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Overcoming the Data Limitation that Restrict Drilling Optimization across Multiple Regression Approach

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ABSTRACT

An extensive review conducted before this study, showed data limitation is the main constrain for multiple regression approach. Thus, new technique has been innovated through bit wear distribution over drilled interval depends on formation fingerprint. Field geological, drilling and logging data collected from three wells located in Blue Nile basin subjected to considerable concentrated analysis. Drilling rate predicted as a function of optimum weight on bit and rotation per minute using Bourgoyne and Young model. The Unknown Bourgoyne and Young coefficients have been determined. Correlations of multiple regressions using Statistica-12.5 software predict acceptable values of nine unknown coefficients. Hypothesis test of predicted coefficients showed over 95% confidence interval which simulated saving in time of drilling by 25%. Out comes was verified through Payzone drilling simulator via simulating actual field observations and re-simulate predicted ROP values. Results revealed the proficiency of predicted drilling rate values. The rate of penetration general equation constructed for each formation; then graphs produced for each formation individually depends on bit type and operational conditions.The methodology and out comes presented in this paper enable prediction of optimum penetration rates directly through accurately produced graphs that is during the well planning period for next wells to be drilled in Blue Nile Basin or other similar formations. This research offers new technique via distribution of drill bits dullness over drilled interval to overcome data limitation constrain. Together with qualitative and quantitative analysis of the optimized results that revealed high potentiality of new technique through both operation and economic benefits on drilling.

Introduction

The new sources of oil and gas are expecting to fill demand gaps for both oil and gas all over the world. Therefore, future management of oilfield drilling operations will face new hurdles to reduce overall costs, increase performances and reduce the probability of encountering problems. Many detailed and effective research studies for different areas and from different disciplines has been performed in the area of drilling optimization since 1958 up to date mainly aiming at safe, environment friendly, less down hole problems and minimum expenditure well construction [1] [2] [3]. Early drilling optimization researches considered only ROP-WOB-RPM under condition of perfect cleaning together with neglecting depth effect such as Maurer model (1962) [4] that had been developed by Bingham (1965) [5]. Over the following decades, many efforts exerted to optimize drilling through different criteria's and from different disciplines considering both controllable and uncontrollable variables and it is relationship with rate of penetration [6] [7] [8]. Mathematical drilling optimization models developed over last decades consider only the available technology. Starting from previous simple model together with manual applications, simple programs as excel, computer programming languages, real-time and recently artificial neural network (ANN) which introduced in 1991 [1]. Although no available mathematical models for rate of penetration with full percent accuracy have been achieved yet (100% accuracy). Some early studies or proposed models were considered as basis for most of drilling optimization researches up to date such as Bourgoyne and Young model 1974 [8], which considered as one of best proposed models due to large number of drilling parameters considered in the model .

Problem Statement, Scope and Assumptions of Study

An extensive literature survey on Bourgoyne and Young model conducted which concluded to consider Bourgoyne and Young model together with multiple regression approach one of best models to optimize drilling. However, due to multi-collinearity because of data limitation constrain all researches looking for alternative solution methods to overcome data limitation [9]. This study reveals new technique to overcome data limitation constrain during multiple regression process to avoid multicollinearity, through distributing bit wear over drilled interval for both tri-cone and PDC drill bit applications. Both numerical simulation applications and statistical hypothesis tests carried for more strong verifications.

Blue Nile Basin selected as study area (one of oldest Sudanese Rift Basins) which consists of five formations: Damazin, Dindir-1, Dindir-2, Dindir-3 and Blue Nile formations. Blue Nile Basin covered block 8, located some 200 Km southeast of Khartoum. The surface area is around

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60513.3 Km^2 with a ground elevation approximately 400 Meters. Block 8 totally covered by Magnetic, Gravity Survey and 7523 Km (2D) Seismic Line. Eleven wildcat exploration wells drilled and most of the wells encountered good hydrocarbon shows and high gas reading. There are also two Gas and Condensate discoveries.

Main constrain for drilling operation during previous drilled wells was low penetration rate, thus drilling operations have significant potential for optimizing and reducing costs. This study characterize how to perform new proposed technique to previous drilling data in order to predict ROP for future wells. This technique utilized by modifying Bourgoyne and Young model for better plan, optimize drilling and expenses for all areas regardless volume of historical data. Proposed technique applied to Blue Nile basin, considering some assumptions as the following:

- Drilling fluid system properly designed.
- The drill bit properly selected.
- BHA assembly combination in use properly selected.
- Homogeneous drilled formation interval.
- Rig personnel and equipment's are efficiently functioning.

Model Theory

Bourgoyne and Youngs' Model is a linear relationship between rate of penetration and eight of drilling variables based on statistical synthesis of the past drilling parameters as equation (1). Model developed by REZA [10] will be applied for this study, which it developed for both roller cone and PDC drill bits and three additional drilling parameters for hole cleaning effect.

$$\frac{dD}{dt} = Exp\ (a_1 + \sum_{j=2}^{8}(a_j\, x_j) \qquad \text{……………..} (1)$$

Data Description

Three wells sets of Blue Nile Basin (BNB) data collected from three located in Block 8. The BNB data consists of nine exploration wells. Three wells selected for this study: Hosan-1, West Dindir-1 and Baraka-1 wells. Data collected from these wells including geological description data, drilling data collected through mud logging unit, wire line logging data, Drill bits data and drilling fluid data. The following reveal brief historical background for selected wells:

Hosan-1 well

It is a vertical exploration well drilled using ZPEB 747 mechanical rig, spudded 1st September 2004, 12-1/4in pilot hole was drilled to 552m, hole was opened with 17-1/2in hole opener to 552m, ran 13-3/8in casing followed by G-Class cement. Intermediate hole drilled to 1735m with high mud weight (11.5ppg@TD) to control background gas and caving. Main hole drilled to 2911m with increase in mud weight to 12ppg due 57000ppm of gas and then mud weight cut to 11.7ppg due to partial losses. Rig released in 31 January 2005.

West Dindir-1 well

An exploration vertical drilled well using ZPEB 767 mechanical rig, spudded 17 December 2007, 12-1/4in hole drilled till 605m, ran 9-5/8in casing followed by G-Class cementing. 8-1/2in main hole drilled to TD@2035m while mud weight raised to 11.2ppg to control caving. Nine bullets were lost in hole during CST-GR logging operation and retrieved via successful fishing job. 7in liner run in hole. Perforation job carried successfully above TOC behind casing and below liner hunger and regain circulation. Cement squeeze job performed through perforation and cement quality confirmed through CBL-VDL-CCL log, and then Rig handed over to testing operation on 10 February 2008.

Baraka-1 well

Vertical wildcat well drilled using ZPEB 767 mechanical rig, spudded 7 May 2009. 17-1/2in surface hole drilled to 475m then ran 13-3/8in casing followed by G-Class cementing. Unexpected Low ROP encountered comparing to previous drilled wells (Average ROP 3.5m/hr.) due to hard formation. 12-1/4in hole drilled to 820m, BHA changed to directional and resumed drilling from 904m with same slow drilling rate problem until revised FTD@1050m.

Each well data has divided to groups depends on formation type (Damazin, Dindir-1, Dindir-2, Dindir-3 and Blue Nile) as each formation has homogenous properties for more consolidation and validation of result. Depend on collected samples and confirmation of wire line logging data the collected three wells data plotted, analyze and results showed the following:

❖Normal trend for ROP considering RPM and WOB curves for the three wells, except Hosan-1 well which operator intended to control drilling parameters due to increase in background gas.

