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Review Article

Role of Drilling Fluids in Solving Drilling Challenges: A Major Focus on Plugged Drill Strings

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Abstract

Drill string plugging is a complex challenge in the oil and gas industry, often caused by a combination of factors related to fluid properties, wellbore conditions, and the nature of the formation. It can have severe consequences, including increased downtime, safety hazards, equipment damage, and higher operational costs. However, with proper planning, real-time monitoring, and effective fluid management strategies, the risks associated with drill string plugging can be mitigated, ensuring the smooth and efficient progression of drilling operations. The study however, explores the effectiveness of efficient drilling fluids properties optimization and management, together with real time monitoring of parameters, as a major means of providing solution to the challenge of drill string plugging during drilling operations. The study reveals that results from field experience, shows that adjusting drilling parameters, using LCMs, anti – sticking agents, monitoring performance and reacting promptly to signs of potential plugging, can help drillers to mitigate the risks of drill string plugging. Optimizing drilling fluid properties enables drillers to use the right fluid parameters for a specific region of the formation, while real time monitoring of parameters helps to ensure that the required fluid parameters are always met while drilling is in progress, especially in terms of solids control, rheological properties and mud weight. Real time monitoring of the formation properties is also useful in directing operators on the right fluid properties to use while drilling across formation of any specific property. This approach is rather a proactive/ preventive method, rather than a reactive method of solution to drill string plugging issues.

Keywords

Drilling Fluids Functions, Drill String Plugging, Solids Control Efficiency, Common Drilling Challenges, Left Over Debris, Effective Cuttings Removal, Mud Cake Flakes, Rig Downtime Cause

1. Introduction

Drilling fluids, also known as drilling muds, are essential liquids used in the process of drilling wells, especially in the oil and gas industry and Geothermal wells. These fluids serve multiple purposes to ensure the smooth and efficient drilling

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process.

There are different types of drilling fluids used in the oil and gas industry drilling operations. The major difference in the drilling fluids is basically due to its compositions. Drilling fluid composition varies depending on the type of formation, depth of the well, and the specific challenges faced during drilling, and they are continuously monitored and adjusted to meet operational requirements [1]. The different types of drilling fluids are discussed below:

1.1. Types of Drilling Fluids

1. Water-Based Fluids (WBF): These are the most commonly used fluids, where water is the primary liquid phase. They are generally cheaper and easier to handle but are less effective in high-temperature or high-pressure environments.
2. Oil-Based Fluids (OBM): These use oil as the base fluid. They are more stable at high temperatures and pressures and provide better lubrication but are more expensive and less environmentally friendly.
3. Synthetic-Based Fluids (SBF): These fluids combine the properties of both water-based and oil-based fluids, offering the advantages of oil-based fluids with less environmental impact.

However, in the oil and gas industry, drilling fluids (or drilling muds) are crucial for the efficient, safe, and cost-effective drilling of wells. Their primary functions are designed to address the challenges encountered during drilling operations, such as wellbore stability, equipment protection, and efficient cuttings removal [1, 2].

1.2. Functions of Drilling Fluids

Here are the key functions of drilling fluids:

1.2.1. Lubrication of the Drill Bit

Drilling fluids help reduce friction between the rotating drill bit and the walls of the wellbore. This lubrication ensures that the bit operates smoothly, preventing wear and tear, and reducing the power needed for drilling. Efficient lubrication also prevents the drill bit from getting stuck in the formation.

1.2.2. Cooling the Drill Bit

The drilling process generates significant heat due to friction between the bit and the rock. Drilling fluids help cool the drill bit by carrying away heat, preventing overheating and potential damage to both the bit and the drilling equipment.

1.2.3. Removal of Cuttings

As the drill bit penetrates rock formations, it generates rock fragments or "cuttings." Drilling fluids help lift these cuttings from the bottom of the well to the surface, where they can be removed. Without effective cuttings removal, the wellbore could become clogged, leading to inefficiencies, equipment damage, or even wellbore collapse.

