SPE/IADC-221441-MS

Simplified Deepwater FMCD Strategy

A. A. Fernandes and M. V. B. Malfitani, Petrobras, Santos, SP, Brazil; I. M. Sales, K. S. Vasconcelos, and G. C. M Pena, Petrobras, Macaé, RJ, Brazil

Managed pressure Drilling Surface Back Pressure (MPD SBP) and Mud Cap Drilling (MCD) techniques provides operational flexibility when compared to conventional drilling techniques. By using SBP techniques it is possible to drill wells with narrow operational windows, Fernandes et al (1) and (2) describes the positive impact of having the capability of the maintaining the wellbore pressure within operational limits. However, in some cases, even with a precise control of the annulus pressure it is not possible to drill with returns to the surface.

One typical scenario without operational window on Brazilian offshore wells is fractured zones and karsts reservoirs. In these cases, even with the use of MPD SBP technique, it is not possible to continue drilling without severe or total losses to the formation. An alternative drilling technique for these cases is Mud Cap Drilling (MCD). In MCD, total losses are not controlled, all the fluid pumped through the string and cuttings are injected to the loss zone formation. Surface pressure and mud properties do not define the well pressure. Pore pressure from the loss zone and the friction losses to inject the fluid and cuttings are the governing factors for well pressure. On deepwater application, Pressurized Mud Cap Drilling (PMCD) and Floating Mud Cap Drilling (FMCD) techniques are considered when drilling carbonate reservoirs offshore.

IADC and ABS (3) defines Floating Mud Cap Drilling (FMCD) as a drilling technique used to drill without returns while sacrificial fluid is continuously pumped down drill string and the annulus to avoid all possibility of formation fluid migrating to the surface. Open-hole formation is taking all injected (sacrificial) fluid and drilled cuttings without surface pressure assistance.

MPD SBP and MCD techniques

Managed pressure Drilling Surface Back Pressure (MPD SBP) and Mud Cap Drilling (MCD) techniques provides operational flexibility when compared to conventional drilling techniques. By using SBP techniques it is possible to drill wells with narrow operational windows, Fernandes et al (1) and (2) describes the positive impact of having the capability of the maintaining the wellbore pressure within operational limits. However, in some cases, even with a precise control of the annulus pressure it is not possible to drill with returns to the surface.

One typical scenario without operational window on Brazilian offshore wells is fractured zones and karsts reservoirs. In these cases, even with the use of MPD SBP technique, it is not possible to continue drilling without severe or total losses to the formation. An alternative drilling technique for these cases is Mud Cap Drilling (MCD). In MCD, total losses are not controlled, all the fluid pumped through the string and cuttings are injected to the loss zone formation. Surface pressure and mud properties do not define the well pressure. Pore pressure from the loss zone and the friction losses to inject the fluid and cuttings are the governing factors for well pressure. On deepwater application, Pressurized Mud Cap Drilling (PMCD) and Floating Mud Cap Drilling (FMCD) techniques are considered when drilling carbonate reservoirs offshore.

IADC and ABS (3) defines Floating Mud Cap Drilling (FMCD) as a drilling technique used to drill without returns while sacrificial fluid is continuously pumped down drill string and the annulus to avoid all possibility of formation fluid migrating to the surface. Open-hole formation is taking all injected (sacrificial) fluid and drilled cuttings without surface pressure assistance.

On FMCD operations, the fluid level is below surface, as the fluid pumped to the annulus have a higher density than the equivalent pore pressure density. There is no direct indication of annulus conditions. FMCD is also known as blind drilling. To avoid hydrocarbons inflow or migration, it is necessary to deliver a minimum downward flow rate to the annulus. Hydraulic simulators are used to calculate the minimum flow rate required down the annulus to guarantee operational safety. Currently there is no industry standard defining the procedure to guarantee that any hydrocarbon migration in the annular is contained at the bottom of the well.

