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Use of Advanced Simulation Software to Understand Drilling Challenges that Leads to the Selection of PDC Drill Bit, Reduced the Risk of Failure and Improves Performance by 22% at South Argentina.

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Abstract

The objective of this paper is to demonstrate a comprehensive methodology for an efficient selection process of a Polycrystalline Diamond Compact (PDC) drill bit design tailored to a given drilling conditions with the use of digitalization. This is achieved by utilizing a software that recreates the PDC design with a polygonal mesh model. Then it's subjected to dynamic drilling conditions; which include the application of loads equivalent to Weight on Bit (WOB), and a rotational motion, equivalent to Revolution Per Minute; of solids that have mechanical properties calibrated with data from pressurized drilling tests in specific rock types. After the incorporation of data from offset wells and the target well, the software is capable to simulate the loads and stress that the PDC will be subjected to when drilling the specific environment. This will allow to analyze the bits performance and durability, thus predicting the challenges, to verify if the drill bit design itself will comply with the application's requirements.

After completing an iterative simulation process, where the geometries and positioning of features of the PDC drill bit are modified until a desired response is completed; a final design is obtained that can be tested in a real life well. The implications of this approach are promising to enhance efficiencies that can ultimately reduce time and cost for operators, fostering more efficient drilling practices for the industry.

Introduction

As the demand for energy resources continues to surge and the need for safer and more sustainable drilling operations intensifies; like in the past decade, where the Oil and Gas Industry has been using unconventional ways to extract hydrocarbons, so does the need to operate with tools and practices that can be more reliable, and adaptive to the specific challenges that this brings.

Since decades ago, where the use of several number of roller cone bits to drill a section at a low rate of penetration, evolved to PDC Designs, that can drill the same interval in one run, at an increased rate of penetration. The optimization of drill bits stands as a corner stone within the oil and gas industry, deeply shaping the efficiency, productivity, and cost-effectiveness of field operations. This process and its technological advancements have consistently influenced drilling practices.

Traditionally, PDC designs underwent a lengthy trial and error process, requiring numerous build and run iterations that consumes physical inventory and operational time. This incurs additional costs and general inefficiencies that are detrimental to development of projects.

In response to these pressing challenges, digitalization has emerged as a pivotal element for enhancing and optimizing drilling performance. The integration of digital tools offers a paradigm shift in drill bit design optimization. This approach offers an evaluation of a drill bit design in a virtual environment before the costly venture of physical testing which enables to make design changes with more confidence to reduce risk.

The analysis covered in this document is based on the transformative potential of digitalization, offering ways to save valuable resources while delivering solutions that align more precisely to the demands of the application, more rapidly than the more traditional method. Specifically, it shows how a new digital tool can be utilized to comprehensively replicate the drilling environment and test features on the PDC drill bit design to adjust its behavior to the desired parameters, expediting the selection process, thus reducing the time and cost. The scope of the paper covers a summary of the information necessary to input into the software, and a sample of outputs which are analyzed to assist in the understanding of the environment. Increased understanding of the bit response thru iterations, led to faster drill bit optimization in the application of curve and horizontal sections in the Golfo San Jorge's Basin at Southern Argentina, which until recently were only vertical wells.

Background Information

The drilling operations in the Golfo San Jorge's Basin at Southern Argentina have been historically conventional where nearly all wells drilled were vertical. The most common target formation is Mina El Carmen, which is a sandy shale body with medium Unconfined Compressive Strength (UCS) (Stinko, 2004). The most common drilling practice is to approach the target formation at a vertical or slightly angled entry.

However, as stated previously the need for increased productivity has led to propose an unconventional approach, requiring reaching the target formation at a horizontal entry, which will need to drill the section building a curved trajectory from surface.

To achieve this, a positive displacement motor with a bend is utilized to direct the bottom hole assembly in the proposed trajectory. The PDC drill bit design is required to be compatible with the expected directional performance and within the durability range that permits the completion of the section in one run, without compromising the expected rate of penetration.

A full bit drilling model has been utilized to evaluate behavior for PDC drill bit and for cutter geometry as well. Using a 3D polygonal mesh, the model more accurately simulates the stress and reactionary forces on the cutting elements that are engaged in the drilling process. To further enhance the bit-rock interaction and bottom hole pattern accuracy, an advanced Boolean operator works with the simulation to more accurately identify and update interacting surfaces between the bit model and digital rock analog. The simulation converts the interactions between these polygonal faces into cutting forces (Figure 1 and 2). The force model discussed in this paper is calibrated using high pressure lab data (Ledgerwood and Kelly 1991). The authors of this paper acknowledge the importance of the force model utilized in the software (Matthews 2021), that has been applied to the simulations and resulting analysis.

