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Drilling Fluid Characterization (Filtration Test)

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Abstract

This report explores the formulation and testing of a water-based drilling mud used in drilling operations, where fluid circulates through the drillstring and returns to the surface. The study mixes 315 ml of water with 35 ml of corn oil to create the drilling mud and investigates the role of barite in increasing mud density to maintain a hydrostatic pressure capable of managing formation pressure. The findings reveal that increasing barite from 15g to at least 27g is necessary to sustain a formation gradient of 0.561 psi/ft, effectively preventing formation fluid influx and loss of circulation. A filtration analysis assesses the filtrate volume loss to shale over 30 minutes for two samples: one without a filtration control agent (Mud B) and another with PAC as an additive (Sample C). Mud B shows a filtrate volume of 12.2 ml, while Sample C, with PAC, exhibits a reduced volume of 4.8 ml, marking a 61% reduction. PAC significantly reduces filtrate invasion, controls mud thickening, and prevents shale damage, as evidenced by thinner filter cakes—3mm for Mud B and 2mm for Sample C. Spurt loss measurements for samples B and C differ by nearly 10%. The study recommends further research into pore plugging and particulate sizing for effective drilling fluid management and cost reduction. Additionally, it suggests comparative performance analyses between oil-based and water-based fluids to enhance understanding and efficiency in drilling operations.

Keywords: Drilling Fluid, Filtration Test, Bentonite, Barite, Polyanionic Cellulose PAC, pH, Mud density, filter cake

INTRODUCTION

A drilling fluid is described as a substance employed in the practical aspects of drilling, where it is pumped down the drillstring from the surface, passes through the drilling bit, and is subsequently circulated back to the surface through the annular region [1]. Drilling fluids can be categorized based on their composition, we have water-based, oil-based, gas-based, or synthetic-based. These various types are applied in diverse scenarios and may involve different additives [1]. Notably, water-based mud stands out as the most frequently used drilling fluid among these categories [1].

To prevent the entry of formation fluids into the wellbore, the hydrostatic pressure of the mud should slightly exceed the formation pressure. The pressure difference propels the mud into the borehole, reaching the permeable rocks. Extensive mud loss into the formations typically occurs only in instances of fractured formations. In such cases, mud solids are filtered into the hole, creating a thin, low-permeability filter cake that permits only the passage of filtrate (such as oil and water) [2]. The generated filter cake serves to stabilize the wellbore and manage the intrusion of mud into the permeable zone, thereby mitigating formation fracturing. Consequently, both borehole stability and formation integrity hinge on the filtration characteristics of drilling fluids. Filtration has consistently posed a significant challenge to the petroleum industry, as it is a primary cause of permeability damage. It is evident that minimizing filtrate volume would be

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beneficial for production. Various operational factors, including borehole temperature, pressure, time, and particle size, significantly influence filtration [3]. This report will thoroughly examine these factors, along with other aspects such as the impact of pH on drilling integrity and the concern of spurt loss.

In addition to the points mentioned earlier, this report will examine the impact of adding barite to the mud. The primary emphasis will be on presenting the findings from an experimental investigation of the filtration properties of drilling fluids under borehole conditions and drawing pertinent comparisons with existing literature studies. The report outlines the experimental procedures employed, presents both calculated and observed results and conducts an in-depth analysis leading to the conclusion drawn. Finally, the report provides recommendations for future research work.[4].

EXPERIMENTAL PROCEDURE

Preparation of the mud

The formulation of Samples A, B, and C for the experiment involved specific steps. To prepare each sample, 22.5g of Bentonite was combined with 350 ml of liquids, consisting of 90% water and 10% Corn oil. To achieve a homogeneous mixture, the mixer was used to stir these for approximately 20 minutes. After stirring, any aggregated components adhering to the spindle were carefully scraped down 15 minutes following the stirring. Following the preparation steps, pH test strips were employed to measure the pH of all the formulated samples. To allow for ageing, the samples were left in the mixing device for a minimum of 2 minutes under room temperature conditions [5]. This is illustrated in Figure 1 (a)

Weighing Determination of Sample A

In the laboratory procedure, the measurement of Sample A's mud density was carried out using a Mud balance. The Mud balance, described as a cup with a consistent volume featuring a level arm and a calibrated rider, was employed for the direct determination of mud density in pounds per gallon [4]. This is shown in Figure 1(b).

