Journal of Advanced Science and Engineering Research Vol 3, No 3 September (2013) 193-208

Mathematical Model Correlation Optimizing the Drilling Parameters in Tharjas Oil Field – Sudan

Article Info

Received: 10/1/2013
Accepted: 28/7 2013
Published online: 1/9/2013

[1, 2]Ahmed Abdelaziz Ibrahim, [1]Tagwa Ahmed Musa, [1] Abusabah Elfatieh Elemam, [1]Fatima Ahmed Eltigani

[1]Sudan U. of Science and Technology – Petroleum Engineering Department – Sudan

[2]Universiti Teknologi PETRONAS – Petrolrum Engineering Department - Malaysia

ISSN 2231-8844

Abstract

Drilling is one of the most complicated and expensive operations in oil exploration and field development. Generally the most problems happened while drilling depends on the formation type; shale/clay formation considered as one of the wildest type causes the instability problems. This study focuses on the physico-chemical mechanical mud properties to get the optimum drilling performance (fewer problems – less cost). Meanwhile, the resulted rate of penetrations using the mathematical model have been plotted to get the optimum weight on bit and rotational speed. This study could be applied over the area using more data for the optimum drilling performance in Tharjas oil field Sudan

Key Word: Drilling Parameter Drilling Optimization Drilling Performance Physico-Chemical Mechanical Mud Properties Simulation Sensoring

Introduction

Holes are drilled in geological strata for a wide range of application, as consequence, drilling experience is very important for successful operation. For any given drilling operation, several drilling technologies are available to optimize the process of drilling safely and in the most possible cost effective manner (Philip, 1991). In any optimization process, a decision has to be made on what parameters are to be optimized. Therefore, within the drilling industry a great amount of attention is directed towards the understanding of increasing the drilling performance. Many of the currently employed systems in the drilling industry prefer to use off-line technique, where historical data from previous wells are correlated with other, in an attempt to predict the nature of a similar hole to be drilled in the same area (James and Azar, 1958). Others relay on drill off test, to predict the likely response of operation in certain rock strata. The results are fed back through various equations and in the same time the field work experience, to determine the optimum operating conditions.

Objectives and Scope

The studying of all drilling parameters is very difficult, but through developing mathematical model this study intended to optimize the drilling performance in the Tharjas Oil Field (Sudan).

Overviews of Study Area

The Tharjath onshore field, located in Block 5A in the Muglad Basin of southern Sudan 950km south of Khartoum, 75km South East of the Bentiu field and 11km west of the White Nile in the Upper Nile Region. This field has been discovered by Lundin in May-1999 with the drilling of TJ-1 well. Following the acquisition of 3D seismic over the field area and drilling of one appraisal well during 2001, Lundin suspended field operations due to security reasons. In June-2003, PETRONAS Carigali Overseas Sudan Bhd (PCOSB) bought Lundin's share and White Nile Petroleum Operating Company (WNPOC) took over the operator ship of Block 5A. By the end of 2003, WNPOC completed the drilling of additional three appraisal wells in Tharjath (Drilling Department, 2006 and Gass, 1981).

Five types of depositional systems are identified that are, alluviafan, braided stream, meander belt, marginal lacustrine and open lacustrine systems from land ward to lacustrine center (Galle and Woods, 1963), table (1).

Table (1): Field Structure Evaluation of Tharjath

Well	Objective Fm	Oil Showing	Pay Zone
Azraq-l	AbuGabra& Bentue	Abu Gabra (trace)	None
May 25-I	Nyile & Tentdi Sands	Nayil Fm (3240-3520m)	None
Amal -I	Amal (Wildcat)	Amal Fm (3300,3410m)	None
El Majak -1	Nayil & Tendi Sands	None	None
Kaikang -2	Amal Sandstone	Nayil Fm (l700-1740m)	None
Kaikang -1	Wildcat	Tendi Fm (1l88,l250m)	Tendi Fm

There are six regional cap rocks in the study area including the mudstone of Abu Gabra, Aradeba Ghezal, Baraka, Nayil and Adok. The mudstone of Aradeiba is the most stable followed by that of the Abu Gabra, which is not only capable of keeping the hydrocarbons from moving down ward and also sealing the sandstone oil pools in the interior of the Abu Gabra formation, figure (1)

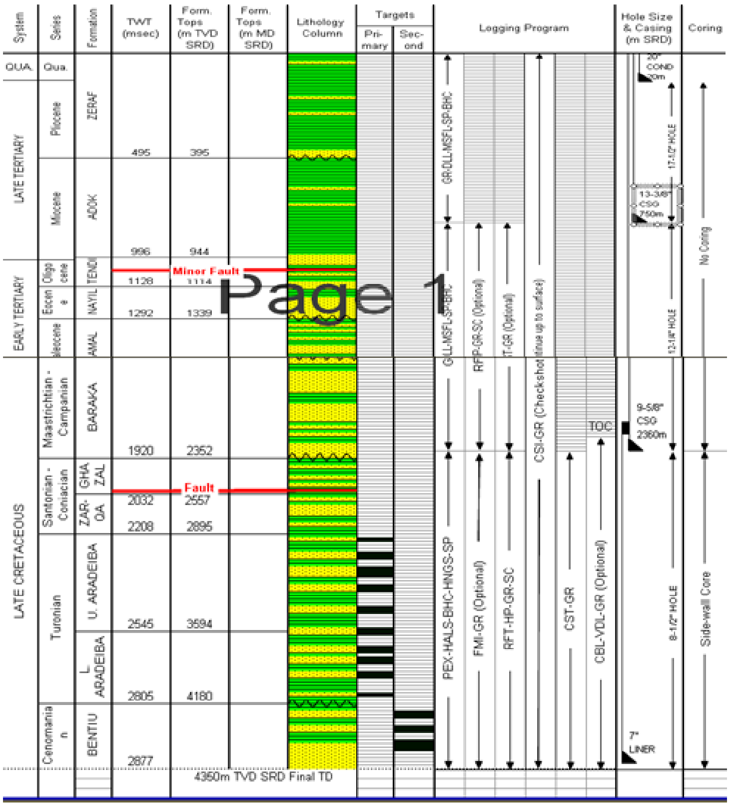


Figure (1): The Planned Well Design Generalized Strategraphic for the Muglad Basin Showing Principle Lithology, Maximum Formation Thickness, Producing Horizon, and Unconformities (Drilling Department, 2006; Gass, 1981; Galle and Woods, 1963).

