss [4]. Consequently, maintaining drilling fluid qualities involves a precise balance between elements like as temperature, pressure, and the insertion of additives.

The purpose of this research is to examine the rheological and corrosion characteristics of drilling mud additives, providing important information on their acceptability and usefulness under various drilling conditions.

2. Materials and methods

The main emphasis of the experiment was on mud, which was made from clay soils that included pure solid mineral samples of barite and bentonite. The process of preparing mud samples included pulverizing and drying the clay, then dissolving it in water to form a slurry. To create clay mud, the slurry was sieved to remove small clay particles. The filtrate was then decanted after it had settled. The American Petroleum Institute (API) standard was followed in the manufacture of the drilling mud, which included different amounts of bentonite clay dissolved in distilled water. In accordance with the established formulation, additional chemicals such hydrated lime, starch, barite, caustic soda, palm kernel oil, and gypsum were added. The rheological characteristics of each formulation, such as density, viscosity, and gel strength, were described.

2.1. Mud sample preparation

The sample of clay was dried, ground into minuscule particles, and then dissolved in water to create a slurry. In order to extract fine clay particles, the slurry was sieved through a mesh size of 100 µm. Sand and organic compounds were deposited as residue. After letting the filtrate settle for the whole night, it was decanted to produce clay mud. To make clay cakes, the clay mud was baked in an oven for eight hours. The cakes were then broken up and sieved through a 50µm screen to produce fine clay powder.

2.2. Drilling mud preparation

The API standard 13A was adopted. 10g to 20g of bentonite clay was dispersed into 350mL of distilled water with the aid of an overhead stirrer. The prepared mud sample was kept for 24hours to age and its rheological properties were determined. The mud balance was standardized using distilled water. 5g of starch was added, mixed and heated to 80^{o}C (pregelatinizing) to breakdown the starch and 10g of barite ($BaSO_4$) sample was added to provide density to control formation pressures, 5g caustic soda (NaOH) was added for pH and alkalinity control. 3g of palm kernel oil was also added to serve as a lubricating material designed to reduce torque and drag between drill pipe and the formation. 5g gypsum was added as a flocculating material and increase the carrying capacity of water-base spud muds. 5g hydrated lime ($Ca(OH)_2$) was added as a corrosion inhibitors. The whole mixture was mixed thoroughly with a homogenizer to obtain a uniform blend. Each formulation containing a specific mass of bentonite clay was characterized for its rheological properties such as density, viscosity, and gel strength value. This formulation is as presented in Table 1.

Table 1: Drilling mud experimental design

Sample	Bentonite (g)	Water (mL)	Barite (g)	Caustic soda (g)	Gypsum (g)	Palm kernel oil (g)	Hydrated lime (g)
1	2	350	10	5	5	3	5
2	5	350	10	5	5	3	5
3	8	350	10	5	5	3	5
4	12	350	10	5	5	3	5
5	15	350	10	5	5	3	5

The drilling mud experimental design is shown in Table 1, which also lists the various formulations that were tried throughout the investigation. The quantity of bentonite clay used (in grams) and the amounts of additional additives, such as water, barite, caustic soda, gypsum, palm kernel oil, and hydrated lime, are indicated on each sample's label, which also bears a unique identification. The influence of bentonite clay on the rheological features and corrosion characteristics of the drilling mud may be examined due to the fluctuations in its concentration. Furthermore, the constant concentrations of other additives guarantee that variations in bentonite content is the primary cause of the impacts seen. With the help of this methodical methodology, it is possible to conduct a thorough investigation of the effects of varying bentonite addition levels on the functionality of water-based drilling mud. This research yields insightful information that can be used to optimize mud compositions for actual drilling operations.

2.3. Rheological parameters determination

Five distinct combinations with varied quantities of bentonite clay were prepared to analyze the rheological qualities, as indicated in Table 1. Batoid Rheometer made it simpler to calculate multipoint viscosities. With the RPM knob, the user may select between preset rates of 3 (GEL), 100, 200, 300, and 600 RPM (revolutions per minute) for this coaxial cylindrical spinning viscometer [9]. Many rheological properties were then calculated from the available experimental data.

$$\mu_P = 600RPM_{Reading} - 300RPM_{Reading} \quad (1)$$

$$\mu_A = \frac{600RPM_{Reading}}{2} \quad (2)$$

$$\tau_y = 300RPM_{reading} - \mu_P \quad (3)$$

where: μ_P = plastic viscosity; μ_A = apparent viscosity; τ_y = yield point in lb/100ft^2.