The calibration process involved several steps: first, the lid was removed from the cup, and it was filled with water. The lid was then replaced, wiped dry, and the balance arm was positioned on the base with the knife-edge resting on the fulcrum. Care was taken to ensure that the level vial was centered when the rider was set at 8.33 pounds per gallon of water. Following this, the cup was filled with the mud to be tested. After replacing and properly rotating the lid to expel some mud through the hole in the cup, the external surfaces of the cup were cleaned.

The balance arm was then positioned on the base with the knife-edge on the fulcrum, and the rider was adjusted to level the graduated arm. The leveling was confirmed using the level dial on the beam. The density of the mud could then be read on either side of the lever. After ageing, Sample A was stirred for 5 minutes, and Barite, a weighing agent, was added to the sample. Additions of 5g, 10g, and 10g of Barite were made successively, and density readings were recorded after each addition [5].

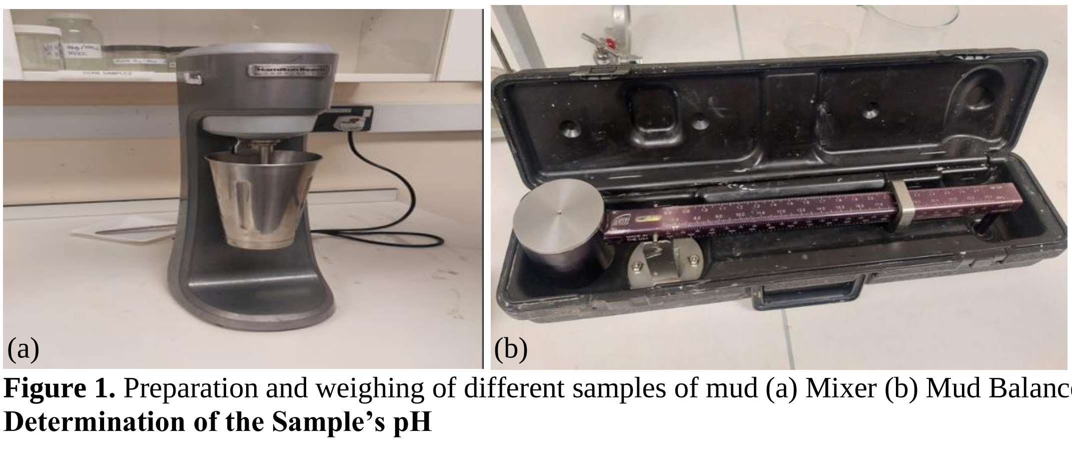

Figure 1. Preparation and weighing of different samples of mud (a) Mixer (b) Mud Balance

Determination of the Sample's pH

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The pH test strips were employed to measure the pH of all the formulated samples after mixing. The pH strips are shown in Figure 2(a)

Filtration Loss Test

In the laboratory procedure, the demonstration of this test was conducted using Samples B Figure 2(b) and C. It's important to note that a chemical additive Polyanionic Cellulose (PAC) of 5g was introduced to Sample C Figure 2(c) before the filtration process. To carry out this procedure, a low-pressure filter press was used. This device plays a crucial role in assessing the filtration and filter cake properties of muds, providing valuable insights for a wide range of applications [5]. A visual representation of the process is presented in Figure 3, captured within the laboratory setting.

The filter press was set to operate at 100psi. The filtration steps proceeded as follows: the mud cell was detached from the filter press frame, and the filter paper of the appropriate size was positioned at the bottom of the cell. Subsequently, the mud was introduced into the cup assembly, and the filter paper and screen were placed on top, secured with the mud clamp. The air pressure valve was tightly closed, and the mud cup assembly was clamped to the frame while ensuring a secure hold on the filtrate outlet end, tightened finger-tight. Figure 3(a, b, c).

The next step involved positioning a graduated cylinder beneath to collect the filtrate. The air pressure valve was then opened, and timing commenced simultaneously. Filtrate volume was recorded at specified intervals (5 minutes) for up to half an hour. Additionally, a vernier caliper was employed to measure the thickness of both samples [5].