IADC and ABS (3) also defines Pressurized Mud Cap Drilling (PMCD). A drilling technique used to drill without returns while balancing full annular fluid column by using a Light Annular Mud (LAM) cap maintained above an open-hole formation that is taking all injected (sacrificial) fluid and drilled cuttings assisted by surface pressure. The LAM density is chosen based on ability to make LAM and the desired surface pressure that can be maintained and observed. Periodically injecting more of the same fluid into the annulus provides a means to control the surface back-pressure within the operating limits of the RCD and/or riser system.

The hydrostatic pressure exerted by LAM on the annulus is lower than the pore pressure from the exposed reservoir. In this way, there is pressure at surface. The surface pressure is an indication of the annulus conditions and determine the need of fluid injection down the annulus. As the well pressure is governed by the formation pressure, whenever an increase of surface pressure occurs in an isolated way, it is an indication that there is a lighter fluid in the annular, in these conditions the LAM injection is initiated.

From an operations point of view, the direct measurement on PMCD operations permits a direct analysis of the well conditions. The intermittent injection of fluid to the annulus reduces the amount of fluid consumed. In case of severe losses or no operational window, the selection between PMCD or FMCD techniques is the dependent on the reservoir pressure and fluid logistics. In some cases, it is possible to use both PMDC and FMCD techniques on the same well (4).

FMCD on depleted wells

For carbonate offshore Brazilian deepwater wells there were two different scenarios: severely depleted carbonates that had no operational window and required the use of FMCD technology and wells with almost original pressure, these required PMCD application. Both scenarios faced significant NPT could not be concluded with conventional drilling techniques or MPD SBP alone.

LAM densitu should be below the equivalent pore pressure density. Considering the technical limits of a single-phase fluid density, it is not possible to have LAM in the annular on depleted wells. The density limit eliminates the option for PMCD technique for total losses in these scenarios. Therefore, for the carbonate offshore Brazilian deepwater depleted wells the main technique used to be able to construct (drill and complete) these wells is FMCD.

The use of gas and liquid fluid in the well was not developed for deepwater scenarios, as the FMCD technique attends the well challenges, and the use of multiple stages fluids would add complexity and cost without clear benefits. Fernandes et al (5) and Teixeira et al (6) describe lessons learned and description of the first applications of the technology.

Until this moment, when drilling the Brazilian offshore carbonate wells, MCD techniques had no success when "forced" to the formation. Therefore, FMCD is a backup plan for wells that have no operational window or wells that is not possible to apply pressure within the operational limits due to depletion.

As FMCD is a back up plan, the regular wells that used this technique where first drilled using MPD SBP. When the well could no longer procced with SBP, and the proper conditions were present, MCD techniques where used.

When FMCD was applied on deepwater wells the MPD riser joint and sealing element were installed as the MPD SBP was being used previously. Although the presence of the sealing element is not strictly necessary from the point of pressure control, its presence provides an additional barrier to any migration that can occur. Considering the existing controls and potential impact, the option is to always have FMCD operations with a sealing element installed on the MPD riser joint.

MPD impact and inefficiency for lightly depleted reservoirs

Despite all the benefits MPD brings, it's not without some disadvantages since the technique has a considerable impact in cost and time of well construction.

At first, the need of additional equipment in comparison to conventional drilling increase the daily rate the MPD rigs when compared to conventional rigs. Additional to the equipment, MPD services are also required.

For MPD SBP/MCD operations additional steps are required for proper use of the technique. Fingerprint, pressure test, crew training are time consuming, but needed to guarantee the safety and efficiency of the operation.

For the application of MPD being worthwhile, it is necessary to consider all these costs and time spent to inherent MPD operations, A comparison with the duration of well construction with and without MPD should be made to evaluate the benefit for the whole campaign, in this comparison it should be considered the impossibility of well construction using conventional techniques. The optimal way of using MPD would be when it is strictly necessary, Aranha et al (7) and (8) describes how different factors impact the usage of MPD and definition of the best strategy for application such as reactive (where the first attempt is to drill the well conventionally and only use MPD when it is not possible to continue without it) or proactive strategy (anticipated use of MPD), number of MPD rigs on a campaign and risk considerations.

