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Optimization of Drilling Parameters with Aid of Real Time Data for Buzurgan Oil Field

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Abstract: This paper showed how real-time data that obtained during drilling operation can be used for optimizing drilling parameter such as weight on bit (WOB), and rotary speed (RPM) in term of drilling cost per foot. The real-time data that obtained from mud logging unit included the rate of penetration (ROP), WOB, RPM, depth …. etc. In this work, the real-time data obtained from Buzurgan oil well (BU-50) were used for drilling optimization. Rock strength for each drilling foot of section obtained from a sonic log, using SPSS (Statistics) software to calculate it correction factors a,b, and c for Mishrif formation and apply nonlinear regression method after that make drill behind for validation purpose. Finally, the optimal drilling parameters were estimated with the cost model. Based on the results obtained, a good agreement achieved between results of rate of penetration that obtained from drilling model and actual penetration rate along the drilling section. Also, cost analysis shows that the optimal weight on bit and rotary speed for drilling that section are 18 klb and 116 rpm respectively which achieves a minimum cost per foot.

1. Introduction
The drilling is one of the most expensive operations in exploration well and development well for oil and gas field. More than (25 – 35 %) of total development costs, is the cost of drilling operation[1]. In addition, exploration in extreme environment, complex well designs, deeper well, and environmental pressure lead to more increase in drilling costs. In a most drilling operation, rotating on time has less than half of the total find spent on drilling well. Thus, optimizing of drilling velocity leads to more reduction in the total drilling component cost like daily rig rate and fuel consumption [2]. Generally, drilling optimization is the application of technology that yields a decrease of drilling prices related to drill the well, also there are a different definition of drilling optimization: “is Optimized drilling techniques have considerably reduced drilling price. Results indicate that higher knowledge, additional expertise, and confidence can end in great savings within the future [3]. The process involves the post-appraisal of offset well record to calculate the costs effectiveness of choice control variables.

To understand optimization drilling operations should know all drilling variable which effects on drilling cost. The drilling parameters such as rotary speed (RPM), weight on bit, pump parameters, the rate of penetration (ROP), fluid properties, inclination and azimuth, depth and torque[4]
2. Real Time Data
The data which obtained from the previous well are very necessary for optimization operation where all drilling model work on data acquisition from old drilling well. Advanced computer technologies are working on storing a lot of data, and calculate difficult problems. From the beginning, all companies seek to reduce the cost of drilling by increasing weight on bit and rotary speed[5].

3. PDC Bit Model
The PDC bit model is created depending on design comprehensive for the cutter of PDC bit in (1994). The equation of rate of penetration for PDC bit some times utilized to determine confined compressive strength for rock[6].

Also, there is simple form derived from the same model and modified in (2008) for predicting the rate of penetration (ROP) for the polycrystalline diamond compact bit (PDC) that take in consider dealings between the rock strength and cutters, wear of bit, and lithology. New parameters are presented for the equivalent bit radius, lithology coefficients, dynamic cutter action, and cutter wear[7] as illustrated below:

\[
ROP = W_f \frac{14.14 \times \text{WOB} \times \text{RPM} \times \cos(\alpha)}{S \times d_b \times \tan(\theta) + f_c(P_e)} \times \frac{a}{\text{RPM}^b \times \text{WOB}^c}
\]  

(1)

Where:
- \(S\): Confined compressive strength, psi
- \(\text{WOB}\): Weight on bit, lbf
- \(d_b\): Bit diameter, in.
- \(\theta\): PDC cutter back rake angle, degrees
- \(\alpha\): PDC side rake angle
- \(\text{RPM}\): Rotary speed
- \(W_f\): Wear function, dimensionless
- \(f_c(P_e)\): Chip hold down function, dimensionless.
- \(a, b, c\): Correction factors for cutter geometry

The values of correction factors\((a, b, \text{ and } c)\) were determined in laboratory or information apply nonlinear regression on drill-off tests data for each formation. \(f_c(P_e)\) function is an estimate of the resultant forces on-chip when it is generated by the bit. The correlation for estimating this \(f_c(P_e)\) function as follows[8]:

\[
f_c(P_e) = C_c + a_c(P_e - 120)^{bc}
\]  

(2)

Where \(P_e\) is the difference between hydrostatic mud pressure and pore pressure (in psi) as follows:

\[
P_e = P_{hy} - P_p
\]  

(3)

Where \(P_p\) is the pore pressure in psi.