RESULTS AND DISCUSSION

Mud Weight and Hydrostatic Pressure of Sample

This presents the relationship between the amount of Barite added and the corresponding measured mud weight and pH readings for Sample A. As Barite is added in increments of 5 grams, the mud weight increases, while the pH reading is only provided for the initial measurement with no Barite added. Table 1

From Figure 4 it can be observed that the mud density increased proportionally with the addition of different amounts of barite. In essence, an increase in mud density corresponds to a concurrent increase in its associated hydrostatic pressure, as illustrated in Figure 3 (refer to the appendix). Equation 1 below establishes a connection between pressure, density, and true vertical depth;

$$P = 0.052\rho h \qquad (1)$$

By way of illustration, the hydrostatic pressure at a presumed depth of 10,000 feet can be calculated using the initial equation, prior to the introduction of barite. Consequently,

$$P = 0.052 \times 6.95 \times 10{,}000 \; = \; 3614\, psi$$

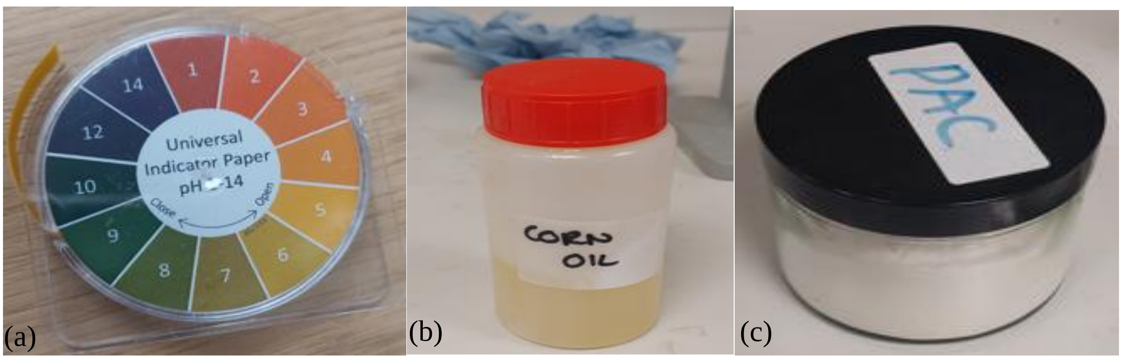


Figure 2. Determination of the Sample's pH (a) pH strips (b) Corn Oil (c) Polyanionic Cellulose (PAC)

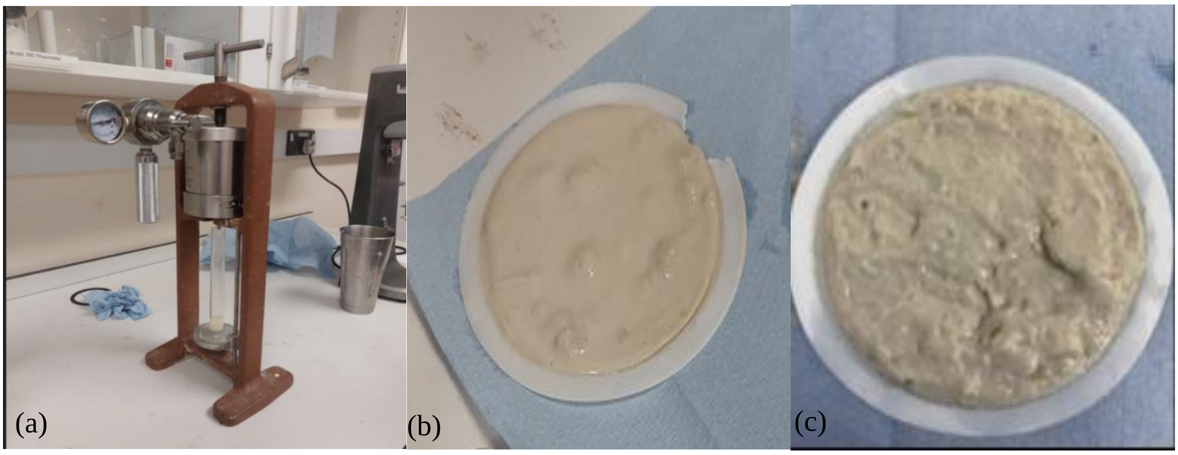


Figure 3. Filteration Loss Test (a) Filter Press (b) Image of Sample B Filter Cake (c) Image of Sample C Filter Cake.