1.2.4. Pressure Control

One of the most critical functions of drilling fluids is to maintain pressure control within the wellbore. The drilling fluid creates hydrostatic pressure that counteracts the pressure from the oil, gas, or water formations in the surrounding rock. This balance prevents blowouts (uncontrolled release of fluids or gas) and keeps the wellbore from collapsing. The density and composition of the drilling fluid can be adjusted to match the formation pressures encountered.

1.2.5. Wellbore Stability

Drilling fluids help stabilize the wellbore by preventing the walls from caving in. They do this by forming a protective "filter cake" on the wellbore walls, which acts as a barrier to fluids from the surrounding formation. This prevents excessive fluid loss to the formation and helps prevent wellbore instability during drilling.

1.2.6. Formation Damage Prevention

Drilling fluids must be carefully selected to minimize damage to the formation being drilled. For example, some drilling fluids may contain chemicals that prevent the wellbore from absorbing water, which could cause swelling in sensitive rock formations. Additionally, the right fluid ensures that the formation remains undamaged, allowing for efficient hydrocarbon production later.

1.2.7. Corrosion Protection

The components of the drilling rig, such as pipes and the well casing, are exposed to harsh conditions like high temperatures, pressures, and potentially corrosive fluids. Drilling fluids often contain additives that help prevent corrosion of metal equipment by forming a protective film on metal surfaces.

1.2.8. Facilitating Well Logging and Casing Operations

Drilling fluids support the safe and efficient execution of well logging, casing, and cementing operations. They can help with transporting logging tools down the wellbore and maintaining the integrity of the casing during installation, ensuring that cement bonds effectively around the casing.

1.2.9. Maintaining Hole Cleanliness

Drilling fluids assist in maintaining the cleanliness of the wellbore during drilling. They remove the drilled rock cuttings and any debris that might interfere with drilling operations, ensuring that the wellbore remains clear and that the drilling process proceeds smoothly.

1.2.10. Environmental and Safety Considerations

The formulation of drilling fluids can include environmentally friendly options, such as biodegradable additives, to minimize the impact of fluids on the surrounding environment. The proper disposal and management of used drilling fluids are also critical to avoid contamination.

1.2.11. Formation Fluid Control

Drilling fluids play a vital role in controlling the influx of formation fluids (e.g., gas, oil, water) into the wellbore. This is crucial for preventing dangerous situations like blowouts. By adjusting the density of the drilling fluid, operators can control the hydrostatic pressure to prevent formation fluids from entering the wellbore.

Overall, drilling fluids are indispensable for the safe, efficient, and environmentally responsible extraction of oil and gas, ensuring that drilling operations proceed without interruption, equipment is protected, and the wellbore remains stable throughout the process.

1.3. Drilling Challenges

A lot of challenges are being faced by drillers during drilling operations. Drilling challenges in the oil and gas industry refer to the various operational, technical, and environmental obstacles encountered during the drilling process. These challenges can impact the efficiency, safety, and cost-effectiveness of drilling operations [3]. Different types of drilling challenges arise from a variety of factors such as wellbore conditions, formation characteristics, equipment performance, and external environmental factors. Below are some common drilling challenges.

1.3.1. Drill String Plugging

Drill string plugging occurs when the flow of drilling fluid through the drill string becomes obstructed, preventing the efficient removal of cuttings and circulation of the drilling fluid. This can lead to significant operational delays, wellbore instability, and even equipment damage.

1.3.2. Wellbore Instability

Wellbore instability is one of the most common drilling challenges and occurs when the wellbore walls collapse or become deformed during drilling. This can lead to significant operational delays, costly repairs, and even the abandonment of the well.

1.3.3. Lost Circulation

Lost circulation occurs when the drilling fluid "leaks" into the surrounding formation instead of returning to the surface. This can result in reduced hydrostatic pressure, which compromises well control and increases the risk of blowouts or formation damage. Lost circulation is especially common in fractured or highly permeable formations.

