DRILLING STRATEGIES IN RED CLAY ZONE TO MANAGE IRON OXIDE MINERALS EXPERIENCE FROM P-FIELD, INDONESIA

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ABSTRACT

Geothermal drilling activities in Indonesia face many challenges especially comes from the formation. One of the challenges is the presence of iron oxide minerals in the red clay zone. Originating from the decomposition of volcanic rocks enriched with iron minerals, red clay exhibits its distinctive reddish hue owing to the omnipresent iron oxide. Hematite (Fe_2O_3) and Magnetite (Fe_3O_4), the predominant iron oxide minerals in geothermal fields, wield considerable influence over the overall mineral composition of reservoir rocks. Encounters with red clay zone which comprise iron oxide minerals during drilling activities necessitate an understanding of their types and abundance, as they can significantly impact the hardness and abrasiveness of subsurface rocks. Mismanagement can result in formation collapse and stuck pipes, thereby elongating drilling time and escalating project costs.

This study offers insights drawn from operational experiences in the P-Field, a noteworthy geothermal site in Indonesia. The discussion encompasses an overview of general iron oxide mineral characteristics and delves into specific strategies for addressing challenges in drilling operations. Emphasis is placed on mud strategies in production zone, defensive drilling methods, the strategic introduction of slightly underbalance drilling by modified ratio of fluid and aerated in the presence of the red clay zone, modify BHA when experiencing high torque in reservoir zone, and the application of economic reservoir zoning. Implementation of these strategies aims to enhance drilling efficiency, mitigate risks, and optimize project costs.

1. INTRODUCTION

Indonesia is one of the countries in the world with greatest geothermal energy potential. According to ESDM (ESDM, 2020), the geothermal potential in Indonesia reached 23,900 Mega Watt (MW). However, the utilization of geothermal in 2022 was still around 2,360 MW according to International Renewable Energy Agency (IRENA, 2023). In order to harnessing the geothermal utilization which still uncovered, drilling project become one of the way to accelerate this matter. Drilling is the one of the way activity for the respective geothermal operator to enhance their business starting from exploration phase to the development wells. Drilling activity is the main way to gain any new discovered of geothermal potential, despite of there are many challenges during the operation and impact on the high cost needed. Therefore, it is necessary to perform the exploration/development drilling and/or workover operation to sustain and/or escalating their operating capacity.

P-field is one of the biggest geothermal field in Indonesia located in West Java, with one unit operating at 55 MW capacity. In order to accelerate their business, a new geothermal power plant is planned to be built in that area which can covered for an additional 55 MW. To support this, the drilling campaign for 12 development wells have been performed started from September 2021 and ended on the March 2024. During the more than two-year drilling campaign, the drilling team faced many challenges, particularly when drilling in reservoir zone. The red clay zone, which contain Iron Oxide mineral, often to be a root cause of drilling problems after they significantly impact regarding the hardness and abrasiveness. This study will explain some drilling strategies to overcome the problems encountered in the red clay formation, providing valuable lessons for other geothermal operators in Indonesia facing similar challenges.

2. OBJECTIVE AND METHODOLOGY

The objective of this study is to discuss the types and characteristics of Iron oxide Minerals in Red Clay zone in P-field during the campaign. Before delving into the details, the drilling performance in P-Field will be explained, with the rate of the well completion being a key parameter for analysis. Additionally, the representation of drilling challenges/problem in reservoir zone will be illustrated using high torque and/or stuck pipe chart for each well. At the end, the drilling strategies during the campaign namely the transformation of mud strategies during drilling in production zone, perform defensive drilling methods, the application of slightly underbalance drilling when there is an indication of iron oxide, modify BHA when experiencing high torque in reservoir zone particularly, and also the application of economic reservoir zone, are explained into the detail and eventually become a lesson learn and impact to the overall of the drilling campaign.

3. DRILLING CAMPAIGN SUMMARY

P-Field Drilling Campaign had finished to drill 12 big hole development wells. The drilling campaign was started from the rig demobilization in September 2021 and ended in March 2024 as the rig release for last well. As a summary, the project involves one Mobilization, one Demobilization, four Skidding job, seven Moving inter pad. Majority of the wells drilled in four sections: 26” Surface, 17-1/2” Production, 12-1/4” Production Liner and 9-7/8” Production Liner 2 section. However, there are five wells were needed to be drilled until 7-7/8” Production Liner 3 section as the fifth section as contingency plan in order to reach target depth. The drilling depth wells range start from 1506 mMD to 2107 mMD. In terms of drilling days, the duration range within 26 days to 86 days with 53.9 days average. Figure below shows the rate of well completion in P-Field after the campaign.

