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Abstract

Drilling challenging wells requires a combination of drilling analytics and comprehensive simulation to prevent poor drilling performance and avoid drilling issues for the upcoming drilling campaign. This work focuses on the capabilities of a drilling simulator that can simulate the directional drilling process with the use of actual field data for the training of students and professionals. This paper presents the results of simulating both rotating and sliding modes and successfully matching the rate of penetration and the trajectory of an S-type well.

Monitored drilling data from the well were used to simulate the drilling process. These included weight on bit, revolutions per minute, flow rate, bit type, inclination and drilling fluid properties. The well was an S-type well with maximum inclination of 16 degrees. There were continuous variations from rotating to sliding mode, and the challenge was approached by classifying drilling data into intervals of 20 feet to obtain an appropriate resolution and efficient simulation. The simulator requires formation strength, pore and fracture pressures, and details of well lithology, thus simulating the actual drilling environment. The uniaxial compressive strength of the rock layer is calculated from p-wave velocity data from an offset field. Rock drillability is finally estimated as a function of the rock properties of the drilled layer, bit type and the values of the drilling parameters. It is then converted to rate of penetration and matched to actual data.

Changes in the drilling parameters were followed as per the field data. The simulator reproduces the drilling process in real-time and allows the driller to make instantaneous changes to all drilling parameters. The simulator provides the rate of penetration, torque, standpipe pressure, and trajectory as output. This enables the user to have on-the-fly interference with the drilling process and allows him/her to modify any of the important drilling parameters. Thus, the user can determine the effect of such changes on the effectiveness of drilling, which can lead to effective drilling optimization.

Certain intervals were investigated independently to give a more detailed analysis of the simulation outcome. Additional drilling data such as hook load and standpipe pressure were analyzed to determine and evaluate the drilling performance of a particular interval and to consider them in the optimization process.

The resulting rate of penetration and well trajectory simulation results show an excellent match with

field data. The simulation illustrates the continuous change between rotating and sliding mode as well as the accurate synchronous matching of the rate of penetration and trajectory. The results prove that the simulator is an excellent tool for students and professionals to simulate the drilling process prior to actual drilling of the next inclined well.

Introduction

During the last 40 years, research institutions and companies have established teams in order to work on drilling simulators to prevent drilling-related issues and optimize drilling performance. This was documented in publications over the years [1]. Simulations are mainly used in the planning phase but can also contribute to risk awareness and cost reduction during operation.

Milheim [1] describes the development of a drilling simulator that merged several components, including geology and the drilling rig. Each system is built with a set of algorithms that represents the physics behind the drilling process. Similarly, Milheim [2] published another paper that describes how the drilling simulator could be evolved by including interactive graphics and pictures.

Cooper et al. [3] developed a simulator that allows students and professionals to simulate the drilling process of an oil or gas well, and be able to optimize the performance by simulating several drilling scenarios and choose the optimum. The simulator allows the user to change the operating parameters in order to optimize the drilling performance. In the following year, Cooper et al. [4] published another paper describing the simulator as a training tool that can link several disciplines of petroleum engineering.

Mahmoud et al. [5] reported the simulation and optimization of the drilling process for a casing drilling study. The case study was a 2000 ft well in Haynesville shale with different lithology across the wellbore that was defined in terms of rock type and properties from the collected data. The results showed that the simulator was able to match the rate of penetration with the use of historical data, even in casing drilling simulations, and then the authors were able to apply different scenarios to optimize drilling performance.

A work that focused on tripping operations was published by Mirjah et al. [6]. The simulator is able to upload different case data to mimic the exact rig site environment, hence, the different drilling scenarios. The rig crew that was trained in that specific environment was found more efficient in real operation and which resulted in reducing the cost due to non-productive time for a stuck-pipe scenario.

Kelessidis et al. [7] worked on testing the performance and demonstrating different drilling optimization concepts for sandstone and limestone rocks. An interesting finding was the ability of the simulator to recreate the drilling conditions and optimize drilling performance. The results show that matching the field data was successful for both lithologies.

