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Scenario study on the choice of drilling method for oil wells in the context of the Brazilian pre-salt layer

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Abstract

This work aims to show the techniques and operational procedures that are used on an Offshore Drilling Rig, as well as application on each step of the process to the construction of an oil and gas well to prevent operational mistakes that cause non productive time. In the present work, an analysis regarding on a “Pre-Salt” well-constructed by a conventional drilling method, as well as difficulties encountered due to the method chosen. The results observed on case study show that the correct choose of the drilling method can determine significant advance in the “Pre-Salt” wells, in order to reduce the lost time and not to affect the well construction chronology.

Keywords: Oil well; Operational procedures; Drilling method; Pre-salt

1. Introduction

The oil well drilling techniques originated with the percussive method. However, as drilling depths increased, this method became obsolete. The rotary method was then developed, incorporating concepts such as well stability and drilling fluids. This method has been successfully used for many years. Over the years, new deposits have been discovered in wells that challenge in terms of stability and control. With the advancement of drilling technologies, methods and solutions have emerged to minimize and eliminate Non-Productive Time (NPT) [1].

The term Pre-Salt refers to hydrocarbon deposits in limestone rocks located beneath salt layers. Geological and geophysical professionals had already suspected the existence of deposits in this region, although their volumes were unknown. In the early 1980s, Petrobras drilled wells in shallow water offshore and successfully reached the Pre-Salt in the Campos and Sergipe-Alagoas basins. However, the new discoveries were not significant due to technological limitations at the time [2].

Therefore, the extracting of subsea wells, especially those at great depths like those in the Pre-Salt, it will require investment and technological innovation in drilling engineering. This paper presents practical concepts used in oil and gas well drilling rigs and a case study of a pre-salt well. The paper then discusses possible improvements with a focus on drilling operations.

Section 2 comments on a pre-salt well, carrying out a scenario study and summarising the operations required for safe drilling. Section 3 compares drilling methods, focusing on the conventional method and the MPD method [3]. Finally, Section 4 summarises the main results obtained and the conclusions of this work.

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2. Material and Methods

The purpose of this case study is to provide a brief demonstration of the operations on an offshore rig, including its operational reality and the necessary precautions that must be taken during each operation, particularly in a pre-salt well.

2.1. Summary of Operations at a Pre-Salt Well

The procedures performed for the four phases of the operations in well 1-FSMA-5-RJS (Table 1) are shown below.

Table 1 Characteristics of the studied well

Well Data	Water Depth	Air Gap
1-FSMA-5-RJS	1938 m	24 m

2.1.1. Phase I

Drilling commenced on well 1-FSMA-5-RJS with the objective of using a 36" drill bit, casing with a 30" casing, installing an ABP wellhead, and cementing the cased section. The initial drilling phase involved lowering the 36" bottom hole assembly (BHA) to the buoy triangle (Figure 1).

The triangle of buoys serves as markers installed by the remotely operated vehicle (ROV) to identify the location where drilling and wellhead assembly will commence. The first stage of drilling a well, which is located on the seabed (mud line), is characterized by a clayey formation that offers little resistance to drilling. To advance the well, flow combinations are used and the weight of the drill bit is kept low. Seawater fluid is used to drill each section due to the formation's low resistance, and conventional fluid, consisting mainly of barite and bentonite, it is pumped in to help clean the drilled well. During this phase, drilling parameters such as bit weight, flow rate, torque, and rotation are kept to a minimum.