Mathematical Drilling Model

Generally the drilling optimization program is a collection of controllable equations, that includes the suitable drilling controllable variables directly effects rate and cost of drilling. Galle et al., 1960 and Aswad, 1986 gave these essential equations

Penetration Rate:

$$\frac{dF}{dT} = \frac{C_F W^K N^r}{a^p} \tag{1}$$

Rate of bit teeth wear:

$$\frac{dD}{dT} = \left(\frac{1}{A_f}\right)\frac{R}{am} \tag{2}$$

Rate of bit bearing wear:

$$\frac{dB_x}{dT} = \frac{N}{SL} \tag{3}$$

Where:

F is footage drilling (ft), T is rotating time (hrs), CF is formation drillability Reflect factor, W is weight on bit (WOB) (1000 Ib), K is power constant of weight on bit, N is rotational

Speed (RPM). D is rate of standard wear in bit teeth, and a is a variable depend on (D): (a = 0.928125D2+6.0D+1). r is power constant of rotational speed and p is power constant of variable (a), the value of p depend on type of bit teeth wear. AF is Formation Abrasiveness Factor, and R is function between rotational speed and rate of bit teeth wear: (R = N+0.00004348N3). m is function between weight on bit (WOB) and bit teeth wear: (m = 13591-71419logW). Bx is the consuming part from total bit life. S is drilling fluid factor, reflect the effect of mud properties on bit bearing life. L is Function between weight on bit and bit bearing wear

$$L = \frac{21340}{(1 + 0.03W)^{3.23}} \tag{4}$$

Solving Equation (1), (2), and (3) to bit dullness (D) and the rotating time (T) the main factors controlling bit life are defined.

$$\frac{dF}{dD} = \frac{C_F A_F W^K N^r m}{R} a^{(1-P)} \tag{5}$$

This model was developed to correct the effects of six variables control the drilling rate, these variables are: weight on bit (W), rotational speed (N), drilling fluid density (ρ), drilling fluid viscosity (μ), flow rate, nozzle size (dn), effects of differential pressure and bit wear on penetration rate as:

$$\frac{dF}{dT} = \frac{C_F W^Y N^z}{(1+C_2 D)} \cdot \frac{1}{(1+\Delta P^x)} \cdot \log\left(\frac{Kq\rho}{d_n \mu}\right) \tag{6}$$

Where: q is flow rate (gallon/min) , Δp is differentia pressure (103 Ib/in), ρ is drilling fluid density (Ib/gal), μ is drilling fluid viscosity (cp), X, Y and Z are constants depend on bit nozzle selection, and dn is the nozzle diameter (in).

Tharjas ROP Developed Mathematical Model

With water as the drilling fluid, the increase in ROP as a result of increasing WOB and RPM ducted from equation 7. This represents the perfect-cleaning model, and reviewed as a starting point for development of an imperfect-cleaning model:

$$\frac{dF}{dT} [\Leftrightarrow] \frac{aS^2 d_b^2}{NW^2} + \frac{b}{Nd_n^2} + \frac{C_F \gamma_F \mu}{NWF_j} \tag{7}$$

Where: γ_F is the drilling fluid weight (ppg). , Fj is the hydraulic energy at the bit (HP). d_b is the bit diameter (in). b is a constant depends on the nozzle diameter. Estimating the hydraulic energy at the bit face and evaluating the ability of the jet stream to transfer energy to the bottom of the hole. Theoretically, the impact pressure should be independent of the nozzle size for a fixed bit size and affixed value of impact force calculated from equation 8.

$$F_j = 3.361\left[\frac{PS^2 q}{d_n^2 v_n}\right] \tag{8}$$

The reduction in impact pressure as the nozzle diameter increases is causes by an accelerated entrainment of fluid into the jet stream resulting from the return flow of fluid from under the bit. The area available for fluid return flow from under the bit is equal to about 15% of the total bit area. The impact force modified for nozzle size effects and the influence of the return flow is given by:

$$F_{jm} = (1 - A_n^{-0.1241})F_j$$

where An is the total nozzles area (in^2).

$$\frac{dF}{dT} = \frac{\dfrac{C_F W^y N^z}{(1+C_2 D)} \bullet \dfrac{1}{1+\Delta P^x} \bullet \log\left(\dfrac{kq\rho}{d_n \mu}\right)}{\dfrac{aS^2 d_b^2}{NW^2} + \dfrac{b}{Nd_n^2} + \dfrac{C_F \gamma_F \mu}{NWF_{jm}}}$$

b is very small and can be neglected.

$$\Rightarrow \frac{dF}{dT} = \frac{F_{jm}^2 C_F N^y W^z \log\left(\dfrac{kq\rho}{d_n \mu}\right)}{(1 + C_2 D)(1 + \Delta P^x)(aS^2 d_b^2 + C_F \gamma_F \mu)}$$

Physico-Chemical Mud Properties

The data below describe the properties of the mud (mud weight, plastic viscosity etc,) and the increase of cutting concentration with the survey of the well (measure depth, inclination, azimuth and vertical section). These data show real time relationship between the depth and parameters, which affect the physico-chemical mud properties and bore stability.