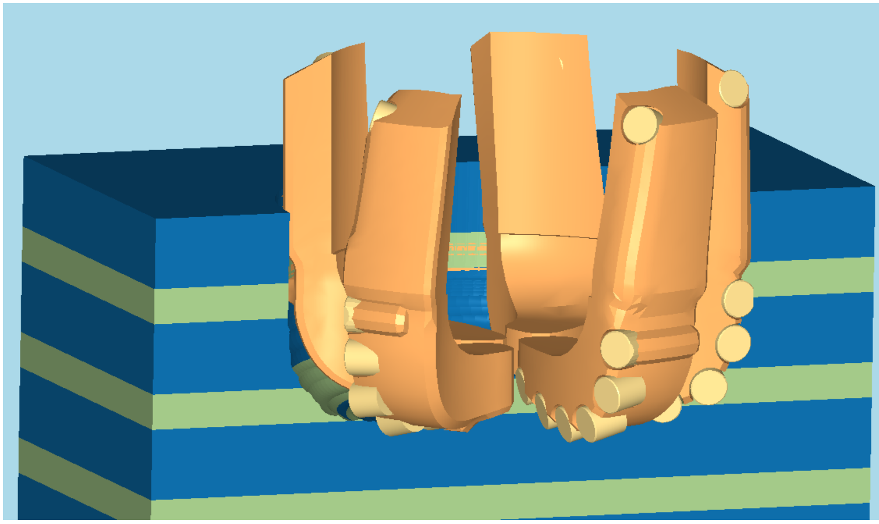

Figure 1. Drill bit geometry placed on a solid that has rock properties.

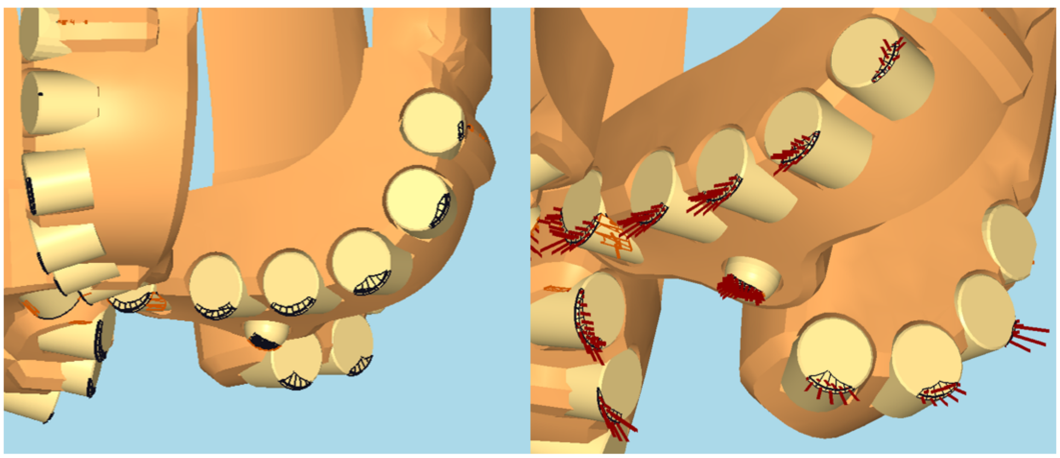

Figure 2. Interaction geometries and force vectors from those interactions.

Taking these considerations into account, the drilling model will need to contemplate the operational parameters, formation characterization, drilling mode, and bit geometry, which will include the cutter diameter, positioning and exposure. The model will simulate the specific drilling environment produced by these parameters to generate outputs that include torque on bit (TOB), rate of penetration, (ROP), drill bit aggressiveness (Mu), mechanical specific energy (MSE), and various cutting forces (Russell 2022). (Figure 3 and 4)