❖Mud weight showed normal trend for the three wells, except:

- Hosan-1 well showed decrease in mud weight due to background gas as it is common in this area [11].
- Hosan-1 well showed too much mud weight for surface hole with considering high values of PV and YP that indicate hole-cleaning concern.

❖D-Exponent Normal trend for the three wells except noticed drop due to commencing new sections with fresh mud especially in hosan-1 well.

❖Considering flow rate curve for the three wells standpipe pressure gave a normal trend.

❖Many fluctuating points for the three wells for RPM, GPM and SPM due to rig equipment's malfunctions or other reasons, which indicate general trend odd values.

❖Low drilling parameters applied for the three wells to pattern new drill bit or in the beginning of new section until second stabilizer pass casing shoe as a good drilling practice.

❖Many drill bits used to drill both Hosan-1 and Baraka-1 well, which indicates poor drilling performance.

Data Process

Data filtering process performed from drilling point of view, however, odd data point due to equipment's repair or calibration mistakes excluded. Drilling data collected from mud logging unit for the three vertical wells divided in Excel sheets for each formation for each well individually. The data prepared accordingly in order to provide suitable means for the multiple regression application based on the defined general rate of penetration equation. All additional data essential to perform rate of penetration model including drill bit data, drilling expenses and Multiple Regression Analysis prepared and included to separate Excel sheets for each formation. Bit wear have been divided equally for same formation or 1:2 for different formation to overcome data limitation constrain for conventional multiple regression. Number in data points in whole data set divided to two proportion of data for training, validation and verification as the following portions:

− One-third of data used for validation.

− Remaining data divided into 70% for training and 30% for final validation.

Multiple Regression Process and Analysis

Statistica-12.5 Software used to perform multiple regression process, in order to achieve more accurate regression constants deliverables. The first run showed negative values for most of unknown coefficients because drilling parameter did not variate well on the scale of drilling with the necessary comprehensiveness and adequacy. Considering R2 value was high enough indicating data consolidation from statistics point of view but physical meaningless values. Correction performed by excluding data points with high residual values and the achieved results reflect acceptable nine unknown coefficient values together with excellent R2 hypotheses test value for the second data run, table (1).

Although, most of unknown coefficients' has positive values but clearly noticed there are negative values as the following:

❖a_2, a_3 and a_4 showed negative values mainly for Damazin Formation for the three wells.

❖a_7 showed negative values for:

- Hosan-1 and Baraka-1 wells expressing Damazin Formation.
- West Dindir-1 well expressing Dindir-2 Formation.
- Hosan-1 well expressing Dindir-3 Formation.
- Hosan-1 well expressing Blue Nile Formation.

❖a_2 and a_3 showed negative values for Hosan-1 well expressing Dindir-2 formation.

❖a_4 showed negative values mainly for the three wells expressing Damazin Formation, in addition to Hosan-1 well expressing Dindir-2 formation.

Negative Value Justification

❖The negative values of a_2, a_3 and a_4 caused by the dependency between X_2, X_3, and X_4. As the depth increases, X_2 decrease and both X_4 and X_3 are increase with negative values due to:

- Damazin formation located at the top of well and drilled using gel or bentonite mud that lead to unavailability of drilling fluid rheology affected values of ECD.
- Presence of low formation pressure or subnormal formation pressure that affect both values of X_3 and X_4.

❖Presence of negative value for a_7 caused due to unavailability of enough range for X_7 values as the following:

- Recommended minimum range as proposed by Bourgoyne and Young supposed to be at least 0.2.
- All bits wear values to drill Damazin formation are less than 0.2 due to presence of soft formation.
- Bit wear estimated to be equal 0.125 for both bits used to drill Dindir-2 formation for West Dindir-1 well.
- Four drill bits used to drill Dindir-3 formation (Hosan-1 well) as bit selection problem and the calculated bit wear less than 0.2.
- Five drill bits used to drill Blue Nile formation in Hosan-1 well (same bit selection problem) but here four bits out of five have been changed with bit wears less than 0.2.

Table (1). Regression Result Summary for Blue Nile Basin

Well name	Formation	a1	a2	a3	a4	a5	a6	a7	a8	a9
Hosan-1	Damazin	8.5362880	-0.0000444	-0.0002910	-0.0000313	0.0022027	0.0504394	-0.2623138	0.4566832	0.8377421
	Dindir-1	4.7900369	0.0003368	-0.0076294	0.0000302	0.0089370	0.0534642	0.1046225	0.5619636	1.0022807
	Dindir-2	10.1612300	-0.0001789	-0.0003925	0.0000265	0.0127226	0.0445719	0.2220588	0.6289199	1.0029294
	Dindir-3	9.2595833	0.0000650	0.0026961	0.0000200	0.0285923	0.1546057	-1.1577231	0.4389956	0.8331329
	Blue Nile	15.6083522	-0.0004469	0.0168063	-0.0000009	0.0706973	0.0400902	-0.0140117	0.4484365	1.0048409
WD-1	Damazin	19.658790	-0.0012424	-0.0473982	-0.0005651	0.0107829	0.2364329	75.9138077	0.5500221	0.9644149
	Dindir-1	24.8560671	-0.0014259	0.0212703	0.00010713	0.0108510	0.3022385	5.7644604	0.6883983	1.0066043
	Dindir-2	9.9357631	0.0001820	0.0081548	0.0000066	0.0318466	0.4354789	-0.0754600	1.2173851	0.8776340
Baraka-1	Damazin	8.5009916	-0.0000889	-0.0004416	-0.0000838	0.0124569	0.4639568	-0.4373717	0.8973271	0.8740811
	Dindir-1	22.8984676	-0.0013353	0.0234863	-0.0001117	0.1060091	0.2713476	1.2931359	0.7272759	0.9914173

Table (2). Optimum values of drilling RPM and WOB for each bit run

Item	Well Name	Formation	Bit type	Hole size (in)	Drilled depth interval	Optimum WOB	Optimum RPM
1	Hosan-1	Damazin	Smith MX-1	12-1/4"	From 18 to 259m	0.615	196
2		Dindir-1	Smith MX-1	12-1/4"	From 259 to 552m	0.25	175
3			Reed HP41H	12-1/4"	From 552 to 990m	0.285	167
4		Dindir-2	REED EPH41H	12-1/4"	From 990 to 1018m	3.27	184
5			HTC MX-C1	12-1/4"	From 1018 to 1364m	2.46	157
6			HTC HC -606	8.5	From 1394 to 1590 m	2.7	142
7		Dindir-3	HTC HC -606	8.5	From 1590 to 1735m	3.2	174
8			SMITH MA89BK	8.5	From 1590 to 1959m	3.2	149
9			HTC MX-C1	8.5	From 1986 to 2117m	2.34	167
10			HTC MX-C1	8.5	From 2117 to 2349m	2.34	164
11		Blue Nile	HTC MX-C1	8.5	From 2349.5 to 2355m	5.4	174
12			HTC MXB-CX	8.5	From 2355 to 2551m	5.4	171
13			HTC MX-C1	8.5	From 2551 to 2849m	5.39	187
14			HTC MX-C1	8.5	From 2849 to 2884m	5.39	178
15			Smith MF2OTO	8.5	From 2884 to 2911m	5.39	190
19	WD-1	Damazin	Smith M91BHL	12-1/4"	From 31 to 450m	0.204	186
20		Dindir-1	Smith M91BHL	12-1/4"	From 450 to 605m	0.34	110
21			Varel VTD619GX	8.5	From 605 to 1750m	0.01	193
22		Dindir-2	Varel VTD619GX	8.5	From 1750 to 1770m	0.939	166
23			Varel VTD616GX	8.5	From 1770 to 2034m	0.864	198
24	Baraka-1	Damazin	Reed T11	17-1/2"	From 22 to 253m	0.377	167
25		Dindir-1	Reed T11	17-1/2"	From 253 to 422m	2.98	97
26			HUGHES GTXC1	17-1/2"	From 422 to 470m	2.98	98
27			HUGHES HTC	12-1/4"	From 470 to 820m	1.265	141
28			REED MX-C1	12-1/4"	From 820 to 846m	2.98	130
29			VAREL ETD24D	12-1/4"	From 846 to 895m	3.69	99

- Unavailability of enough data range between data points as recommended by Bourgoyne and Young (especially bit wear
- range) and distributed over wide range of data points, which leading to negative drilling parameters affect to vary over a very narrow range.

