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Evaluation of Kaolin Clay as a Lost Circulation Material in Water Based Mud

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Abstract: This project aims to analyse how local lost circulation material affects drilling fluid rheology and fluid loss in water-based muds. Local lost circulation material used in carrying out these experiments is kaolin clay. Five mud samples were formulated, the first mud which was the base mud had no LCM, 10g of kaolin clay was added to the second sample, 20g of kaolin clay was added to the third mud, while 30g and 40g of kaolin was added to the fourth and fifth sample respectively, results showed that increase in particle size and concentration of LCMs increased the plastic viscosity, apparent viscosity, yield point as well as gel strength, also the ability of the LCM to seal off fractures in time and reduce fluid loss was affected by particle size of the LCM. This research showed that kaolin clay had a good effect on rheological properties of the mud and had adequate mud cake thickness and is suitable to be used as LCM.

Keywords: Lost Circulation, Water-Based Mud, Kaolin Clay, Particle Size, Plastic Viscosity, Yield Point, Gel Strength, Fluid Loss, Rheological Property

1. Introduction

The drilling process is a critical operation in the oil and gas industry, involving the creation of boreholes in the subsurface to access and extract hydrocarbon reserves. It is a complex and multi-stage procedure that requires specialised equipment, skilled personnel, and meticulous planning [1].

Well Planning and Design

Geoscientists and drilling engineers analyse geological data, including seismic surveys and well logs, to determine optimal drilling locations [2]. Factors such as reservoir characteristics, target depth, and potential hazards are considered during this phase. A drilling program is developed, outlining methods, equipment requirements, and safety procedures.

Rig Mobilisation

The drilling rig is transported to the drilling site, along with the necessary equipment [2]. Rig components, such as the derrick, mast, draw works, and drilling fluid systems, are assembled and positioned. Safety measures, including securing the rig and establishing a safe working environment, are implemented.

Spud-In and Drilling

The drilling process begins with spud-in, where a drill bit is attached to the bottom of the drill pipe, and the rotary table or top drive rotates the drill string, causing the bit to penetrate the formations [2]. Drilling mud is circulated to cool and lubricate the bit, carry cuttings to the surface, and provide pressure control. The drilling progresses in sections, extending the wellbore deeper into the earth.

Casing and Cementing

Casing is installed at specific depths to reinforce the wellbore and prevent formation collapse [2]. Steel casing strings are lowered and cemented in place, creating a barrier between different geological zones. Cement is pumped down the casing and up the annular space, ensuring well integrity.

Formation Evaluation

Various tools and techniques are used to evaluate subsurface formations during drilling [2]. Wireline logging tools are deployed to measure properties such as porosity, resistivity, and formation pressure. This information aids in identifying hydrocarbon-bearing zones and understanding reservoir characteristics.

Drill stem Testing

In some cases, drill stem testing (DST) is conducted to assess well productivity [2]. A DST tool is deployed to the bottom of the well, and formation fluids are flowed to the surface for analysis. DST provides data on reservoir flow rates, pressure gradients, and fluid properties, facilitating reservoir characterization and production planning.

Completion and Production

Once drilling operations are complete, the well enters the completion phase [2]. Production equipment, such as tubing, packers, and valves, is installed to enable hydrocarbon flow. Well connection to production facilities is established, and production testing is conducted to assess productivity. If economically viable, the well proceeds to full-scale production.

It's important to note that the drilling process can vary depending on factors such as well type, drilling method, and geological conditions. Safety measures and environmental considerations are integral components to minimize risks and ensure sustainable operations [1].

1.1. Challenges Associated with Lost Circulation Referring to the Un-intended Loss of Drilling Fluids into the Formation

Lost circulation is a significant challenge encountered during drilling operations, referring to the unintended loss of drilling fluids into the formation [3]. This problem can have various consequences and pose several challenges to drilling operations. Some of the key challenges associated with lost circulation include:

1. Increased Costs: Lost circulation incidents lead to additional expenses in drilling operations. When drilling fluids are lost into the formation, more drilling fluid is required to maintain proper circulation, resulting in increased mud consumption and higher operational costs [4]. Moreover, additional time and resources are needed to address the lost circulation and implement remedial measures, further adding to the overall drilling expenses [5].
2. Wellbore Instability: Lost circulation can cause wellbore instability, leading to wellbore collapse, caving, or ballooning. The loss of drilling fluids weakens the wellbore walls, making them prone to instability and collapse [6]. This instability can jeopardise the integrity of the well, hinder further drilling progress, and pose safety risks to personnel and equipment [7].
3. Non-Productive Time: Lost circulation incidents often result in non-productive time (NPT), where drilling operations are temporarily halted or delayed to address the issue. NPT can have significant financial implications for drilling projects, as it leads to reduced efficiency, increased labour costs, and potential contractual penalties due to project delays [8].
4. Formation Damage: The loss of drilling fluids into the formation can cause damage to the surrounding geological formations. The invasion of drilling fluids can alter the properties of the reservoir, reducing its permeability and damaging the productive zones [9]. Formation damage can result in decreased well productivity, reduced hydrocarbon recovery, and the need for costly remedial treatments to restore reservoir performance [10].
5. Environmental Concerns: Lost circulation can have environmental implications, particularly if the drilling fluids contain additives or chemicals. When drilling fluids are lost into the formation, they can migrate into groundwater resources, potentially contaminating drinking water supplies and affecting the local ecosystem [11]. Proper management and mitigation of lost circulation are essential to minimize the environmental impact of drilling operations [12].
6. Operational Delays: Lost circulation incidents often require the implementation of remedial measures to regain control over the drilling process. These measures can include the use of specialized lost circulation materials (LCMs), such as bridging agents or plugging materials, which may need to be sourced, tested, and deployed [13]. The time required for the implementation of such measures can result in operational delays and extended drilling timelines [3].

Addressing the challenges associated with lost circulation requires the use of effective lost circulation mitigation techniques and suitable LCMs. Research and development efforts continue to focus on identifying innovative solutions to mitigate lost circulation, reduce costs, enhance drilling efficiency, and minimize the impact on the environment [4].

1.2. Lost Circulation Materials (LCMs)

The purpose of Lost Circulation Materials (LCMs) in drilling operations is to mitigate lost circulation incidents, which refer to the unintentional loss of drilling fluids from the wellbore into the surrounding formation. LCMs are designed to seal off or bridge fractures, slugs, or permeable zones in the formation, preventing or minimizing fluid losses during drilling.

LCMs play a crucial role in mitigating lost circulation by sealing fluid loss pathways and enhancing wellbore stability. When introduced into the wellbore, LCMs can migrate towards the fluid loss zones and create a barrier that reduces or stops fluid losses, thereby preventing wellbore instability and the associated challenges.

According to [14], LCMs are used to bridge and seal off fractures and highly permeable zones in the formation, helping to maintain wellbore stability and control lost circulation incidents. By sealing off the pathways through which drilling fluids escape, LCMs effectively minimize fluid losses and prevent wellbore collapse or differential sticking [15].

LCMs also contribute to improved drilling efficiency by minimizing operational interruptions and maintaining proper drilling fluid circulation. They enable drilling operations to proceed smoothly, enhancing drilling efficiency and productivity [16]. By effectively controlling lost circulation, LCMs reduce non-productive time associated with lost circulation incidents and optimize drilling performance [17].

In drilling operations, a variety of Lost Circulation Materials (LCMs) are commonly used to mitigate lost circulation incidents. These LCMs can be categorized into conventional materials, such as fibrous materials and bridging agents, and non-conventional materials, including microparticles and polymers. Each type of LCM serves a specific purpose in sealing fluid loss pathways and controlling lost circulation.

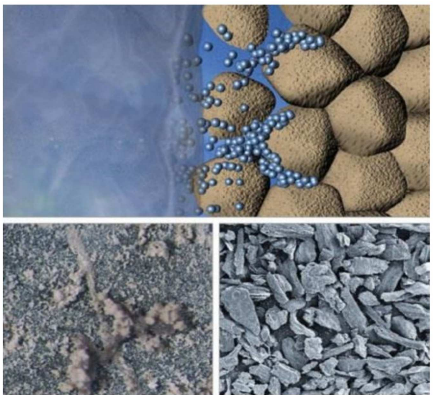

Figure 1. *Lost Circulation Materials (LCM) [18].*

Conventional Materials:

Fibrous Materials: Fibrous LCMs, such as cotton, hemp, or synthetic fibres, are commonly used to control lost circulation. These materials are introduced into the wellbore as a part of the drilling fluid to bridge and plug fractures or permeable zones [19]. Fibrous LCMs create a network of fibres that can form a mechanical barrier to prevent fluid losses and maintain wellbore stability [14].