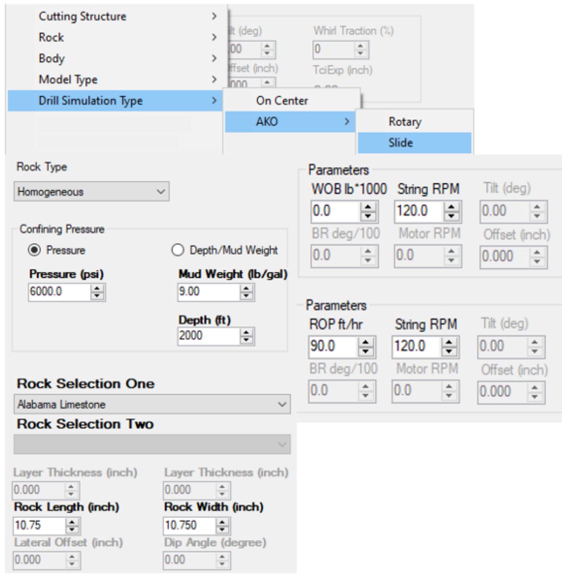

Figure 3. Sample of input parameters

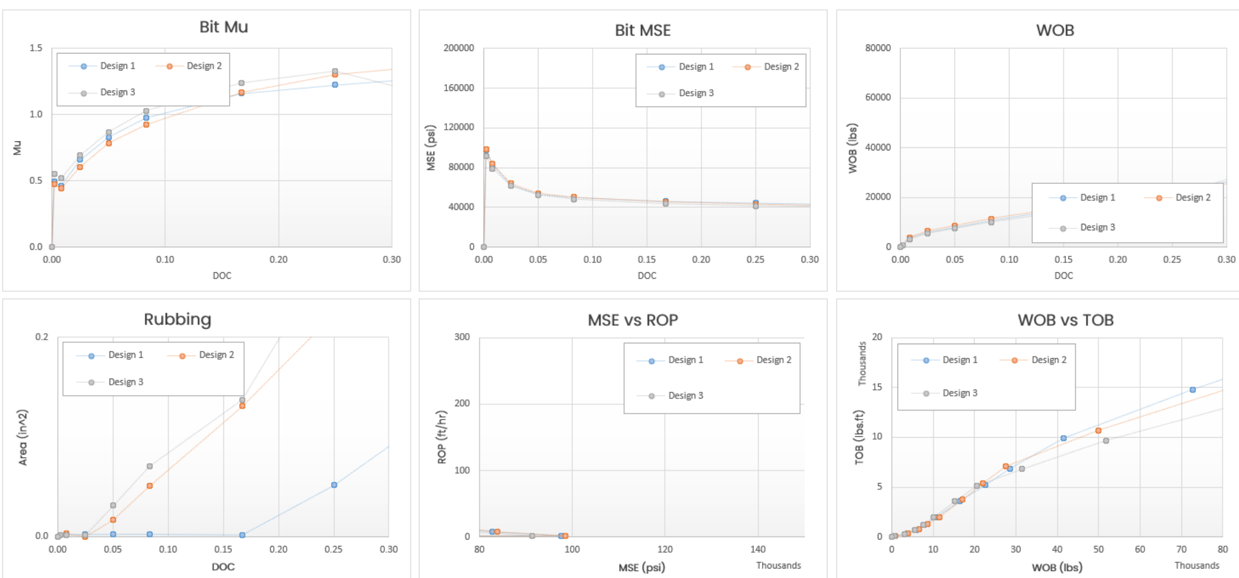

Figure 4. Sample set of simulation outputs.

Understanding Drilling Challenges

The first step of this analysis process began with a revision of offset well information that can be converted to a comprehensive list of setpoints to run the simulation on the software. Within this stage, it was necessary to identify both the rock properties and strength, as well as the proposed trajectory and drilling mode.

Unconfined Compressive Strength can be determined by acquiring log data from offset wells which includes Gamma Ray Readings as well as Compressive Acoustic Transit time readings (Spaar & Ledgerwood 1995). (Figure 5)

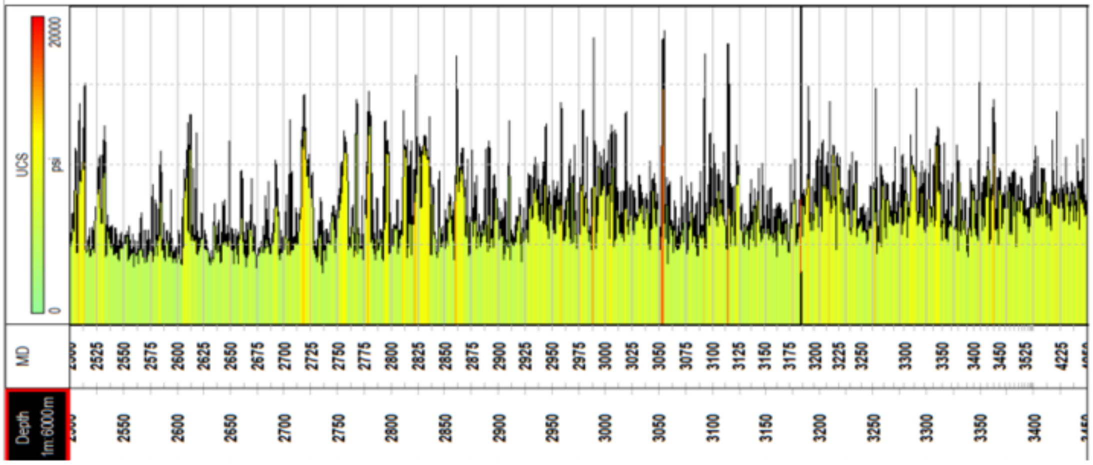

Figure 5. Sample visualization of rock's unconfined compressive strength measurement.