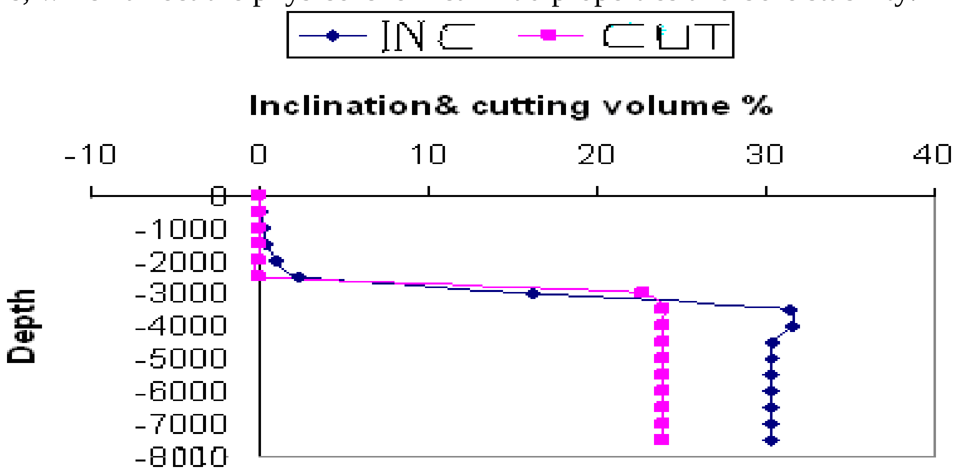


Figure (2): The Depth vs Cutting Transport (inclination-cutting volume)

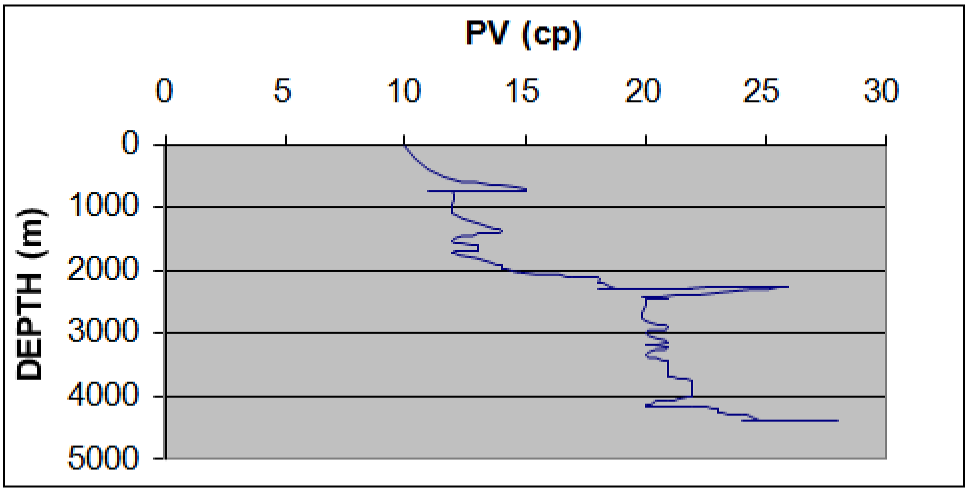


Figure (3): The Depth vs Plastic Viscosity.

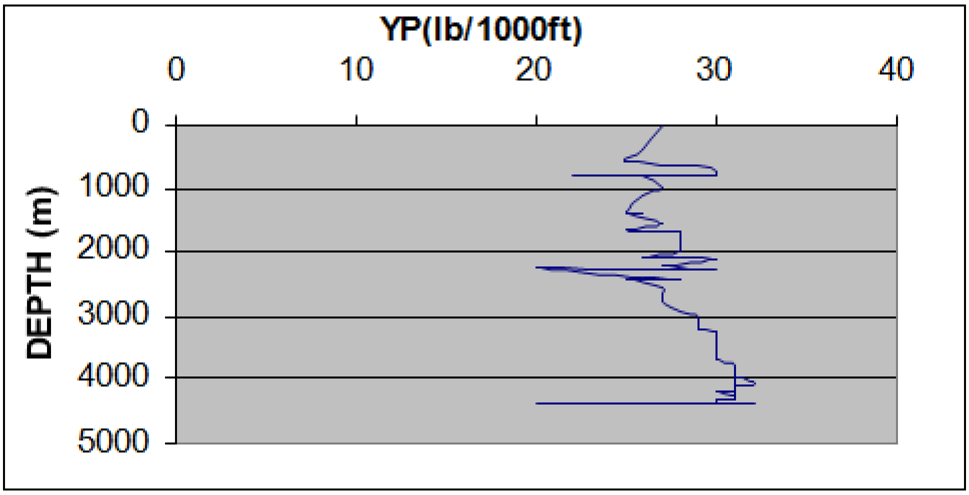


Figure (4): The Depth vs Yield Point

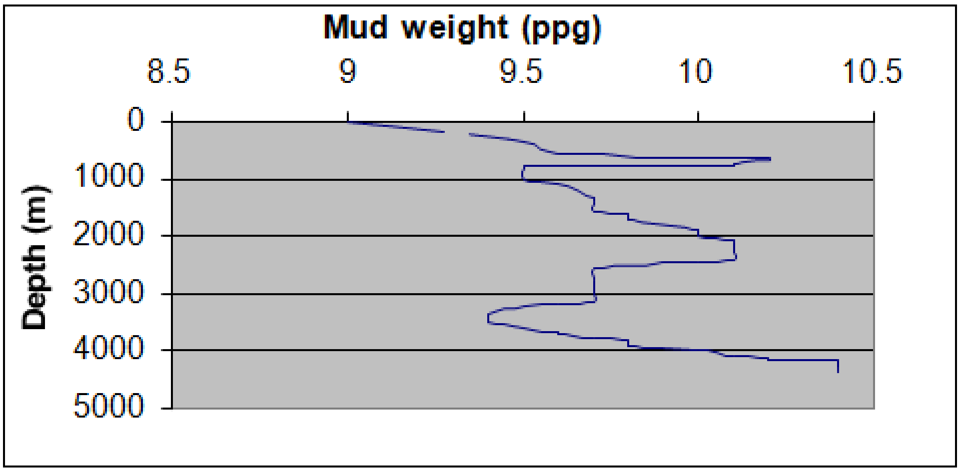


Figure (5): The Depth vs Mud Weight.

From the above figures (2, 3, 4, and 5) it is obvious and clear there is a certain problem by the go a head drilling from the depth 1200m to approximately 2780m. This 1580 long meter subjected to a very concentrated study governing the performance and drillability by different two scenarios. Scenario (A): Theoretically and as boundary condition for the operation in this scenario; the bit is new and in good condition with nozzle diameter up to 0.39 in, the flow rate fixed to 625 gpm, assume the formation drillability is good.