1.3.4. Hydrocarbon Kicks and Blowouts

A kick occurs when formation fluids (oil, gas, or water) flow into the wellbore due to an imbalance between formation pressure and the pressure exerted by the drilling fluid. A blowout is an uncontrolled release of formation fluids, often accompanied by an explosion, which can lead to catastrophic safety risks.

1.3.5. Temperature and Pressure Variability

Extreme temperature and pressure conditions at depth can complicate drilling operations, especially in deepwater or ultra-deep drilling projects.

1.3.6. Stuck Pipe

Stuck pipe occurs when the drill string becomes immobilized in the wellbore, making it difficult or impossible to continue drilling.

1.3.7. Formation Damage

Formation damage refers to the impairment of the reservoir’s ability to produce hydrocarbons due to the invasion of drilling fluids or other operational factors.

Drilling challenges such as drill string plugging, wellbore instability, lost circulation, kicks and blowouts, and stuck pipe are common in the oil and gas industry and can significantly impact operations. Addressing these challenges requires careful planning, the use of appropriate drilling fluids, continuous monitoring, and the application of specialized techniques and equipment [3, 4]. By understanding and mitigating these challenges, operators can improve the safety, efficiency, and success of drilling operations.

Based on the functions of drilling fluids explained earlier, it is obvious that most of the drilling challenges mentioned here can be controlled or managed by monitoring and adjusting the drilling fluid properties during drilling operations to prevent the occurrence of most of the challenges mentioned above.

Drill string plugging is a very serious drilling challenge which occurs when the drill string has been clogged by cuttings, debris or other foreign particles such as scales from drill pipes, etc [5, 6]. It is however important to note that all the various causes of drill string plugging can be prevented or controlled by adjusting the various properties of the drilling fluid being used in the drilling operation. The drilling fluid is key to preventing and solving the problem of drill sting plugging. This can be achieved by using drilling fluids of the right mud density and rheology which would ensure proper cuttings suspension and removal from the wellbore, and maintain well stability. Adequate monitoring and control of the drilling fluids flow rate and circulation to ensure proper hole cleaning would be beneficial in solving the problem of drill string plugging.

It is based on these reasons, that this study focuses on the ‘Role of Drilling Fluids in Solving Drilling Challenges; a Major Focus on Drill String Plugging’.

2. Drill String Plugging Challenge in Drilling Operations

Drill string plugging occurs when the flow of drilling fluid through the drill string becomes obstructed, preventing the efficient removal of cuttings and circulation of the drilling fluid [6]. This can lead to significant operational delays, wellbore instability, and even equipment damage. Drill string plugging is a significant operational challenge in the oil and gas industry, and it occurs when the flow of drilling fluid is obstructed or blocked within the drill string or the wellbore, impeding the circulation process. This blockage disrupts the efficient flow of drilling fluid, resulting in various operational difficulties. Plugged drill string can lead to serious delays, increased costs, and potential risks to the safety and stability of the wellbore [4, 7].

2.1. Causes and Effects of A Plugged Drill String in the Oil and Gas Industry

Drill string plugging can occur due to a combination of factors that are typically related to the properties of the drilling fluid, wellbore conditions, and the nature of the formation being drilled [1, 7, 8]. The following are some of the primary causes:

2.1.1. Excessive Cuttings Accumulation

Description: When drill cuttings produced by the drill bit, which was not screened out by the surface solids control equipment, finds its way and accumulate inside the drill string or at the bottom of the wellbore, they can create blockages, reducing fluid flow.

Cause: This typically happens when the solids control equipment is not functional optimally.

Effect: The accumulation of cuttings can lead to partial or complete blockages in the drill string, preventing proper circulation and compromising the ability to cool and lubricate the drill bit.

2.1.2. Poor Solids Control Efficiency/Mud Pump Strainers

Description: In the process of circulation of drilling fluid during drilling operation, SCE are usually the first line of defense, the drilling fluid which comes from the formation, laden with cuttings from the wellbore are usually passed through shaker screens of various sizes in order to release the cuttings and pass on the drilling fluid free from any cuttings [8, 9]. This is usually done before the drilling fluid is then reconditioned to meet the required properties to suit the present need of the wellbore, after which it is sent back into the well through the process of circulation. Poor solids control, however, occurs when some of the cuttings, other solids in the drilling fluid are not properly removed at this stage by the solids control equipment. However, it is highly recommended the fluid goes through a mud pump strainer which is cleaned from time to time.