A visualization that juxtaposes the rock strength variation and the offset Trajectory can provide a better understanding of rock drilling dynamics which the drill bit would be subject to in real life conditions. (Figure 6).

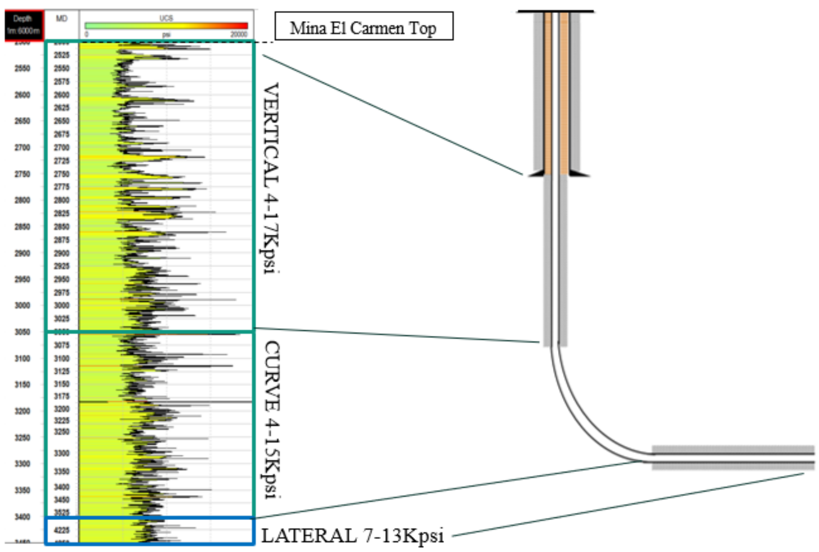

Figure 6. rock strength visualization compared to the proposed trajectory to which these formations will be drilled.

It is worth to mention, that the curve and horizontal portion of the proposed well has never been drilled before in this rock, using the trajectory. To predict potential bit performance, it was necessary to consider the reviewing the drill bit records from vertical offset wells that drilled the target formation top, to observe the dull condition of the PDC drill bits and the rate of penetration. This provided an understanding of how certain PDC drill bit features and geometries behave in this rock.

In addition, pictures from dulls, and parameter run data, is useful to specify drilling conditions and can be input in the simulation software to compare the outputs with the reality (Figure 7), providing a consistent base to evaluate future response of a PDC drill bit design that would drill in this condition, but in a different trajectory.

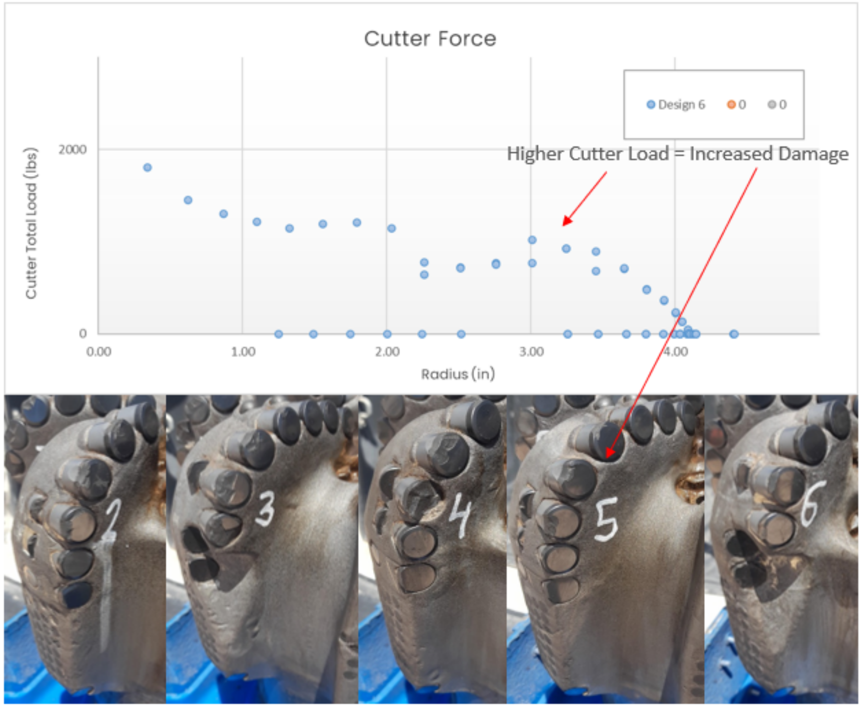

Figure 7. Sample drill bit dull compared to the loads applied observed in the software under conditions that mimics real life well.