2.4. Density

Weight per unit volume, or drilling mud density, is an essential quantity that is measured in pounds per gallon (lb/gal) [10]. A typical weighing element in mud compositions is barite. A static mud column's hydrostatic pressure relies on the depth and density of the mud. The equation published by Abdou *et al.* [11] demonstrates the intricate link between mud density, depth, and pressure exertion that leads in the hydrostatic pressure at a specific depth (D) for a mud column with density (ρ).

$$P = 0.052 \times \rho \times D \quad (4)$$

where; P = hydrostatic pressure (psi); ρ = mud density (lb/gal); D = depth (ft).

All materials present in mud contribute to its density. The resulting mud mixture from all the additives and water is assumed to be ideal; hence the total volume as stated in equation 5 is equal to sum of the component volume.

$$V_t = V_1 + V_2 + V_3 + \cdots + V_n \quad (5)$$

The equation 6 provides the volume V_i of the specified additives, characterized by density ρ_i, and sample mass m_i.

$$V_i = \frac{m_i}{\rho_i} \quad (6)$$

Thus, the resulting density may be determined applying the formula stated in equation 7.

$$\rho = \frac{m_1 + m_2 + m_3 + \cdots + m_n}{V_1 + V_2 + V_3 + \cdots + V_4} \quad (7)$$

2.5. Aging effects on mud rheology

Examining how different aging times affect drilling mud sample rheological characteristics was the aim of the study. 250 cc of clean tap water was thoroughly mixed with each 5-gram sample of muck. Furthermore, precisely one gram of bentonite viscosifier was added to the samples, and they were then subjected to a vigorous 10-minute shearing process. The samples were then allowed to rest for 16 hours at room temperature in order to facilitate proper mixing and interaction. The viscosities and gel strengths were closely observed after this time.

After that, same procedure was repeated for samples that were aged for 20, 24, and 32 hours at room temperature. Through an analysis of the measured viscosities and gel strengths obtained from the viscometer, the effects of age on the samples' rheological properties were made clear. This methodical examination sheds light on the ways that time affects drilling mud performance in various contexts.

3. Effects of bentonite additive

Figures 1 through 4 show how adding bentonite dramatically affects the drilling mud's density, plastic viscosity, yield point, and gel strength. These qualities are important because they have an impact on many drilling-related concerns, either directly or indirectly. Karagüzel *et al.* [12] demonstrated that variations in drilling fluid properties, no matter how little, might result in unforeseen challenges. The findings highlight how rheological characteristics are dynamic and respond to changes in bentonite concentration. Gaining an understanding of these variations is essential to enhancing drilling operations and averting potential problems related to drilling fluid performance. The intricate relationship between additives and drilling mud characteristics, which affects techniques for increasing drilling efficiency and reliability, is helpfully shown by these graphics [13].

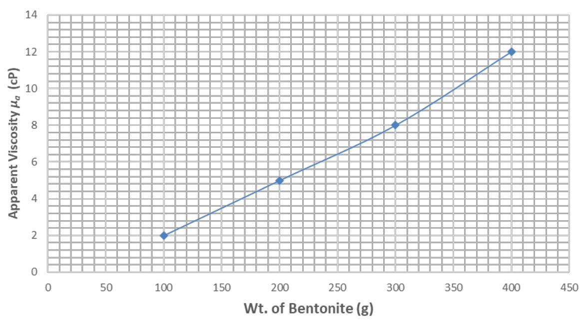

Figure 1 Plot of apparent viscosity against weight of bentonite.

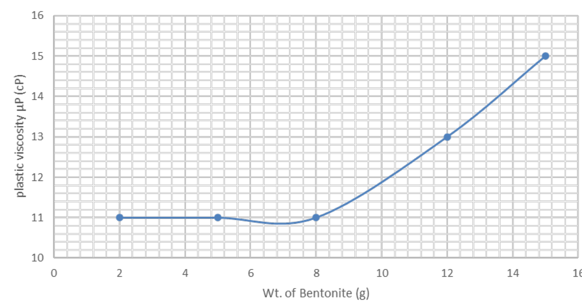

Figure 2. Plot of plastic viscosity against weight of bentonite.