On the other hand, Statistical analysis showed high R^2 values for all wells formations, which enables to test hypotheses or predict future outcomes by statistically measuring how close the original data are to the fitted regression line.

Optimum Drilling Parameters and Predicted Penetration Rate

Depends on previous nine unknown coefficient values as table (1), optimum values of drilling mechanical parameters determined for each Bit run individually is indicated in table (2).

The optimized magnitudes predicted based on interpolated and corrected data applied to develop Bourogyne and Young model. Then a comparison performed between calculated rates of penetration versus field measured one. Developed model predicted ROP's values proved better measures by about **25%** as the following breakdown Table (3) explain.

Numerical PayZone Simulator Verification

The input files loaded and simulation process began with tuning simulator for each bit run through ROP adjust factor, in order to set simulator to match field condition. PayZone simulator in this study used two times. Firstly, run and simulate the selected wells through applying field parameters obtained during drilling. Then re-simulate existing wells through applying optimum weight on bit and rotation per minute for each bit run achieved. Table (5) and figures (1, 2 and 3) are explaining simulation and re-simulation result for Hosan-1, west dindir-1 and Baraka-1 wells respectively.

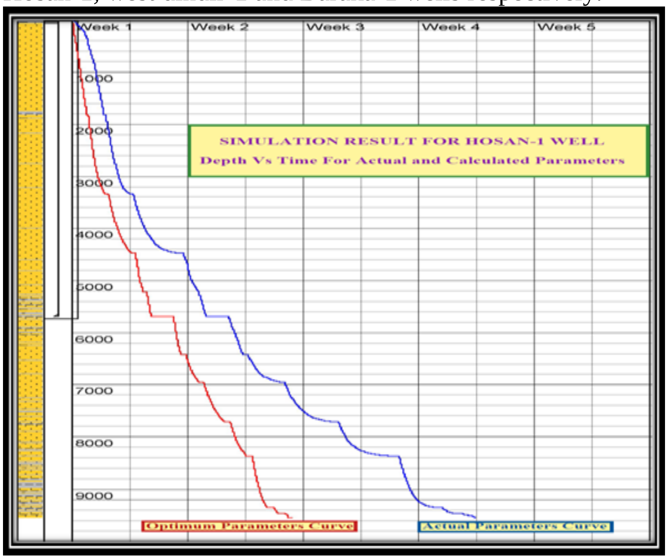

Figure 1. Hosan-1 well simulation and re-simulation

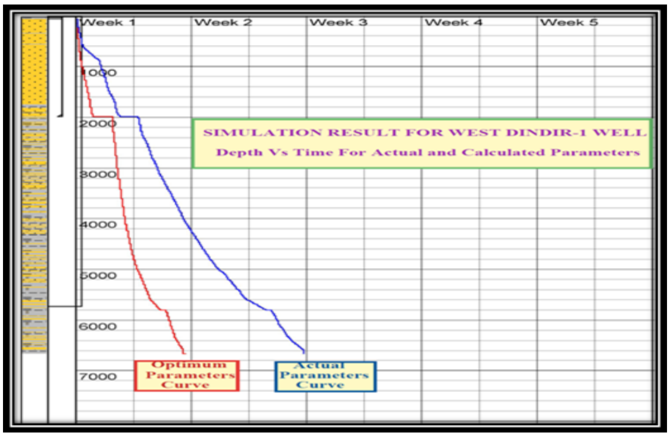

Figure 2. West Dindir-1 well simulation and re-simulation.

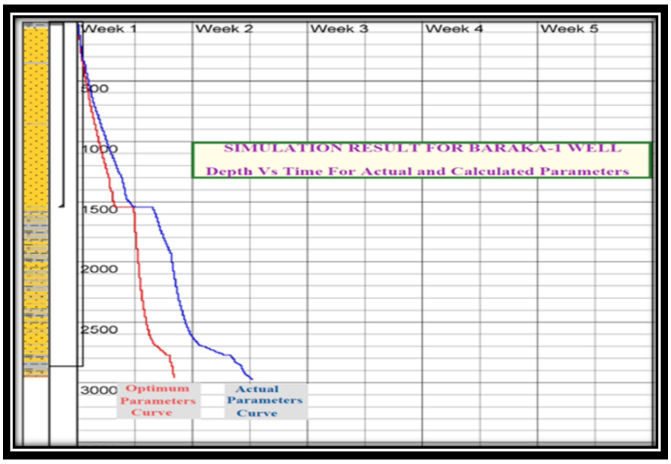

Figure 3. Baraka-1 well simulation and re-simulation.

Re-simulation results for the three wells showed better result than rate of penetration predictions as the following:

- Hosan-1 well showed saving of about 43% drilling time.
- West Dindir-1 well showed saving of about 50% drilling time.
- Baraka-1 well showed saving of about 35% drilling time.

Much better re-simulation results than both measured and predicted rate of penetrations due to the following:

- Presence of additional factors in PayZone simulator more than existing factors in the developed model. Especially Lithological descriptions and drill bit type, which reflect more realistic simulation result than rate of penetration prediction values.
- PayZone simulator neglect normal drilling practices that are extend drilling time. These practices are compulsory to follow to avoid drilling problems as controlling drilling parameters and bit pattern in beginning of each bit run.

Blue Nile Basin Model Generalization

Once simulation prove the new technique accuracy, generalization for both roller cone and PDC drill bits individually for each formation as follows:

Table (3). Actual and Calculated drilling hours Breakdown

Well Name	Formation	Acual hrs	Calculated hrs	Saving hrs percentage	Simulator saving percentage
Hosan-1	Damazin	9.35649	7.44185	24.39%	42.00%
	Dindir-1	65.45401	38.71542		
	Dindir-2	86.61278	72.07892		
	Dindir-3	214.33898	143.18021		
	Blue Nile	221.06354	189.84388		
WD-1	Damazin	27.00000	16.20000	25.43%	50.00%
	Dindir-1	120.22465	91.40584		
	Dindir-2	34.08714	27.59498		
Baraka-1	Damazin	22.07676	16.30450	24.53%	35.00%
	Dindir-1	168.11524	127.22543		

Damazin Formation

1. Roller cone bits general equation

$$\frac{dD}{dt} = e^{3.9710766164413} + e^{0.000344247957281191(10000-D)} + e^{0.0035743387751927\,D^{0.69}(g_p-9.0)} + e^{-0.00105492728506786D(g_p-\rho_C)} + \left[\frac{WOB/d_b}{\left[WOB/d_b\right]_c}\right]^{0.0100161264743326} + e^{0.120242657242603\ln\left[\frac{N}{100}\right]} + e^{0.0437202761462321(-h)} + e^{0.798486676003953\left(\frac{\rho q}{350\mu d_n}\right)} + \left[\frac{C_c}{100}\right]^{0.828265973789453}$$