A key behavior identified in the rock strength analysis, is the variability of it. That is, one layer to have lower strength, and the next layer with increased strength. This observation led to theorize that rock strength variance caused the torque response to vary as well, hence the orientation of a bent motor, or tool face to be unstable. Once an operator found an appropriate WOB to apply to be stable, if a change in layer happen (change in strength), then at the same WOB, the Torque would change, hence changing the tool face orientation, and forcing to start over again.

This would typically result in low ROP response, that for this case, would be around 5 m/h.

The simulations can be separated into two drilling modes, such as on center rotation, that will mimic the "Slide Mode" rotational drilling when using a bent motor. Geometry for the bend angle and bit to bend distance can be input to the software (Figure 8). The other drilling mode is off-center rotation, which will mimic the "Rotary Mode" rotational drilling on a bent motor. This split allows the user to observe the drill bit behavior in both modes in a way that features and geometries can be adjusted to obtain the best performance in each mode, without compromising the other.

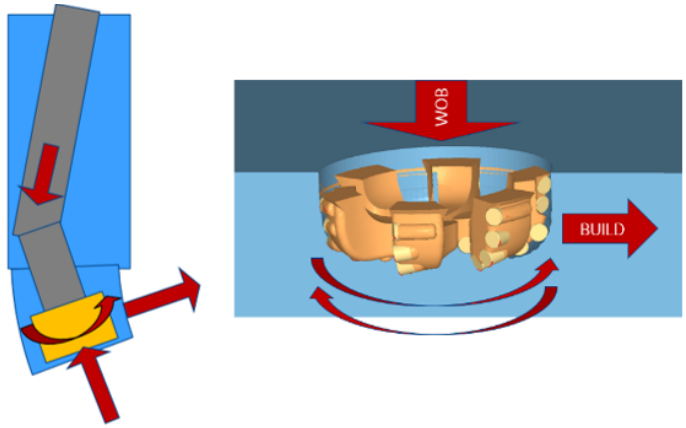

Figure 8. Graphic visualization on how to input bent motor geometry to the software.

The challenges identified for a PDC Drill bit to complete a Curve-Horizontal section of a well at Golfo San Jorge's Basin in Southern Argentina, are mainly two.

The first challenge, given the nature of the variability in rock strength, that can produce changes in orientation, the design needs to provide a stable torque response to mitigate this effect.

The other challenge, also attributed to rock strength variance, is the durability of the design, since this ever-changing condition can place cyclic loads on the cutting structure, inducing vibrations that could create impacts that may reduce the optimal life of the drill bit.

Real Case Drilling Simulation Iterations

Upon completion of the drilling environment analysis, the baseline for the next stage is set. That is create versions of drill bit designs whose responses better accommodate the needs of the application.

With the use of the software a performance-based analysis is performed, which estimates the torque response variation in any design that is simulated. (Figure 9).

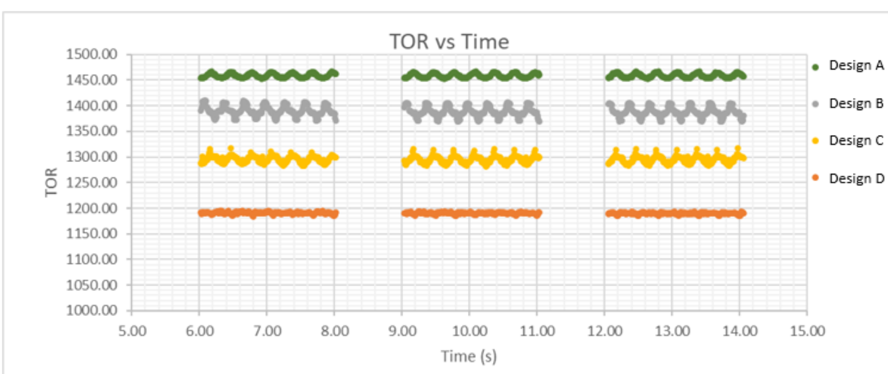

Figure 9. Graphic visualization of drill bit design torque response, in the simulation time to drill the rock.

From the previous chart, an ideal torque response would be the Design D; however, a low torque response is related to the aggressiveness of the bit, which in at the same time is related to the ROP potential. In this sense the aggressiveness of the bit, called Mu for the analysis purposes, also needs to be evaluated, in both rotate mode, and slide mode. (Figure 10.)