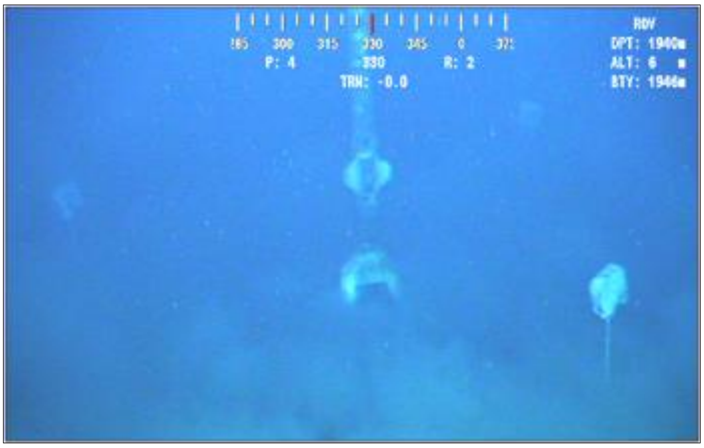

Figure 1 The 36-inch BHA column entering the seabed during Phase 1

The drilling continued with a 36'' phase from 1,962 m to 2,046.5 m, with guidance from the mark on the column in relation to the seabed. If the conductor casing were to descend further than intended, it would hit the seabed, and the Low-Pressure Housing (LPH) region would be below the acceptable level for wellhead construction. This mark is crucial for visually identifying the depth drilled. The only way to correct the error would be to wait for the cement to cure at the desired height, which could unnecessarily waste time in the well construction.

At the end of the phase, the goal is to pump fluid for well cleaning and leave conventional fluid in the well so that barite can act as an overbalance in the formation to maintain the walls with intact 'plaster'. At the end of the displacement, the column is pulled out of the open well. It is important to inform the ROV when the drill bit exits, as its correct positioning must be sought to avoid the risk of collision with the column when exiting with the ROV. During phase I, it was also necessary to reposition the buoys that were too close to the well (Figures 2, 3, and 4).

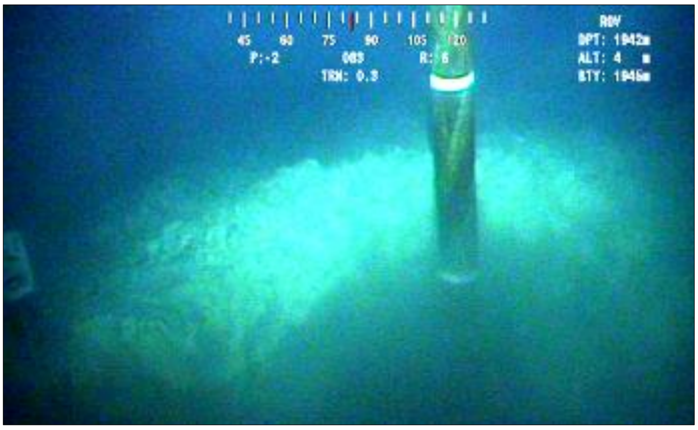

Figure 2 Phase 1: Column Marking

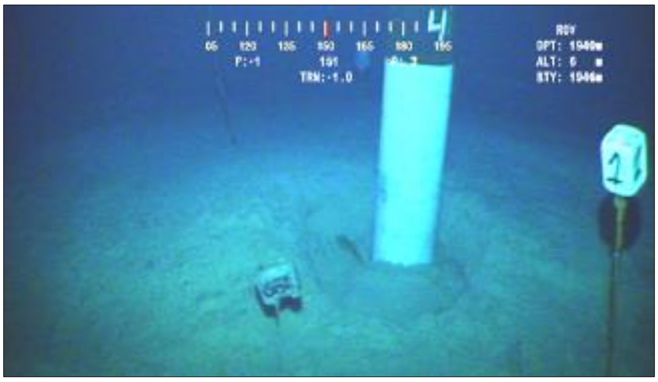

Figure 3 Phase 1: Marking the column in relation to the mud line

Figure 4 Phase 1: Marking the turn in the column

After drilling with a 36" bottom hole assembly (BHA), the 30" conductor was lowered from the surface to a depth of 87.43 meters using a stinger section inside the casing and full opening safety valve.

It is important to monitor the current during the conductor's descent to prevent the ABP assembly from rotating. If the rotation exceeds that shown in Figure 4, we need to carry out the procedures: raise the column, correct the rotation, and lower the column again, it taking into account the sea current conditions.

It following the conductor lowering procedure, the well-laying column was lowered, and the 30" casing-laying column was lowered into the open well until it reached the footing at the bottom at 2,043.5 m, as marked on the control during phase I drilling. Cementing commenced after verifying the bull's eye. As the well was being cemented, the weight of the casing string was gradually lowered.