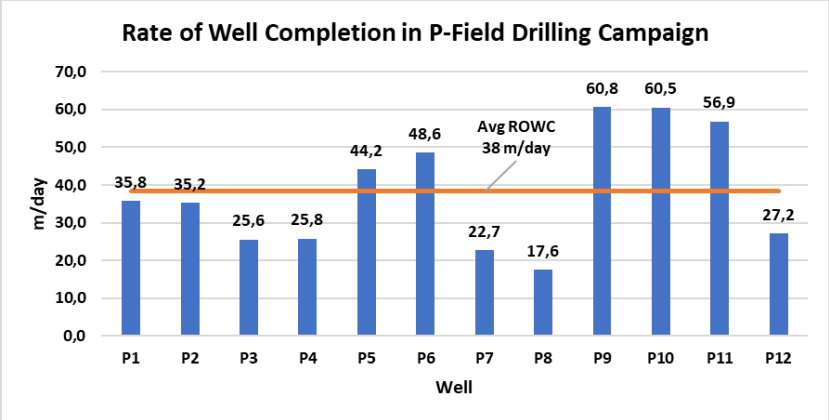


Figure 1 - Rate of Well Completion in P-Field

If looking more detail, there are only five wells which higher than 38 m/day which are P5, P6, P9, P10, and P11. Most of the wells which below average ROWC influenced by hole problem occurred during drilling hence exceed planned days. In addition, drilling campaign generated five wells sidetracked occurred in P3, P4, P7, P8, and P12 which hole problem occurred in these wells specifically. As mentioned above, drilling in Red Clay Zone which contain Iron Oxide mineral generated many drilling problems. The specific explanation of hole problem in Red Clay Zone will discuss in next chapter.

4. RED CLAY FORMATION AND IRON OXIDE MINERALS

Red clay formation is formed by the composition of volcanic rocks that are structured by many of minerals. Iron oxide is one of the mineral composition in red clay formation. Iron Oxide (Fe_2O_3) is composed from the elements between Iron (Fe) and Oxygen (O_2). Hematite/Ferric Oxide (Fe_2O_3) and Magnetite (Fe_3O_4) become the most iron oxide minerals frequently found. Between these types, Hematite/Ferric Oxide is the most iron oxide mineral composition in red clay zone since this kind of mineral has red/brown color which represent the red clay formation. Iron Oxide is a predominant minerals in geothermal fields, wield considerable influence over the overall mineral composition of reservoir rocks in particular. Iron oxide has very unique characteristics with complicated handle. This kind of mineral will react and become rust when meet with oxygen and water. The oxidation process then will occur and cause the solid material, in this case rock, degrade and become brittle. Due to majority of geothermal rocks come from lava which has been deposited from surface over many years, oxidation will occur.

During drilling campaign in P-Field for 3 years, the characteristic of iron oxide minerals have been identified. This type of mineral is reddish and soluble to liquid, particularly when using water in the drilling process. Iron oxide mineral is spreading out in all over P-Field area on two well pads (Pad X & Pad Y) in particular with depth range within 1000 – 1800 m which known as the reservoir zone. Become a soluble and brittle when face the liquid conclude this iron oxide mineral is clearly will affect the hole stability.

5. DRILLING CHALLENGES IN RESERVOIR ZONE

During the drilling campaign in P-Field, stuck pipe incidents accounted for the second highest non-productive time, contributing 699.5 hours or 25.7% of the total NPT. Figure 2 illustrates the high torque and stuck pipe events across all wells in P-Field during drilling campaign.