Cause: Poor or bad choice of shaker screen size, poor efficiency of the desander, desilter, centrifuge due to lack of maintenance.

Effect: This usually results in sending back drilling fluid that still contains some undesirable solid particles into the wellbore though the drill string. This usually result in the agglomeration of these solid particles which eventually lead to the clogging of the drill string.

2.1.3. Poor pit Cleaning/ Drifting of Drill pipes

Description: If the mud tank is not properly cleaned, left over debris from the previous section can find its way to the string which could lead to a blockage.

Additionally, unused or undrifted drill pipes that has been stacked for a long time has a very high potential of having scales in its internal diameter, which when subjected to high flow rate during drilling operations could fall off and plug the string.

Cause: poor supervision from the rig crew, not following pit cleaning and pipe drifting guidelines.

Effect: Old solids particles get mixed with fresh mud; unwanted scales fall off the drill pipe thereby leading to increased solids content above specification.

2.1.4. Improper Drilling Fluid Properties

Description: The composition of drilling fluids plays a critical role in ensuring smooth operations. If the drilling fluid is improperly formulated, it may lack the right properties to prevent plugging.

Cause: Low viscosity or improper rheological properties of the drilling fluid can lead to the inability to carry cuttings efficiently. Similarly, if the drilling fluid's density is too high without adequate rheology, sagging effect could occur, thereby leading to string plugging.

Effect: Inadequate fluid properties can result in fluid sagging which has a high potential to plug the string.

2.1.5. Pipe Stuck / Differential Sticking

Description: Differential sticking occurs when the drill string becomes stuck due to a pressure imbalance between the wellbore and the drill pipe. If the pressure exerted by the drilling fluid is too high or too low, it can cause the pipe to stick to the formation, especially when drilling through low-pressure zones.

Cause: The imbalance between the pressure in the wellbore and the pressure exerted by the drilling fluid causes a "differential" force that can make the drill string adhere to the wellbore walls. This can also lead to the accumulation of cuttings around the stuck section of the drill string.

Effect: As the drill string becomes stuck, fluid circulation may be blocked, leading to insufficient removal of cuttings. If cuttings are not efficiently removed, they can clog the drill string.

2.1.6. Use of Inappropriate Additives

Description: The use of inappropriate or excessive additives in drilling fluids can lead to the development of undesirable conditions within the fluid, when base brines used to prepare mud is mixed to saturation point, this in turn forms crystals which are insoluble contributing to plugging.

Cause: Certain additives, such as heavy-weight materials or additives meant for fluid loss control or LCM, may agglomerate under certain conditions, causing them to form lumps or clusters that clog the drill string. For example, excessive use of barite (a weighting agent) or lost circulation materials LCM can cause excessive particle aggregation.

Effect: The resulting aggregates or clusters of additives can clog the drilling fluid's flow path, leading to blockages within the drill string.

2.2. Commercial and Technical Impact of Plugged Strings

The effects of plugged drill string can be severe, impacting both the operational efficiency and the safety of the drilling process. Some of the major consequences include:

2.2.1. Well Control and Safety Hazards

a. Unable to establish circulation: If drilling fluid cannot circulate properly due to plugging, it may lead to a loss of pressure control in the wellbore, during dangerous situations like kicks (influx of formation fluids), circulation is very crucial to be able to circulate the kick out or kill the well through any approved IWCF method to prevent blowout.
b. Blowout risks: Inadequate well control from plugged drill strings can prevent operators from detecting or managing kicks in real time, leading to blowouts, which pose significant safety risks.

2.2.2. Increased Non-Productive Time (NPT)

a. Operational delays: plugged drill string significantly hampers fluid circulation, forcing operators to stop or slow down operations to clear the blockage. This leads to non-productive time (NPT), which increases drilling costs [9, 10].
b. Well abandonment: In extreme cases, persistent plugging and circulation problems may lead to the abandonment of a well, resulting in the loss of significant investment.