Bridging Agents: Bridging agents, also known as particulate LCMs, are solid materials that are larger than the formation pore throats. These materials are designed to bridge across fractures or permeable zones, forming a physical barrier to fluid loss. Common bridging agents include ground calcium carbonate (GCC), calcium carbonate fibres, mica, and graphite [19]. Bridging agents effectively block the fluid flow through the fractures or vugs, reducing fluid losses and maintaining wellbore integrity [20].

Non-Conventional Materials:

Microparticles: Microparticles, such as ground nutshells, nut plug, or synthetic polymers, are non-conventional LCMs used to control lost circulation. These materials are smaller in size than bridging agents and can enter into smaller fractures or pore throats [19]. Microparticles form a filter cake on the fracture faces, reducing fluid loss and preventing further particle migration [14]. They create a plugging effect and enhance wellbore stability.

Polymers: Polymer-based LCMs, including gelling agents or viscosifiers, are used to control lost circulation incidents. These polymers are added to the drilling fluid to increase its viscosity and create a high-viscosity pill in the loss zone [19]. Polymers improve the fluid's bridging and sealing capabilities by reducing fluid mobility and effectively plugging fractures or vugs [20]. Examples of polymers used as LCMs include xanthan gum, hydroxyethyl cellulose (HEC), and polyacrylamides [19].

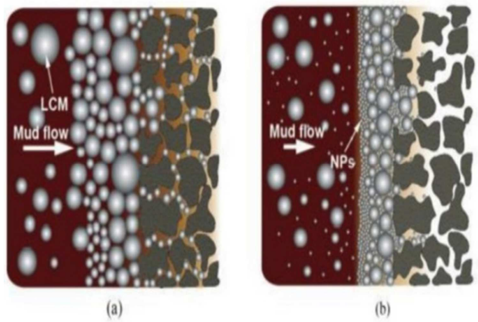

Figure 2. *Mud filtration using (a) Conventional LCM (b) Unconventional LCM [18].*

By utilizing a combination of conventional and non-conventional LCMs, operators can tailor the lost circulation control strategy based on the specific formation characteristics and lost circulation severity.

2. Materials and Methods

2.1. Materials

The materials used for this experimental research study include;

