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Implementation Drilling with Casing ROP Optimization with Multi Regression Mathematical Model in KHALDA co. Fields in the Western Desert, Egypt

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Abstract

Casing While Drilling (CWD) technique allows the operator to simultaneously drill and case a wellbore section in only one run without the necessity to pull the drill string out of the hole. This innovative technology comes into play in a time when oil and gas well drilling faces a lot of challenges such as excessive lost circulation, formation fluid influx, formation instability, etc. CWD is implemented into today's drilling activities in order to safely and economically deal with these obstructive challenges. In addition to eliminating/minimizing the effects of these challenges, it remarkably improves the entire economics of the drilling project. Researches and developments are continuously on their way to further improve the performance of the technique in order to minimize its limitations. A lot of case studies all over the world have been analyzed and their related practical lessons have been stated. Based on this paper is about evaluating the drilling with casing ROP optimization model of the drilling parameters to surface hole section drilling of vertical wells by a statistical-regression model using the linear equation analysis technique. The model will be evaluated by deriving the unknown proportionality constant and five exponents utilizing the statistical - regression curve of the least-squares fitting method. The prepared field data used from (ASCII) drilling parameters to three drilled wells in two fields (X, Y) in KHALDA Company. Then, the model's equation will be a regression with respect to five of the independent parameters which are a weight on bit (WOB), drill string rotation (RPM), standpipe pressure (SPP), torque, impact force (IF) and rate of penetration (ROP). Then it will be evaluated over a range of values for these parameters. The parametric study presents KHALDA two field data based on ROP model development and testing with near and far way field wells. Two different modeling approaches have been implemented, and their application and limitations have been tested. ROP optimization procedures are also developed with the objective of increasing ROP, reducing drilling time and hence reducing drilling costs. By Integrated model for the field data, we can compromise with a new well in the different location taking into account any deviation in geological lithology or depth, etc. will make a change in the predicted data then we can predicate the percentage of success according to the optimization of the drilling parameters and best practices to drilling team. Finally, it is recommended that the model can be applied in the oil well drilling industry in different oil wells fields rather than the vertical wells used in this paper.

Keywords: *Drilling with Casing (DwC); KHALDA Field; Multi Regression; Mathematical model; API; HAZID; ASCII; weight on bit; drill string rotation; standpipe pressure; torque, impact force; and rate of penetration.*

1. Introduction

The fields (X, Y) located onshore in KHALDA Co. in the Western desert of Egypt, encountered major challenges in both drilling and cased off problematic zone during running casing due to severe lost circulation conditions. Specifically, severe mud losses in the major loss zone recorded in MOGHRA formation. The operator has experienced massive loss problems while drilling the 12-1/4-inch section. Unsuccessful operations with conventional drilling techniques have urged the operator to look for alternative drilling methods to the case of the massive thief zone. The (DwC) system has been identified as one drilling technique that may repair the troublesome thief zone. This is a non-retrievable system, which utilizes casing as a drill string.

This is a developing of (DwC) well drilled and using the well data of pre-drilled wells helps for obtaining the drilling optimization parameters by reducing cost and time of drilling. The process of analyzing the drilling parameters and factors from previous experiences makes the drilling process faster and efficient when drilling in the same geology Colum. The methods to be implemented by estimating model fitting parameters from old drilling with casing well called a (Reference well). Applying these parameters for another drilling with casing wells to predict the ROP by using the optimum drilling parameter coefficients. The predicted ROP profiles will be compared with the collected profiles. The ROP model is based on applying the techniques of multiple regression methods on the collected drilling data. The model is improved by simulated drilling parameters to achieve more ROP values and reflected to cost reduction [1]. Using the modelling method Fig. 1, and the ROP model is developed from the reference well data based on two hypotheses:

For **hypothesis** I, For hypothesis II. For **hypothesis** I, the ROP model is developed based on MOGHARA formation in the surface section of the reference well, which is Well #2 in field X in KHALDA company.

For hypothesis II, the ROP model is developed based on DABAA formation in the surface section of the reference well, which is Well #2 in (field -X) in KHALDA company. For verification, the models are tested on nearby, and far wells. They are first tested locally. On one nearby well in the same block (Well # 4) and on one far well in another block in the faraway field (i.e. Wells #6 in (field -Y).