When severe losses are possible, the option of MudCap Drilling (MCD) can be difference of completing the objectives or having to abandon the well. The MCD technique, Floating or Pressurized MCD, will depend on the relation between pore pressure and drilling fluid density. So, when severe losses are expected, SBP can be used and MCD will be the contingency plan.

For a depleted well with loss possibilities, the strategy would be initiate drilling with SBP, converting to FMCD in case of total losses. The problem is that total losses are difficult to predict and, despite the geological prospect pointing out to its probability of happening, most of the time severe losses are not observed. Depending on the field, drilling and completion can be concluded using SBP technique without the use of MCD techniques.

The problem with this strategy, proactive MPD use SBP/MCD for every well is that it can not be the best option for a drilling campaign with uncertainty on losses. The additional cost can in some cases impact the robustness of the project.

For deepwater offshore wells is not economically viable to use conventional drilling fluid with complex formulation as a continuous sacrificial fluid. Sea water is used as the base of sacrificial fluid, with different

components depending on the field and reservoir characteristics. Any well with an equivalent pore pressure density below sea water and with expected fluid losses will depend on the FMCD contingency.

In this case, since sea water can be used as overbalanced mud, SBP is not essential, for its object would be to prevent losses by maintaining well pressure with minimal overbalance to the formation. For overbalanced mud, SBP will only add pressure to Bottom Hole Pressure (BHP) due to friction in surface lines and MPD choke, making it worse than drilling conventionally. The benefit of better well control using a mass flowmeter does not compensate for the additional risk of partial to total losses on depleted wells.

The wells with higher depletion do not benefit from MPD SBP for maintaining the pressure inside the operational window. The reduced equivalent pore pressure density from depleted formations makes it harder or even impossible to use a liquid fluid that has a lower density.

The challenge was how to optimize the MPD operation for depleted reservoirs and loss prevision uncertainty.

How to properly simplify a complex technique

Despite all the details that the planning of an FMCD operation requires, the application in the scenario of carbonate reservoirs in the Brazilian Pre-Salt allowed a simplification of the technique, regarding contingency loss scenarios (MPD SBP, PMCD or FMCD).

Considering the depletion of reservoirs and reliability in estimating pore pressure, which is different than loss prediction, it was possible to simplify the scenarios foreseen in the project between conventional drilling and FMCD mode, also reducing preparation steps for the technique. The feasibility of these scenarios made it possible to optimize drilling in wells with high losses, where the use of LCM is innocuous, and impacts well construction time and resource consumption. By using seawater as a sacrificial fluid, the cost on fluids and associated resources is reduced. These scenarios are also compatible with open well completion in a severe or total loss scenario.

By defining that the possible scenarios for the reservoir drilling are only conventional drilling or FMCD allows bypassing the MPD manifold (choke, coriolis, junk catcher), where only the additional alignments for attacking the well via subsea lines/booster and the connection of the flow spool line to the mud gas separator are needed. As the MPD SBP scenario is of low probability, the existence of the manifold that allows these alignments is sufficient (along with the presence of PRVs for the system).

The use of the MPD integrated riser joint is mandatory for the simplified FMCD scenario, as it allows, in addition to aligning the Riser for the mud gas separator, the bearing assembly to serve as a barrier against gas exposure to the rotating table, serving as physical barrier for personnel protection. Installing the MPD riser joint adds time to the intervention, but it is necessary to allow for the technique, its contingencies, and the safety standard from the operator.

Considering the expected scenario of conventional drilling and severe/total loss, it was possible to implement simplifications in the technique's preparations when compared to drilling in MPD SBP mode. This was one of the key factors to make the simplified technique more attractive when compared to a reactive or proactive drilling campaign strategy. Among the simplifications, the following stand out:.