.... (2)

2. PDC bits general equation

$$\frac{dD}{dt} = e^{19.6508789551842} + e^{-0.0012423985178634(10000-D)} + e^{-0.0473981661544355\,D^{0.69}(g_p-9.0)} + e^{-0.000565132367624954D(g_p-\rho_C)} + \left[\frac{\left[WOB/d_b\right]_{mech}}{\left[WOB/d_b\right]_c}\right]^{0.0107829068945954} + e^{0.236432869181926\ln\left[\frac{N}{100}\right]} + e^{75.9138077465967(-h)} + e^{0.550022059535884\left(\frac{\rho q}{350\mu d_n}\right)} + \left[\frac{C_c}{100}\right]^{0.964414941869564}$$

.... (3)

Dindir-1 Formation

1. roller cone bits general equation

$$\frac{dD}{dt} = e^{11.19603} + e^{-0.000252448721(10000-D)} + e^{0.000189158182\,D^{0.69}(g_p-9.0)} + e^{0.0000553488728D(g_p-\rho_C)} + \left[\frac{WOB/d_b}{\left[WOB/d_b\right]_c}\right]^{0.00845669735} + e^{0.222583978\ln\left[\frac{N}{100}\right]} + e^{0.290085719(-h)} + e^{0.957937127\left(\frac{\rho q}{350\mu d_n}\right)} + \left[\frac{C_c}{100}\right]^{1.00045809}$$

.... (4)

2. PDC bits general equation

$$\frac{dD}{dt} = e^{5.51446864} + e^{0.000226706069(10000-D)} + e^{-0.0129067655\,D^{0.69}(g_p-9.0)} + e^{0.0000832898017D(g_p-\rho_C)} + \left[\frac{\left[WOB/d_b\right]_{mech}}{\left[WOB/d_b\right]_c}\right]^{0.0092251485} + e^{0.478787113\ln\left[\frac{N}{100}\right]} + e^{1.88532072(-h)} + e^{0.0185131246\left(\frac{\rho q}{350\mu d_n}\right)} + \left[\frac{C_c}{100}\right]^{0.981298851}$$

.... (5)

Dindir-2 Formation

1. Roller cone bits general equation

$$\frac{dD}{dt} = e^{9.83344310815519} + e^{-0.00013502069130902(10000-D)} + e^{-0.0000690363656501027\,D^{0.69}(g_p-9.0)} + e^{0.0000299254165536225D(g_p-\rho_C)} + \left[\frac{WOB/d_b}{\left[WOB/d_b\right]_c}\right]^{0.0148792483252955} + e^{0.118669056440153\ln\left[\frac{N}{100}\right]} + e^{-0.0284877266369879(-h)} + e^{0.891492286169398\left(\frac{\rho q}{350\mu d_n}\right)} + \left[\frac{C_c}{100}\right]^{1.00134198737486}$$

.... (6)

2. PDC bits general equation

$$\frac{dD}{dt} = e^{7.49962805691566} + e^{-0.0000150973232070416(10000-D)} + e^{-0.000620920919904272\,D^{0.69}(g_p-9.0)} + e^{4.81831416610678E-07D(g_p-\rho_C)} + \left[\frac{\left[WOB/d_b\right]_{mech}}{\left[WOB/d_b\right]_c}\right]^{0.00264100422355107} + e^{0.677071722120865\ln\left[\frac{N}{100}\right]} + e^{0.237700876668414(-h)} + e^{-0.0941626098234324\left(\frac{\rho q}{350\mu d_n}\right)} + \left[\frac{C_c}{100}\right]^{0.728233277968816}$$

.... (7)

Dindir-3 Formation

1. Roller cone bits general equation

$$\frac{dD}{dt} = e^{9.25958333964756} + e^{0.0000649516367961227(10000-D)} + e^{0.00269613542944613D^{0.69}(g_p-9.0)} + e^{0.0000200254385792140\,D(g_p-\rho_C)} + \left[\frac{WOB/d_b}{\left[WOB/d_b\right]_c}\right]^{0.0285923148419047} + e^{0.154605678973994\ln\left[\frac{N}{100}\right]} + e^{-1.15772314113849(-h)} + e^{0.438995588625612\left(\frac{\rho q}{350\mu\, d_n}\right)} + \left[\frac{C_c}{100}\right]^{0.833132851993656}$$

.... (8)

2. PDC bits general equation

$$\frac{dD}{dt} = e^{9.25958333964756} + e^{0.0000649516367961227(10000-D)} + e^{0.00269613542944613D^{0.69}(g_p-9.0)} + e^{0.0000200254385792140\,D(g_p-\rho_C)} + \left[\frac{\left[WOB/d_b\right]_{mech}}{\left[WOB/d_b\right]_c}\right]^{0.0285923148419047} + e^{0.154605678973994\ln\left[\frac{N}{100}\right]} + e^{-1.15772314113849(-h)} + e^{0.438995588625612\left(\frac{\rho q}{350\mu\, d_n}\right)} + \left[\frac{C_c}{100}\right]^{0.833132851993656}$$

.... (9)

Blue Nile Formation

1. Roller cone bits general equation

$$\frac{dD}{dt} = e^{15.6083522465063} + e^{-0.000446881752381636(10000-D)} + e^{0.0168062967957586D^{0.69}(g_p-9.0)} + e^{-9.42688948635812E-07D(g_p-\rho_C)} + \left[\frac{WOB/d_b}{\left[WOB/d_b\right]_c}\right]^{0.0706973260798466} + e^{0.0400901566110318\ln\left[\frac{N}{100}\right]} + e^{-0.0140117476781035(-h)} + e^{0.448436525779656\left(\frac{\rho q}{350\mu\, d_n}\right)} + \left[\frac{C_c}{100}\right]^{1.00484090892696}$$

.... (10)

2. PDC bits general equation

$$\frac{dD}{dt} = e^{15.6083522465063} + e^{-0.000446881752381636(10000-D)} + e^{0.0168062967957586D^{0.69}(g_p-9.0)} + e^{-9.42688948635812E-07D(g_p-\rho_C)} + \left[\frac{\left[WOB/d_b\right]_{mech}}{\left[WOB/d_b\right]_c}\right]^{0.0706973260798466} + e^{0.0400901566110318\ln\left[\frac{N}{100}\right]} + e^{-0.0140117476781035(-h)} + e^{0.448436525779656\left(\frac{\rho q}{350\mu\, d_n}\right)} + \left[\frac{C_c}{100}\right]^{1.00484090892696}$$

.... (11)

Blue Nile Basin Graphical Generalization

Depends on previous generalized equations (refer with: Equations 2 to 11) for Blue Nile basin formations, below graphs have been produced for each individual bit run depends on it is IADC code and operational conditions (flow rate, rheology and hydraulics). Below Figures (refer with: Figures 4 to 20) explains ROP Vs RPM for constant WOB for each colored line.

How to use Generalization graphs for Blue Nile Basin

Generated graphs from fig. 4 to fig. 20 revealed connection or relationship between drilling mechanical parameters (weight on bit and rotation per minute) and rate of penetration. Below steps considered as essential guide lines to be more familiar with graphs:

Firstly: have to select suitable graph through answering the following four questions:

Look at graphs title, is it for tri-cone or PDC drill bit? Is it match your bit type?