2.2.3. Increased Drilling Costs

a. Rig downtime: Plugging-related delays often require additional equipment, manpower, and time to resolve, which can increase the overall cost of drilling operations.
b. Equipment wears and damage: Blockages can cause excessive wear on the drill string, pumps, and other equipment due to increased pressure and friction. This results in higher maintenance costs and the potential need for replacement parts.

2.2.4. Loss of Wellbore Stability

a. Formation damage: If plugging causes irregular fluid circulation or wellbore instability, it can lead to the formation of unstable sections in the well. This could result in a collapsed or deformed wellbore, further complicating drilling operations.
b. Poor cementing and casing operations: A blocked drill string can also affect the quality of cementing and casing operations, potentially leading to inadequate zonal isolation or casing failures.

2.2.5. Impact on Hole Cleaning

Poor cuttings removal: Blockages hinder the ability to efficiently remove cuttings from the wellbore, which can lead to hole cleaning problems. If cuttings are not removed, they may settle in the wellbore, creating a situation where the drill string is increasingly likely to become stuck or damaged.

2.2.6. Operational Interruptions

a. Need for intervention: Drill string plugging often requires intervention measures such as backwashing, wellbore cleaning, or even pulling the drill string out of the hole to clear the blockage. These interventions add time and complexity to the operation.
b. Loss of drilling momentum: Continuous plugging problems can cause frequent halts in drilling progress, reducing the overall efficiency of the drilling operation and delaying project timelines.

3. Discussion of Preventive and Mitigative Solutions to String Plugs

To mitigate or prevent strings from getting plugged, several strategies can be employed:

1. Optimizing Drilling Fluid Properties: Ensuring that the fluid has the right viscosity and density to carry cuttings efficiently can reduce the chances of string getting plugged.
   a. Use drilling fluids with proper rheological properties (viscosity, yield point and gel strength) to ensure efficient cuttings transport and prevent settling.
   b. Adjust the fluid's density and viscosity based on formation conditions to ensure optimal circulation.
2. Proper Hole Cleaning Techniques: Adjusting the flow rate and circulation to help remove cuttings more effectively.
   a. Implement the right flow rates and pressure to ensure

that cuttings are lifted and carried efficiently to the surface.

b. Use high-quality, well-formulated drilling fluids that can handle the expected formation conditions.

3. Frequent Monitoring and Maintenance: Monitoring the condition of the string and performing maintenance when required to ensure proper fluid flow.
   a. Continuously monitor the fluid flow, pressure, and volume to detect any signs of blockage early and address them promptly.
   b. Perform regular checks on the condition of the drill string, and clean it periodically if necessary.
4. Wellbore Stability Management:

Ensure proper formation evaluation and adjust drilling fluid properties to prevent wellbore instability, which can lead to plugging.

3.1. Impact of Optimizing Drilling Fluid Properties in Solving String Plug Challenges (Pro-Active Approach)

Drill - string plugs is a serious downhole issue where solids or debris obstruct the internal bore of the drill pipe, potentially causing pressure surges, loss of circulation, or even failure to circulate drilling fluid [11]. Optimization of drilling fluid properties and functions is one of the most effective ways to prevent and solve drill string plugging and are discussed below:

3.1.1. Rheology Control (Viscosity, YP and Gel Strength)

Prevention: Properly tuned viscosity ensures efficient suspension and transport of cuttings out of the wellbore. If viscosity is too low, solids can settle and accumulate inside the drill string.

Solution: Adjusting rheology (e.g. rheology modifiers and viscosifiers) helps mobilize settled cuttings and clear blockages within the drill pipe or bottom hole assembly (BHA) [12, 13].

3.1.2. Solids Control and Mud Pump Screen (Strainers)

Prevention: High solids content in drilling fluid increases the risk of accumulating debris inside the drill string. Optimizing solids control systems (e.g., shale shakers, desanders, centrifuges) ensures cleaner fluid re-entering the drill pipe [11, 12].