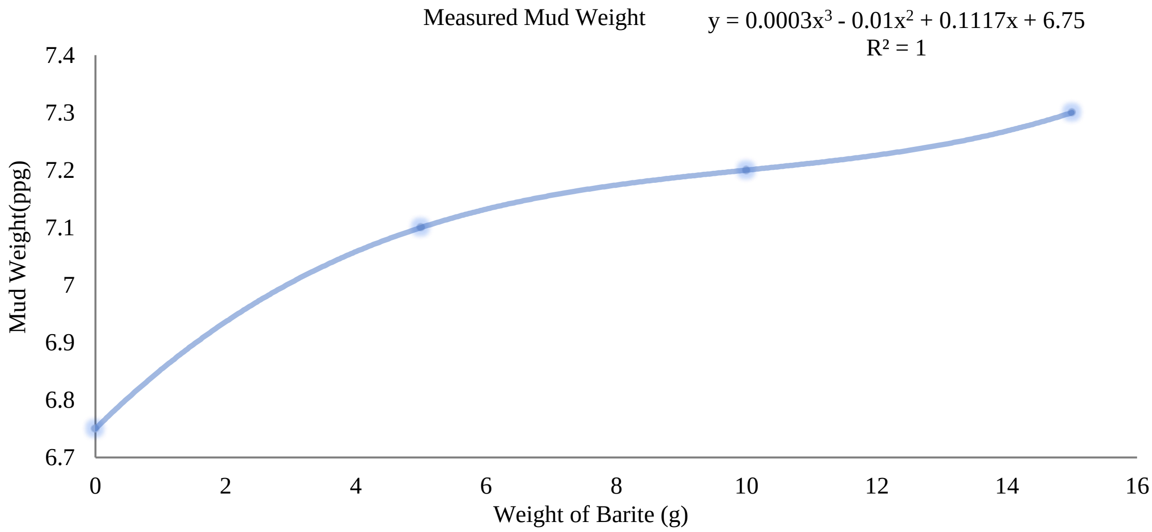


Figure 4. Mud Density Increased with Addition of Barite.

Table 1. Mud Weight of Sample A.

S/N	Barite Added (g)	Measured Mud Weight (ppg)	pH Reading
1	0.00	6.95	9.00
2	5.00	7.10	
3	10.00	7.20	
4	15.00	7.30	

The remaining hydrostatic pressure will be calculated using equation (1) and the results are presented in Table 2.

The highest achievable mud density determines the maximum pressure gradient, as illustrated in the following equation (equation 2).

$$\frac{P}{h} = 0.052\rho \; = \; 0.052 \times 7.30 \; = \; 0.3796 \, Psi/ft \quad (2)$$

We can also determine the mud weight needed to balance the formation pressure, considering the established pressure gradient of the formation [4] at a true depth of 10,000 feet. Therefore,

$$\frac{0.561}{0.052} = 10.788\ ppg$$

Filtration Analysis and pH of Sample B and C

Table 3 displays the recorded filtrate volumes and pressure readings at 5-minute intervals while using the filter press set to 100 psi. The pH readings are also recorded in Table 3 as 9.00 for both samples. In this experiment, there was no adjustment for the pH value. 9.00 was maintained for both samples throughout the experiment.

Comparison of Average Mud Cake Thickness shows that the addition of PAC (Polyanionic Cellulose) reduces the thickness of mud cake from 3 mm in Sample B (without PAC) to 2 mm in Sample C (with PAC), indicating improved fluid loss control. Table 4

COMPREHENSIVE ANALYSIS OF RESULTS

The Impact of Barite on Mud Density

Table 1 and Figure 2 clearly demonstrate the variability in Mud weight resulting from the addition of Barite. Specifically, the density of Sample A exhibited a consistent increase with the addition of Barite, transitioning from 6.95 ppg to 7.3 ppg. To elaborate, Figure 4 illustrates that at zero Barite content, the mud weight was 6.95 ppg, progressively rising with each increment of added Barite, ultimately reaching the peak value of 7.3 ppg after the introduction of 15g of Barite. This analysis proves the significant impact of Barite, recognized as an inert solid and extender [6] and as a pivotal weighting component capable of elevating mud density to meet desired standards, ensuring its resilience against formation pressure.

Table 2. Results for corresponding hydrostatic pressures against their mud densities.

Mud Weight (ppg)	6.95	7.10	7.20	7.30
Hydrostatic Pressure (psi)	3614	3692	3744	3796

Table 3. Volume of the filtrate and pH reading for both samples.

Filtration Time (min)	**Filtration Volume (ml) for Sample B (Without PAC)**	**Filter Press Pressure (psi) for Sample B**	**Filtration Volume (ml) for Sample C (With PAC)**	**Filter Press Pressure (psi) for Sample C**
0	0.00	100	0.00	100
5	6.00	100	1.80	100
10	7.75	100	2.50	100
15	9.00	100	3.50	100
20	9.60	100	3.90	100
25	11.10	100	4.40	100
30	12.20	100	4.80	100
pH reading	9.00		9.00	

Table 4. Average Mud Cake Thickness.