Strivastana et al. [8] published a paper using a drilling simulator that explicitly simulates the processes and operations that are taking place on the rig floor. An essential part of the simulator is to train young and experienced rig crews and evaluate them.

Despite several efforts in the past, the drilling industry failed to maintain the progress in the development of drilling simulators compared to other industries [9]. The objective of this paper is to illustrate the capabilities of an innovative drilling simulator that is able to simulate the drilling process by taking into consideration appropriate physical models in combination with rock properties across the entire well or any given section. The capabilities and successful applications of this approach have been tested, and data were published before for drilling vertical wells for oil and gas exploration [7] and geothermal drilling [10]. However, the simulation of directional wells using this approach was not done as of today. Rotating and sliding mode is a common practice to drill a directional well, and drilling optimization requires sophisticated data analysis. The purpose of this paper is thus, to analyze directional data and attempt to simulate the drilling process and propose optimized drilling parameters values for future wells to be drilled directionally in the area.

Methodology and Modeling

Optimization of the drilling process is done by simulating the cutting of the rock by the bit. More

detailed information was given in prior work [3, 5, 7, 10]. The main feature of the model is the prediction of the rate of penetration by:

$$ROP = (flow_factor)(C)(aggressivity)(RPM)(tooth_length)(G) \quad (1)$$

with,

$$G = 1 - \exp\left[-\left(\frac{WOB}{UCS}\right)^{curve} \left(\frac{12}{D^{2.5}(0.4tooth_length)}\right)\right] \quad (2)$$

where, ROP is the rate of penetration, RPM is revolutions per minute, tooth_length is the average length of the bit teeth, UCS is the uniaxial compressive strength of the formation, D is bit diameter, and WOB is weight on bit. The user is able to modify the following constants: C is a constant; aggressivity is a formation and bit characteristic constant ranging between 20% and 100% and normally is given the value of 35%; curve is a formation-bit interaction constant and it is usually given the value of 1.5; flow_factor is a constant, ranging between 50% and 100% and defines the capability of the system to adequately clean the bit front by the cuttings.

Teale [11] published a very insightful and innovative paper regarding drilling optimization. He introduced the concept of mechanical specific energy (MSE), which is the input energy by the rig applied to the bit, which removes a unit volume of rock. Obviously, MSE changes as drilling progresses and can be associated with formation strength. By solving the MSE equation suggested by Teale for the rate of penetration, and introducing an efficiency factor (*eff*) [10], one derives:

$$ROP = \frac{(8)(RPM)(\mu D)\left(\frac{WOB}{A_{bit}}\right)}{\frac{UCS}{eff} - \frac{WOB}{A_{bit}}} \quad (3)$$

where A_{bit} is the bit diameter, μ is the coefficient of friction between the drill string and formation, converting applied WOB to torque, and (*eff*) is the efficiency of transmitting the rock destruction power of the drilling rig to the rock. The concept of MSE is still applicable in the industry till today and it can be used to predict drilling performance efficiently by calculating the transferred and the wasted mechanical energy [12]. It has been shown before [13] that the use of a model utilizing equations (1) and (2) gives the same results for the rate of penetration, as does the application of Teale's equation of MSE (equation 3).

Drilling data analysis is an essential factor in applying the drilling simulator concept for drilling optimization. A simulator can only recreate the actual well by 'knowing' that drilling issues occurred or there was poor bit performance prior to the simulation of the given intervals. The user needs to identify areas where optimization is needed to improve performance and then import the required data for simulation in order to recreate the drilling environment and start the simulation with the objective of improving performance.