Bit wear function \((W_f)\) is the effect of bit wear on the rate of penetration. Eqs. (4) and (5) are used for determining wear of bit in term of RPM, WOB, confined rock strength and abrasiveness of rock as follows:

\[
\Delta BG = W_f \sum_{i=1}^{n} WOB_i \cdot RPM_i \cdot A_{ABRI} \cdot S_i
\]  

(4)

\[
W_f = 1 - \frac{\Delta BG}{8}
\]  

(5)

Where
- \(\Delta BG\): the change in the bit tooth wear, dimensionless.
4. Rock Strength

Rock strength value along the drilled wellbore is very important. This value is important when detection the safe drilling fluid window for determining the stability of the well, choosing mud weights and designing casing program, and for completion and stimulation purposes. Assessment of rock strength along the wellbore could be achieved by well logs, mechanical rock tests, and from drilling data.

In drilling operations, the rock strength of drilled formation has a major impact on the velocity of drilling. Its well known from field practice that as the compressive strength of rocks increases with depth, the rate of penetration decreased which leads to an increase in cost per foot[9].

In normal drilling situations, the drill bit is operated at a condition where the mud hydrostatic pressure is greater than formation pressure(overbalance drilling). This means that there is confined pressure on the drilled formations. Thus, the compressive strength derived from drilling models is confined compressive strength (CCS). Unconfined compressive strength (UCS) is another measurement of rock strength but without applying confining pressure. In order to relate these two rock strength parameters, an empirical expression was formulated as a function of effective differential pressure as follows[10].

\[
S = S_0\left(1 + a_sp_e^{b_s}\right)
\]  

(6)

\(S_0\) : (CCS) in MPa, \(S_o\) : (UCS) in MPa, \(P_e\) different between hydrostatic and pore pressure, \(a_s, b_s\)are fitting constants. The permeability coefficients for chip hold down are show in table (1).

| Coefficients | Permeable formations | Impermeable formations |
|--------------|----------------------|------------------------|
| \(P_e\)     | \(P_{by}-P_p\)       | \(P_{by}\)             |
| \(a_s\)     | 0.00497              | 0.0141                 |
| \(b_s\)     | 0.757                | 0.470                  |
| \(c_s\)     | 0.103                | 0.569                  |
| \(a_0\)     | 0.0133               | 0.00432                |
| \(b_0\)     | 0.577                | 0.782                  |

4.1. Calculation of rock strength from sonic log

The usage of sonic velocity log for calculates rock elastic properties are good established. At present, there are many correlations between sonic travel time and rock strength or a grouping of different logs[11]. The rock strength depends mainly on lithology, so the rock strength was high for low porosity rock or low traveling time. The equation used in this study is shown below[12].

\[
S_{os} = \left(\frac{1}{k_1(\Delta t_c-k_2)^2} + 2\right) \times \frac{1}{145.08}
\]  

(7)

Where

\(\Delta t_c\) : time of traveling, msec/ft.

\(S_{os}\) : unconfined compressive strength (UCS), mpa.

\(k_1, k_2\) are constants obtaind from table(2)
Table 2. values of $k_1$, $k_2$ constant

|   |   |
|---|---|
| $K_1$ | $5.15 \times 10^{-8}$ |
| $K_2$ | 23 |

5. Calculation of Drilled cost per foot
The calculation of cost per foot is done by the conventional cost equation as follows:[13]

$$COST = \frac{cost_{Rig}(T_{Rotating} + T_{Tripping}) + cost_{bit}}{footage~drilling}$$ (8)

Where
- $T_{Rotating}$: Rotating time, hr
- $T_{Tripping}$: Tripping time, hr

$$T_{Tripping} = (D_1 + D_2) \left(\frac{0.75 hr}{1000 ft}\right)$$ (9)

$$T_{Rotating} = \sum_{i=1}^{n} \frac{\Delta D_i}{ROP_i}$$ (10)

D1: depth in, D2: depth out, $\Delta D_i$: drilling depth.

6. Workflow of study
The work planner summary that will be used during this study is shown in the figure (1). This figure is described all the steps that will take place during this research.

6.1 Filtration of sonic and drilling parameter Data
This is the first step of this process. The data of transition from the travel time of references well formation are filtered and averaged for every ten meters because of there high quality. Also, the measured drilling parameters such as rate of penetration, weight on bit and rotary speed that recorded in mud log were subjected to the same proceeding procedure in order to apply the model. The implementation of this procedure was an aid with the Microsoft Excel program.