Figure 2 makes it clear that the goal of reducing plastic viscosity and improving the yield point may be adversely affected by an increase in bentonite content. Bentonite has a natural tendency to increase plastic viscosity and de-flocculate, according to Kumar and Mandal [14]. Notably, when bentonite addition surpasses 8.0g, there is a noticeable increase in plastic viscosity. These results highlight the need for a careful balance when adjusting bentonite concentrations in drilling mud in order to achieve desired rheological properties.

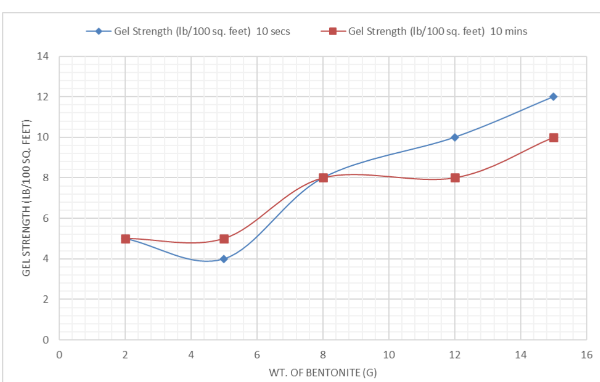

Figure 3. Plot of gel strength against weight of bentonite.

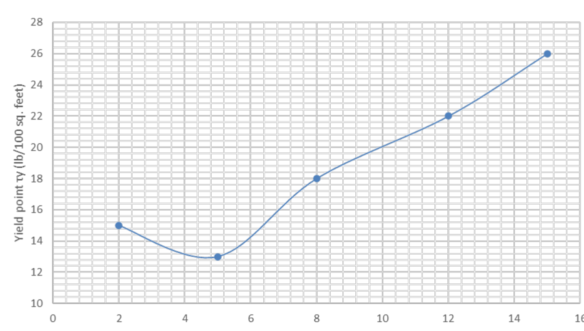

Figure 4 Plot of yield point against weight of bentonite.

The surge in additive usage, notably bentonite, correlates with the documented escalation in gel strengths. Bentonite, an adsorbent aluminum phyllosilicate clay primarily comprised of montmorillonite, exhibits water-soluble characteristics. It functions similarly to lignosulfonate at lower levels, dispersing clay solutions and causing a decrease in both yield point and fluid loss [15].

Moreover, the addition of bentonite additive significantly increases gel strengths, as seen in Figure 5. Bentonite's thixotropic propensity comes in handy, especially when drilling operations come to a stop and mud circulation temporarily stops. Bentonite's ability to gelate in these kinds of circumstances is highly sought as it increases drilling operations' operational efficiency and safety[16]. Comprehending the properties and behaviors of bentonite facilitates the development of drilling mud compositions that effectively tackle the many issues encountered during drilling operations.

Figure 4 shows a direct correlation between the quantity of bentonite added and the subsequent increase in drilling mud's yield point. According to Kumar and Mandal [14], this phenomenon is associated with an increase in the liquid phase's viscosity, namely that of water. Greater bentonite concentration increases plastic viscosity, which reduces fluid loss since it depends on the viscosity of the liquid phase as well as the number of particles in the mud.

Bentonite's molecular structure promotes the formation of lengthy chains that entangle and bond fast, raising the yield point more than plastic viscosity. This feature is very desirable in a viscosifier since it allows for effective hole cleaning, even that lower plastic viscosities are still advantageous. But higher concentrations of bentonite result in higher plastic viscosities, which in turn lead to higher viscosity at the drill bit and an increase in the rate of penetration (ROP) [17].

However, it's important to understand that a high plastic viscosity also increases the pressure drop along the drill string, which reduces the flow rate that is available. Any potential increase in the cutting-lifting capabilities to the surface is negated by this action. Therefore, even though bentonite augmentation improves certain drilling parameters, such hole cleaning and ROP, it's critical to strike a balance to prevent potential drawbacks, like reduced flow rates, guaranteeing overall drilling productivity and efficiency.

Table 2. Aging results for fresh water at ambient temperature for mud with bentonite additive.