Sample	**Average Mud Cake Thickness (mm)**
Sample B (Without PAC)	3
Sample C (With PAC)	2

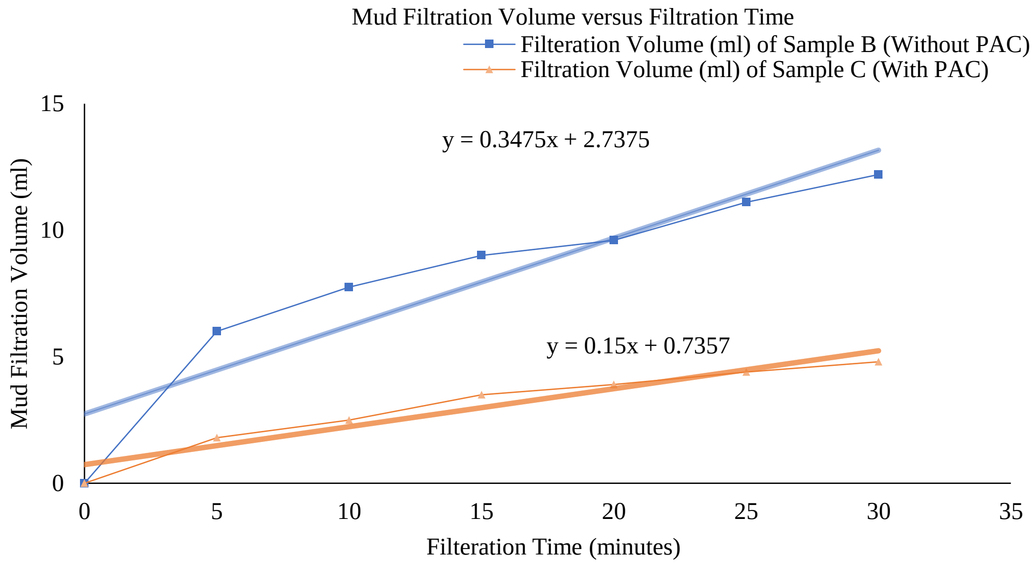


Figure 5. Mud Filtration Volume variation for Sample B and C.

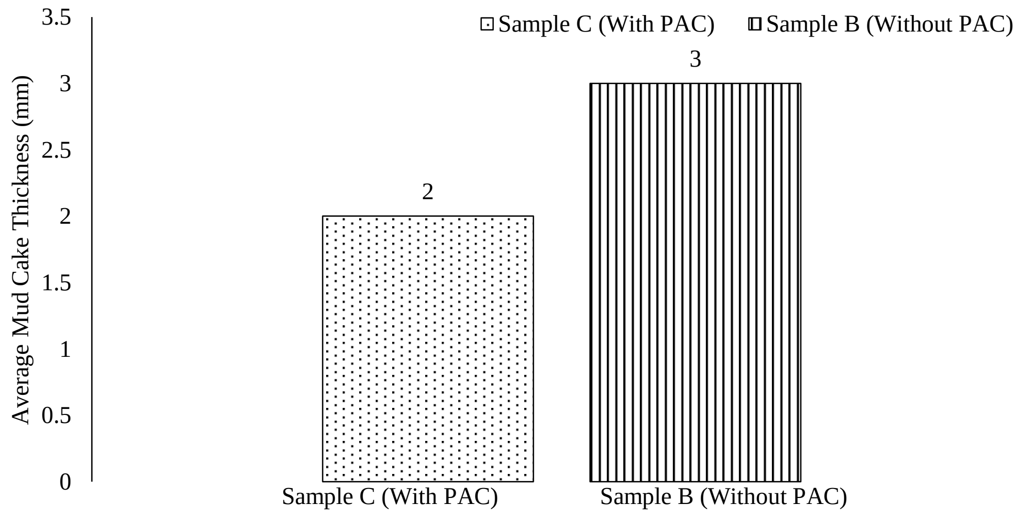


Figure 6. Mud Thickness of Sample B and C.