Look at graphs title, what's drill bit size? Is it match yours?

Look at graph title, what is IADC for drill bit? Is it match your drill bit IADC?

Look at graph title, what is graph operation condition? Is graph operation condition match yours? (operation condition consists flow rate, mud weight and total flow area)

Secondly: have to specify which one of three parameters you are looking for? As graphs are pictures that show you how one parameter changes in relation to another two (parameters are: rate of penetration, weight on bit and rotation per minute).

Assume: Looking for rate of penetration for specific weight on bit and rotation per minutes.

Thirdly: Specify weight on bit line depends on key located in lower right corner of graph and have to determine rate of penetration scale location considering that both line and scale in y-axis has same color.

Fourthly: Determine rotation per minute value in X-axes and draw line upward till cross specified line in step three.

Fifthly: From the hit point go to y-axis; either right or left depends on specified weight on bit scale location.

Finally: Read amount of rate of penetration.

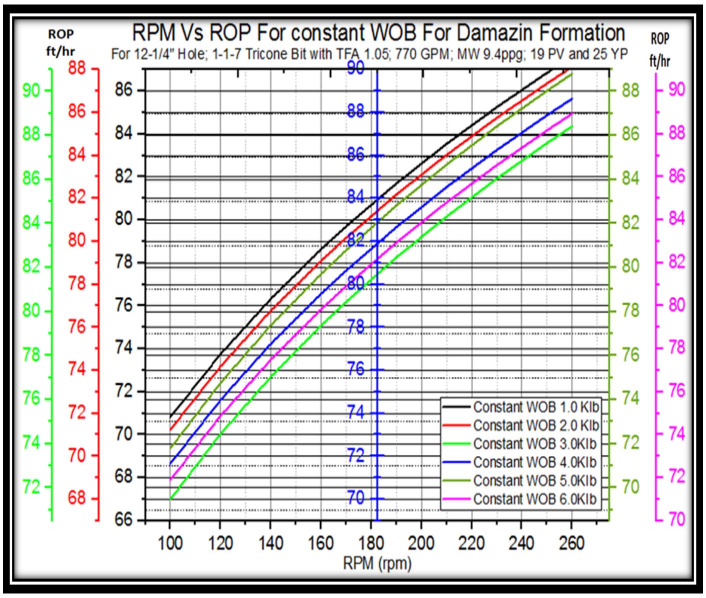

Figure 4. Predicted ROP Vs RPM for Damazin Formation for 117 bits, 12-1/4in hole

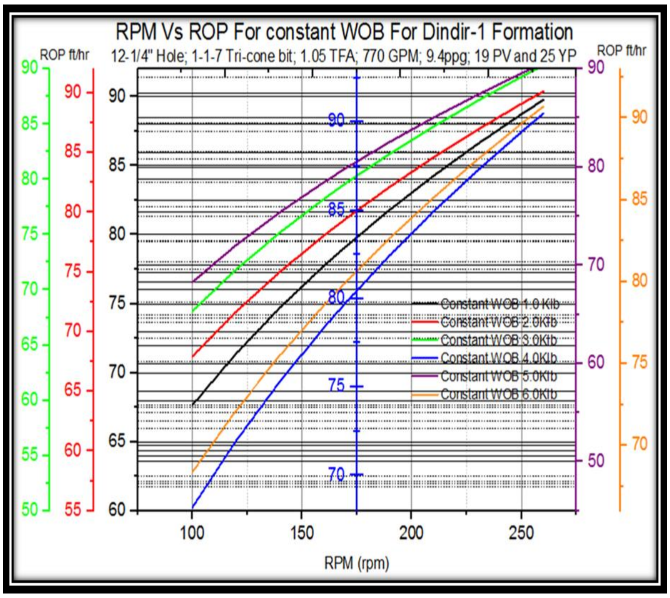

Figure 7. Predicted ROP Vs RPM for Dindir-1 Formation for 117 bits, 12-1/4" hole

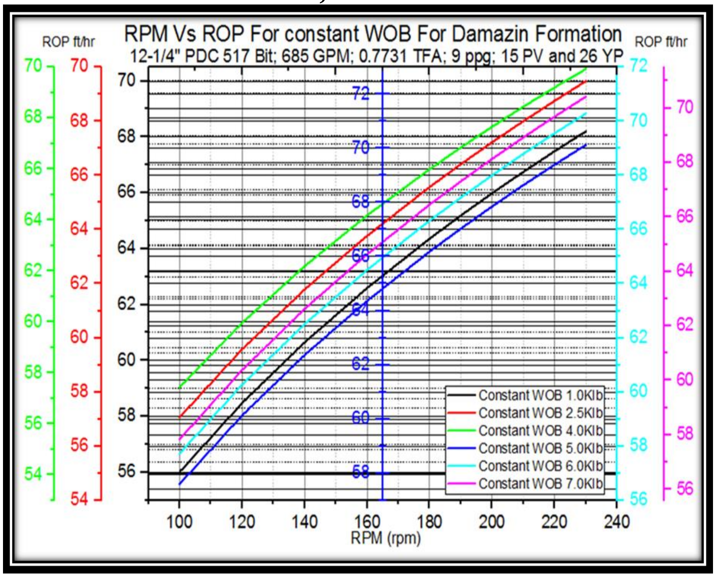

Figure 5. Predicted ROP Vs RPM for Damazin Formation for 517 bits, 12-1/4in hole

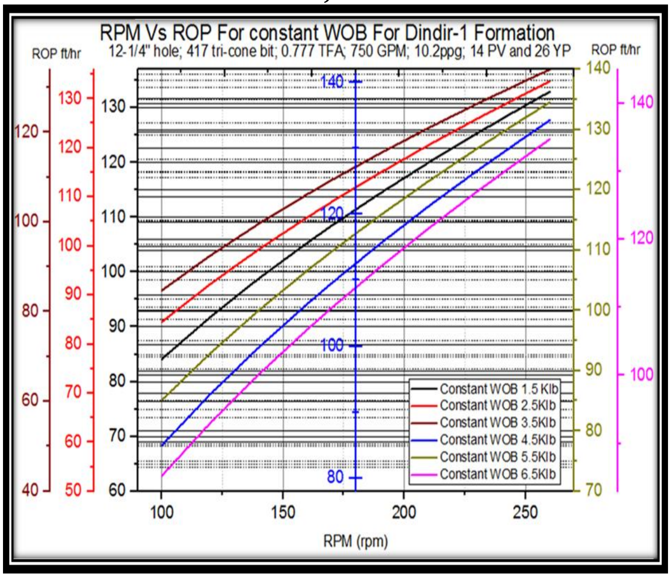

Figure 8. Predicted ROP Vs RPM for Dindir-1 Formation for 417 bits, 12-1/4" hole

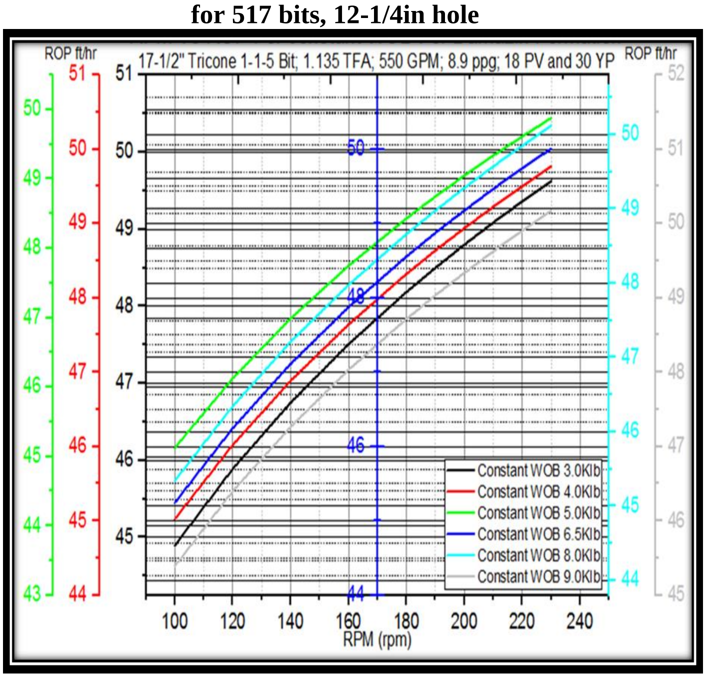

Figure 6. Predicted ROP Vs RPM for Damazin Formation for 115 bits, 17-1/2in hole

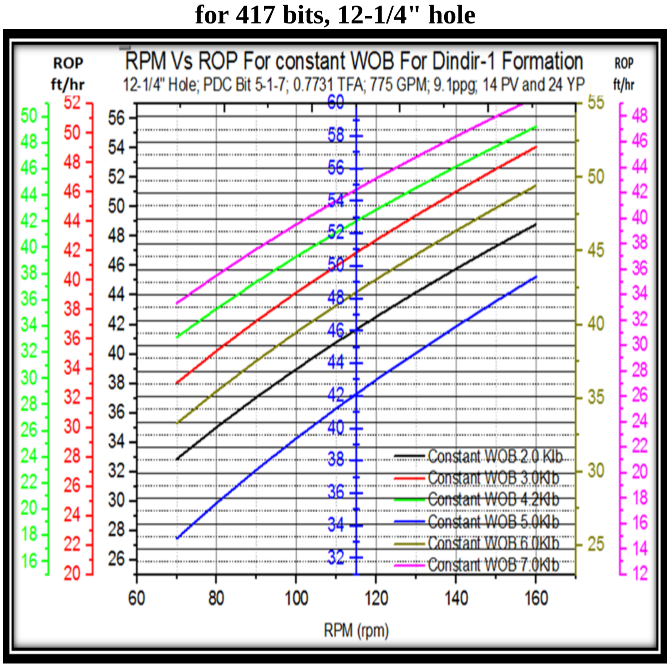

Figure 9. Predicted ROP Vs RPM for Dindir-1 Formation for 517 bits, 12-1/4" hole

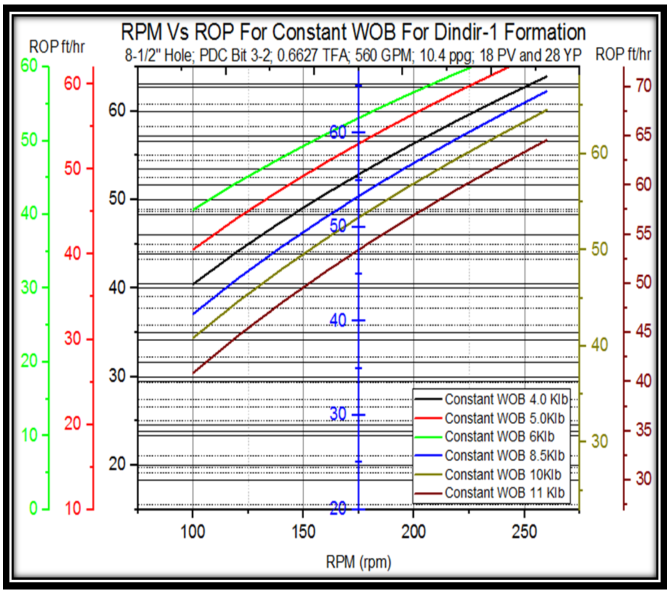

Figure 10. Predicted ROP Vs RPM for Dindir-1 Formation for PDC 3-2 bits, 8-1/2" hole

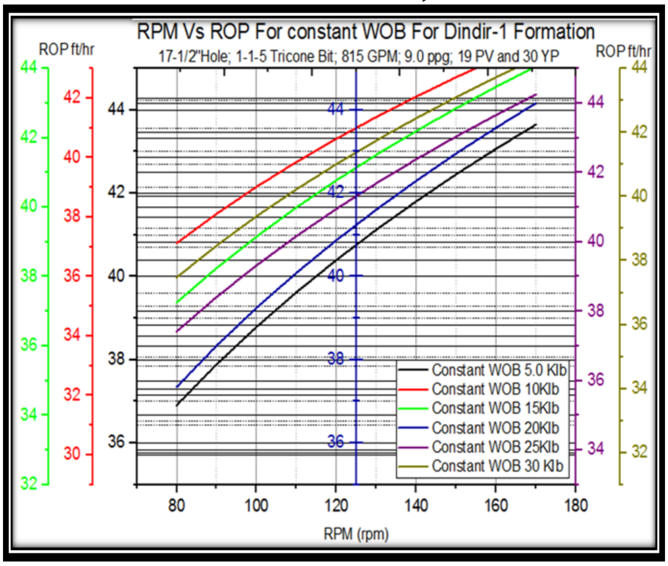

Figure 11. Predicted ROP Vs RPM for Dindir-1 Formation for 115 bits, 17-1/2" hole

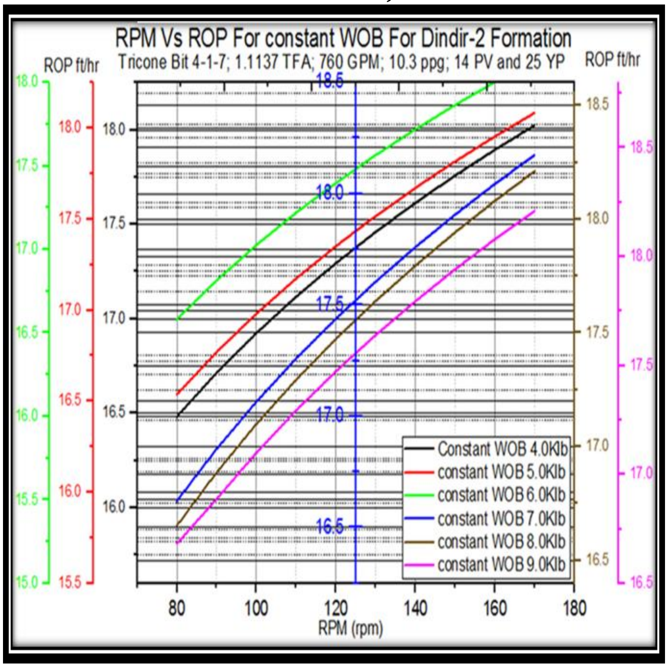

Figure 12. Predicted ROP Vs RPM for Dindir-2 Formation for 417 bits, 12-1/4" hole'