- Skip fingerprinting prior to drilling the reservoir since the rheological parameters and hydraulic behavior of the well/rig have no influence on the FMCD scenario. Instead of fine tuning the rheological models for MPD SBP technique, the most important factor is to define the downhole flow operational values. There are different simulations that can provide the values for proper well control flow, assuring that the well barrier (fluid and descending flow) is capable to avoid fluid migration and bullhead the hydrocarbon to the formation. The simulations can be done offline.
- All the tests of the flowspool and DSIT flow hoses, valves and buffer manifold lines can be done in parallel to other well operations. The tests are performed at reduced pressure (around 300 psi) to confirm the isolation and tightness of the system. As the FMCD scenario does not work with

pressure, the leak tightness of the system is important in the event of recovery of the fluid level at the table or migration of gas that may reach the Riser in the event of a badly performed operation. The tightness is also important for environmental protection.

- The PRV's system test is done in parallel to the well operation, as well as testing the NRVs, which must be in the drilling BHA, even in conventional drilling.
- Initially, the reservoir drilling is done without the sealing element installed, as it starts as a conventional drilling scenario.

1. If severe losses in the well are identified, after tests to confirm the injectivity of the formation, the bearing assembly is installed.
2. The well is always attacked (control flow), even during the sealing element installation, by submarine lines.
3. As sealing element is not a safety barrier element of the well in the FMCD scenario, the sealing element is tested with low pressure, 300 psi, to guarantee tightness against possible hydrocarbon that could migrate to the Riser.Body text 2 paragraphs.

Another technical aspect that facilitated the adoption of the simplified FMCD was the technical feasibility of drilling depleted reservoirs using seawater. In an FMCD scenario, where injectivity decreases while drilling the phase, reestablishing the returns, it is necessary to continue drilling in conventional mode. As there it is technically possible of drilling the reservoir conventionally using seawater with returns, the migration between FMCD and conventional drilling becomes simpler with less resource consumption.

These simplifications bring economic and efficiency gains to the severe loss scenario, typical of the Brazilian Pre-Salt. It also brings robustness to the campaign, as a proactive strategy is more attractive to be used, and exceptional well conditions could be covered within the original plan and resources allocated to the rig.

It is essential that the planning of the FMCD scenario adopts all precautions for the method, still in the design stage, such as BHA design, contingency in the supply of seawater to the well, redundancy of energy generation for the mud systems, well cleaning, training of the rig team in installation of the sealing assembly, sealing friction and different alignments to be performed based on the operational conditions.

Simplified FMCD results

After the first operation in 2022, other projects followed this strategy in depleted reservoirs. It was possible to collect the results of the application of the simplified FMCD technique.

Until this moment 7 simplified FMCD operations were performed, in different Brazilian offshore fields, while 2 wells did not attend the conditions for conversion. All the fields where the simplified technique was applied had previous cases with severe or total losses in past wells. The wells scenarios where the simplified technique was applied or considered can be divided in following:

- Simplified FMCD was previously planned. In these wells the MPD riser joint was installed and the technique was used after the formation presented conditions for FMCD conversion;
  - The initial plan did not include simplified FMCD, but after total losses, there was abandonment and reentry with simplified FMCD (Well 2);
  - Wells in which it was decided to live with the severe loss and not convert to simplified FMCD (wells 7 and 8). Note partial return was always present and conventional well control procedures were applicable.

The first implementation, well 1, of the new technique was in a well where the pore pressure was known and significant depletion present. Even if non-water-based fluid was available it would not be possible to have an underbalanced fluid in the annular.

In well 1, after cutting the cement and verifying total losses, the conditions to use the FMCD technique were present. Making it not necessary to drill with SBP, in that way the conversion procedure from SBP to FMCD could be avoided. From this first operation a new procedure was developed.

After the success of the first operation, other projects followed this strategy when drilling wells in depleted fields. The reduced impact in time, allowed a more proactive use of the FMCD contingency.