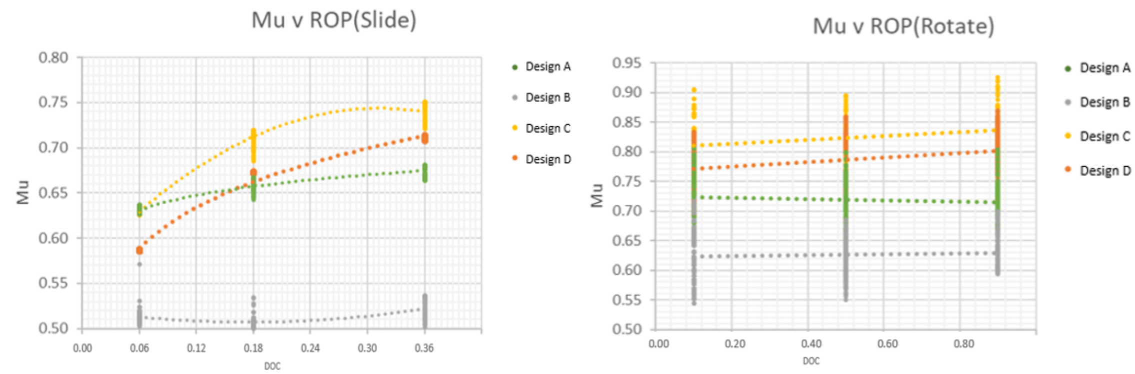

Figure 10. Graphic visualization of drill bit design aggressiveness Mu, at various depth of cut

By having this information, design features such back rake, and cutter layout are changed in the drill bit design until a desired response is obtained.

The software outputs can be visualized in different ways to assist in the process of evaluation of drill bit designs. Such is the case as follows. Where the torque variation response and RPM variation (which could be interpreted as the variation of tool face orientation), are visualized for two designs (Figure 11).

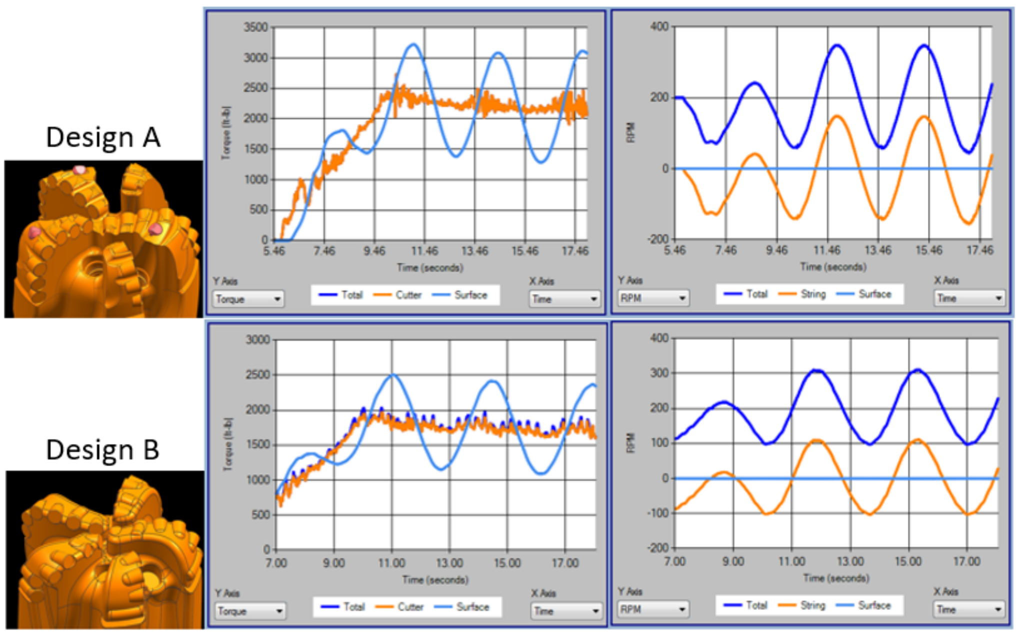

Figure 11. Graphic visualization of software's output, for two specific drill bit designs.

From the previous image, it is show that for the design B, the wave height for total torque is less than 1500 lb.ft, yet for design A, is above 1500 lb.ft. This could be interpreted that the design B would be more stable. At the same time, the variation in torque produces variation in RPM, and for this example, the wave height is also lower on the design B, than the design A. For the wavelength, the design B is longer, that can be interpreted that the acceleration and deceleration is smoother which would imply that it can benefit the stability of the tool face orientation.