Subsequently, the ROV verified the bull's eye to ensure that the angle was within the ABP settlement pattern (Figure 5).

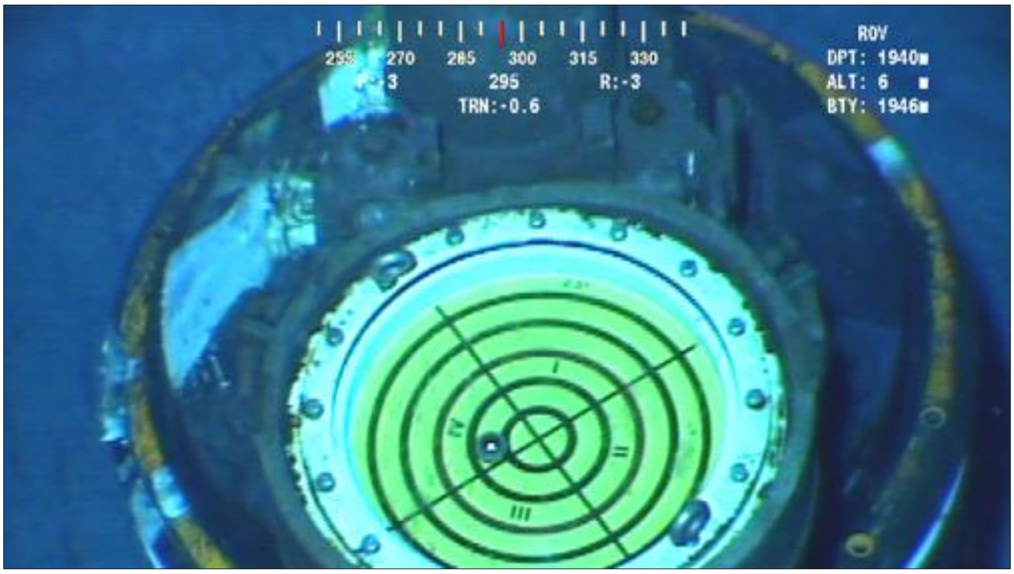

Figure 5 Phase 1: Marking the bull´s eye

After inspecting the ROV, circulation with seawater began while the operational meeting for cementing took place. Once the circulation stopped, the solids were allowed to settle, as they were invisible to the ROV image. The ROV photographed around the ABP before the start of the cementing operation on the 30 conductor. The checkered mattress was pumped to help visualize the exit and analyse the return from the well and the pressure test of the surface lines that was carried out. The cementing was carried out by moving the paste. The ROV collected the cement sample from around the well. The corresponding weight of the casing column was lowered and the lodger mark was observed. Finally, the running tool was unlocked and the column with the ABP tail was removed, finishing the cementing operation (Figure 6). As can be seen in Figure 6, the surrounding area shows debris of chess powder and cement from the Phase I cementing operation.