1) Kaolin Clay
2) Barite
3) Bentonite
4) Caustic Soda
5) Water

Figure 3. *Kaolin Clay.*

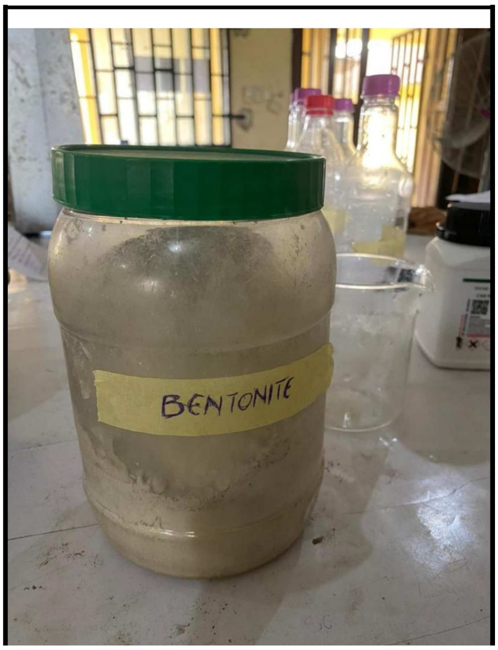

Figure 4. *Bentonite.*

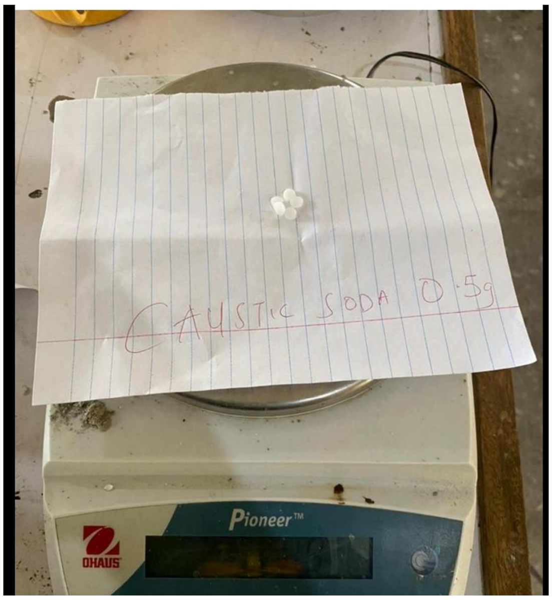

Figure 5. *Caustic Soda.*

2.2. Methods

Experimental Setup and Materials Preparation:

1. Gather all the required materials: Kaolin Clay, Barite, Bentonite, Caustic Soda, and Water.
2. Grind the Kaolin Clay to a consistent particle size using appropriate equipment.
3. Filter the grinded Kaolin Clay using a mesh size of 250 to obtain a uniform particle size distribution.
4. Prepare different concentrations of Kaolin Clay suspensions (Samples A, B, C, and D) by mixing the clay with water in varying ratios. Sample A will serve as the control sample without Kaolin Clay.

Figure 6. *Kaolin Clay being Crushed.*

Experimental Design:

Plan a series of tests to evaluate the lost circulation properties of the Kaolin Clay suspensions. Consider using a suitable test apparatus such as a simulated wellbore setup.

Preparation of Kaolin Clay as LCMs:

i. Sieve Analysis:

A sieve analysis was conducted to assess the particle size distribution of the crushed Kaolin Clay LCM samples. The following procedure was followed:

1. Sieves with a sieve aperture of 250 microns were utilized for the analysis.
2. The sieves were cleaned by washing and brushing to remove any particles stuck in them.
3. The sieves were arranged in order of decreasing sieve opening size from bottom to top.
4. The initial weight of each sieve and receiving pan was recorded.

Figure 7. *250 mesh size used to sieve the grinded kaolin clay.*

ii. Preparation of Mud Sample:

The mud sample preparation involved formulating water-based mud by adding additives into the base fluid (water). The following steps were taken:

1. 350ml of water was measured and poured into the Hamilton mixing cup
2. The mixing cup was placed in the Hamilton beach mixer.
3. 15grams of Bentonite was added and prehydrated for 15 minutes under stirring conditions.
4. 0.5grams of caustic soda was added into the mixture
5. 0.6 grams of Pac-R was also added to the mixing cup
6. 30grams of Barite was added to the mixture.
7. Allow the sample to age for 24-hrs under lab conditions.
8. Stir it continuously with the Hamilton beach mixer.
9. The mixture was stirred further for another 20 minutes for homogeneity before taking the rheological readings and (10 seconds/minutes) gel strength.

Figure 8. *Hamilton beach mixer used to mix the sample concentration.*

iii. Determination of Mud Density

Mud density, vital for controlling subsurface pressures and stabilizing the wellbore, was determined using a mud balance. The procedure was as follows:

Figure 9. *Mud balance used to determine mud density.*

1. Fill the mud balance cup to the brim.
2. Cover the cup with a cap to allow excess mud and air to escape.
3. Wipe off any excess mud from the balance while securely holding the cup.
4. Balance the mud balance on the provided knife edge using the rider.
5. Record the reading indicated by the arrow on the scale when the balance is stable.

iv. Determination of Water Based Mud (WBM) Rheology

Rheological properties of the water-based mud were measured using a fan viscometer to calculate plastic viscosity (PV), apparent viscosity (AV), yield point (YP), and gel strength. The following steps were followed:

Figure 10. *VG meter used to determine gel strength.*

1. The VG Meter cup containing the sample was placed on the VG Meter platform.
2. The platform was raised to align the mud level with the scribed line around the VG Meter sleeve.
3. The switch was toggled to high-speed, and the first reading was recorded at 600rpm.
4. The switch was toggled to low-speed, and the second reading was recorded at 300rpm.
5. The 10-second and 10-minute gel strengths were recorded from the dial's highest values.
6. The procedure was repeated for samples containing LCMs.

v. Determination of Filtrate Volume and Mud Cake Thickness

This test assessed the fluid filtration rate through filter paper under specified conditions. The procedure was as follows:

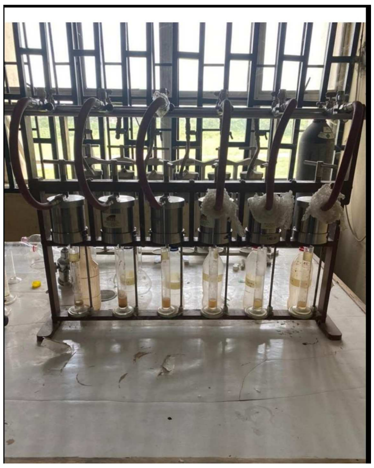

Figure 11. API filter press.