The simulator used in this paper utilizes equations (1) & (2) and allows the user to create the bottom hole assembly (BHA), select a drilling fluid with specified density and rheological properties for different sections of the drilling process and to select the bit from provided lists with varying features [7, 10, 13]. Rock strength, needed in equation (2) is estimated as a function of the rock properties of the drilled layer. Information about bit type and the utilization of the values of the drilling parameters are all converted to a rate of penetration, which is then matched to actual data from a drilled well. As the whole model and simulator are set up, it can be used as an exercise for students or professionals to become familiar with detection and prevention principles for several drilling issues. Similarly, by matching the actual drilling

data, optimized values of drilling parameters can then be derived and applied in the drilling campaign for a future nearby well.

From the hydraulics point of view, the Herschel-Bulkley model is used to determine the rheological parameters needed for calculating the pressure losses along the drill string and annulus. The flow rate and mud type can be changed from the main panel and fluid properties from the mud editor. Thus the resulted output is the standpipe pressure (SPP) and the horsepower (HP) that is required from the surface pump.

Rock Properties

Formation strength is needed, as per equations (2) and (3). Such values can be estimated either from uniaxial compression tests on rock samples (if exist) or from sonic velocity data logged onsite. Several empirical equations were published in the past which correlate sonic velocity or p-wave velocity with formation strength for different rock types. Table 1 gives information regarding such proposed correlations of UCS prediction from p-wave velocity for different rock types.

Table 1: Correlation of UCS with p-wave velocities (Δt is sonic transit time ($\mu\text{s}/\text{ft}$))

Reference	Location	Rock Type	Equation	UCS
[14]	Ahwaz field, Iran	Carbonate	$UCS = 570,808 \exp^{-(0.031\Delta t)}$	MPa
[15]	Pennsylvania	Sandstone	$UCS = 212,000 \exp^{-(0.043\Delta t)}$	psi
[16]	Australia	Coal	$UCS = 143,000 \exp^{-(0.035\Delta t)}$	psi
[15]	West Virginia	Coal	$UCS = 468,000 \exp^{-(0.054\Delta t)}$	psi
[17]	North Sea	Tertiary Shales	$UCS = 0.77(304.8 / \Delta t)^{2.93}$	MPa
[18]	Bowen Basin, Australia	Fine-grained, consolidated and unconsolidated sandstones	$UCS = 1200 \exp^{-(0.036\Delta t)}$	MPa

In order to fully simulate the wellbore environment for the drilling application and perform optimization, one needs to describe the various formations to be drilled. This can be done with a lithology editor. In the editor, one provides information about the thickness of the layer (ft), the formation type and strength, and the pore and fracture pressure as the main components. An example of such an editor is shown in Figure 1.

Layer #	Layer Depth	Layer Thickness	Rock Type	Rock Strength	Rock Abrasivity	Pore Press.	Frac. Grad.	Log Por.	Log Res.	Log Gamma	Fluid Type
1	0.0	600.0	Shale	7.0	10.0	9.00	12.00	22.0	4.00	35.0	-
2	600.0	50.0	Sand Soft	2.0	10.0	9.00	12.00	25.0	1.00	5.0	Water
3	650.0	50.0	Shale	7.0	10.0	8.00	12.00	25.0	1.00	5.0	-
4	700.0	100.0	Sand Soft	8.0	10.0	8.00	12.00	25.0	1.00	5.0	Water
5	800.0	20.0	Shale	6.0	10.0	8.00	12.00	25.0	1.00	5.0	-
6	820.0	50.0	Limestone	10.0	10.0	8.00	12.00	25.0	1.00	5.0	Water
7	870.0	100.0	Shale	7.0	10.0	11.00	12.00	25.0	1.00	5.0	-
8	970.0	75.0	Sand Soft	6.0	10.0	11.00	12.00	25.0	1.00	5.0	Water
9	1,045.0	50.0	Shale	7.0	10.0	11.00	12.00	25.0	1.00	5.0	-
10	1,095.0	20.0	Gypsum	7.0	10.0	10.00	11.00	25.0	1.00	5.0	-
11	1,115.0	100.0	Shale	6.0	10.0	10.00	11.97	25.0	1.00	5.0	-
12	1,215.0	70.0	Dolomite	12.0	10.0	10.00	12.00	25.0	1.00	5.0	Water
13	1,285.0	50.0	Salt	5.0	5.0	10.00	12.00	25.0	1.00	5.0	-
14	1,335.0	20.0	Anhydrite	10.0	10.0	10.00	12.00	25.0	1.00	5.0	-
15	1,355.0	30.0	Sand Soft	6.0	10.0	10.00	12.00	25.0	1.00	5.0	Water