To evaluate a drill bit design endurance, the software can also perform a durability-based analysis which would back-calculate what level of WOB is required to achieve certain ROP. The last one compares the maximum forces a design can withstand without reaching a failure point, that way a maximum limit of ROP, or translated to a maximum depth of cut limit allowable in simulated conditions.

In this project, from the analyzed dull data, a level of wear is identified at the shoulder location of the PDC drill bit design and it's compared to the load distribution output from the simulation. A baseline is set to begin the iteration process where features in the body of the drill bit can be tested on the virtual environment until obtaining a response that would see less cutter forces in the shoulder location (Figure 12).

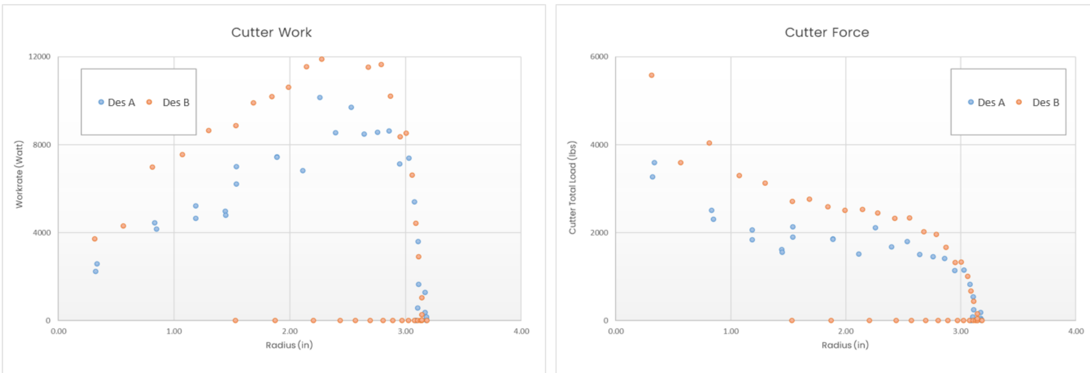

Figure 12. Graphic visualization on how to loads are distributed across drill bit profile for design A or design B.

Based on the previous chart, although Design B would be more evenly distributed, the Design A would be less loaded, thus better opportunity for durability on the simulated conditions.

After the first result, more modifications, like cutter layout disposition for Design A, may evenly distribute these loads, thus increasing the cutting structure efficiency, promoting a more efficient concept that can enhance ROP potential.

Another alternative on a subsequent iteration can observe the same conditions, yet aiming to reduce the loads on Design B, which would enhance the cutter life, hence mitigating the risk of premature failure.

The iteration process length and complexity can vary depending on the user's dexterity and the goals for the project. Simulations can be used for a simple comparison between drill bits design to make a best suited selection, or as far as the basis for completely redesigning a drill bit. Yet the software offers different visualizations that can accommodate the specific needs.

Results. Case Study Horizontal Drilling Golfo San Jorge

The simulation and design iteration methodology described was applied for two operators, and although some variables may differ in the specific bottom hole assemblies (BHA) and strategies on the number of runs and hole sizes to drill unconventionally; the goal is similar since they will be targeting Mina El Carmen Top formation. Successful completion of the section heavily relies on using the fewest possible number of runs, which makes the torsional stability along with durability of a drill bit the keys to achieving it.

For one operator, the goal was to drill a 6.125 in. hole using a bent motor that will conduct a vertical trajectory followed by a curve, and then a horizontal section. In this case, the section needed to be completed in one single run.

The PDC drill bit that resulted from the process, is a PDC drill bit design that has 13mm cutters and 5 blades. The design has features of depth of cut control that minimizes torsional variations in the drill string (David, Pastusek, 2012), that offers the required torsional stability in slide mode, obtaining at some points double or triple the Sliding ROP from offset wells. This was confirmed thru the observed tool face orientation stability, that allowed the operator to increase the WOB regime, thus increasing the cutting action.

In addition, the selected design demonstrated a lower level of wear, compared to offset reference, consistent with the results from the software's output, being able to mitigate the effects of the formation strength and variability, which provided the reliability to complete the section (Figure 13).