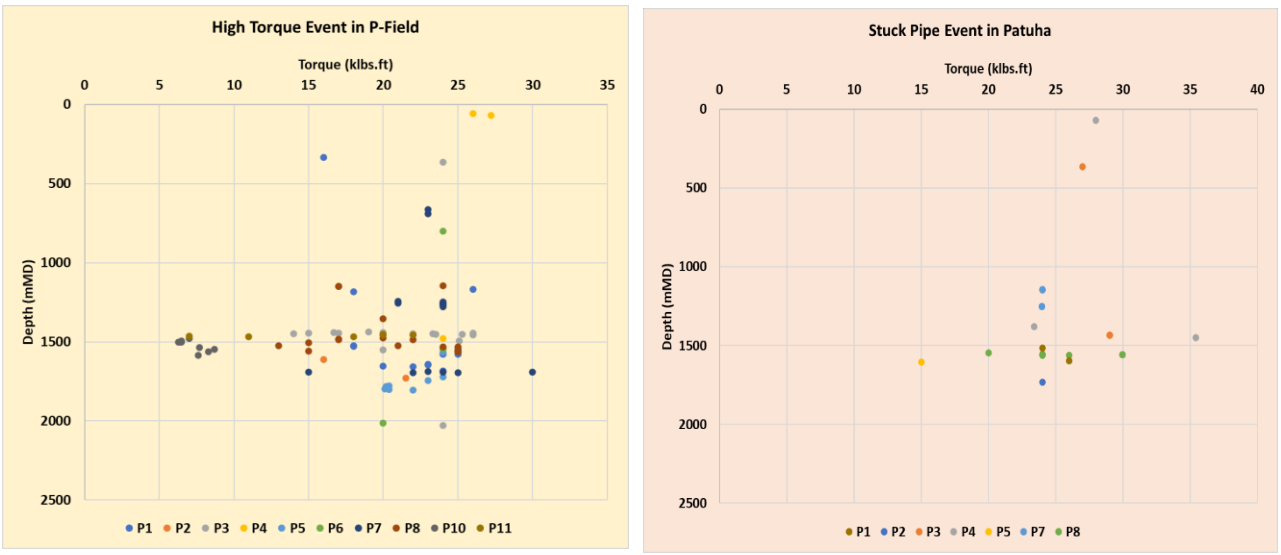


Figure 2 - High Torque and Stuck Pipe Distribution in P-Field

The figure shows that high torque event occurred in all wells with the depth ranging from surface to target depth of 2000 m. However, events most frequent between 1200 m to 2000 m depth, which corresponds to the reservoir zone. High torque events arise due to cuttings and/or formations, which most composed by iron oxide minerals, are not properly circulated to the surface and eventually accumulate below the hole. In addition, since the P-Field reservoir zone does not have a large fault zone to accommodate the cuttings when loss circulation, makes the high torque during drilling happen and stuck pipe then occurred.

Moreover, stuck pipes happen influenced by hole pack off from the formation in most wells. This is particularly problematic in the P-Field reservoir zone, which is composed of red clay formations containing iron oxide minerals that significantly impact formation pack-off. As discussed in the previous chapter, iron oxide minerals fall into three categories, all of which affect formation stability in P-Field. The drilling strategies to optimize handling of iron oxide minerals will be detailed in the following chapter.

6. DRILLING STRATEGIES

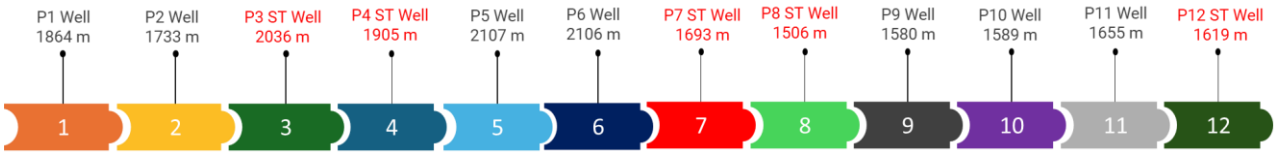


Figure 3 - Drilling Journey in P-Field

Presence of iron oxide mineral in red clay zone become one of the reason hole problem occurred in P-Field. Figure 3 showing the drilling journey in P-Field. Along the campaign, the drilling team continuously learned how the best practice to do the drilling operation since the first and second sidetrack well occurred in P3 & P4 well. The different approaches in terms of drilling operation had been taken to drill in P5 and P6 well. Slightly underbalance drilling and defensive drilling method were applied for the first time and resulting these wells into TD target. However, in the next drilling in P7 and P8 well, since the return condition was PLC and the pad location close to the crater, there was limitation to applied underbalance method, made hole pack off problem occurred suspected by presence of iron oxide in red clay formation. The continuation of drilling problems despite different approaches taken necessitated drilling team to thoroughly review the drilling program. Drilling team concluded that changing mud strategies in production zone, modify drilling BHA when experiencing high torque, maintaining defensive and slightly underbalanced drilling method, and apply the economic reservoir zoning were the best strategies to be applied. The detail of drilling strategies are explained in below.