Layers: 21, Total Depth: 2,315.0

Buttons: New Layer Above, New Layer Below, Delete Layer, Edit Layer, Edit Surface

Figure 1: Lithology editor example with general data

For the current well, rock type, layer thickness, rock strength pore and fracture pressure were input in the editor. Rock abrasivity can be modeled accordingly to account for the abrasion of the drill bit [10], but

additional data are required regarding bit condition and thus abrasivity was not taken into account for the current simulation. Logging data (porosity, resistivity and gamma-ray) can be used for an overall visualization of the drilled formations and for building a database for the drilling of a next nearby well.

Directional Drilling Principal

A common practice to control the direction of the drill bit is with the use of a downhole mud motor, which provides control of the drill bit direction in combination with increasing drilling performance due to the additional rotations at the drill bit. The driller has to continually change from rotating to the sliding mode by adjusting the top drive (TD) rotations to zero. Successful simulation of rotating and sliding mode can be identified by matching the original survey data and rate of penetration. The trajectory can be controlled by changing the motor RPM and orientation (tool face). The simulator is using the exact same principle by allowing the user to create a BHA that contains a downhole motor and by specifying the building tendency (degrees/100 ft). The focus of this paper lies in the capabilities of testing the simulator in direction wells.

Drilling Optimization in Vertical and Directional Wells

Drilling optimization is the process by which engineers aim to increase the rate of penetration in combination with extending the bit life by reducing bit wear. From the optimization point of view, the initial step is to analyze all the data, including hook load and standpipe pressure, in order to detect and avoid problems that occurred in specific intervals (e.g. loss of circulation). The second step is to calculate the mechanical specific energy (MSE) until the target depth (2100 ft). MSE is the energy that is required to break or remove a volume of rock [11]. Equation 4 shows the parameters that are essential for the calculation of MSE [19, 20]:

$$MSE_{surface} = \frac{4(WOB)}{(D^2)(\pi)} + \frac{480(Tor_{surface})(RPM_{motor} + RPM_{surface})}{(D^2)(ROP)} \quad (4)$$

where, ($Tor_{surface}$) is the surface torque (ft-lbf) and RPM_{motor} can be calculated by knowing the flow rate and the motor flow factor q (rpm/gal). The first part of equation (4) is stems from the axial force applied to the bit and the second is accounts for the rotational motion of the bit. The downhole MSE can be calculated as in (5) [20, 21]:

$$MSE_{downhole} = \frac{4(WOB)}{(D^2)(\pi)} + \frac{480(Tor_{motor})(RPM_{motor} + RPM_{surface})}{(D^2)(ROP)} \quad (5)$$

The difference between surface and downhole MSE is the energy that is due to the drill string rotation which has to be removed to obtain a corrected MSE estimate. We assume the downhole torque is the same as the bit torque because the bit is connected on the end of the rotor shaft. While in sliding mode, the surface torque decreases to zero, and as a result, only downhole torque gives values of MSE. Torque (Tor_{motor}) on the motor (ft-lbf) can be estimated by knowing the differential pressure Δp_{motor} (psi) and torque factor (Tor_{factor} , ft-lbf/psi), which can be extracted from the motor performance graph:

$$Tor_{motor} = Tor_{factor}(\Delta p_{motor}) \quad (6)$$

Case Study

The 12.25-in. well is a directional S-Shape from the surface to a depth of 2129 ft. A positive