Figure 12. determination of mud cake thickness.

1. The API filter press apparatus was mounted on the work table.
2. The cell was filled with mud sample to 3-4 cm from the brim.
3. The cell was covered with the regulator cap and placed into the filter press stand.
4. The T screw on the regulator was adjusted to pressurize the cell to 100psi.
5. A 25ml graduated cylinder was positioned under the cell to collect filtrate.
6. The test was run for 30 minutes, and mud filtrate values were taken at specific intervals.
7. Filtrate values were recorded at 7.5 minutes, 15 minutes, 22.5 minutes, and 30 minutes.
8. The thickness of the solid filter cake was measured after the test.

2.3. Data Collection and Analysis

Collect data from each lost circulation test, including mud loss rates, pressure differentials, and any other observations.

Analyze the data to evaluate the effectiveness of Kaolin Clay in mitigating lost circulation. Compare the performance of different concentrations with the control sample.

Consider using statistical methods to assess the significance of the results.

2.4. Interpretation of Results

Interpret the results based on the performance of each Kaolin Clay concentration in terms of lost circulation prevention and pressure containment.

Discuss the rheological behavior and density of the Kaolin Clay suspensions in relation to their performance.

3. Results and Discussion

3.1. Result

Table 1. Experimental Result.

Sample	Kaolin Content (g)	pH	Mud Density (ppg)	300rpm	600rpm	Gel Strength (10s)	Gel Strength (10min)	Filtrate Volume (7.5min)	Filtrate Volume (15min)	Mud Cake Thickness (inches)
A	0	12	9.0	13	17	24	30	18ml	23ml	3/32
B	10	13	9.2	18	21	30	39	15ml	17ml	4/32
C	20	13	9.3	23	27	32	42	13.5ml	16ml	4/32
D	30	13	9.5	29	34	35	44	12ml	14ml	4/32
E	40	13	9.6	35	40	37	47	12ml	14ml	4/32

Table 2. Rheology of the Mud.

Sample	Kaolin Content (g)	pH	Mud Density (ppg)	300rpm	600rpm	Gel Strength (10s)	Gel Strength (10min)
A	0	12	9.0	13	17	24	30
B	10	13	9.2	18	21	30	39
C	20	13	9.3	23	27	32	42
D	30	13	9.5	29	34	35	44
E	40	13	9.6	35	40	37	47