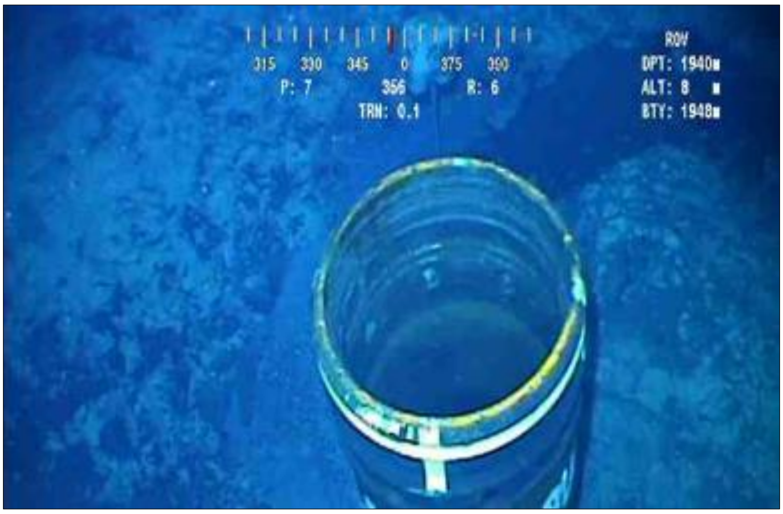

Figure 6 Phase 1: Dust and cement debris around the BPA

2.1.2. Phase II

During the second phase of drilling the well, the initial step involved is the lowering the column with a cement cutting BHA and commencing drilling phase II, by verifying the top of the cement and beginning to cut. The 26" phase was drilled from 2,047 m to 3,578 m, and the well was cased with 20" casing. Inside, a Drill Pipe column known as a Stinger was assembled. The aim of this column is to transport the slurry for cementing the well and filling the annulus.

Once the well is cemented and the High Pressure Lodger (AAP) is seated in the Low Pressure Lodger (ABP), the rig is prepared for lowering and seating the Blowout Preventer (BOP). A Bottom Hole Assembly (BHA) of 26 was drilled around the ABP, and cement cutting began. The second phase was drilled to a final depth of 3,578 meters. The initial sequence of Phase 2 is illustrated in Figures 7, 8, 9 and 10.

Figure 7 Phase 2: 26" hybrid drill enters ABP

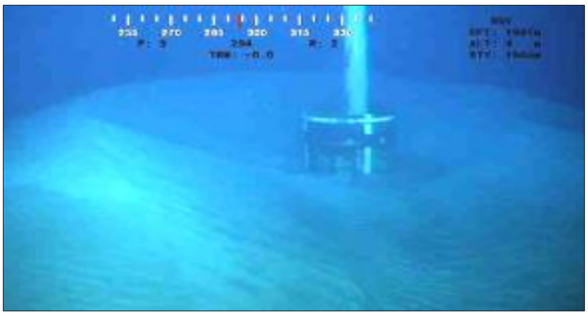

Figure 8 Phase 2: Drilling control around the ABP

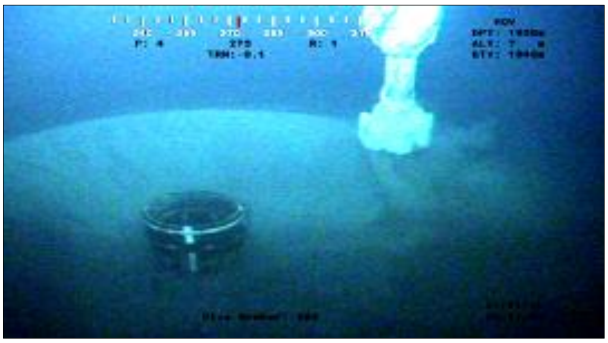

Figure 9 Phase 2: 26" drill outlet

Figure 10 Phase 2: 20" shoe inlet

It following the completion of drilling Phase 2, the 20" casing was lowered using the high pressure liner (AAP) to rest on the low pressure liner ABP (Figure 11).

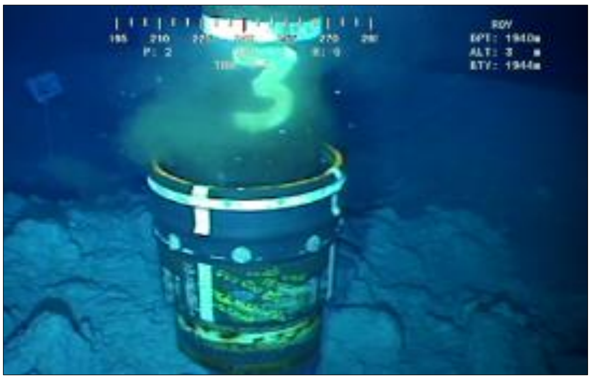

Figure 11 Phase 2: 20" shoe passing the ABP

The 20" shoe used to lower the second stage liner passes through the Low Pressure Lodger anchored to the Seabed (Figure 12).

Figure 12 Phase 2 AAP 20" passing ABP

We anchor the 20" High Pressure Housing (AAP) to the Low Pressure Housing (ABP) (Figure 13).