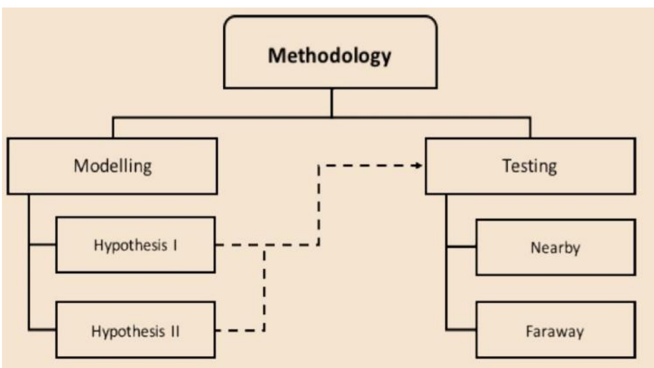

Fig. 1. Structure and methodology of the ROP model [3]

For hypothesis II, the ROP model is developed based on DABAA formation in the surface section of the reference well, which is Well #2 in (field -X) in KHALDA company. For verification, the models are tested on nearby, and far wells. They are first tested locally. On one nearby well in the same block (Well # 4) and on one far well in another block in the faraway field (i.e. Wells #6 in (field -Y).

Factors affecting ROP in drilling with casing:

The drilling parameters affecting on ROP are shown as follow:

- The casing design and seating depth selection;
- Bit optimization (formation hardness);
- The hydraulic drilling parameters such as (flow rate (GPM), surface pump pressure (SPP) and jet impact force);
- The mechanical drilling parameters such as (weight on a bit (WOB), torque and drag, revolution per min (RPM), and bit types),

2. ROP calculation with multiple regression workflow

The analysis is done for the drilling with the casing surface hole section (e.g. the 12 1/4" hole section). The data used in multiple regression analyses are in the form WOB, Torque, RPM, SSP, and calculated jet impact force (IF), together with the observation factor ROP. A parametric sensitivity analysis is performed later in this formula to find out which parameters have a greater impact on the ROP model. The model can control these parameters if it is proven to affect the ROP. The implementation of this method using Microsoft Excel software is presented in Fig. 5 to give a better explanation. The regression data analysis is first performed as described above, the (b) range represents the ROP, while (b) range is the remaining data. The depth, on the other hand, is only included as a reference and is not included in the analysis. The coefficients, which is the area of interest, are provided by the analysis. The intercept value is represented by the initial value of coefficients (b0). The other coefficients (b1−5) are multiplied according to the order with the regression variables (b1−5). Eq. (1) is used to model the ROP:-

$$Y = b0 + b1X1 + b2X2 + b3X3 + b4X4 + b5X5 \tag{1}$$

Equation (1) can also be written in terms of ROP and the other drilling parameters as:

$$Modelled\ ROP = b0 + b1WOB + b2Torque + b3RPM + b4\ \mathrm{SPP} + b5\ \mathrm{IF} \tag{2}$$

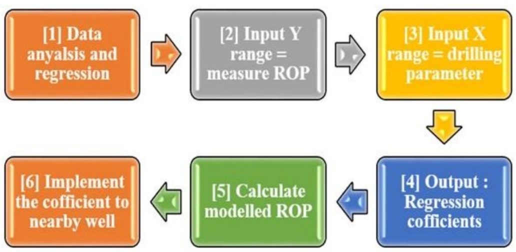

Fig. 2. Multiple regression process flowchart [1].

The multiple regression procedures are shown in Fig.(3 is applied to both hypotheses. In hypothesis I (b0) given from intercept to offset wells and (b1−5) the slope to each ROP in Y axes and drilling parameter in X-axes.

The multiple regression procedures are applied to the drilling section of the reference selected well, providing the five coefficients (b 1−5). By using Eq. (2), the coefficients are then implemented to surface section of Wells (1-3) in order to predict the ROP. In the first hypothesis, the multiple regression procedures are applied on the (MOGHRA formation) and the second hypothesis on the (DABAA formation) all in surface section of the reference well (1-3), providing five other coefficients (b 0−5).