Table (4): Computational Value of Drilling Rate (WOB =10 kIbs)

		calculated		
N	W	$(dF/dT)_{p=10.1}$	$(dF/dT)_{p=9.7}$	(dF/dT)
40	10	13.72	12.80	14.3_{actual}
80	10	20.79	19.40	$21.9_{predicted}$
120	10	26.52	24.75	$27.7_{predicted}$

Table (5): Computational Value of Drilling Rate (WOB = 30 kIbs)

		calculated		
N	W	$(dF/dT)_{p=10.1}$	$(dF/dT)_{p=9.7}$	(dF/dT)
40	30	41.16	38.41	$42.9_{predicted}$
80	30	62.38	58.22	$65.1_{predicted}$
120	30	79.56	74.26	$83.02_{predicted}$

Table (6): Computational Value of Drilling Rate (WOB = 50 kIbs)

		calculated		
N	W	$(dF/dT)_{p=10.1}$	$(dF/dT)_{p=9.7}$	(dF/dT)
40	50	68.59	64.02	$71.5_{predicted}$
80	50	103.97	97.04	$108.83_{predicted}$
120	50	132.61	123.77	$138.2_{predicted}$

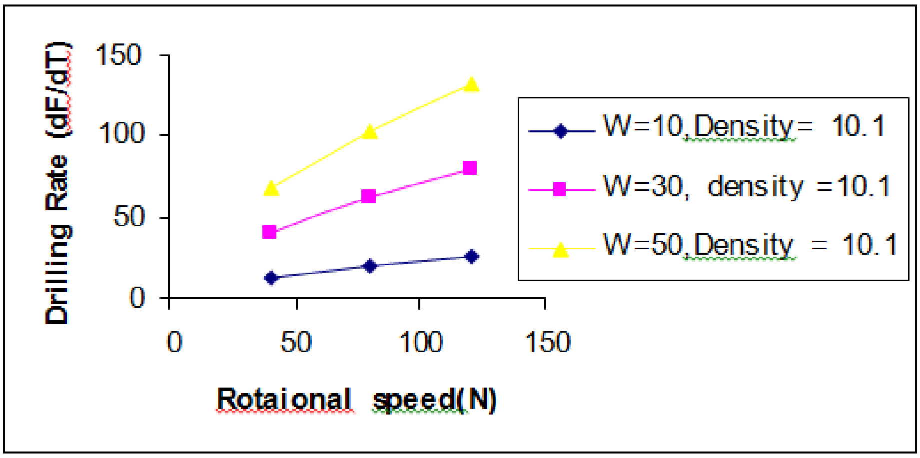


Figure (6): Drilling rate vs rotational speed (N) with various values of weight on bit (WOB) and constant density 10.1 PPG

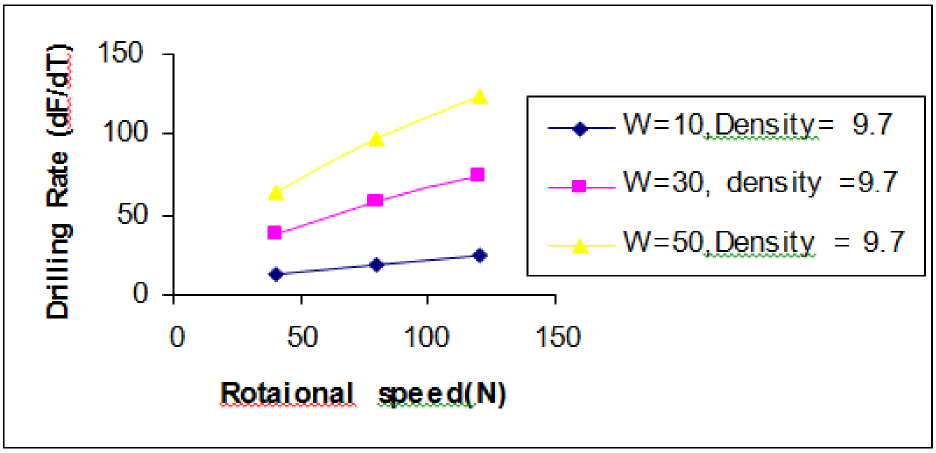


Figure (7): Drilling rate vs rotational speed (N) with various values of weight on bit (WOB) and constant density 9.7 PPG

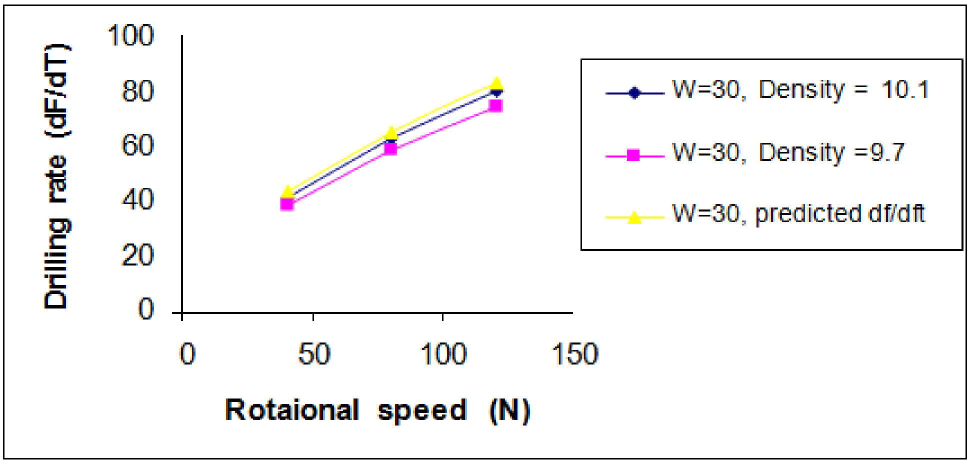


Figure (8): Drilling rate vs rotational speed (N) with various densities (WOB = 30 kIbs)