Solution: If plugged string is detected, treating the mud to reduce solids content can help clear the obstruction through improved flowability.

3.1.3. Proper Lubricity and Flow Rate Optimization

Prevention: Drilling fluids with good lubricity and proper flow rates reduce cuttings accumulation and help maintain consistent flow in narrow or complex geometries [9, 13, 14].

Solution: Increasing pump rates temporarily, combined with optimized fluid properties, can dislodge plugs by enhancing hydraulic cleaning action.

3.1.4. Density (Mud Weight) Management

Prevention: Maintaining optimal mud weight prevents formation collapse or sloughing shale from entering the string and causing plugs.

Solution: In case of plug formation due to formation influx, adjusting mud weight may help stabilize the wellbore and reduce further intrusion of solids.

3.1.5. Use of Specialized Additives

Prevention: Additives like dispersants, detergents, and deflocculants can break up clumps of solids and prevent agglomeration inside the drill string.

Solution: Pills containing surfactants or dispersants can be circulated to help chemically break up and remove plugs.

3.1.6. Hydraulics Optimization

Prevention: Optimized annular velocity and nozzle configurations in the BHA ensure effective cuttings transportation efficiency.

Solution: Hydraulic modelling helps identify areas of low flow or turbulence that could lead to plugging, allowing targeted intervention on time.

3.1.7. Real-Time Monitoring and Adjustments

Prevention: Real-time monitoring of standpipe pressure, return flow, and torque/drag trends can indicate early signs of plugging [15].

Solution: Immediate mud property adjustment (e.g., thinning a high-viscosity fluid or circulating with a cleaning pill) can resolve issues before they worsen.

3.2. Practical Field Experience and Solutions to Drill String Plugging in Oil and Gas Industry

Drill string plugging is a persistent challenge in the oil and gas industry, as it can result in operational inefficiencies, safety risks, and financial losses [16]. However, field experience and the application of innovative solutions have allowed operators to mitigate this challenge effectively [16, 17]. The solutions to drill string plugging generally revolve around optimizing drilling fluid properties, improving hole cleaning techniques, monitoring operations, and applying specialized treatments [18, 19]. Below, we discuss practical field experiences and the solutions that have been successfully implemented based on real-world results.

3.2.1. Optimizing Drilling Fluid Properties

Drilling fluid properties are critical in preventing drill string plugging. In a field experience in the North Sea, where the drilling operation involved challenging shale formations, the drilling team faced significant issues with cuttings accumulation and excessive mud cake formation, which caused plugging in the drill string.

Solution Implemented:

Enhanced Rheological Properties: The drilling team optimized the viscosity and yield point of the drilling fluid to ensure better carrying capacity for cuttings. By using a high-yield-point fluid combined with thinner additives, the drilling fluid was able to lift and carry the rock cuttings more efficiently to the surface, thus preventing cuttings accumulation within the drill string.

a. Use of Polymeric Additives: Special polymeric additives were introduced to prevent the formation of a thick mud cake. These additives enhanced the stability of the fluid in high-pressure formations, preventing excessive cake formation and minimizing the risk of plugging.
b. Field Result: With these adjustments, the incidence of drill string plugging decreased significantly, and the wellbore remained clear of excessive debris, resulting in improved circulation and faster drilling progress.

3.2.2. Optimizing Hole Cleaning

Effective hole cleaning is key to preventing plug formation in the drill string. In the Gulf of Mexico, a deepwater drilling operation faced issues with cuttings settling at the bottom of the wellbore, leading to partial plugging of the drill string. This occurred primarily because of a mismatch between the circulation rate and the required hole-cleaning capacity.