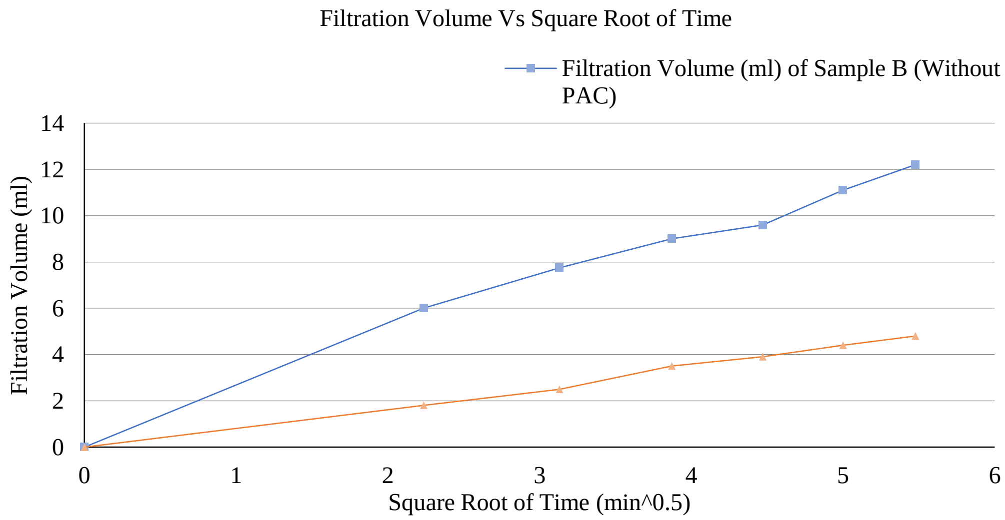


Figure 7. Spurt Loss.

API Barite remains the sole inert solid option for muds, distinguishing itself from other materials like limestone and feldspar that can lead to a reduction in frictional pressure on the fluid surface. Nevertheless, it carries the drawback of being less effective in lifting rock cuttings to the wellhead [6]. In Figure 4, the general trend of data increase is initially modeled linearly. However, upon utilizing an Excel plot, it became evident that the trend is more accurately captured by a cubic equation, as depicted in Figure 4. Upon analyzing the recorded values, the final dataset (indicating the maximum measured mud density at 15g Barite) exhibits a slight deviation from the polynomial results, registering at 7.3ppg and introducing an error of approximately 1.4%. The discrepancy may be attributed to potential issues such as a malfunctioning mud balance, inadequate human interpretation, or visual distortions (e.g., zero error or parallax). As a recommendation for enhanced precision, it is advisable to conduct multiple repetitions of this test. This approach minimizes the risk of obtaining misleading and non-representative data, thereby ensuring more accurate and reliable results. Examining another aspect of it, the significance of incorporating a density control agent into the mud sample to ensure its hydrostatic pressure can withstand the formation pressure for secure oil production from the subsurface cannot be overstated. The figure provided in the appendix confirms that hydrostatic pressure increases linearly with mud weight in our case. It is evident that the obtained mud density (7.3 ppg) yielded an optimal pressure of 3796 Psi and a pressure gradient of 0.3796 Psi/ft within the mud. This suggests that this particular mud weight is only suitable for subnormal formations with a pressure gradient ranging from 0.35 psi/ft to 0.37 psi/ft, a circumstance arising from the insufficient water drive to facilitate hydrocarbon flow [7]. In formations where the pressure gradient exceeds 0.466 psi/ft, indicating an overburden, the necessity for heavier mud becomes crucial to withstand the formation pore pressure [8]. In the context of this experiment, the system represents an abnormal pressure system with a pressure gradient of 0.561 ft. This implies that the maximum pressure gradient achieved is insufficient. Several factors could contribute to this, foremost among them being inadequate barite. Additionally, the presence of observed bubbles in the mud indicates the existence of gaseous matter, thereby reducing the overall mud density. It is recommended that in the laboratory setting, proper ventilation is ensured, and a more effective density control mud, such as hematite and ilmenite, should be considered [8]. Moreover, it is essential to raise the quantity of barite, and the precise amount required to sustain the 10.8 ppg formation was determined to be approximately 27g of barite. This calculation was based on the cubic relationship.

pH Adjustments

In this experiment, the pH of the Mud was not varied. It was not adjusted. We only measured it once and it was through throughout the experiment. My observation and from what I read from literature, pH should be varied or adjusted so as to understand the effect of varying pH on the mud density.[9].

Filtration Test and Its Properties using Sample B and C

Filtration loss refers to the drilling fluid lost to the formation upon contact with permeable zones. In drilling, experts must consistently maintain a delicate balance between the bottom pressure of the mud column and that of the drilling fluid. Any deviation from this equilibrium can result in a pressure differential leading to loss of circulation, and in more severe cases, a kick may occur, causing the deposition of solids and the formation of a mud cake on the well walls. Over time, this mud cake acts as a barrier, preventing further loss of mud. The frequency of filtration is influenced by factors such as mud cake thickness, pressure, temperature, and inevitably, time. The ultimate objective is to achieve a thin and permeable filter cake [10].