Figure 1 present the reservoir drilling times in hours for the wells that used or were candidates to use the simplified FMCD strategy:

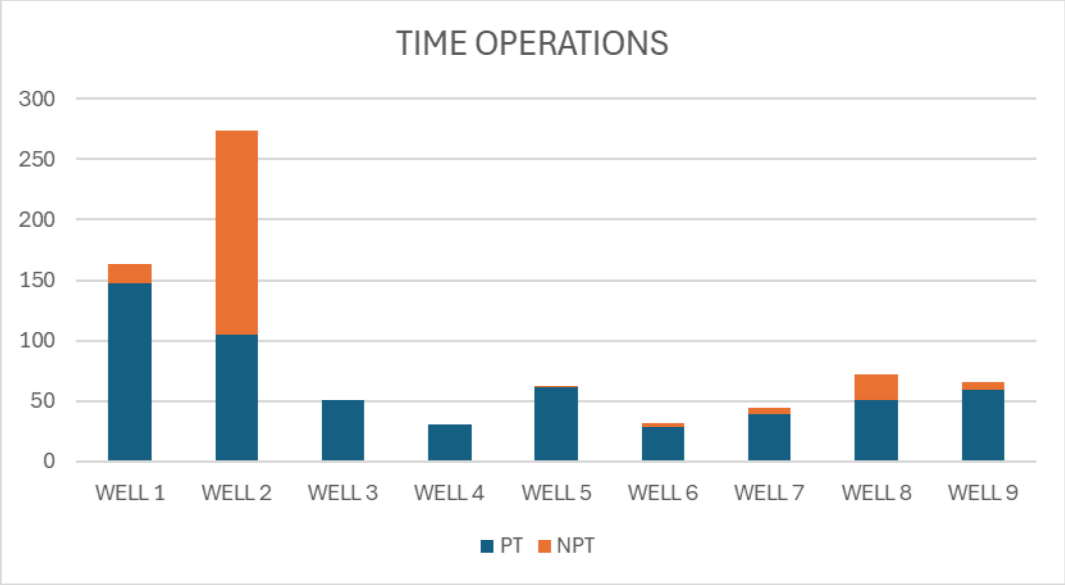

Figure 1—Reservoir drilling time (hours)

The application of the simplified FMCD technique reduced the amount of time to conclude the drilling of the reservoir section when compared to wells in similar conditions. The additional time to deploy and install the MPD joint is not significant on the total time when compared to historical data. Even on wells with higher uncertainty, the benefits of one FMCD simplified success case overcomes the penalty of proactive usage.

Conclusions

The use of simplified Floating Mud Cap Drilling technique demonstrated to be beneficial for the construction of deepwater depleted wells. The simplified technique offers flexibility, efficiency, and economy when compared to other MPD SBP/MCD projects.

Deepwater wells, particularly those that are depleted, present technical challenges due to their complex pressure environments and often unpredictable conditions. Traditional drilling techniques are unable to conclude some wells. At the same time the strategy of approaching all wells with the SBP/MCD combination impact the cost and execution time of the wells, not being the most effective strategy for all conditions.

The results collected in less than two years, indicate that when properly applied a noticeable enhancement in overall operational performance was achieved while maintaining operational safety at the same standard.

The simplification for in deepwater well operations is important as different resources might not be available for all the rigs on the fleet at the same time, it allows a better distribution among different projects.

The new technique confirms its robustness as it can accommodate a range of well pressures and fluid characteristics without the need for complex projects, services, and operational procedures. This adaptability is crucial during the development of deepwater campaign, where minimal changes on well conditions can impact the ability to conclude the well objectives in a safe manner or can impact the availability of critical materials.

Efficiency in deepwater drilling operations is critical, given the high costs and technical demands involved. The simplified FMCD system streamlines operations by reducing the complexity of the drilling process. MPD SBP combined with FMDC often involve multiple steps and extensive equipment. The simplified FMCD, when applicable, reduces these steps by employing a straightforward setup that minimizes the equipment and time required to establish and maintain a mud cap. This streamlined approach not only speeds up the drilling process but also reduces the probability of operational disruptions caused by equipment failure or procedural errors.