Solution Implemented:

a. Increased Circulation Rate: The drilling team increased the pump rate to enhance the lift capacity of the drilling fluid. By increasing the flow rate, they ensured that the cuttings were carried upward at a faster rate, preventing them from settling in the wellbore and drill string.
b. Optimized Fluid Rheology: The fluid rheological properties were adjusted to prevent cuttings from agglomerating. This was achieved by using high-viscosity polymeric-based fluids to increase the suspension capability of the drilling fluid.
c. Directional Drilling Adjustments: As the wellbore angle increased, hole cleaning became more challenging. The team adjusted the drilling parameters, such as bit speed and weight on bit (WOB), to optimize the hole cleaning process in deviated and horizontal sections of the well.
d. Field Result: By enhancing the circulation rate and optimizing the fluid's rheology, the risk of drill string plugging due to cuttings accumulation was minimized, and the operation progressed without significant delays.

3.2.3. Use of Lost Circulation Materials (LCMs) and Hole Stabilization

In a field operation in the Middle East, a drilling team encountered a situation where the drilling fluid was lost into highly permeable formations, leading to a decrease in hydrostatic pressure and resulting in the risk of the drill string becoming plugged by cuttings that were not effectively carried to the surface.

Solution Implemented:

a. Lost Circulation Materials (LCMs): The team used LCMs, such as cellulose fibers, nutshells, and granular materials, to plug fractures and lost circulation zones in the formation. These materials helped reduce fluid loss and maintain pressure while also preventing excessive fluid loss from entering the formation.
b. Use of Shale Inhibitors: Shale inhibitors were introduced to prevent swelling and instability of shale formations, which could lead to the formation of debris that could block the drill string.
c. Optimizing Mud Weight: The team carefully adjusted the mud weight to provide an optimal balance between wellbore stability and fluid circulation. This reduced the risk of fluid loss into porous formations while ensuring adequate wellbore pressure to avoid kicks or blowouts.
d. Field Result: The combined use of LCMs, shale inhibitors, and proper mud weight control prevented fluid loss into the formation and minimized the risks associated with plugging. The drilling operation was able to continue without interruptions, and the wellbore remained stable and clear of debris.

3.2.4. Monitoring and Real-Time Data to Detect Early Signs of Plugging

In a recent drilling operation in the Arctic, the drilling team implemented real-time monitoring to detect early signs of drill string plugging and formation instability. The team faced a challenge where early detection of potential blockages was critical due to the extreme environment.

Solution Implemented:

a. Real-Time Monitoring of Drilling Parameters: The team employed real-time monitoring tools to track parameters such as pump pressure, flow rate, mud weight, and torque on the drill string. These sensors helped detect anomalies in circulation or changes in torque that indicated a developing plug.
b. Advanced Mud Logging: The team used mud logging systems to monitor the characteristics of the cuttings being brought to the surface. Changes in the size or shape of the cuttings could indicate problems in the wellbore that might lead to plugging.
c. Early Intervention: Upon detecting slight increases in pressure or torque, the team made adjustments to the circulation rate or modified the mud properties to prevent a full blockage.

d. Field Result: The real-time monitoring allowed the team to take immediate corrective actions before the situation escalated. As a result, they were able to prevent drill string plugging, maintain effective circulation, and complete the well on schedule.

3.2.5. Proper Drilling Practices to Prevent Differential Sticking

In an offshore field in Southeast Asia, the drilling team faced a challenge with differential sticking, where the drill string became stuck due to a pressure differential between the drill pipe and the formation. This caused partial plugging and restricted the flow of drilling fluid.

Solution Implemented:

a. Mud Weight Adjustment: The team adjusted the mud weight to ensure that the pressure exerted by the drilling fluid was balanced with the formation pressure. This prevented differential sticking and helped maintain fluid circulation.

b. Anti-Sticking Agents: They used anti-sticking agents to coat the drill string and reduce the chances of sticking to the formation. These agents are designed to create a thin, slippery layer on the drill pipe, preventing it from bonding to the wellbore.

c. Optimized Drilling Parameters: The team adjusted the drilling parameters, such as the rotary speed and weight on bit, to reduce the friction between the drill pipe and the wellbore, making it less likely for the pipe to become stuck.

d. Field Result: The implementation of these techniques reduced the incidence of differential sticking and minimized the risk of plugging. As a result, the drilling operations ran more smoothly, and the team avoided unnecessary delays.