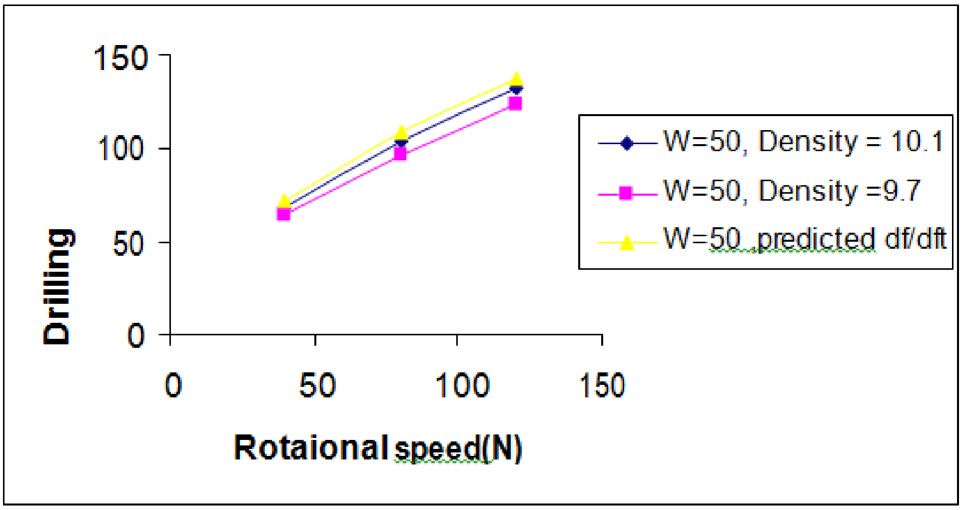


Figure (9): Drilling rate vs rotational speed (N) with various densities (WOB = 50 klbs)

Table (7): Computational Value of Drilling Rate (N = 40 rev/mint)

		Calculated	
N	W	$(dF/dT)_{\rho=10.1}$	$dF/dT)_{\rho=9.7}$
40	15	19.21	18.66
40	45	57.62	55.97
40	75	96.03	93.29

Table (8): Computational Value of Drilling Rate (N = 80rev/mint)

		Calculated	
N	W	$(dF/dT)_{\rho=10.1}$	$dF/dT)_{\rho=9.7}$
80	15	29.11	28.28
80	45	87.34	84.84
80	75	145.56	141.40

Table (9): Computational Value of Drilling Rate (N = 120 rev/mint)

		Calculated	
N	W	$(dF/dT)_{\rho=10.1}$	$dF/dT)_{\rho=9.7}$
120	15	37.13	36.07
120	45	111.39	108.21
120	75	185.65	180.35

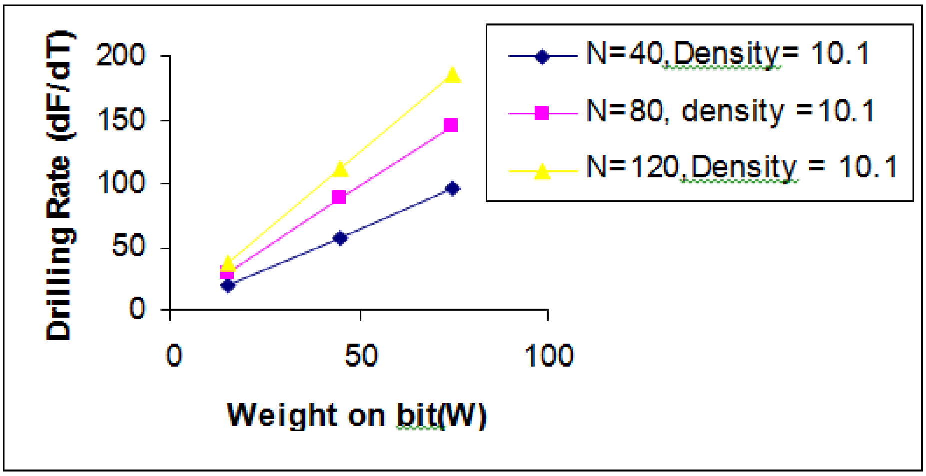


Figure (10): Drilling rate vs weight on bit (W) with various values of rotational speed (N) and constant density 10.1 PPG

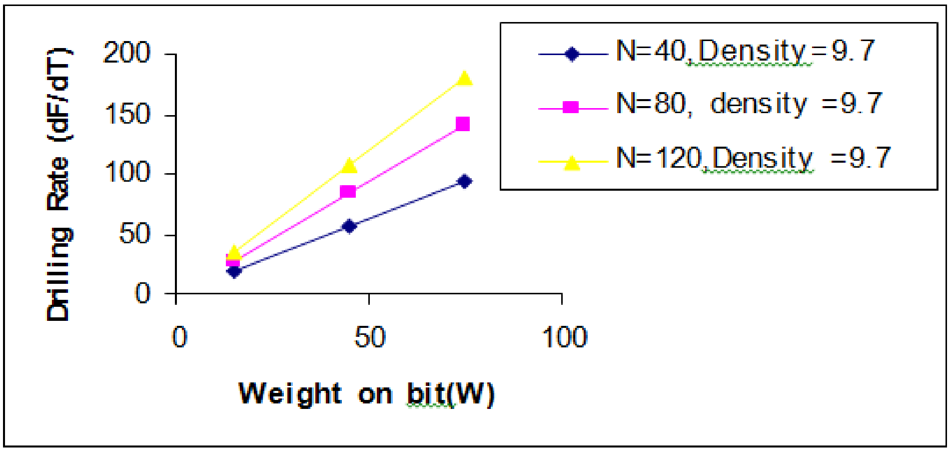


Figure (11): Drilling rate vs weight on bit (W) with various values of rotational speed (N) and constant density 9.7 PPG