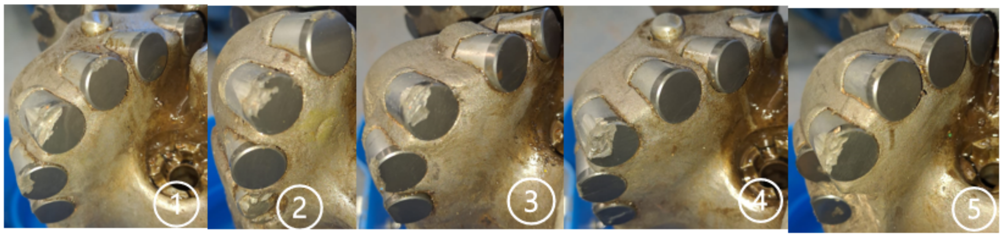

Figure 13. Observed Dull Wear of the selected bit. Less wear than offset

The other operator, planned to drill the vertical and curve portion using a different hole size than the horizontal section. The use of the advanced simulation software was applied only for the 6.75 in. horizontal reach section using a bent motor, which the operator considered has the more risk of not completing the section, hence using the same process to mitigate risk failure and increase reliability.

In this case, since the operator planned for three wells with the same geometry, the PDC drill bit design that resulted from the analysis was utilized on all three of them, yet thru parameter analysis, the subsequent performance could be improved, achieving 22% increase in rate of penetration from the first well to the last (Figure 14).

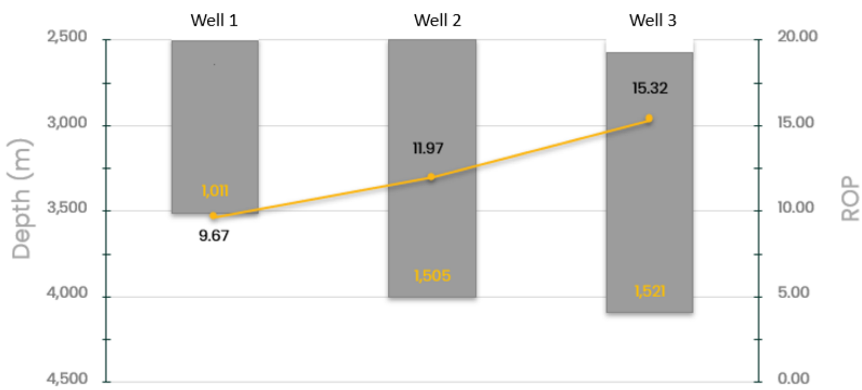

Figure 14. Graphic comparison of performance for all three horizontal sections that were drilled in one run.

Discussion

The results of this study demonstrate the effectiveness of using a drilling simulation software, to replicate, analyze and understand the challenges that may be present on a given application, that a PDC Drill bit would face in real life conditions. The method provides a tool to create a hypothetical range of conditions that may affect the rate of penetration of the drill bit and the life of the drill bit itself, which, thru modification can be improved to achieve significantly better performance. All this with the speed and safety of the digital environment.

The capability of the model in predicting the forces and stresses to which a drill bit would be subject to, plus how it's going to behave under specific conditions can be of great significance. These insights are important not only to the selection of design, but to the creation of novel geometries that can push the boundaries of PDC Drill bits, that otherwise wouldn't be able to create, and ultimately enhancing the efficiency of drilling. Another aspect to consider of great help is that this kind of tool can aid in the investigation of failure events to better understand the causes and arrive quickly to mitigating and corrective actions.

However, it's worth to mention that the software requires a knowledgeable and trained user to maximize the benefits from its use, along with an understanding and correct interpretation of outputs. This will directly influence the accuracy of its application. Another aspect to consider is that by making calculations based on perfect models, any slight variation from the model observed in real life, can be detrimental for the success of implementation, and any analysis should be conducted with this condition in consideration.

Conclusions

Through the course of the project, the use of a simulation software helped in determining what kind of challenge a PDC drill bit design would face in the conditions set for unconventional drilling at Golfo San Jorge's basin. Thanks to this method, a drill bit design was selected that complied with the operators' requirements, that is, completing all planned sections in one run, in the first attempt, plus the significance of increasing performance in subsequent wells.

The findings, illustrated in this paper, display the benefits of applying digitalization in oil and gas industry operations, specifically to the drill bit selection process. Then the capacity of this software can converge on solutions more quickly with a higher rate of confidence, converting it to a more efficient process than the traditional process of analyzing after run data, and proposing conjectures to build a drill bit and then test it on field, before having an estimate on how would behave.

A key benefit of this kind of digital tool is that it will allow to test several design options without conducting field trials that are lengthy in time, but also costly to the overall development of projects. In that sense, engineers can identify potential problems before they are present in real life. Plus, this method can create tests that can be executed in extreme conditions to observe the drill bit limits without the perils to replicate them in real life.

Further development of the software, specifically with the incipient conception of artificial intelligence, can evolve into new models that examine more realistic variables which can ultimately predict accurately the response and behavior of drilling tools in advance of the project execution.

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