By using Eq. (2), the coefficients are then implemented to the other nearby wells. Multiple Regression Workflow regression analysis is used to estimate the relationships among one dependent and two or more independent variables [3]. The method of data analysis is useful when examining a quantitative variable in relation to other factors. The Multivariate analysis describes an observation factor by having several variables, taking into account all changes in properties that may happen simultaneously. I.e. the multiple regression equation of (Y) factor on variables (X1, X2, …, Xn) is given by Eq (3) [1]:

$$Y = \beta 0 + \beta 1X1 + \beta 2X2 + \beta 3X3 + \cdots + \beta nXn \tag{3}$$

where Y is the dependent variable; β0 is the intercept term; and the regression coefficients (β1, β2, …, βn) are the analogs to the slope in the linear regression equation. The ROP is based on several different variables. Based on Eq. (2), the ROP would be referred to as the factor of observation (Y) in the paper.

The (Y) value is based on its turn on several properties simultaneously, in addition to the drilling operational factors. Relevant drilling parameters make up the regression variables (***X*1−5**). Taken these values in a Microsoft Excel sheet and Visual Basic and by processing the regression data analysis, then we will obtain the values of the coefficients (***b*0**–**5**). Now, by having the values of the coefficients, we will be able to estimate the (Y) value.

3. ROP simulation model

For ROP simulation-drilling parameters from three DwC Wells (W#2. W#4, W#6) have been taken from real field drilling parameters from Khalda Co. fields (X, Y), The variables required which can be collected through drilling from (ASCII) data file are:

1. Penetration rate [ft /hr]; 2. Weight-on-bit [lb]; 3. Rotary speed [rpm]; 4. Stand pipe pressure [psi]; 5. Torque [lb.ft]; 6. Calculated jet impact force.

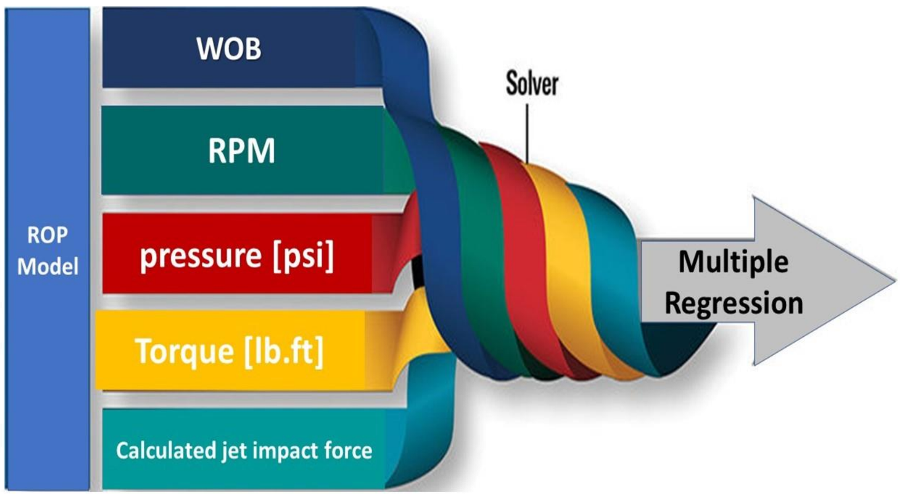

Fig. 3. The input drilling parameter into multiple regression process

The six variables listed above, five are directly controllable (weight-on-bit, rotary speed, pressure, torque, and calculated jet impact force) and one is indirectly controllable (ROP). During data collection, the five directly controllable variables must be utilized over the entire machine operating range for each. This will ensure a good data set is acquired. Ideally, this dataset will include multiple measurements of each of the five variables at several clusters which, together, encompass the entire machine operating range for that variable. If the five directly controllable variables are collected in such a fashion the one indirectly controllable variable should be well represented and the common machine operating range for it will also be defined. Before attempting to collect the field data it is important, the machine capabilities and the realistic machine operating range are well understood. The machine capabilities flow from the technical specifications of the unit to be studied while the realistic operating range is often dictated by mine site-specific policies. For the machine of interest, a realistic operating range for each of the three controllable variables given below [2]

15 000 ≤ WOB [lb] ≤ 35 000 ; 60 ≤ RPM [rpm] ≤ 13 and;
1500 ≤ Rotation pressure [psi] ≤ 300

4. Stratigraphic correlation

To study lateral geological features among the considered wells in this paper, a stratigraphic correlation is performed to compare rock sequences that cross through the wells used in the paper.