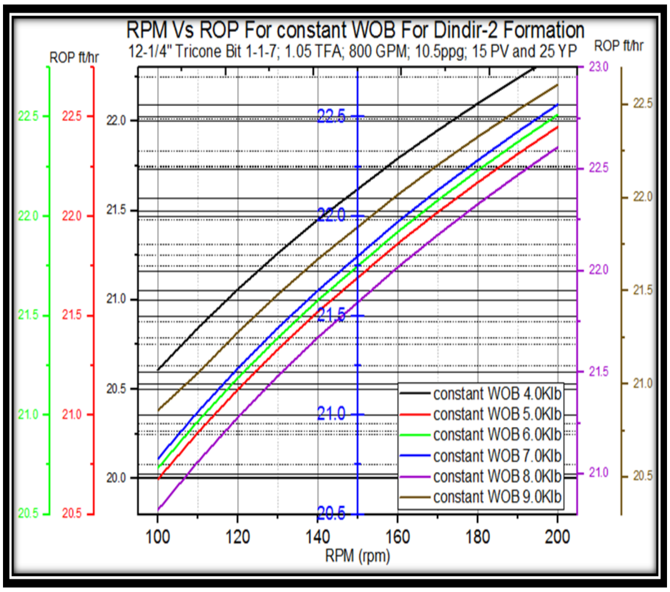

Figure 13. Predicted ROP Vs RPM for Dindir-2 Formation for 117 bits, 12-1/4" hole

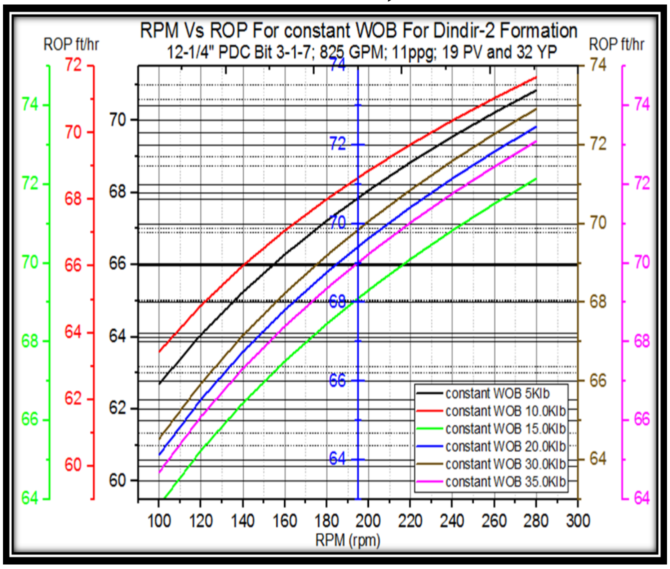

Figure 14. Predicted ROP Vs RPM for Dindir-2 Formation for PDC 317 bits, 12-1/4" hole

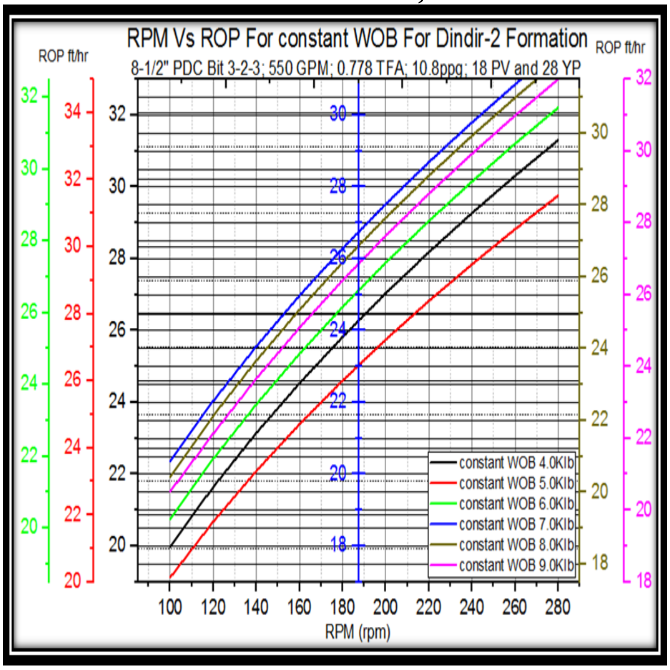

Figure 15. Predicted ROP Vs RPM for Dindir-2 Formation for PDC 323 bits, 8-1/2" hole

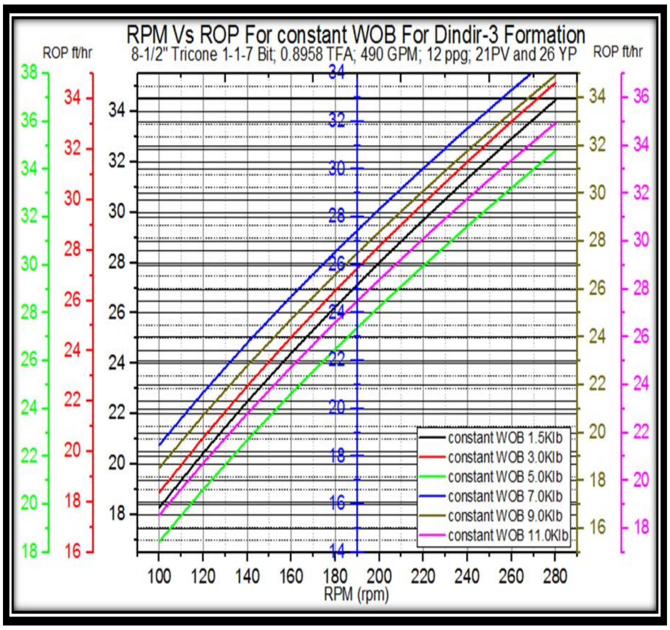

Figure 16. Predicted ROP Vs RPM for Dindir-3 Formation for 117 bits, 8-1/2" hole

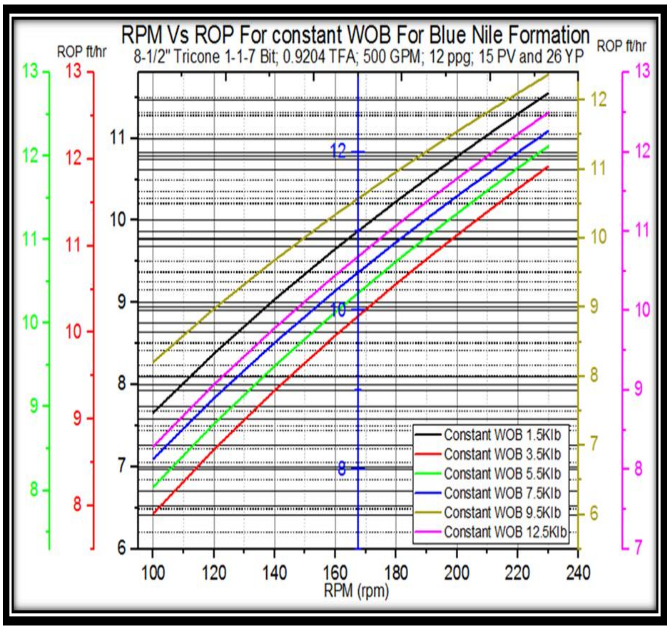

Figure 19. Predicted ROP Vs RPM for Blue Nile Formation for 117 bits, 8-1/2" hole