From an informative standpoint, there are numerous reasons why it is crucial to prevent drilling fluids from infiltrating pore formations, with cost being the foremost concern due to their expense. Moreover, the intrusion of these fluids into the rock can disrupt surrounding zones, leading to changes in both mud and formation chemical properties. It is consistently preferable to maintain a consistent filtration loss during drilling to facilitate uninterrupted circulation between the surface and the wellbore, thereby preventing the formation of a thick mud cake or excessive filtration.

Figure 5 illustrates a noticeable increase in filtrate volume for both samples over time, with sample B exhibiting a significantly higher filtration rate compared to C, which includes PAC. In examining the impact of PAC, a filtration control agent, on the filtration process, samples A and B were utilized. This experiment spanned a 30-minute interval, with volume measurements recorded every 5 minutes. According to the experimental results, Mud B achieved a final filtration volume of 12.2 ml, in contrast to the 4.8 ml recorded for sample C containing PAC. The observations suggest that PAC led to a reduction in the filtration rate of Mud C, causing its final filtration volume to decrease by 61%. This implies that, for Mud B to achieve better filtration performance, the use of a control additive is essential [11]. This is further confirmed by the slopes depicted in Figure 5, where Sample B achieved a higher volumetric flow rate of 0.326 ml/min in comparison to the 0.1214 ml/min observed for Sample C. However, a consistent discrepancy in Figure 5 is notable: while the recorded filtrate volumes over the interval for C are nearly precise, those for Sample B, particularly in the first 15 minutes, exhibit a slight inaccuracy, deviating by approximately 15-20% from the best-fit line. This discrepancy may have stemmed from potential delays in timekeeping or inaccuracies in reading the test tubes. In Figure 7, pertaining to spurt loss analysis, the volumes for both samples were graphed against the square root of time, revealing a proportional relationship. Spurt loss refers to the rapid influx of mud and filtrate rate to the exposed rock just before the formation of a permeable and thin filter cake [11].

The spurt loss, representing the intercept, was determined by connecting linear points (points with the same slope). For Sample B, the points at 7.75 ml and 9.6 ml were selected for this purpose, while for Sample C, it ranged from 3.5 ml and beyond. The spurt loss for Sample B was approximately 2.5 ml, in contrast to 0.2 ml for Sample C. Based on these findings, it would be prudent to consider using a control agent for Sample B, though to a minimal extent. Notably, there was an abnormal increase in pressure observed in the filter press for Sample B, posing a significant concern. The cause of this issue could potentially be a fault in the equipment. Conversely, Table 3 reveals a decline in pressure for Sample C over the given time period. This decrease can be attributed to the influence of PAC, which induces pressure loss, consequently reducing the quantity of filtrate.

Regarding Shale Sloughing, it occurs when shale mixes with water from the mud, leading to the erosion of the external formation surface. This condition results in borehole deterioration and pipe sticking [12]. Challenges associated with shale sloughing include increased drilling costs, hole bridging, an escalation in the solid component of the drilling fluid, and, due to the formidable task of reaching the anticipated pay depth, wells often face abandonment [11]. A recognized approach to address sloughing is the application of invert emulsion mud. In this mud, oil serves as the continuous phase, while water acts as the dispersed phase. The rationale behind the widespread use of this mud globally lies in its ability to enhance wellbore stability and provide a conducive environment for easier perforation while drilling through shale formations. Moreover, this mud operates on the principle of maintaining a lower water content than that of the shale, thereby generating osmotic pressure that directs water from the shale into the mud. This process results in shale dehydration, consequently reducing fluid circulation or loss [13]. Another organic substance, Gilsonite, is suggested to be introduced into the mud unit in a refined form. This addition is intended to diminish the fluid's invasive characteristics and establish a cohesive bond to prevent shale sloughing [13].