displacement 9 5/8-in. motor (PDM) with 1.50° bent housing was used to allow the direction control of the drill string and build an angle of approximately 16° before dropping and reaching the target depth, as is shown in Figure 2. In Figure 3, the drilling data is shown. While drilling in sliding mode, the surface torque is zero, but in reality, the downhole torque still exists (Figure 3). A single PDC bit was used from the surface to 2100 ft with seven nozzles of 12/32 in. size. After reaching the target depth, the dull grading of the bit indicate that the worn cutters were located in the nose of the bit. After the section was drilled, a 9 5/8 in. casing was Run in Hole (RIH) and cemented to surface.

Figure 2: Actual well trajectory obtained from the initial simulation of the current well

Lithology data were available from the current well, an offset well and an offset field. The data were at every one ft, but the various intervals were following similar trends of rotating and sliding mode, which was approximately 20-30 ft. This road map gives an excellent resolution of the data in combination with a proper simulation. The drilled section consists of variations of shale and limestone with several intervals that might have possible loss circulation. The drilling fluid that was used was clear water of 8.4 ppg density.

Source drilling data can have very low or high variations due to lithology changes or vibrations, and thus create a challenge for the analysis team. Performing a simulation with a resolution of 1 ft is not recommended because it requires a significant amount of time. Since the rotating and sliding mode were varying from drilling a 20 to 30 ft interval, the final simulation resolution was according to the drilling mode. The user has to average the values of drilling parameters (WOB, RPM, etc.) as he/she has defined the intervals. For instance, if the drilled interval is 20 ft, then the WOB will be averaged for those 20 ft. A smooth mean average (SMA) was applied every 10 ft in order to identify trends in the data and allow better visualization, as Figure 3 shows.

Figure 3 also provides information regarding the drilling mode. To distinguish between the rotating and sliding mode, the surface RPM and torque measurements were used as a benchmark. When top drive (TD) rotations or torque is equal to zero, only the downhole motor is providing rotation to the bit. The downhole RPM was calculated from the specifications of the motor, which can provide 0.22 RPM/gallon.

Figure 3: Actual drilling data and calculated bit torque and bit RPM

The rate of penetration was generally high and without significant variations across the entire section. This could also be an indication that the strength of the drilled formations is typically low as expected at a depth of 2000 ft. A decrease in ROP can be observed from 1100 to 1600 ft and then an increase until target depth.

Unfortunately, sonic log data were not available for the current well. In order to have an estimation of formation strength, offset field data were taken into consideration. Due to the fact that the ROP across the entire section is high, an assumption was made that UCS is low. This assumption can be removed if actual data is available. The empirical equations that were used for limestone and shale formations are those (7) and (8) [14, 17]:

$$UCS = 570,808 \exp^{-(0.031\Delta t)} \quad (7)$$

$$UCS = 0.77(304.8 / \Delta t)^{2.93} \quad (8)$$

Drilling Data Assessment and Identified Problems

While drilling, several problems and challenges can be encountered. It is a crucial step to identify the intervals and avoid these sections for the optimization process. For the current case study, there were some problematic intervals, as illustrated in Figure 4. It can be seen that at around 1200 ft there was a sudden decrease in the standpipe pressure, even though the flow rate was constant. Also, at around 1750 ft an increase of the standpipe pressure was noticed.

Figure 4: Original hydraulic drilling data after 800 ft depth

Considering also the data of Figure 5, it can be seen that at the same depth, there was a sudden increase in hook load, which can be combined with the decrease of the standpipe pressure. Taking also into account the Daily Drilling Operation Reports (DDOR), it can be said that in this section, there was probably loss circulation. The hook load is increasing because the hydrostatic column is decreasing, also affecting the standpipe pressure.