Aging time (hrs)	Viscosity dial		PV μ_P (cP)	YP (lb/100sq.feet)	Gel strength (lb/100 sq. feet)		Start pH	End pH
	600rpm	300rpm			10secs	10mins		
16	35	23	12	11	5	7	10.22	9.83
20	17	8	9	5	7	10.22	9.93	2.5
24	25	12	13	7	8	10.22	9.69	3.7
32	20	10	10	5	6	10.22	9.56	3.0

Table 2 shows the aging findings for drilling mud samples including bentonite additive in fresh water at room temperature. A range of rheological parameters, including viscosity dial readings at 600 rpm and 300 rpm, plastic viscosity (PV) in centipoise (cP), yield point (YP) in pounds per 100 square feet, and gel strength in pounds per 100 square feet at both 10 seconds and 10 minutes, are included in the table along with data for various aging times, measured in hours. The starting and end pH values of the mud samples are also included in the table. These findings give light on the aging behavior of mud formulations including bentonite addition and reveal how the rheological characteristics of drilling mud vary with time at room temperature.

The findings show how the sample characteristics of the drilling mud are affected by an increase in bentonite mass, as shown in Table 3. The weight of the mud sample in grams and the weight of bentonite added in equivalent grams are shown in the table. Additionally, it offers rheological parameters like yield point (τy) in pounds per 100 square feet, gel strength in pounds per 100 square feet at both 10 seconds and 10 minutes, apparent viscosity (μA) in centipoises (cP), plastic viscosity (μP) in centipoises (cP), and viscosity dial readings at 600 rpm and 300 rpm. The table shows how changing the quantity of bentonite injected affects the drilling mud's rheological properties. There are noticeable variations in viscosity, perceived viscosity, plastic viscosity, yield point, and gel strength as bentonite weight rises. These findings help optimize mud compositions for improved drilling performance by shedding light on the connection between bentonite content and the rheological characteristics of the drilling mud.

Table 3. Results showing effect of increased Bentonite mass on sample properties.

Sample weight (g)	Bentonite weight (g)	Viscosity dial		μ_A (cP)	μ_P (cP)	τ_Y (lb/100 sq. feet)	Gel strength (lb/100 sq. feet)	
		600 rpm	300 rpm				10 secs	10 mins
10	2	37	26	18.5	11	15	5	5
10	5	35	24	17.5	11	13	4	5
10	8	40	29	20	11	18	8	8
10	12	48	35	24	13	22	10	8
10	15	56	41	28	15	26	12	10

According to Nayberg [18], drilling fluid characteristics are crucial in reducing a variety of drilling difficulties. It is very important to understand and optimize these parameters since even little variations in the qualities of the drilling fluid may cause unanticipated problems. The purpose of this experimental investigation was to examine the corrosion characteristics and rheological features of drilling mud additives. Mud samples were painstakingly made with different additive concentrations, enabling a thorough examination of their characteristics [19]. These drilling mud samples' rheological characteristics, which range in additive content, are graphically shown in Figures 1 through 4. These illustrations provide important new understandings of the connection between rheological behavior and additive concentration.

The differences in additive concentration and rheological characteristics that have been found align with the conclusions made by Iqbal *et al*. [20]. They found that mud that had been weighted with iron oxides had better rheological characteristics and showed a slower rate of sedimentation. The significance of additive concentration and selection in drilling fluid formulation optimization is further highlighted by these relationships between additive composition and rheological performance.

Furthermore, the investigation also examined the corrosion properties of the drilling mud additives, offering further understanding of their functionality and appropriateness for certain drilling conditions. This work advances our knowledge of drilling fluid behavior and facilitates the creation of more dependable and efficient drilling fluid compositions by thoroughly evaluating both rheological qualities and corrosion characteristics.

4. Conclusion

This research examines at how drilling mud additives affect the rheological properties of drilling mud, highlighting the critical role that mud concentration plays in defining these properties. The research discovered a strong relationship between variations in mud density, plastic viscosity, yield point, and gel strength and changes in the proportion of mud additives. Bentonite is a crucial ingredient in many drilling mud formulas since it significantly raises the gel strength, yield point, density, and plastic viscosity. The comment emphasizes how much bentonite impacts the rheological characteristics of drilling mud. The density, plastic viscosity, yield point, and 10-second gel strength are all intrinsically related to the sample weight percentage. The bentonite component's specific gravity also has a significant impact on how well the mud performs. It has an impact on density, yield point, 10-second gel strength, plastic viscosity, and yield point. Mud engineering's basic principles place a strong emphasis on maintaining hole stability, reducing friction between the drill string and the casing or formation, and achieving effective hole cleaning. These considerations become much more crucial when drilling heavily deviated wells since proper drilling fluid properties are necessary for safe and effective operations.

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