Figure 13 Phase 2: Attach the 20-inch high-pressure housing (AAP) to the low-pressure housing (ABP)

After securing the 20-inch high-pressure housing to the low-pressure housing, the cementing operation commenced. It following the completion of the cementing operation, the handling tool was disconnected from the 20-inch high-pressure lodger (AAP). The platform was demobilised after laying the BOP, along with all the manoeuvring equipment for the BOP lowering operation. The column assembly and lowering operation commenced with the Integrity Test Tool (ITT), which is responsible for testing the BOP components such as annuli, drawers, and subsea valves (Figures 14, 15, and 16) [4].

Figure 14 Phase 2: Disconnecting the handling tool from the 20" AAP

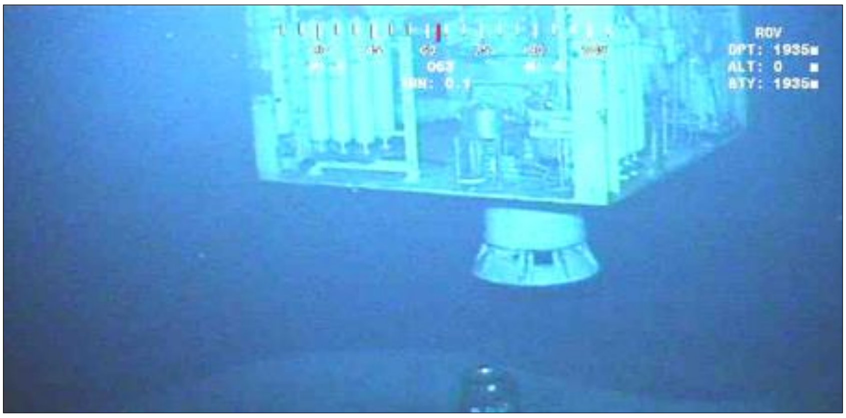

Figure 15 Phase 2: Approach of the BOP to the wellhead

Figure 16 displays the conclusion of phase II, with the BOP securely seated and locked in the wellhead. As an operational procedure, the BOP is locked in place with 50 Kips lowered as soon as it descends to settle on the wellhead. This process is known as Overpull. Once the locking function is confirmed by the gallonage count, a tension equivalent to 50 Kips is applied above the weight of the column to verify that the BOP connector has locked into the wellhead. After, it confirming the surface locking, the equipment that operated the BOP is demobilised, and the final assembly of the surface equipment commences.

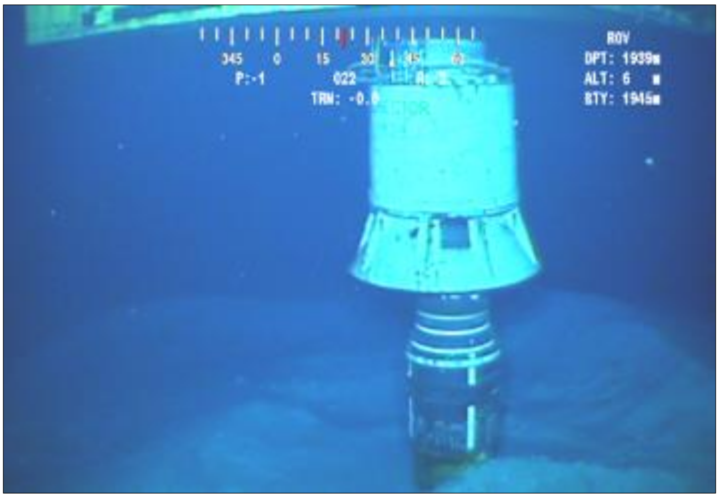

Figure 16 Phase 2: Seating the BOP in the wellhead

2.1.3. Phase III

The third phase of the well began with the lowering of the Integrity Test Tool (ITT), which is responsible for testing the Blowout Preventer (BOP) components, including annuli, drawers, and subsea valves. The ITT is assembled by the rig with technical assistance from the tool's supervisor. After assembly, the ITT with the drill pipes is lowered into place along with the nominal bushing, which protects the sealing area around the AAP (High Pressure Housing) during drilling. The bushing is removed only before the casing is laid.