Figure 5: Original drilling data

The surface torque in the latest part of the section was around 10 ft-klbf, with fluctuations going up to 12 ft-klbf. Those variations were probably partly due to the higher decrease of inclination reaching the vertical point by causing greater contact area with the lower part of the wellbore and partly due to the higher torque that was produced from the bit.

Results and Discussions

The main adjustment factor of the drilling model in order to fine-tune the ROP is the ROP_factor, in which the user can vary over a specific range of values in order to do the matching of ROP. The surface and the downhole RPM were also changed as required to emulate the rotating and sliding mode.

Figure 6 shows the results of the ROP matching process using the simulator for the entire drilled interval. Changes in the drilling parameters were followed as per field data. It should be mentioned that the lithology was varying over depths ranging from 5 ft to 50 ft. During the simulation, as it is in actual drilling, the values of drilling parameters are oscillating due to vibrations and lithology changes. The drill bit rotations were varying between 270 for rotating mode and 210 for sliding mode.

The simulated ROP matched the actual ROP data very well. This was achieved with ROP_factor values varying over a small range between 1 and 10 in order to match with the actual ROP, indicating the accuracy of the approach, as it was shown in prior cases as well [5, 7]. There is little discrepancy between predicted and actual ROP (at around 750 and 1100 ft), but this could easily be alleviated with further adjustment of ROP_factor if needed. This good matching with the original data is essential for the optimization process, as will be shown below.

Figure 6: Actual and simulated ROP with the respected ROP_factor

Drilling Optimization

The optimization process can be considered from different perspectives. Depending on the interval of interest and the problems/issues that occurred, the engineering team can optimize the process accordingly. For the current case study, the optimization procedure is focusing on the increase of ROP.

During the optimization process, several limitations have to be considered. Hole-cleaning or generally, the hydraulic system was very efficiently optimized. That also concludes that the downhole RPM can't be changed more since it is related to the flow rates and the capabilities of the mud pumps. This leaves us with three parameters to change for optimization; weight on bit, nozzle configuration on the drill bit and surface RPM.

We will focus on the interval of 750 to 2129 ft. From the DDOR, useful data such as the torque-off bottom, loss of circulation intervals, and other information were extracted in order to assist in the optimization process.

A critical analysis was done to identify the intervals that the drill bit performance was reduced and to

detect the drilling mode. As it was shown previously in Figure 6 and 7, the deeper part of the well, which is shale, generally has higher ROP than the upper layer.

The depth of cut (DOC) for the majority of the intervals is around 10 mm. A sudden increase of DOC, which can be seen at around 750 ft (Figure 7), is an indication of very low strength rock. At that particular point, both surface and downhole MSE drop significantly, which indicates that the formation strength is very low and it doesn't require much energy to remove that rock volume. At 660 ft, the rapid increase of ROP can be correlated with the lithology changes until 830 ft. In the final section, at around 1700 ft a rapid increase of torque and MSE can be observed even though a similar weight on bit is applied.

Figure 7: The graph shows the estimated Mechanical Specific Energy together with relevant drilling parameters

Weight on bit and rate of penetration data were analyzed separately with regards to the drilling mode, when rotating or sliding and are shown in Figure 8. This approach can provide more insightful information for the optimization process. Data analysis showed that the standard deviation of WOB in rotating mode was 3.63 klbf with a coefficient of variation 24.62%, which is less than in the sliding mode of 4.84 klbf and coefficient of variation 33.33%. This indicates that weight on bit values for rotating mode is not as erratic as in sliding mode. Similarly, the standard deviation of the ROP in rotating mode was 140.31 ft/hr with a coefficient of variation 33.77%, and 167.86 ft/hr with a coefficient of variation 54.36% for sliding mode.

It can be observed that at around 1200 ft, WOB has a decreasing trend for either mode, which has as a result, a further reduction of the rate of penetration. The initiation of dropping angle was at 1270 ft, which is the interval that the weight on bit for both modes is decreasing compared with the upper section.