3.2.6. Clearing Plugged Drill String Using Back-Flow Circulation

During a well construction operation in a shale play, a significant blockage occurred in the drill string due to a combination of mud cake buildup and the accumulation of cuttings. The drill string was partially plugged, and circulation was lost.

Solution Implemented:

a. Back-Flow Circulation: The team used a reverse circulation technique (also known as back-flow circulation) to clear the blockage. This method involved reversing the flow of drilling fluid through the drill string to flush out the debris.

b. High-Pressure Fluid Jets: High-pressure pumps were used to apply forceful jets of fluid down the drill pipe to dislodge and clear the blockages.

c. Use of High-Viscosity Fluids: To prevent future plugging, the team switched to a higher-viscosity fluid that was better able to carry cuttings to the surface and reduce the chances of accumulation inside the drill string.

d. Field Result: The combination of back-flow circulation and high-pressure fluid jets successfully cleared the blockage. The team was able to resume normal operations, and the well continued to be drilled without further plugging incidents.

3.3. Summary of Preventive Measures Based on Field Experience in Minimising String Plug Possibility

From fluid perspective, the only solution to drill string plug is to prevent it in the first place and here are some of the preventive approaches.

1. Ensure secondary screens are installed in the mud pump.
2. Ensure the right shaker screens with appropriate mesh sizes are installed in the mud shale shakers, this is the first primary defense in terms of solids control.
3. Ensure the solids control equipment like shale shaker, desander, desilter, and mud cleaners are working optimally.
4. Ensure the fluid rheology are in perfect acceptable range to be able to suspend the solids in the drilling fluids.
5. Ensure to place a screen on top of the mixing hopper to prevent unwanted materials into the active mud tanks.
6. Do not mix directly into the active tank, instead, mix in another tank and transfer same to the active system tank.
7. Mix polymers slowly to prevent fish eyes.

4. Conclusion

Through practical field experience, drilling teams have developed and implemented a variety of effective solutions to address drill string plugging. These solutions focus on optimizing fluid properties, improving hole cleaning practices, using real-time monitoring, and employing specialized treatments like lost circulation materials (LCMs) and anti-sticking agents. By adjusting drilling parameters, monitoring performance, and reacting promptly to signs of potential blockages, operators can mitigate the risks associated with drill string plugging and ensure smoother, more efficient drilling operations. In all, adopting a preventative approach is more rewarding in addressing the issue of drill string plugging.

5. Recommendations

From the findings of the study, the safety and economic implications of experiencing drill string plugging challenge in the rig, the following recommendations are made, based on field experiences. These recommendations are more of preventive measures to be taken in order to avoid recording the incident of drill string plugging.

a. During the preparation of drilling fluids, proper care should be taken to ensure proper mixing of the fluid components, to avoid formation of lumps of solid particles or undissolved solids.

b. The drilling should be designed to have the right rheological properties required for any particular section (depth) of the formation being drilled.
c. Ensure the fluid meets the adequate pH balance required for any particular section (depth) of the formation being drilled, especially for water – based fluids.
d. Adequate amount of biocides should be added in the preparation of the drilling fluid especially in water – based fluids, to prevent degradation of additives of fluid. This is especially important as most polymers tend to deteriorate over time thereby leading to loss of some rheological properties and the consequent sagging of solids.
e. Operators should ensure proper and adequate screen size is installed in the shaker screen, as a very important component of the entire system, and this should be frequently monitored for effectiveness.
f. Ensure solids control equipment (such as Desander, Desilter and Centrifuge) are working optimally at all times during drilling operations.

Abbreviations

OBM	Oil – Based Mud
WBF	Water – Based Fluids
SBF	Synthetic – Based Fluids
LCM	Loss Circulation Material
NPT	Non - Productive Time
BHA	Bottom Hole Assembly
YP	Yield Point
WOB	Weight on Bit

Author Contributions

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Conflicts of Interest

The authors declare no conflicts of interest.

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