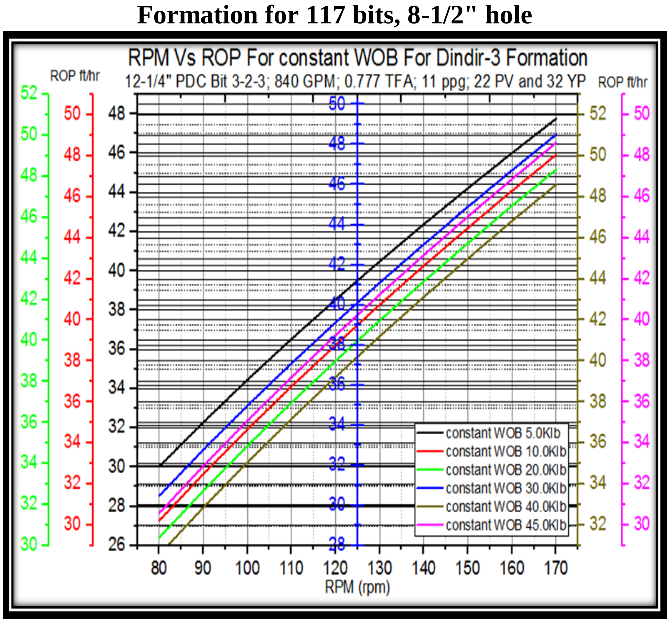

Figure 17. Predicted ROP Vs RPM for Dindir-3 Formation for PDC 323 bits, 12-1/4" hole

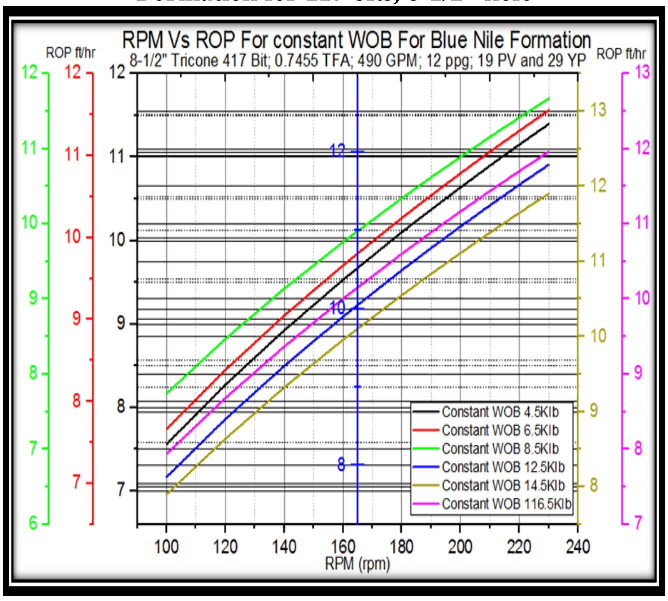

Figure 20. Predicted ROP Vs RPM for Blue Nile Formation for 417 bits, 8-1/2" hole

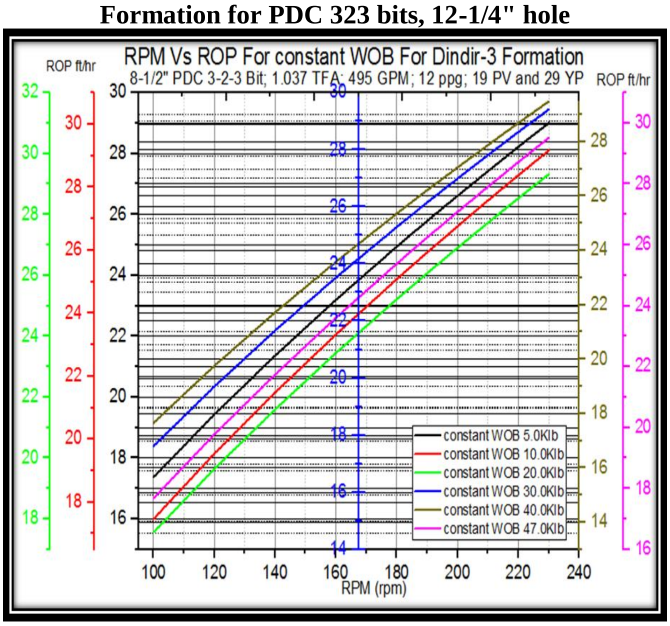

Figure 18. Predicted ROP Vs RPM for Dindir-3 Formation for PDC 323 bits, 8-1/2" hole

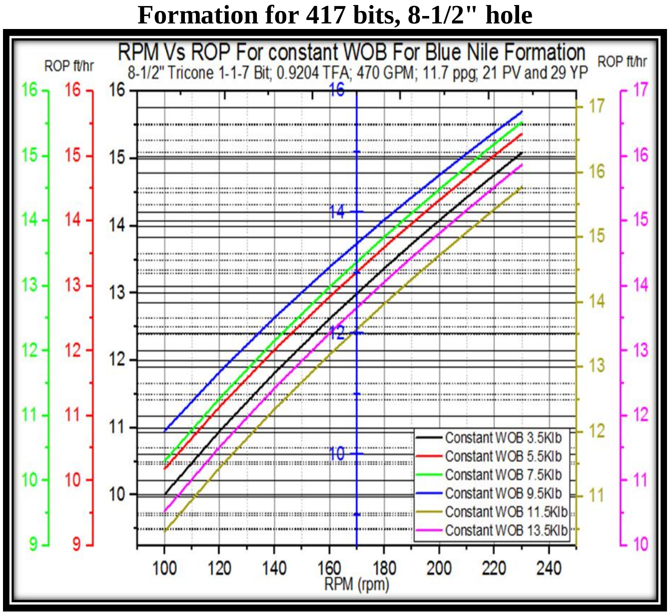

Figure 21. Predicted ROP Vs RPM for Blue Nile Formation for 117 bits, 8-1/2" hole

Conclusion and Recommendations

Three vertical wells selected from Blue Nile Basin respectively Hosan-1, West Dindir-1 and Baraka-1 wells. Wells data collected including operational parameters, drilling fluid parameters and geological description, drilling data matched to each other for each data point individually.

Each well data divided to groups depend on type and locate of formation in Blue Nile basin that consists of five formations: Damazin, Dindir-1, Dindir-2, Dindir-3 and Blue Nile. Then X-values calculated as pre-multiple regression process.

Data correlation have been conducted through residuals, which gave reasonable results together with statistical findings and R^2 values that indicated the data ended up with better results, but still including some negative values.

Absence of drilling fluid rheology during top hole drilling, presence of subnormal formation pressure, absence of enough data range for bit wear and wear distribution over wide range of data points are the main causes of negative values.

Bit wear distributed over drilled interval depends on both formation fingerprint and bit runs in order to overcome data limitation problem across multiple regression technique.

Developed Bourgoyne and Yong model illustrated by the use of field data. Multiple regression technique handled with aid of statistica-12.5 software. Nine unknown coefficients have been determined for each formation individually showing large number of negative values indicating physical meaningless coefficients.

Drilling mechanical parameters, weight on bit and string revolution optimized for both tri-cone and PDC bits for each bit run individually, then drilling rate predicted. The time for rotation and consequently the time required for drilling have observed to reduce by 25%.

Verification using PayZone simulator carried through simulation and re-simulation for both fields measured and predicted drilling rates showed saving in drilling time by approximately 36% from actual field drilling time.

PayZone simulator reflect better and more realistic result than model predicted rate of penetration due to Presence of additional factors specially formation fingerprint and drill bit type.

Bourgoyne and Young model general equation constructed for each formation of Blue Nile basin for both roller cone and PDC drill bits, and then generalization graphs have been produced for similar formations individually depends on bit type and operational conditions.

Recommendations

1. Strongly recommended to apply proposed technique for bits with high dullness rate, in order to produce bit wear distributed over enough wide range of data points.
2. Future studies will be much valuable if some additional variables as torque, drag and bit selection added either to Bourgoyne and Young model or separately in advance as pre-research.
3. This new technique methodology could modified to be suitable for directional and horizontal wells considering hole cleaning and additional rotating steering device.

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