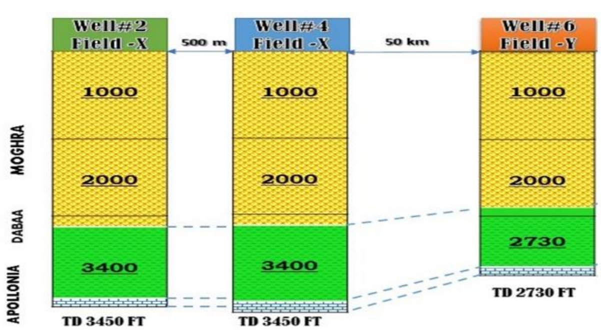

Fig. 4. Stratigraphic correlation between the wells. (not to the scale) [2]

This process attempts to establish a Stratigraphic correlation between different wells from different areas based on either the type of deposited material or the deposition time of the material. Petrel software is used to establish the Stratigraphic relationships for the (DwC) wells in the (X, Y) fields. This will help in general for understanding how the geology varies locally and regionally. In return, this can be used to analyze the performance of the ROP whether it is well modeled as well as to investigate the limitations of the model application. The interval length between two fields in the company about 70 km. The generated Stratigraphic correlation is displayed in Fig. (4). main observations are summarized in table (1) [1]

Table 1. The drilling parameters field data to DwC drilled wells used for ROP modeling [2]

Company name	Field name	Well name	Formation intervals	Formation thickness ,ft	Average ROP, ft/hr	WOB klb	RPM rpm	SSP psi	TORQUE Lb.ft
KHALD	X	Well#1	Moghra	2205	105	6.8	80	407	610
			Dabaa	~1195	120	23	119	1590	1310
			Apollonia	~50	100	22	110	213	1500
KHALD	X	Well#2	Moghra	2205	173	11	90	332	115
			Dabaa	~1195	70	20	105	770	165
			Apollonia	~50	73	13	60	650	110
KHALD	Y	Well#3	Moghra	~1755	81	8	102	285	770
			Dabaa	~980	73	8	102	53	1000
			Apolonia	~50	52	8.5	80	540	103

5. ROP modelling and testing results

The stratigraphic correlation of the wells is first constructed to clarify the geological similarities of the sedimentary lithology. Moreover, the predicted ROP profiles of the drilling section are compared with their corresponding ROP field data. The actual ROP is always plotted in Red in the figures. The Well#2 in the field –X is chosen to be the reference well. By using the multiple regression analysis, a single-well based model is developed from the reference well data from two hypotheses. The ROP model is developed with the data of (MOGHRA formation) in the surface section of the reference well in the first hypothesis and the data of the (DABAA formation) in the same surface section of the reference well in the second hypothesis. To obtain the ROP and implement the developed model, well-to-well correlation procedures and the drilling data of the new well to-be-drilled will facilitate the mission. The model will be tested in two different fields to verify it. It will be at first tested on nearby locally on the remaining field (X) DwC Well (Well #4) and the model will be tested on a far way well located in field Y DwC well (Well #6). Having a variety of data of two different fields with several wells will support the results of testing out the ROP models. This variety of data leads to greater accuracy in results-based conclusions. [1,3]

5.1. Multiple regression

This section presents multiple regression modeling and application. the details of the modeling workflow. Fig. 5 illustrates a sketch of the drilling with casing Well #2 in the field -X (not the scale), which provides perception about the position/shape of the Well. The Fig showed, DwC Well #2 in the field X consists of two main formations in (MOGHRA, DABBA and tagged in APOLLONIA formation by 50 ft. [3]

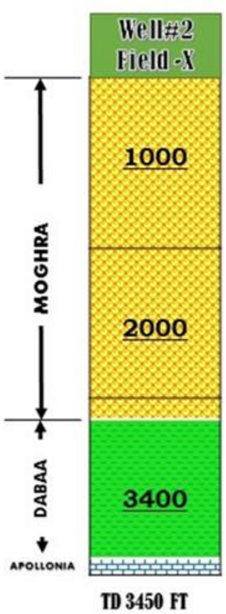

Fig. 5 Sketch of the reference well #2 from the field - X (not-to-scale) [2]

5.2. Hypothesis I

According to Hypothesis I, the MOGHRA formation of the reference well is modeled by multiple regression techniques. The computed curve fitting correlation coefficients are illustrated in Table 2.

