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Rate of penetration optimization using burgoyne and young model (a case study of Niger delta formation)

Abstract

Drilling optimization models provide a technique for predicting and controlling drilling processes. Rate of penetration (ROP) prediction before drilling provides a means of improving overall drilling efficiency, minimization of drilling time and by extension reduction of drilling cost. Several ROP models are available in the oil and gas industry today, however most of these models are inadequate leading to inaccurate predictions. This work employs a different technique for ROP prediction by modifying original Burgoyne and Young's (B&Y) model using data from Niger Delta. The ROP prediction and percentage error were determined at each of the selected well depth intervals The results obtained showed that the Burgoyne &Young model performed well by error of about 0.03%. The model was further optimized to minimize the error and the overall result shows that the error was minimized from 0.03% to 0.003%. Results obtained from the optimized Burgoyne and Young model imply that the model is suitable for ROP prediction in the Niger Delta.

Keywords: drilling operation, optimization, rate of penetration, burgoyne, young model

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Idris Danasabe Tanko, Abubakar Tanko, Abubakar Bello

Department of Mineral and Petroleum Resources Engineering, Nigeria

Correspondence: Abubakar Tanko, Mineral and Petroleum Resources Engineering Department, Kaduna Polytechnic, Nigeria, Email abubakartanko87@gmail.com

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Introduction

The major goal of every drilling operation is to make holes in the ground from surface to a reference depth mainly for oil or gas exploitation. Petroleum industry is a capital intensive industry. There is a need to save time, cost and increases efficiency. One of the most costly aspects of the industry is exploration and drilling and therefore has lot of potential for optimization and reducing cost. Planning and predicting future drilling operation base on controllable variables will be essential in order to realize these efficiency gains.[1–3] This may aid ROP prediction using mathematical models.[4–12] The study area is located in the onshore part of Niger Delta sedimentary basin. The subarea covered by the Niger Delta basin is about 7500km^2 a total area of 300,000km^2 and sediment fill has a depth between 9–12km.[13] It is composed of several different geological formations that indicate how this basin was formed, as well as the regional and large scale tectonics of the area. In addition this basin is an extensional basin surrounded by many other basin in the area that all formed from similar process. The Niger Delta basin is bounded by the Cameroon volcanic line and the transform passive continental margin.[13]

The stratigraphic structure of the Niger Delta basin is divided into three (3) unit Benin formation, Agbada formation and Akata formation. Benin formation is the topmost formation followed by Agbada formation at the middle then the Akata formation which is lowest. The Benin formation is made up continental sand deposit with shale intercalation covered with topmost low velocity layer, which in most cases is weathered within which surface wave are excited and generated. The Agbada formation is below the Benin formation. It contains reservoir sand which traps the hydrocarbon resources of the Niger Delta Basin. The Akata formation is dominated by shale it serves as the main source of hydrocarbon in the Niger Delta Basin. Economically Niger Delta basin has a very high economic value. It contains a very predictive petroleum system, it produce more than 2 million barrels of oil per day. The entire system is predicted to contain 34.5 billion barrels of oil and 95 trillion cubic feet of natural gas.[14] These make it one of the largest oil production provinces in the world.

Rate of penetration models

Mathematical drilling models provide method to predict and control drilling process and minimize drilling cost. Drilling models also provide a means of recognizing unusual effect when the observed but performance deviate from prediction rate, some of this models are Burgoyne and Young (B&Y), Mechanical Specific Energy (M.S.E), D-exponent, modified D-exponent, Cunningham, Maurer, Bingham, Moore, Warren Motahari etc. drilling models. Drilling parameters obtained from two (2) wells (well A & B) drilled within the Niger.[15]

Burgoyne and young (B&Y) drilling models is the most complete mathematical that has been used for rolling cutter bit. In 1973 B&Y suggested a drilling model considering the effect of several drilling variables on the rate of penetration. In this model the effect of the parameters such as WOB, RPM, Bit tooth wear and other assumed to be independent of one another.