As the assembled column descends into the well, a jet sub is used to blast the area where the ITT will be seated, removing any debris from around the sealing area. After the installation of the ITT, pressure tests are conducted on the BOP components, including preventers, drawers, and subsea valves. The assembly is then pulled to the surface with the nominal bushing already installed in the wellhead. Next, the ITT is assembled with the SDR to test the blind gate, which was not previously tested due to the column in front of the gate.

As the bottom assembly is put together, various stages are carried out, such as programming the MWD tool, installing the radioactive source, and conducting shallow testing. The column is then lowered to the base of the cement top, and the fluid is changed from water to synthetic fluid. After this change, the cement is cut and then 10 meters of new formation is drilled to carry out the rock absorption test, which can be either a LOT (Leak off test) or a FIT (Formation integrity test). Once the test has been completed and the fracture gradient of the rock has been verified, the operational limits are then determined during the drilling of the 3rd phase of the well.

After all the onslaughts of operations, Phase 3 was completed with the following stages summarised: Pulled the 17 ½" drill string to the surface and popped the BHA; started lowering the WBRT (Wear bushing running tool) to fish out the nominal bushing (Wear bushing) (because to lower the intermediate casing string, the Hanger must be anchored to the wellhead, so another cementing is carried out); as the phases are built in the well, the wellhead is responsible for anchoring all the casing that is lowered from the 30" conductor casing and 20" surface casing to the intermediate casings such as: 16", 13 3/8" and 13 5/8".

2.1.4. Phase IV

Phase 4 commenced with the installation of the nominal bushing in the wellhead, followed by assembling the 12 ¼" bottom hole assembly (BHA) with a Kymera drill bit [5]. The operational stages in Phase 4 are similar to those in Phase 3, with the exception of the extensive formation of the "Salt". The challenges in this section are unique because they involve mobile formations that can move as the well is drilled. For example, turning the mud pump on and off, which injects drilling fluid into the column, can cause a pressure drop differential in the annulus. This pressure drop can result in the formation moving and potentially trapping the column.

The well's stability depends on a sufficient fluid gradient. However, drilling becomes challenging when the pore gradient is too close to that of the fluid, as it brings the operational limits closer. This can result in unforeseen issues such as fracturing, loss of drilling fluid, and column entrapment due to the instability of the 'salt' itself."

Here are some preventive measures for entrapment in salt marshes:

- To avoid entrapment, keep the fluid gradient close to that of the formation;
- Perform frequent passes with the column;
- Minimise connection time;
- If trapped while working with synthetic fluid, pump the viscous plug followed by industrial water to get the formation moving. It is important to consider well control issues and ensure that the volume of water is sufficient to fill around the trapping point;
- When preparing the spacer plug and water is passing through the trapped zone, move the pipe. Maintain a maximum overpull of the pipe's capacity to signal the release of the column. If this is not effective, repeat the operation.

3. Results and Discussion

It following technical, economic, and flow assurance analyses, exploration companies and service providers have developed a viable well-drilling configuration for the pre-salt layer. Drilling in the salt layer presented significant challenges. Pre-salt wells have a unique characteristic of requiring drilling over large distances of salt section with minimal sediment cover, particularly due to its creep. However, the biggest challenge of drilling pre-salt wells is no longer the case due to the development of new types of fluid and greater knowledge about the behaviour of the salt layer during drilling. Currently, pre-salt wells are drilled in four or five phases, depending on the characteristics of the reservoir to be drilled [6].

The conventional method involves drilling Phases I and II, which are the 36" and 26" phases respectively, before installation using a BHA with drill bits as shown in Figure 1 (36" drill bit) and Figure 11 (26" drill bit). These phases are completed without installing the BOP and using seawater as the drilling fluid, allowing for a return to the seabed. The language used is clear, concise, and objective, with technical terms explained when first used. The sentence structure is simple and the logical flow of information is maintained. The text is free from grammatical errors, spelling mistakes, and punctuation errors. The content of the improved text is as close as possible to the source text, with no additional aspects added. Phases III and IV involve drilling with synthetic-based fluid. The fluid has a density of around 11.5 lb/gal in the salt region and 10.3 to 10.8 lb/gal in the reservoir region to prevent dissolution.