Table 2. Calculated regression coefficients based on hypothesis I

Well #2	Coefficients	Well #2	Coefficients
Intercept (b0)	158.533716	X3 (RPM)	-0.046694476
X1 (WOB)	1.674020287	X4 (SPP)	0.129256229
X2 (Torque)	0.076377108	X5 (IF)	-0.447528794

5.2.1. Testing of hypothesis, I model on nearby well sections

The coefficients illustrated in Table 2 are implemented on the MOGHRA formation surface sections of the nearby wells. the DwC Well #4, which is located in field X and nearby the reference well. We observed that from both wells, the coefficients seem to correlate. The result shows almost the same behavior with the actual ROP than those obtained by multiple regression method [1]. The average ROP (96 ft/hr) and Modeled ROP (97 ft/hr).

5.2.2. Testing of hypothesis I model on far way well sections

The coefficients in Table 3 are implemented on the DABAA formation surface sections of the nearby wells the DwC Well #4, which is located in field X and nearby the reference well. We observed that from both wells, the coefficients seem to correlate. The result shows an excellent match better with the actual ROP than those obtained by multiple regression method [1]. The average ROP (80.8 ft/hr) and Modeled ROP (125.5 ft/hr).

5.3. Hypothesis II

According to Hypothesis II, the DABAA formation of the reference Well is modelled by multiple regression technique. The computed curve fitting correlation coefficients are illustrated in Table 3.

Table 3. Calculated regression coefficients based on hypothesis II

Well #2	Coefficients	Well #2	Coefficients
Intercept (b0)	233.0437	X3 (RPM)	0.054461
X1 (WOB)	-2.13866	X4 (SPP)	0.194073
X2 (Torque)	-1.53441	X5 (IF)	-0.29966

5.3.1. Testing of hypothesis II model on nearby Well sections

The coefficients in Table 3 are implemented on the DABAA formation surface sections of the nearby wells. the DwC Well #4, which is located in field X and nearby the reference well. We observed that from both Wells, the coefficients seem to correlate. The result shows an excellent match better with the actual ROP than those obtained by multiple regression methods [1]. The average ROP (80.8 ft/hr) and modeled ROP (125.5 ft/hr).

5.3.2. Testing of hypothesis II model on far way Well sections

The DwC Well #6, which is located in field Y and nearby the reference well. We observed that from both Wells, the coefficients seem to correlate The result shows almost the same behavior with the actual ROP than those obtained by multiple regression method [1]. The average ROP (72.3 ft/hr) and modeled ROP (73 ft/hr).

5.4. Modelling analysis

The purpose of this analysis is to determine how the modeling of ROP matches the actual ROP. It also aims to analyze the performance of the ROP, whether it is well modeled. Two techniques are developed and discussed to analyze ROP modeling [1].

5.5. Parametric sensitivity analysis

A parametric sensitivity analysis is applied to determine the most influential drilling operational parameters on the developed ROP model. This is intended to predict which parameters have a noticeable effect on the ROP to be aware of these parameters when drilling a new nearby well, also predict the far way wells. The idea is to advise operators when planning to (DwC) in the same formation to drill with high speed to reduce the non-productive time and thereby reduce the costs.

All the operational drilling parameters used in the ROP model (i.e. WOB, torque, RPM, and I_F) are increased and reduced by +15% separately for the reference Well #2.

The results of increasing and reducing the parameters are plotted against the actual modeled ROP to see if any improvement is obtained. That can show us the parameters with the greatest impact on the ROP. After finding these influential parameters, they are adjusted by 15 % in the other two wells to see how the ROP values vary. ROP averages are then calculated for the save time and costs of the adjustments. The analysis is performed on the model which was developed using the multiple regression analysis for the hypothesis I & II presented in (i.e. using coefficients in Tables (2.and 3). The results of increasing and decreasing the operational drilling parameters (WOB, torque, RPM, and I_F)) for the reference well.

5.5.1. Hypothesis I, section 1 (MOGHRA FM), field X, Nearby Well

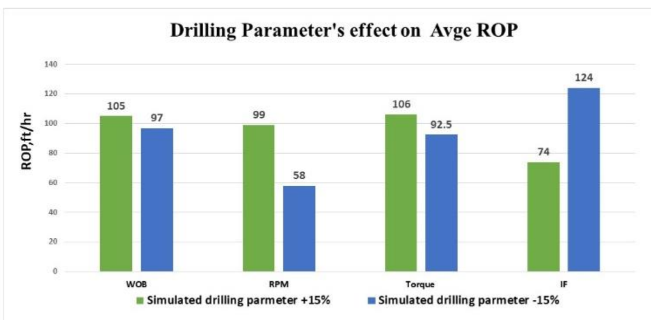

Fig. 6. Sensitivity analysis - Predicted average ROP for increasing/decreasing the different drilling parameterss by 15%

The average ROP of the results is shown in Fig. 6. to make it easier to determine the parameters that affect the model most, the IF and the TORQUE are the parameters with the greatest impact on the ROP model in the reference well. This is expected since the corresponding coefficients for these two parameters have the highest positive values as shown in Table 2. The IF decreased by 15% and the TORQUE increased by 15% for the same formation of other Wells.