Another important benefit of this approach is the reduction of CO2 emissions, as the intervention is done in a smaller amount of time without the need for complicated logistics or additional personnel on the rig.

Bibliography

1. Fernandes, A. A., Vanni, G. S. F, and F. S Terra. "MPD Deepwater Evolution and Interinstitutional Development." Paper presented at the Offshore Technology Conference, Houston, Texas, USA, May 2024. doi: https://doi.org/10.4043/35301-MS
2. Fernandes, André Alonso, Tomita, Reinaldo Akio, Junior, Antonio Carlos, Abdu, João Paulo,Vanni, Guilherme Siqueira, Grandi, Ricardo Freire, Longo, Fabio Leonardo, Machado, Giovani Ferreira, Agostini, Cristiano Eduardo, Vadinal, Rodolfo Balthazar, and Luiz Felipe Silva. "Overview of Different Applications for MPD and MCD Techniques on Deepwater Wells." Paper presented at the IADC/SPE Managed Pressure Drilling & Underbalanced Operations Conference & Exhibition, Rio de Janeiro, Brazil, March 2017. doi: https://doi.org/10.2118/185279-MS
3. IADC ABS Guide for Classification and Certification of Managed Pressure Drilling Systems, September 2017.
4. Fernandes, André Alonso, Schnitzler, Eduardo, Fabri, Fabio, Grabarski, Leandro, Malfitani, Marcos Vinicius Barreto, Roman, Roger Savoldi, and Willian Medina Ascâneo. "Triple MPD Technique for Drilling and Intelligent Completion Deployment on an Abandoned Deepwater Well." Paper presented at the Offshore Technology Conference, Virtual and Houston, Texas, August 2021. doi: https://doi.org/10.4043/31223-MS
5. Fernandes, Andre Alonso, Gozzi, Danilo Signorini, Nogueira, Emmanuel Franco, de Souza Terra, Felipe, Vanni, Guilherme Sirqueira, and Rafael Schettini Filho. "MPD/MCD Offshore Application on a Dynamic Positioning Rig." Paper presented at the SPE/IADC Managed Pressure Drilling and Underbalanced Operations Conference & Exhibition, Dubai, UAE, April 2015. doi: https://doi.org/10.2118/173825-MS
6. Teixeira, G. T., Fabri, F.., de Almeida, L. S., da Silva, P. H., and R. B. Vadinal. "Lessons Learned in Drilling Fluids Projects during MPD and MCD Operations in Brazil's Offshore Wells." Paper presented at the IADC/SPE Managed Pressure Drilling & Underbalanced Operations Conference & Exhibition, Rio de Janeiro, Brazil, March 2017. doi: https://doi.org/10.2118/185277-MS
7. Aranha, Pedro Esteves, Colombo, Danilo, Fernandes, André Alonso, Vanni, Guilherme Siqueira, Tomita, Reinaldo Akio, Benevenuto de Campos Lima, Cláudio, Lima, Gilson Brito, and Júlio César de Faria Alvim Wasserman. "Strategic Evaluation of Managed Pressure Drilling: An Application on Brazilian Dynamic-Positioning Rigs." *SPE Drill & Compl* **34** (2019): 216–222. doi: https://doi.org/10.2118/185281-PA

8. Aranha, Pedro Esteves, Fernandes, André Alonso, Vanni, Guilherme Siqueira, Terra, Felipe de, Tomita, Reinaldo Akio, Tolfo, Marcos Coradini, and Danilo Signorini Gozzi. "Strategic Evaluation of MPD Application on DP Rigs." Paper presented at the IADC/SPE Managed Pressure Drilling & Underbalanced Operations Conference & Exhibition, Rio de Janeiro, Brazil, March 2017. doi: https://doi.org/10.2118/185281-MS