- **Mud Strategies During Drilling in Production Zone**

KCl Polymer is the most often mud type used when drilling for 26” section and 17-1/2” section due to these sections possess swelling clay and sticky clay as the drilling hazard. KCl (Potassium Chloride) is effectively used to inhibit clay hydration and generally KCl levels within 3-5%. Moreover, KCl polymer produce sufficient Plastic Viscosity (PV) and Yield Point (YP) as the mud properties which present the ability to lift the cuttings to the surface. Since the drilling in 26” and 17-1/2” are in full return condition mostly and rarely on partial loss event to total loss, this mud system is suitable.

After drilling in 4-5 first well, the team observed that flow return condition when drilling in reservoir zone was partial loss – full return condition instead of total loss. This indicates that the fault in reservoir zone is not large enough. And the presence of iron oxide which soluble and brittle when face the water only and still contain clay washout, can produce more cutting and lead to hole problems. Therefore, drilling team initiate to continue utilized the KCl Polymer mud when drilling in 12-1/4” and 9-7/8” hole section. Nevertheless, it is really noteworthy that KCl polymer mud type is only utilized when the partial loss – full return is still occurred. When encountered partial loss – total loss and the ability of mud mixing is not sufficient, then aerated mud + viscous water be applied. Moreover, in order to prevent high torque, lubricant additives need to be added within 1-2% range either KCl polymer or aerated water + viscous water mud type. Figure below explain the decision scheme of mud system in reservoir zone.

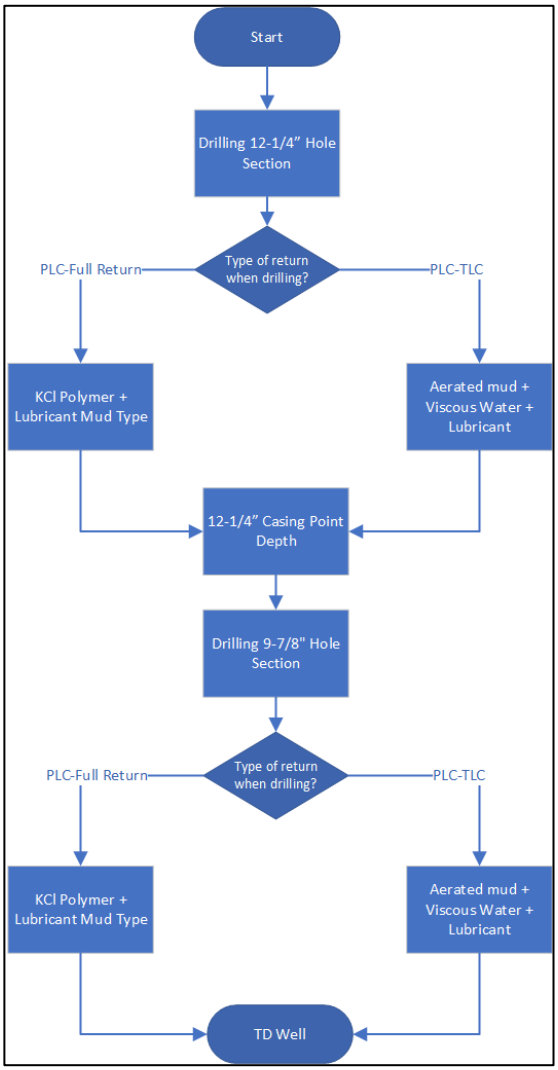


Figure 4 - Mud System Selection Scheme

- **Defensive Drilling Method Application**

Defensive drilling is another drilling strategies applied in P-Field during the campaign. This method was applied firstly in P5 well and continuously maintained to the last well in P12. The principal of this method is perform drilling along 3-5 m progress. Afterwards, drill string picked up full stand while working pipe and circulate hole. This method is to ensure the wellbore in clean condition after drilled and will not lead to high torque, hence the drilling can reached target as per program. Defensive drilling method generally applied when face the iron oxide minerals. However normal drilling condition was conducted if there is no presence of iron oxide.

- **Application of Slightly Underbalance Drilling**

As the terms, slightly underbalance drilling is modify the ratio between liquid (water/mud) and aerated mud which makes the mud flowrate lower than air rate in order to prevent iron oxide face the water/liquid. Moreover, since the mud flowrate was reduce, the borehole temperature become slightly hotter and iron oxide minerals is expected to be stable. Since the slightly underbalance drilling influence the pressure in wellbore keep lower than formation pressure, this make allows cuttings to the surface and keep wellbore in clean condition. The application of aerated mud in slightly underbalance drilling was within 1800-2800 SCFM and influence the foam rate utilization between 8-20 gph. Meanwhile, the liquid ration was keep in 300-500 gpm during drilling.