When the saved time is increased, the IF is decreased by 15% and the TORQUE increased by 15% for the same well which is calculated using Eq. (1).The saved time varies between 5-6 hours. This corresponds to 10 – 12 thousand USD for this part of the section. The assumed average rig rate for semisubmersibles is 45 thousand USD per day included the service company's daily rate; this assumption is based on the data from last year. Figs. 7 and 8 shown the time and the money saved in the form of histograms for all the selected well.

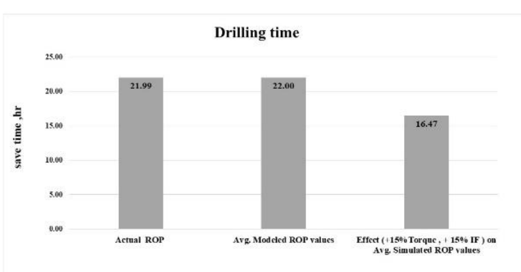

Fig. 7. Amount of time saved after The IF decreased by 15% and the TORQUE increased by 15%

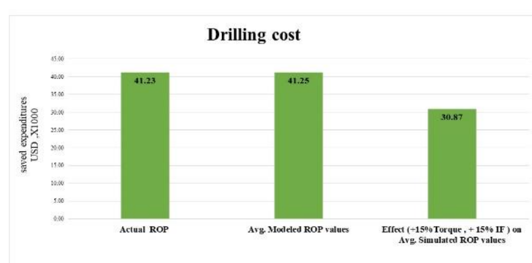

Fig. 8. Amount of money saved after The IF decreased by 15% and the TORQUE increased 15%

This analysis aims to advise drillers when planning to DwC wells in the same formation to optimize the drilling operations.

5.5.2. Hypothesis I, section 1 (MOGHRA FM), field Y, far way Well

The average ROP of the results makes it easier to determine the parameters that affect the model. The IF and the TORQUE are the parameters with the greatest impact on the ROP model in the reference well. This is expected since the corresponding coefficients for these two parameters have the highest positive values as shown in Table 3. The IF increased by 15% and the decreased TORQUE by 15% for the same formation of other wells.

When the saved time is increased the IF is decreased by 15% and the TORQUE also increased by15% for the same well as calculated using Eq. (1).The saved time varies between 10- 12 hours. This corresponds to 19 – 22 thousand USD per section. The assumed average rig rate for semisubmersibles is 45 thousand USD per day included the service company's daily rate; this assumption is based on data from last year.

5.5.3. Hypothesis II, section 2 (DABAA .FM), field X, nearby Well

The average ROP of the results makes it easier to determine the parameters that affect the model. The IF and the TORQUE are obviously the parameters with the greatest impact on the ROP model in the reference well. This is expected since the corresponding coefficients for these two parameters have the highest positive values as shown in Table 3. If the (IF) increased by 15% and the TORQUE increased by 15% for the same formation to other wells

When the saved time is increased, the IF is decreased by 15% and the TORQUE increased 15% for the same well is calculated using Eq. (1).The saved time varies between 5- 6 hours. This corresponds to 19 – 25 thousand USD per section. The assumed average rig rate for semisubmersibles is 45 thousand dollars per day included the service company's daily rate; this assumption is based on data from last year.