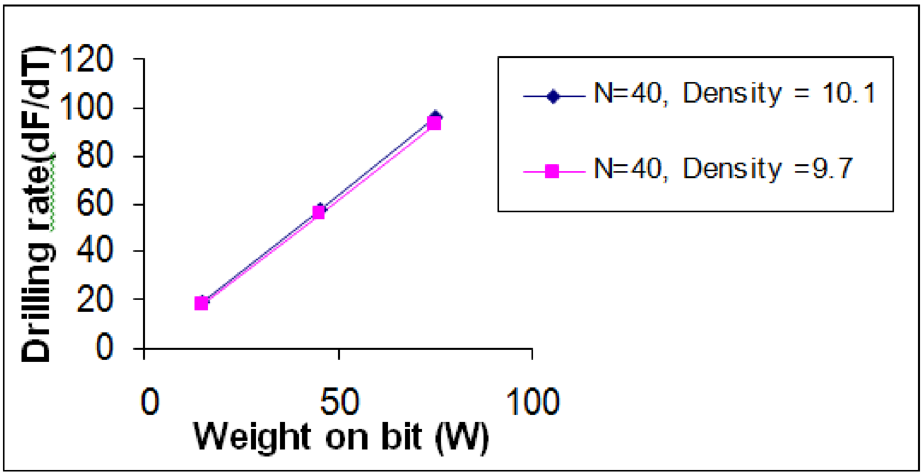


Figure (12): Drilling rate vs weight on bit (W) with various densities (N = 40 rev/mint)

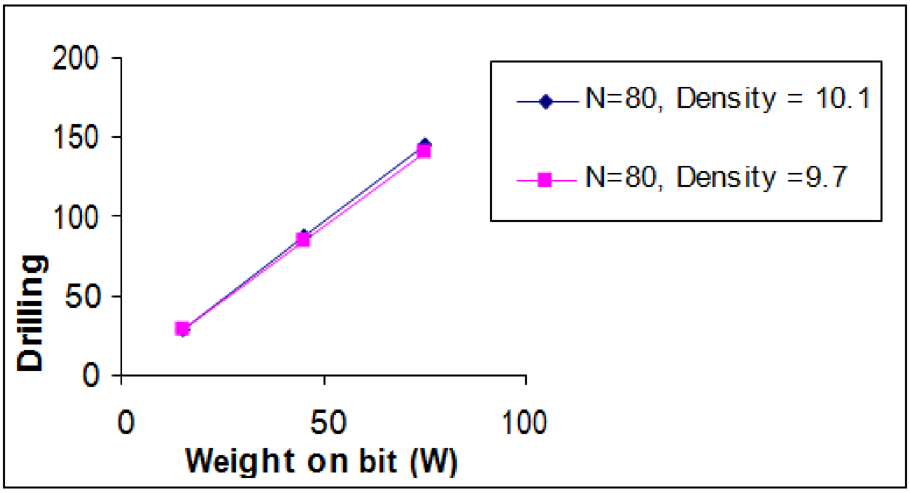


Figure (13): Drilling rate vs weight on bit (W) With various densities (N = 80 rev/mint)

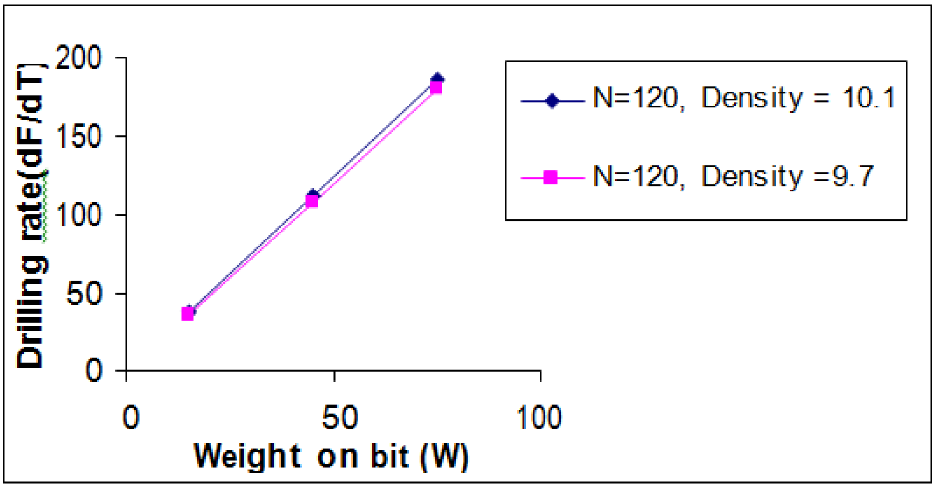


Figure (14): Drilling rate vs weight on bit (W) with various densities (N = 120 rev/mint)

Scenario (B): Theoretically and as boundary condition for the operation in this scenario; the bit is in bad condition with nozzle diameter up to 0.39in, the flow rate fixed to 625gpm, assume the formation drill ability is very bad.

Table (10): Computational Value of Drilling Rate (WOB = 10 kIbs).

		calculated		
N	W	$(dF/dT)_{\rho=10.1}$	$(dF/dT)_{\rho=9.7}$	(dF/dT)
40	10	6.86	6.40	7.15
80	10	10.39	9.70	10.83
120	10	13.26	12.37	13.82

Table (11): Computational Value of Drilling Rate (WOB = 30 kIbs).

		calculated		
N	W	$(dF/dT)_{\rho=10.1}$	$(dF/dT)_{\rho=9.7}$	(dF/dT)
40	30	20.58	19.21	21.45
80	30	31.19	29.11	32.51
120	30	39.78	37.13	41.46

Table (12): Computational Value of drilling rate (WOB = 50 kIbs).

		calculated		
N	W	$(dF/dT)_{\rho=10.1}$	$(dF/dT)_{\rho=9.7}$	(dF/dT)
40	50	34.29	32.01	$35.75_{prdicted}$
80	50	51.98	48.52	$54.19_{prdicted}$
120	50	66.30	61.88	$69.12_{prdicted}$