Liners are installed after drilling each type of rock or salt layer is completed. Figure 10 shows the surface casing shoe (20") located approximately 200m into the salt layer. The intermediate casing, which was installed in phase III, is nominally 14" and is laid on top of the reservoir region. The final lining is the most crucial as it protects practically the entire salt region. Therefore, special materials and weights are used for this section.

It is important to note the peculiarity of geopressure behaviour in the salt layer. This region has a very low pore gradient, which makes it an excellent sealing rock. However, it also exhibits high elasto-plastic behaviour, resulting in a high fracture gradient value, high creep, and susceptibility to the ballooning effect. This effect is caused by the expansion of well walls due to the weight of the circulating drilling fluid (ECD). When the mud pumps are turned off, the diameter of the well decreases due to the drop in pressure, resulting in fluid flowing back into the well. This expansion and contraction effect causes fluid to be lost and then returned, which can give the impression of a kick [6].

The formation test (FIT) was conducted during drilling phase III to determine the working pressures for the third phase of drilling. The results showed satisfactory values for the drilling sequence. The fluid density used in the test was 10.5 lb/gal, resulting in a maximum drilling fluid weight of 12.35 lb/gal. However, fluid was lost to the formation due to the instability of the salt, followed by column entrapment at the depth between the Anhydrite and Microbilithic formations located in the Pre-Salt region.

During drilling phase IV, a formation test (FIT) was conducted using 11.5 lb/gal of fluid. It is worth noting that the maximum weight of fluid to be used was 12.77 lb/gal, indicating a narrow operating window. This is due to difference between the fluid weights in phase IV is much smaller than in phase III. In situations where there is a narrow operating window, the manoeuvring to enter and exit the well column can be challenging as it significantly interferes with the well's pressure profile. This interference can cause changes that exceed the pressure limits of the operating window.

To mitigate this, a closed circulation method can be used, which allows for quick changes in bottomhole pressure during column manoeuvring. This makes Managed Pressure Drilling (MPD) a more efficient and safer method [7]. The method of providing conditions for changing the pressure at the bottom of the well would prevent the loss of fluid and subsequent column entrapments that occurred during the drilling of the 1-FSMA-5-RJS well.

Unlike the conventional method, this approach allows for precise control of the pressure profile in the well, as the system is closed at the surface. In other words, there is no rotating head and corresponding equipment capable of restricting and controlling the pressure at the bottom of the well, known as BHP (Bottom Hole Pressure). For instance, in formations like the pre-salt, the working in narrow windows with a conventional system can cause a pressure drop that keeps the well vulnerable to an influx from the formation when switching a mud pump on and off, or it can result in a loss of circulation to the formation.

In contrast, Managed Pressure Drilling (MPD) is a drilling method that is adapted to control the annular pressure profile throughout the well. Its objectives are to determine the pressure limit at the bottom of the well and to manage the hydraulic pressure in the annulus appropriately. The main objective of MPD is to prevent fluid gain from the formation into the well, it keeping the entire drilling system always in overbalance [6].

In narrow operating windows, the Managed Pressure Drilling (MPD) system aims to control the pressure of the hole bottom to closely follow the limit of the pore pressure profile. This is often referred to as 'walking the line' in the literature. With surface-mounted equipment and the MPD system in place, precise pressure control is possible. This contrasts to the conventional system, which loses control over the variation in pressure drop in the well.

It is possible to drill a well even with a drilling fluid weight lower than the pore pressure of the formation by manipulating the backpressure to compensate for the difference. This makes the well overbalanced, and the pump becomes the variable that cannot be controlled by the conventional system. Despite using many tools designed for Underbalanced Drilling (UBD), Managed Pressure Drilling (MPD) maintains bottomhole pressure above formation pressure to prevent inflow, while UBD aims to prevent reservoir damage and allow controlled inflow.