6.2 Calculation of formation strength for reference well (BU-50)
The second step of this process is to calculate the formation strength of drilled formations in the reference well (BU-50). The unconfined compressive rock strength (UCS) was generated from sonic traveling time measurements. While confined compressive rock strength (CCS) was created from calculated (UCS) by depending on over balance pressure value (100-300 psi) that was used during drilling this formation. The rock strength values were used in drilling model calculation while drilling the measured formation is the confined strength. These strengths represented resistant to the bit penetration during drilling and can be used in drilling simulation and bit selection. This lead to produced unconfined and confined formation strength for reference well (BU-50) along formations for each meter. Figure (2) presents the calculated UCS & CCS for Mshrif formation of well (BU-50).
Figure 1. Workflow of study

Figure 2. Unconfined and confined rock strength from sonic logs for mishrif formation of (BU-50) well.
6.3 Calculation of bit correction factors (a, b, c)

The third step of this process is to calculate bit correction factors a, b and c. As mentioned above, this correction factor was calculated for each drilled formations in the reference well in order to accounts for many effects that are not considered in the theoretical modeling of the penetration rate model. In addition, these correction factors will be the same for particular PDC bit, with a particular geometry, and specific type lithology.

Table (3) shows the calculated bit correction factors values by applying the nonlinear regression method. Real-time data of mud log (ROP, weight on bit, rotary speed) for mishrif formations are fed into SPSS (Statistics) software and apply nonlinear regression method. This bit correction factor values will be used for the same PDC in the future drilling for the same formation. In addition, the value of bit wear coefficient is calculated by using drilling parameter and rock strength.

| Formation | a    | b    | C    | Wc      |
|-----------|------|------|------|---------|
| Mishrif   | 317  | 0.04 | 0.46 | 3.2E-11 |

6.4 Validation of drilling simulation (Drill-behind procedure)

The objective of the drill-behind procedure is to check the accuracy of the results calculated from the sonic log model and bit correction factors used in this study. This process uses the unconfined compressive rock strength which is generated from reference well (BU-50) to calculate the rate of penetration for another well (in this study we use well BU-47) for Mishrif formation, and comparing with actual ROP of this well.

First, the unconfined compressive rock strength for well (BU-50) for Mishrif formation which is calculated from necessary data in past step converted to confined compressive strength according to hydrostatic and pore pressure for (BU-47) well, where the top of Mishrif formation in well (BU-50) matched to the top of the same formation in well (BU-47). The results of this step for Mishrif formation are shown in figure 3.

As illustrated in figure (3), there is very good match between the rate of penetration which calculated from the model in well (BU-47) using rock strength that generated from reference well (BU-50) and the actual value of penetration rate which acquisition from drilling recorder for (BU-47), the value of matching is 94%.
Optimization of weight on bit and rotary speed

Optimization is the procedure to find the optimum drilling parameter which gives a maximum rate of penetration or minimum cost. Now we will find the optimum weight on bit and rotary speed. The first step will express a relationship between weight on bit and rotary speed with cost when all drilling parameters are constant. Figure (4) shows the relationship between WOB (klb), RPM, and cost ($/ft) for Mishrif formation in Buzargan oil field.

![Figure 4. Relationship between WOB (klb), RPM, and cost ($/ft) for Mishrif formation.](image-url)
It is noticed that the cost of drilling decreases as the weight on bit and rotary speed increase and the optimum drilling when the WOB and RPM are in maximum value through the parameter bounds for bit manufacture. The rate of penetration as discussed above decreases when WOB and RPM decrease, then the cost per foot increases.

Finally, In this study, it can be trying to reduce the cost of drilling by increasing the rate of penetration during drilling formation. After modelling the equations on the real-time data by using Microsoft Excel program, the aim of the work is to increase the rate of penetration by making all drilling parameters constant and change the values of weight on bit(WOB) and rotary speed(RPM) until high rate of penetration and less cost of drilling ($/ft)are achieved. These values of Weight on bit(WOB) and rotary speed(RPM) which give good results will assume the optimum drilling parameters. The results in a table (4) show the optimum values of weight on bit and rotary speed which causes higher ROP and lower cost per foot of mishrif formation in comparison with actual data.

| Table 4. Result optimization of drilling parameter for Mishrif formation in well(BU-50) |
| Formation | Parameters | WOB (klb) | RPM | ROP (ft/h) | Cost ($/ft) |
|-----------|-----------|-----------|-----|------------|-------------|
| Mishrif   | Actual    | 14        | 104 | 23         | 77.7        |
|           | Optimization | 18        | 116 | 27         | 70          |
|           | Saving    |           |     |            | 7.7         |

7. Conclusion:
This study presented a methodical approach to optimize drilling parameters for Mishrif formations from Buzargan oil field utilizing real-time data for two wells. The following conclusions of result include:
1- The results of unconfined and confined compressive strength of reference that generated from the sonic log for Mishrif formations increase with depth.
2- Applying the rate of penetration model on data using rock strength, which obtained from reference well for each formation in order to find optimum operational parameters during the wells in Buzargan oil field.
3- The results which obtained from optimization operational parameter, rotary speed and weight on bit for Mishrif formation, could potentially reduce the cost drilling by 7.7$/ft.
4- Analysis of the drilling parameters showed that an increase in WOB and RPM value led to a decrease in cost per foot.

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