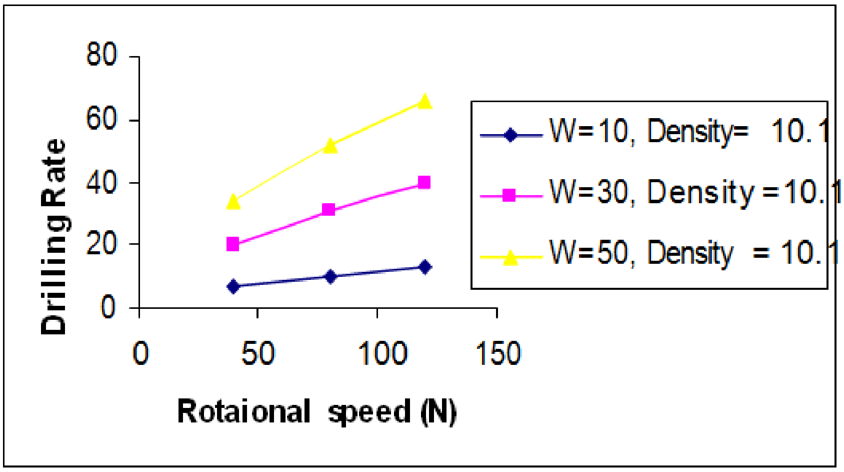


Figure (15): Drilling rate vs rotational speed (N) with various values of weight on bit (WOB) and constant density 10.1 PPG

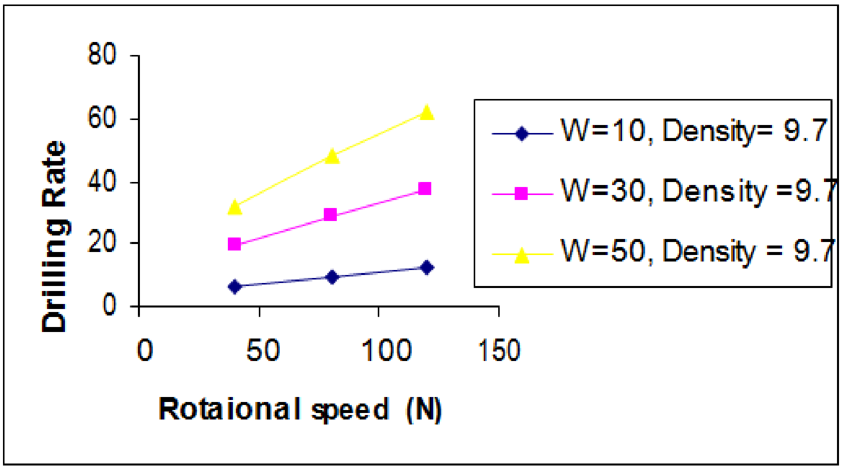


Figure (16): Drilling rate vs rotational speed (N) with various values of weight on bit (WOB) and constant density 9.7 PPG

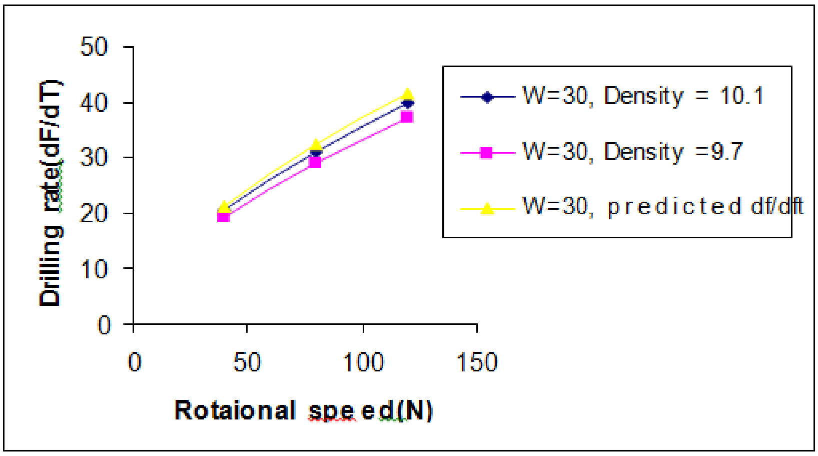
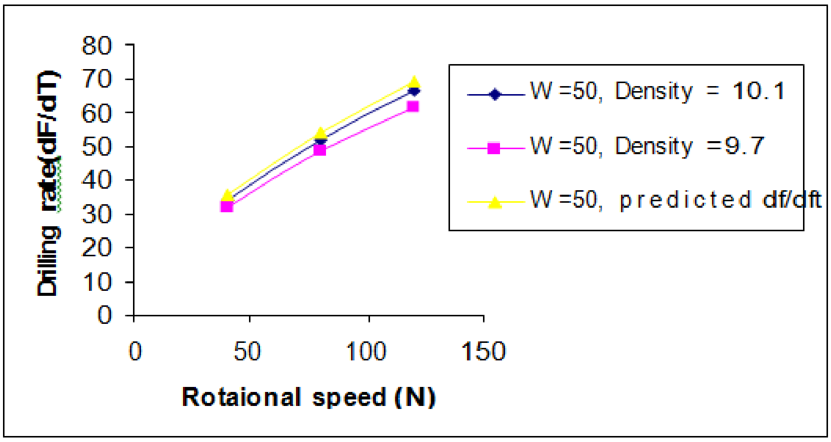


Figure (17): Drilling rate vs rotational speed (N) with various densities (WOB = 30 kIbs)



\ Figure (18): Drilling rate vs rotational speed (N) with various densities (WOB = 50 kIbs)

Table (13): Computational Value of Drilling Rate (N = 40 rev/mint).

		Calculated	
N	W	$(dF/dT)_{\rho=10.1}$	$dF/dT)_{\rho=9.7}$
40	15	9.60	9.33
40	45	28.81	27.99
40	75	48.62	46.65

Table (14): Computational Value of Drilling Rate (N = 80 rev/mint).

		Calculated	
N	W	$(dF/dT)_{\rho=10.1}$	$dF/dT)_{\rho=9.7}$
80	15	14.56	14.14
80	45	43.67	42.42
80	75	72.78	70.70

Table (15): Computational Value of Drilling Rate (N = 120 rev/mint).