Additionally, MPD offers other advantages:

- Drilling in zones with very narrow operating windows (difference between pore and fracture pressure is very small);
- Helps reduce the number of casings by allowing the length of each phase to be extended;
- Reduces the rate of circulation loss by balancing the bottom pressure;
- Increases the penetration rate of the drill bit by reducing the pressure differential which would make it easier to dislodge the gravels generated by the drill bit (reducing the "chip hold down" effect);
- Reduces damage to the formation by reducing overbalance.

The drilling issues experienced during the drilling of 1-FSMA-5-RJS were caused by salt instability, specifically the inability to maintain precise pressure control while drilling with narrow operational windows. This was particularly problematic at depths where unconsolidated microbialites (pre-salt) were present, it resulting in circulation loss and column entrapment, impeding progress with the well schedule.

The use of the Managed Pressure Drilling (MPD) method could have prevented the time wastage and instability issues encountered during the drilling of the well. By controlling the pressure at the bottom of the well. The MPD method would have maintained a constant pressure in the zone of interest, preventing the collapse of the pre-salt layer and ensuring that the pre-salt formations remained free of any significant pressure differential that could lead to entrapment or loss of circulation.

This aid compensates for constant pressure and helps with pressure drop variations throughout the well. The research and scenario analysis indicate that 330 hours were lost during phase III, which drilled from the base of the salt to the pre-salt.

The column was trapped multiple times due to pressure differentials and salt instability. Additionally, the tool was heavily used in an attempt to remove the trapped column from the unstable formation in the pre-salt zone. As a result, two surface changes were necessary.

During phase IV, which involved drilling in the pre-salt, circulation was lost in the well resulting in a total time loss of 100 hours. This had an impact on the end of the phase and had to be combated until it was eliminated in preparation for the next operations. These operations included lowering the wireline tool to analyse the deposit and the intermediate casing, where cementing with a loss of circulation is not desirable.

The total time lost by the well operator in phases III and IV is 430 hours. This equates to a significant cost, with the daily cost of the rig alone, resulting in a total cost of million dollars. Therefore, the MPD could be a game changer, reducing or eliminating lost time during in the complicated phases where there are arrests and loss of circulation, and a narrow operating window between fracture and pore pressure.

4. Conclusion

Upon analysing the events at the 1-FSMA-5-RJS well, it was discovered that the company responsible for the project failed to use pressure control methods, resulting in a sequence of column entrapments. This, in turn, led to a significant loss of time during drilling in the pre-salt region, resulting in approximately 430 hours of lost time and a loss of million dollars in relation to the daily cost of the drilling rig alone.

The exploration company knew about pressure control methods when drilling the 1-FSMA-5-RJS well project, which had a narrow operational window. The inefficient loading of solid debris and entrapment of the drill string were caused by the loss of fluid into the well due to excess pressure on the well wall, also known as fracture pressure, and other adverse conditions.

The analysis of the information obtained from this scenario study suggests that using the MPD method instead of the conventional method would prevent the loss of time incurred during well drilling. Although financial or logistical considerations may initially make it unfeasible to use this method, avoiding the loss of unbilled time would make it worthwhile.

It has been demonstrated that the proper application of pressure control techniques during drilling has multiple benefits. These techniques are used not only to prevent lost rig time but also to facilitate the resumption of primary control of the well and mitigate the effects of any incidents that may occur during these operations.

The monitoring of the pressure control during drilling also helps to reduce the various risks associated with drilling pre-salt hydrocarbon wells to an acceptable level.

By implementing a well return control technique that maintains a controlled pressure profile, it becomes possible to drill in narrow operating windows without operational incidents such as column entrapment and loss of circulation. This is particularly important when exploring wells in pre-salt zones. The technique ensures that the bottom hole pressure (BHP) remains between the pore and fracture pressures, allowing for a safer and more efficient drilling process.

Finally, future work should consider studying the behaviour of salt in contact with drilling fluids commonly used in drilling, as well as exploring new fluids that are better suited for pre-salt layer deposits due to the unique behaviour of salt in comparison to other geological formations. Additionally, it is important to evaluate the detailed economic impact of not using the MPD method for the scenario studied.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare no conflict of interest.

Authors diclaration

All authors have read and approved the final version of this manuscript.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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