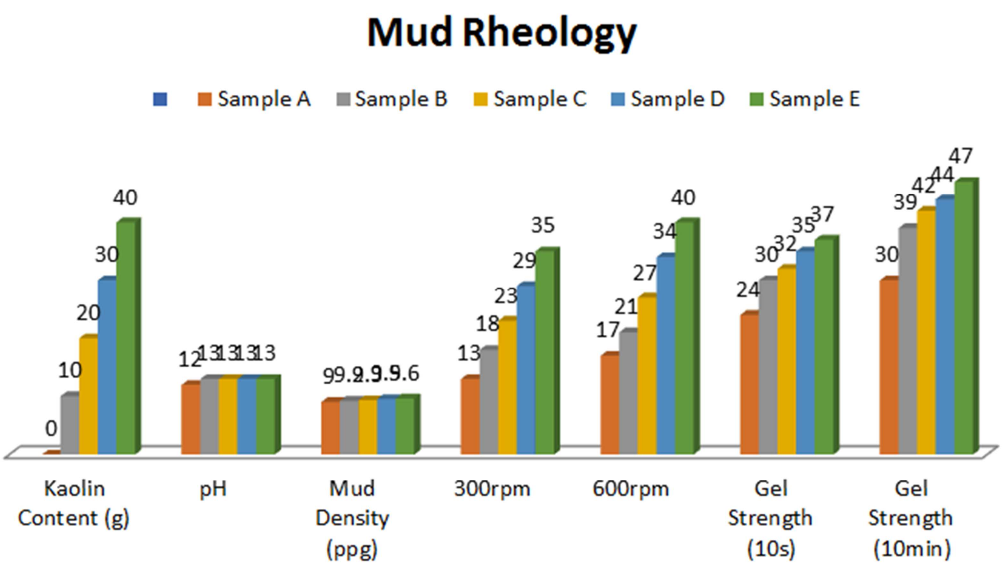

Figure 13. *Mud Rheology Chart.*

Table 3. *Filtration and Mud Cake Thickness.*

Sample	Filtrate Volume (7.5min)	Filtrate Volume (15min)	Mud Cake Thickness (inches)
A	18ml	23ml	3/32
B	15ml	17ml	4/32
C	13.5ml	16ml	4/32
D	12ml	14ml	4/32
E	12ml	14ml	4/32

Table 4. *Concentration of Materials.*

Sample	Kaolin (g)	Barite (g)	Bentonite (g)	Caustic Soda (g)	Water (ml)
A	0	30	15	0.5	350
B	10	30	15	0.5	350
C	20	30	15	0.5	350
D	30	30	15	0.5	350
E	40	30	15	0.5	350

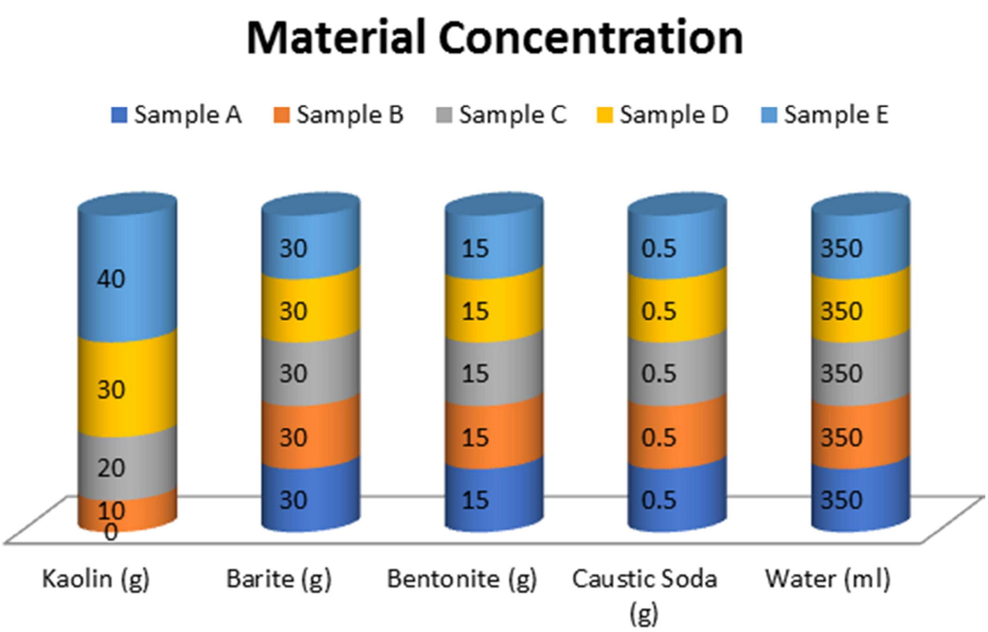

Figure 14. *Concentration Of Mud Samples.*

3.2. Discussion

Rheology Parameters (Table 2)

Sample Variation: As the concentration of kaolin clay increases (from Sample A to E), there is a noticeable increase in the rheological properties of the mud.

Viscosity: Both the 300rpm and 600rpm readings increase with higher kaolin content. This suggests that kaolin clay contributes to higher viscosity and potentially improved suspension of solids in the mud.

Gel Strength: Gel strength, measured at 10 seconds and 10 minutes, also increases as kaolin clay concentration increases. This indicates improved gelation properties, which can help maintain wellbore stability during drilling.

pH and Mud Density: The pH remains relatively constant across the samples, while there's a slight increase in mud density with higher kaolin content.

Filtration and Mud Cake Parameters (Table 3)

Filtrate Volume: The filtrate volume at both 7.5 minutes and 15 minutes shows a decreasing trend as kaolin clay content increases. This implies that the addition of kaolin clay contributes to lower fluid loss, which is a positive sign for preventing lost circulation.