5.5.4. Hypothesis II, section 2 (DABAA .FM), field Y, far way Well

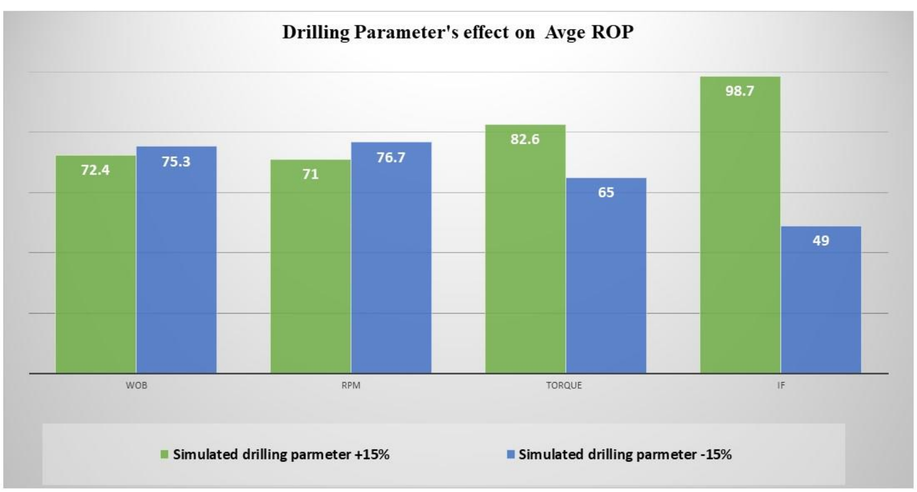

Fig. 9. Sensitivity analysis - Predicted average ROP for increasing/decreasing the different drilling parameters by 15%

The average ROP of the results is easier to determine the parameters that affect the model most. The IF and the TORQUE are obviously the parameters with the greatest impact on the ROP model in the reference well. This is expected since the corresponding coefficients for these two parameters have the highest positive values as shown in Table 3.The IF **increased** by 15% and the TORQUE **increased** by 15% for the same formation to other wells.

When the saved time is increased, the IF is decreased by 15%, and the TORQUE is increased by15% for the same well which is calculated using Eq. (1). The saved time varies between 5-6 hours. This corresponds to 7 – 10 thousand USD per section. The assumed average rig rate for semisubmersibles is 45 thousand USD per day included the service company's daily rate; this assumption is based on the data from last year. Figs. 10 and 11 shown the time and the cost saved in the form of histograms for selected well.

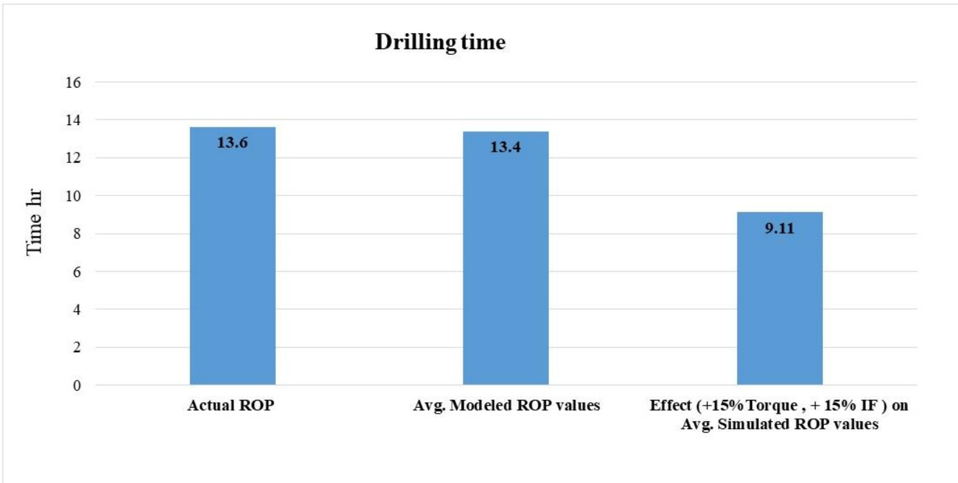

Fig. 10. Amount of time saved after The IF decreased by 15% and the TORQUE increased 15%