		Calculated	
N	W	$(dF/dT)_{\rho=10.1}$	$dF/dT)_{\rho=9.7}$
120	15	18.57	18.03
120	45	55.70	54.10
120	75	92.83	90.17

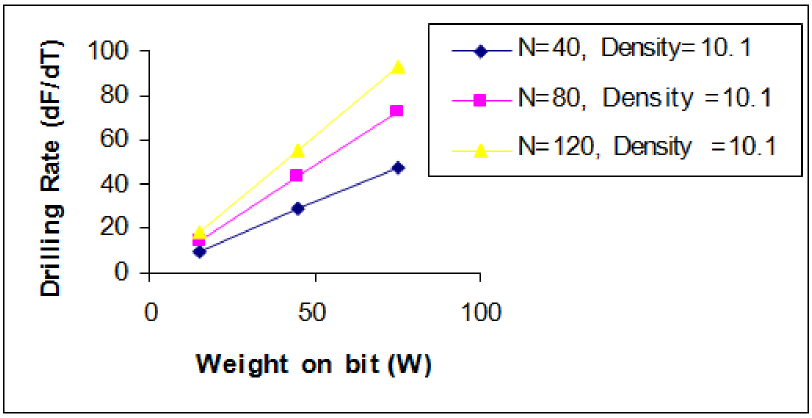


Figure (19): Drilling rate vs weight on bit (W) with various values of rotational speed (N) and constant density 10.1 PPG

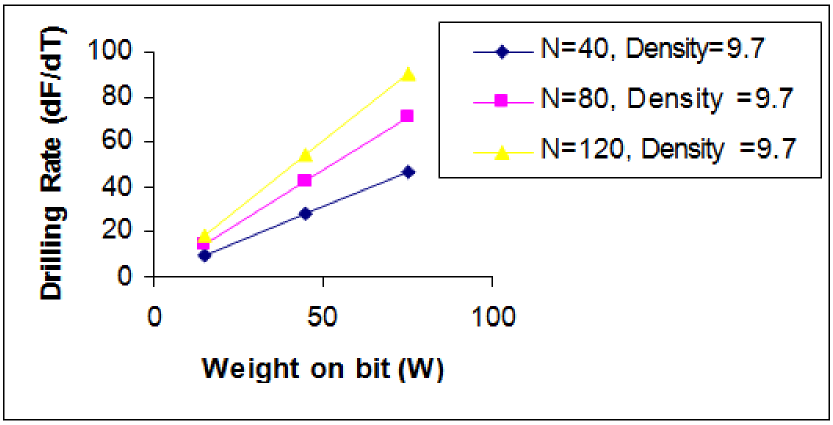


Figure (20): Drilling rate vs weight on bit (W) with various values of rotational speed (N) and constant density 9.7 PPG

Results and Discussion

Data and results of the analytical processes have been subjected to overall correlation, and according to that:
Very poor circulating and hydraulics system and no alternatives for circulation during the repetitive failures; meanwhile very slow rate of penetration in the clay layers. The cuttings volumes start to increase with depth as (2562.25 m, 22.763%) and reached (3000 m, 32.968%).

The pressure drops where very sever and the losses within the pump are greater than the well circulation system (pipe, bit and annulus).

The well program calls for a very long open hole section, i.e. + 2,300 m, which is a very long section especially for a high deviated well, short radius curvature and exposing too many layers with different physical properties. Not to forget the deep kick off point, (i.e. 870 m), resulting in higher average build up rate and higher dog leg severity.

Generally, the inclination in vertical section is not exceeding 5 degree, but it has been found that the inclination with depth (1829.3 m, 0.38º) and have increased to be (2201.5 m. 6.08º) and again (2648.65 m, 0.38º). Finally, the inclination increased with depth (3296.5 m, 33.2º) and continued till the TVD. The azimuth change with depth found to be (1825.3 m, 141.46 º), (2201.46 m, 220.14 º) and increased to (2562.25 m, 348.81 º).

Conclusions and Recommendations

Enhance the hole cleaning efficiency and keep the solid percentage as minimum as acceptable by providing the rig with alternative circulating, rotating facility and to be sure of the drilling crew capabilities. Meanwhile, High attention and hazardous when reaching the BARAKA formation (mud weight has to be between 9.6-9.8 PPG).

The kick-off point has to be shallower at + 300 m and design the well for lower build up rates and increase the frequency of wiping trips (in case of very slow ROP) to avoid the key-seats and over pulls (+35 klbs ~ ±60 kIbs.

The rate of penetration must exceed the critical 15 m/h and must be controlled under the 75 m/h as compatible with cutting generation, lifting capacity and pump capability.Based on the analysis of the drilling data the main problems of the wellbore cleaning are due to the incompact formations, the ROP is fast and there are so many cuttings remained in the wellbore. The loose formations are found to be washed out when the annular velocity of drilling fluid is too high. To deal with these problems, it is recommended the regime of the maximum jet impact force is used to design the hydraulics.

Further studies have to be done to evaluate the KCL/Polymer, the suggested silldril components and simulating the directional path to avoid the formation healing/tiding.

References

Aswad, Z., AL-Khafaji, A. H and Towfeek, T. F., 1986, “Bit Selection is The Key to an Economical Efficient Drilling Operation", the 4th Scientific Conference, Scientifics research Council Vol. 2, Part 1, Bagdad-Iraq.

Drilling Department, 2006, "Daily Drilling Report (DDR)", White Nile Petroleum Operating Company (WNPOC), Khartoum, Sudan.

Drilling Department, 2006, "Daily Mud Report (DMR)", White Nile Petroleum Operating, Company (WNPOC), Khartoum, Sudan.

Galle, E. H. and H.S. Woods, 1960, "How to Calculate Bit weight and Rotary speed for Lowest Cost Drilling”, Oil and Gas Journal.

Galle, E. H. and H. S. Woods, 1963, “Best Constant Weight and Rotary Speed for Rock Bits”, APT Drilling and Production Practice.

Gass, 1981. “Regional Geology and Tectonic Project. The Muglad Basin, Sudan", CNPC Research Center-China.

James, M., and J. J. Azar, 1958, “ Drilling Fluid Optimization ", Gulf Publication.

Philip J. Rowsel, 1991, “The Automatic Optimization of Drilling Performance", Ph.D. Thesis, University of Nottingham, UK.