- **Modify BHA in Reservoir Zone**

Drilling BHA plays another important role when drilling in P-Field. In the first 4 wells, the directional BHA was always applied from the first to last section. However, stuck pipe occurred in P3 and P4 wells in 12-1/4" section and left the important part of directional BHA in hole which impact on drilling cost. The drilling team, after reviewed the drilling program, agreed to consider the utilization of rotary BHA instead of directional BHA when drilling in reservoir zone. In this case, directional BHA was still become a priority after this type of BHA cand adjust and correct the direction of the well as of reservoir target plan. However, when drilling encountered high torque zone, the replacement from directional BHA to rotary should be performed. From the operation, torque was considered as high when the drill string became difficult to rotate – stalled with the maximum torque was limited into 25 klbs.ft. In addition, since slightly underbalance method was applied in reservoir zone in order to maximize allowing on cuttings to the surface, directional BHA could not accommodate after there was a minimum liquid flowrate requirement from the mud motor and also influence to the

temperature. The other objective to utilized rotary BHA in production zone was reduce cost fish and reduce large size of BHA component which impact to the release drill string when stuck. Moreover, even after the high torque and other considerations still occurred during drilling with rotary BHA, decision to utilize slick rotary BHA was conducted.

- **Economic reservoir zone**

At the time after all drilling strategies had been conducted in reservoir zone (change mud strategies in production zone, defensive drilling method, slightly underbalance drilling, and modify BHA) did not help, then the application of economic reservoir zone become the last option. Economic reservoir zone was applied during the campaign in P-Field start from the P9 to P12 well. This method was conducted during drilling in reservoir zone by set casing shallower in order to prevent hole pack off if the well going deeper particularly when the iron oxide was appear. In this regard, after the well had been set casing using 8-5/8" perforated liner 2, a well completion test then carried out to assess whether the well can produce geothermal fluid. If the well completion test results are good, drilling then will be stopped and that depth. However, if the results are not satisfactory, going deeper the well using 7-7/8" hole section as contingency plan will be continued.

Figure below showing the detail of drilling strategies during drilling campaign with the results.