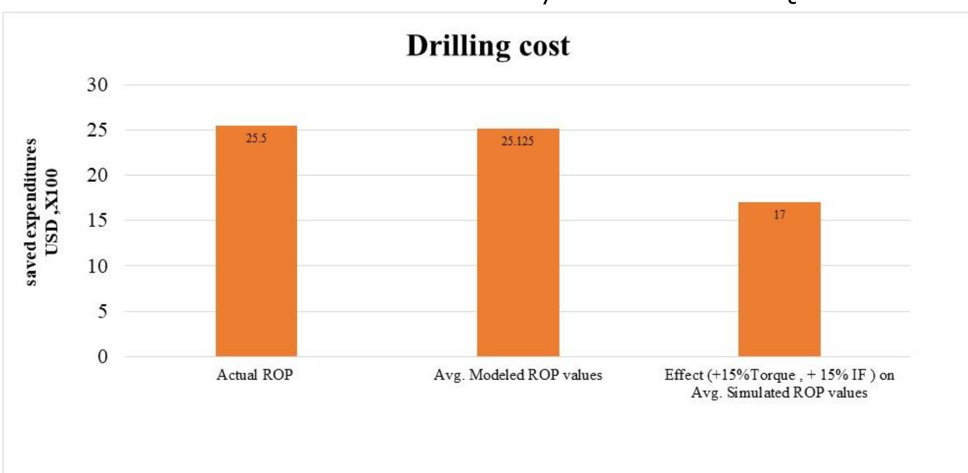

Fig. 11. Amount of money saved after The IF decreased by 15% and the TORQUE increased 15%

5.6. Risk assessment

To identify the risk of DwC in Fields (X, Y) and recognize the weakest components of the chosen DwC system, a "Hazard Identification" (HAZID) workshop was held in conjunction with global reps of participating service companies. Both office and field drilling engineers were actively involved in the discussion where four major groups of uncertain events were identified: DwC the wellbore, casing handling, cementing, and post cementing. The team evaluated both the probability of occurrence and the consequences of each event and highlighted their impact on drilling operations as well as the existing mitigation system to prevent the unexpected. The main potential risk events for which more than 15 % likelihood of occurrence was recorded are bit balling, excessive bit vibration, wellbore collapsing, reduced drilling performance, casing connection premature damage, conventional-float collar damage, deficient cement job, and problems encountered while drilling out a drillable bit.

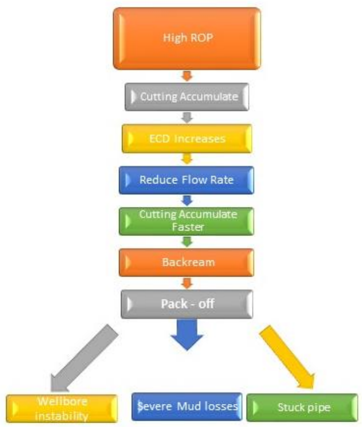

Fig 12. The graphic representation of the high ROP Tap

A list of mitigation measures was put in place to minimize the risk and effect of each event on the planned DwC trial. Before drilling operations, the rig crew was knowledgeable on potential risks associated with DwC and the actions taken to be set in rig-site to minimize such risks. Additionally, to handle DwC operation, we can discuss the uncontrolled high ROP that can lead to some problems shown in Fig. (12). The HAZID session must be considered as a driven teamwork achievement on the success of these first trials KHALDA petroleum company joint venture (Apache) in Egypt [2].

6. Conclusions

Drilling with casing technique is used to drill 12 inches, hole successfully to the planned setting depth and the job was completed successfully. DwC application reduces the total mud losses into the thief zone, mitigates hole pack-off, reduces the stuck pipe due to the loss of circulation, cuttings accumulations, and finally reduces the associated non-productive time in this problematic wellbore. Massive losses were encountered in this well however, the casing reached the TD and cased through the thief zone. During the DwC technique, the size of the cuttings generated is smaller than with conventional drilling. This is due to the casing string grinding effect that pulverizes the cuttings as they travel up the annulus and the Plastering effect shown.

Acknowledgment

The authors dedicate this work to staff members of the petroleum engineering department for their assistance and communion with their academic experience.

Finally, I would like to express my appreciation to my colleagues who helped me in my study by providing me with the materials and sharing field data to complete this research.

Nomenclature

ASCII	*American Standard Code for Information Interchange*	*LCM*	*loss of circulation mud*
BHA	*Bottom Hole Assembly*	*POOH*	*Pull out -off hole*
BPH	*Barrel per Hour*	*PPF*	*Pound per Foot*
BTC	*Buttress type connection*	*PSI*	*Pound per square inch*
BTM	*Bottom*	*RIH*	*Run in hole*
CSG	*Casing*	*ROP*	*Rate of Penetration*
DwC	*Drilling with Casing*	*SPP*	*Stand Pipe Pressure*
FPH	*Feet per Hour*	*TD*	*Total Depth*
GPM	*Gallons per Minute*	*WOB*	*Weight on Bit*
KCL	*potassium chloride salt*		

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