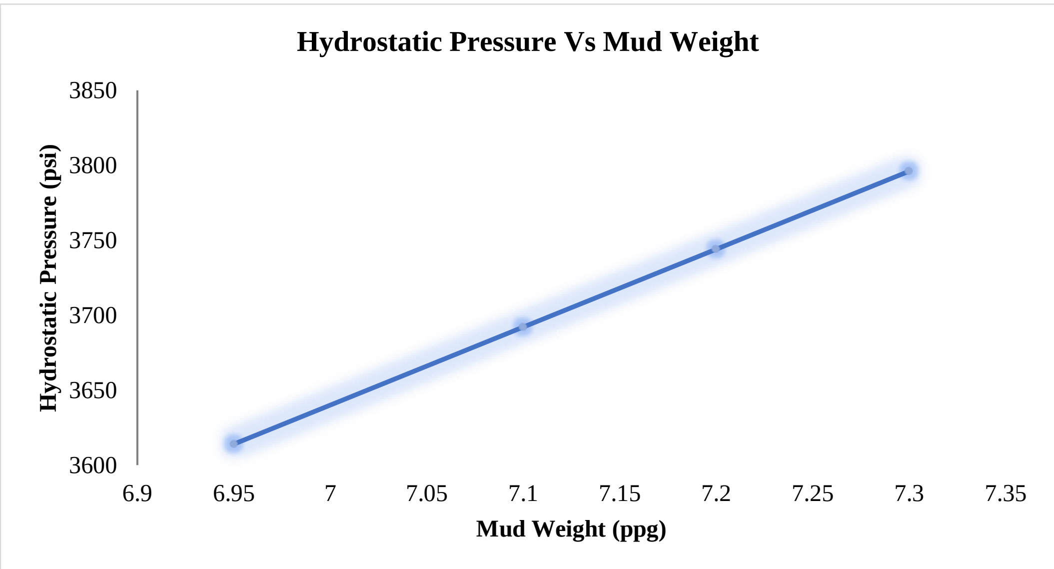
Returning to the discussion of filter cakes, elevating pressure typically results in increased compaction of the mud's filter cake. This compaction tends to elevate the resistance of the filter cake, consequently reducing the filtrate volume, provided that the mud cake can undergo compression [2]. On the contrary, escalating pressure may also enhance the driving force, thereby raising the filtrate volume, aligning with the principles outlined in Darcy's law [2]. In cases of static filtration, such as ours, the compaction is likely to be minimal compared to that induced by a driving force. However, in dynamic filtration, the shear rate and stress on the cake surface can influence compaction, leading to the formation of a highly resistant cake. The thickness of the mud cake is directly linked to the permeability of the shale. According to [14], the mud thickness can range up to 4mm when the overbalance pressure is minimal and reduces to 1.7 mm under the influence of high overbalance pressure factors. As evident in this experiment (refer to Figure 6), Mud B exhibited a mud cake thickness of 3mm, while Mud C had a thickness of 2mm. It can be confidently asserted that, even with chemical control, both samples B and C have met the criteria for the desired mud cake, forming a thin layer of filter cake that conforms to the standard size for regulating filtration in drilling processes (presumably under low overbalance pressure factors for both mud cakes). However, it is worth noting that the measured normal thickness in sample C might have been inaccurate due to the addition of a filtration loss agent. This addition typically results in a thicker cake, unlike Mud B, which did not have any form of filtration-regulating additive. PAC (Polyanionic Cellulose) has been both experimentally and theoretically demonstrated as successful in enhancing drilling integrity. It is essential to note that the thicker the cak, the lower the permeability hence it is important to avoid excessive thickening.

CONCLUSION

The effectiveness of drilling activities hinges significantly on the quality of the drilling mud. The fluid's performance plays a pivotal role in ensuring the successful completion of a wellbore and influences associated expenses. A primary function of mud is to balance formation pressure with its hydrostatic pressure, promoting the stabilization of pore formations and enhancing hydrocarbon production. If the mud weight is not appropriately calibrated, the required pressure in the well may not be attained, leading to the invasion of formation fluid and significant loss of circulation, posing a major setback. Through the development of an initial dataset, a mud weight of 27g barite was determined to be optimal for maintaining formation pressure. Barite serves as an agent to increase the mud weight density and, consequently, its hydrostatic pressure. Key concerns in the production area include the flow of near-wellbore fluid filtrate during drilling, formation fracture, and the buildup of the mud cake. Consequently, there is a need to experimentally examine filtration characteristics by comparing Mud C, which contains PAC, with Mud B. In this context, PAC serves as a material for controlling filtration loss. The addition of PAC to sample C significantly enhanced the effectiveness of the mud by reducing the rate of filtrate volume in the drilling fluid and forming a non-thick and non-impermeable barrier against the shale. In addition, the pH of samples B and C were measured to be 9.0. There was no further adjustment of pH of the samples from laboratory experiments. Therefore, much would not be said about the pH. Adjusting the pH of the Mud is one of the major properties of filtration. It is highly recommended that this experiment should be repeated by investigating the adjustment of the pH of mud.

8.0 Appendix

A linear relationship between hydrostatic pressure (psi) and mud weight (ppg) is shown. As the mud weight increases, hydrostatic pressure also increases, indicating a direct correlation between the two variables.



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