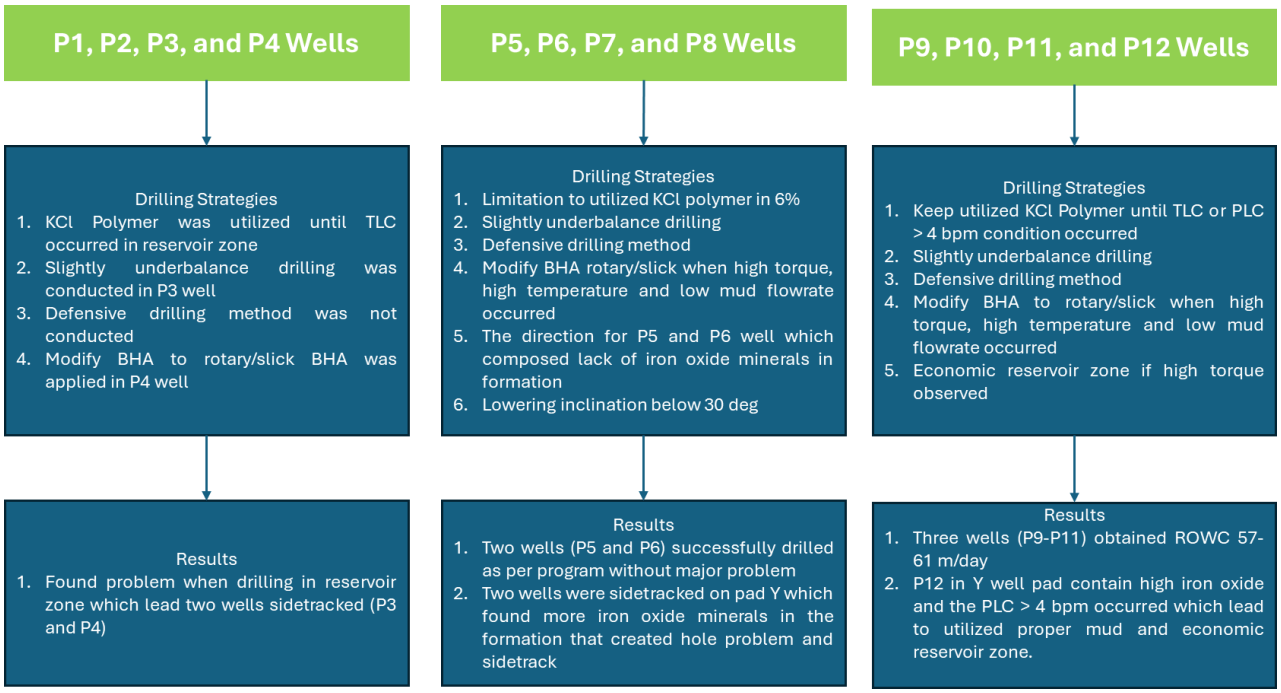


Figure 5 - Drilling Strategies with the Result

As you can see, different drilling approaches were always performed in each of the four wells, resulting in better outcomes. In the first four wells, all wells exceeded the drilling days based on the program, with two wells were sidetracked. Then, in the next four wells, when the defensive drilling method and slightly underbalanced drilling were applied, two wells successfully reached TD (total depth), however P7 and P8 wells experienced sidetrack due to the return condition was PLC and the pad location close to the crater enforced limitation to applied underbalance method. The peak was in wells P9 to P12, where after a review of the drilling program, only one well exceeded the drilling days and performed a sidetrack.

7. CONCLUSION

Drilling campaign in P-Field resulting 12 development wells had been finished, started from 2021 to 2024. Through three years, many lessons learn were obtained during the campaign, particularly in the drilling operation. The presence of iron oxide minerals in the red clay formation within the reservoir zone presents a challenge for the drilling team to execute the entire well to reach the total depth target. Based on drilling operation, the characteristic of iron oxide minerals have been identified. This type of mineral is reddish and soluble to liquid, particularly when using water in the drilling process, predominantly found in two well pads (Pad X & Pad Y) within the depth range of 1000 – 1800 meters. Consequently, during operations, stuck pipe incidents became one of the largest (NPT) contributor during the drilling campaign, accounting for 699.5 hours or 25.7% of the total NPT. This is understandable as high torque and stuck pipe events mostly occur at depths of 1200 to 2000 meters, which correspond to the reservoir zone. This depth range is also where the red clay zone containing iron oxide is distributed.

During the operation, especially after completing the first four wells, the drilling team then applied another approach, namely Slightly Underbalanced Drilling and Defensive Drilling Method. Both methods successfully brought wells P5 and P6 to reach the expected TD target at depths of 2107 and 2106 meters. However, in the next drilling in P7 and P8 well since the return condition was PLC and the pad location close to the crater, there was limitation to applied underbalance method, made hole pack off problem occurred suspected by presence of iron oxide in red clay formation. The continuation of drilling problems despite different approaches taken necessitated drilling team to thoroughly review the drilling program. Drilling team concluded that changing prudent mud composition

and/or system, modify drilling BHA when experiencing high torque, maintaining defensive and slightly underbalanced drilling method, and apply the economic reservoir zoning were the best strategies to be applied.

In terms of applying a mud strategies during drilling in the reservoir under partial loss-full return conditions, a KCl polymer will be used as the mud system to ensure that the cuttings can allow to the surface. A defensive drilling method will also be employed by circulate hole clean and working pipe after drilling 3-5 meters to ensure the wellbore is clean after drilling and to avoid high torque. Slightly underbalanced drilling will also be conducted alongside the defensive drilling method, where the ratio of aerated mud is higher than the liquid. The application of aerated mud in slightly underbalanced drilling ranges from 1800-2800 SCFM, influencing the foam rate utilization between 8-20 gph. Meanwhile, the liquid ratio will be maintained at 300-500 gpm. Modifying the BHA will also be done when high torque is encountered and applied slightly underbalance drilling which influence minimum mud flowrate, by switching from directional to rotary BHA. Moreover, reduce fish cost and reduce large size of BHA component are other objectives to utilized the rotary BHA. However, if this persists, a slick BHA will be used. The economic reservoir zone becomes the last method of the drilling strategy implemented in the P-Field by setting casing shallower to prevent hole packing if the well goes deeper, particularly when iron oxide appears. If the well completion test results are unsatisfactory, then continuing the well deeper using a 7-7/8” hole section as a contingency plan will proceed. The strategies proved successful in the last four wells, which only one well exceeded the drilling days.

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