Figure 8: Statistical analysis for WOB and ROP data. The error bars are calculated based on standard deviation and mean value

In principle, during the rotating mode, higher weight on the bit can be transferred to the bit since less drag forces are acting on the drill string [22] and this can be clearly seen in Figure 8, except for the interval 925 – 1110 ft, where WOB that was applied in rotating mode was significantly less rather in sliding, which gives a window of improvement. The ROP trend for both drilling modes shows a gradual decrease from 800 until 1500 ft. At 1200 ft, the drilled formation is shale until 1770 ft.

We choose the optimized values of the drilling parameters from the analysis of the combination of the values of all drilling parameters and MSE. Current flow rate values are efficient in order to transport the cuttings effectively to surface and provide high Hydraulics Horse Power per area (5 to 6.41 HSI) on the bit. Surface rotations cannot increase further since the drill bit RPM, including mud motor rotation, is up to 280 RPM. Thus the optimum parameter that can be optimized is the WOB. As it was mentioned, the increase of WOB should be only at specific intervals, in which the value of ROP is lower compared to the other sections.

We choose a weight on bit increase of 2 to 4 klbf applied for the rotating and 1 to 2 klbf for sliding drilling mode for re-drilling the interval from 925 to 1150 ft. For the part of the section which starts at 1200 ft, the rotating intervals that have WOB of 11 klbf will be increased by 4 klbf and for the sliding mode by 2 klbf. These changes on WOB and its effect on ROP are shown in Figure 9 for the rotating mode and in Figure 10 for the sliding mode. The concept of choosing the increased values of WOB was conducted with the statistical analysis of the mean value and standard deviation in combination with a realistic approach. A high increase of WOB was avoided since it can result in motor stall [23].

Figure 9: Optimization process with increase of WOB for specific intervals during rotating mode

Figure 10: Optimization process with an increase of WOB for specific intervals during sliding mode

It is important to emphasize that the drilling process could only be optimized if the simulator is fine-tuned with the original data, which was done for this case study, as it was demonstrated above (Figure 6 and 7). As it was stated regarding the section with a sudden increase in ROP, which is related to the increase of DOC, the simulator cannot capture that specific interval since the physical reason behind that isn't clear and hence, not simulated.

It can be observed from Figures 9 and 10, that the rate of penetration shows an average increase of 19.14% for rotating and 17.51% for sliding mode, respectively. A significant increase was noted while drilling in the rotating mode in the interval between 1268 ft and 1513 ft, in which the WOB was the lowest

in the entire section, and thus, the optimization had a more substantial impact. The saved drilling time is approximately 30 min for the entire section, as it is illustrated in Figure 11.

Figure 11: Comparison of drilling time using original data with drilling time using the optimized data. In the computation of drilling time, non-productive time (connections) was not taken into account

Conclusions

It is possible to simulate the drilling process using rig operational data and an appropriate drilling model. Re-creating the actual drilling environment is an essential part of any simulation in order to simulate and optimize drilling performance.

With extensive data analysis, questions can be answered regarding the capabilities of the drilling simulator to be fine-tuned with actual drilling data. ROP has been matched very well for this case study of drilling a directional well, which shows that the simulator models have sound physical grounds even for directional drilling.

Rate of Penetration was already very high in the entire section for the studied well, which narrows the optimization opportunity window. The results of the optimization process, which were limited to increasing WOB as the other drilling parameter values seemed to be optimal, show an average increase in ROP of 19.14% for rotating and 17.51% for sliding mode. By optimizing only specific intervals in which the WOB was lower than the optimal WOB value, it saved approximately 30 minutes. This re-affirms the good drilling practices utilized in this well.

By recreating the drilling environment, the simulation allows the optimization of directional wells by constantly switching between rotating and sliding modes. In this case study, the user is provided with optimized values for WOB for both drilling modes but also for vertical sections. The simulator can be used as a tool to assess opportunities for drilling optimization, which in this case study seems to be quite limited.

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