Mud Cake Thickness: The mud cake thickness remains fairly consistent across the samples, with a slight increase observed at higher kaolin concentrations. This suggests that kaolin may contribute to a slightly thicker and potentially more effective mud cake.

Material Concentrations (Table 4):

The concentrations of different materials used in the mud formulation help understand the composition of each sample:

Kaolin clay concentration increases progressively from Sample A to Sample E.

Barite concentration remains constant across samples, ensuring consistent mud density.

Bentonite and caustic soda concentrations remain constant as well, indicating that these additives are not significantly affected by the presence of kaolin.

Water content remains constant across all samples.

The data suggests that the addition of kaolin clay to the water-based mud affects its rheological properties, resulting in increased viscosity and gel strength. This could be beneficial in preventing lost circulation by creating a more stable mud system. Additionally, the reduction in filtrate volume indicates improved filtration control, which is essential for minimizing fluid loss while drilling. Mud cake thickness remains relatively constant, indicating consistent sealing properties.

These findings suggest that Sample D, with 30g of kaolin clay, strikes a balance between improved rheological properties and effective filtration control. It's important to note that the choice of the "best" concentration depends on the specific drilling conditions, the formation being drilled, and the operational goals.

It's important to note that while the data provides insights into the laboratory behaviour of the mud, real-world drilling conditions could influence the performance of the mud in the field. Further testing and consideration of factors like temperature, pressure, and the specific geological formation are necessary for a comprehensive evaluation.

Overall, the results suggest that kaolin clay has a positive impact on the rheological and filtration properties of the water-based mud, potentially making it an effective lost circulation material. Further analysis and field testing would provide a more accurate assessment of its practical application in drilling operations.

4. Conclusion

In this study, the effectiveness of kaolin clay as a lost circulation material (LCM) in water-based mud (WBM) was comprehensively evaluated. The primary focus was on assessing the impact of different concentrations of kaolin clay on rheological properties, filtration behaviour, mud cake formation, and material concentrations. The study aimed to determine the optimal concentration of kaolin clay for mitigating lost circulation and enhancing drilling fluid performance.

4.1. Rheological Properties and Mud Behaviour

The addition of kaolin clay to water-based mud resulted significant changes in rheological properties. As the concentration of kaolin clay increased, both the 300rpm and 600rpm viscosity values exhibited a noticeable rise, suggesting enhanced resistance to flow. Concurrently, gel strength measurements at 10 seconds and 10 minutes demonstrated increased values, indicating improved suspension properties and better hole stability. These results are indicative of kaolin clay's ability to strengthen the mud's structural integrity, potentially reducing the risk of lost circulation in permeable and fractured formations.

4.2. Filtration Control and Mud Cake Formation

Filtration control is a critical aspect of drilling operations to prevent fluid loss into the formation. The experimental data revealed that as the concentration of kaolin clay increased, the filtrate volume decreased, signifying effective filtration control. This reduction in fluid loss is particularly promising for maintaining wellbore stability and minimizing operational challenges associated with lost circulation. Interestingly, the mud cake thickness remained relatively constant across samples, indicating that the addition of kaolin clay did not significantly affect the sealing ability of the mud cake.

4.3. Optimal Concentration and Practical Implication

Upon analysing the data, it appears that Sample D, containing 30g of kaolin clay, yielded some of the most favourable outcomes across various parameters. This sample exhibited improved rheological properties, enhanced gel strength, and effective filtration control. However, it is important to note that the determination of the "best" concentration must be contextualized within the specific geological conditions, drilling environment, and operational goals. Real-world applications may require further fine-tuning and validation through field trials to ascertain the optimal concentration for effective lost circulation mitigation.

5. Recommendation

1. While Sample D seems promising in this limited laboratory study, it's essential to conduct further testing, including field trials, to determine the most suitable concentration of kaolin clay for actual drilling operations.
2. Additionally, considering other factors such as cost-effectiveness and environmental impact is crucial in making a well-informed decision.
3. Field trials and operational data collection are crucial to validate laboratory findings and optimize the implementation of kaolin clay in real drilling operations.

Conflicts of Interest

The authors declare no known competing interests that could have influenced this report.

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