$$R = (f1)(f2)(f3)(f4) ------(fn) \quad (1)$$

$$f1 = e^{2.303a1} = k \quad (2)$$

$$f2 = e^{2.303a2(10000-D)} \quad (3)$$

$$f3 = e^{2.303a3D^{0.69(gp-9.0)}} \quad (4)$$

$$f4 = e^{2.303a4D(gp-pc)} \quad (5)$$

$$f5 = \left[\frac{(\frac{w}{db}) - (\frac{w}{db})_t}{4 - (\frac{w}{db})_t}\right]^{a5} \quad (6)$$

$$f6 = \left(\frac{N}{60}\right)^{a6} \quad (7)$$

$$f7 = e^{-a7h} \quad (8)$$

$$f8 = \left(\frac{F_j}{1000}\right)^{a8} \quad (9)$$

D= true vertical depth (ft)

gp= Pore pressure gradient (lbm/ft)

ρc =equivalent circulating density

$\left(\frac{w}{db}\right)t$ = Threshold bit weight per inch of bit diameter at which the bit begin to drill 1000lbf/inch

h=fractional hook dullness

Fj=hydraulic impact force beneath the bit force lbf

a1 to a8 = constant that must be chosen based on local drilling conditions

f1=function represent the effect of formation strength and bit type on penetration rate.

$f2$= Function account for the rock strength increase due to normal compaction with depth.

$f3$ =function model effect of under compaction experienced in abnormal pressure formation.

$f4$ =function model the effect of bit weight and rotary speed on penetration rate.

$f5$ & $f6$ function account for the rock strength increase due to normal compaction with depth.

$f7$= Function models the effect of tooth wear.

$f8$ =function model the effect of bit hydraulic on rate of penetration.

h=fractional tooth dullness

Fj =hydraulic impact force beneath the bit (lbf).

The constant a_1 through a_8 can be computed using past drilling data obtained in the area when drilling data is available. The above drilling model can be use for drilling optimization calculation and for detection of changes in formation pore pressure.[16]

Materials and methods

Rate of penetration prediction was done using Burgoyne and Young drilling model. Well data in Niger Delta Basin was collected from Nigeria Petroleum Development Company a subsidiary of Nigeria National Petroleum Company (N.N.P.C). The name of the well was deleted from the given data for confidential purpose, the name of the well was renamed as Well A with a total depth of 9664ft. The Well data consist of drilling parameters such as well depth, rate of penetration, weight on bit, flow rate, rotation per minute, torque, bit diameter, stand pipe pressure, etc. These parameters were analyzed using B&Y models. Well depth from 1000ft to 9000ft at 200ft interval was selected for this analysis. In this model there are some unknown parameters co-efficient which must be determined based on past drilling data obtained from a field in order to determine the unknown parameters, a linear regression technique will be applied which as follows.

$$Y = \alpha_0 + \alpha_1\beta 1 + \alpha_2\beta 2 + \alpha_3\beta + \alpha_4\beta + \alpha_5\beta + ---- \alpha n\beta n \quad (10)$$

Where Y is the dependent variable,α_0 is the intercept term and the regression co-efficient $\alpha_1, \alpha_2, \alpha_3, ...\ \alpha_n$ are the analogues of the shape of linear regression. From the above equation Y is the ROP; relevant drilling parameters will make up the regression variable $[\beta_{1\&}\beta_n]$. α_0 to α_n Co-efficient will be determined by using a software called statistical package for social science (SPSS Software). This SPSS software will perform the regression analysis after all the relevant drilling parameters has been uploaded into it and then run. The analysis will then provide an output computed data. The generated output data are now co-efficient of interest. The first value generated will be α_0 while the values after this are the co-efficient i.e. (α_1 to α_n). These values are to be multiplying with regression variable according to their order which is given as follows:

$$\alpha_1 WOB + \alpha_2 FR + \alpha_3 RPM + \alpha_4 TRQ + \alpha_5 Bd + \alpha_6 SPP \quad (11)$$

After substituting the values of the generated co-efficient (i.e.α_0 to α_6) and drilling factors (β_1 to β_6) in the above equation using Microsoft excel software a new predicted ROP is now obtained in ft. /hrs at every selected depth.

Error calculation

The percentage error at each selected depth was calculated using the formula below

$$PercentageError = \frac{PredictedROP - ActualROP}{ActualROP} * 100\% \quad (12)$$

While the average percentage error was also calculated using the formula below.

$$AveragePercentageError = \frac{\Sigma\left(\frac{PredictedROP - ActualROP}{ActualROP}\right)}{N} * 100\% \quad (13)$$

The above error calculation was carried out using Microsoft excel.

Error minimization

In order to minimize the error the B&Y linear regression model was further developed as follows

$$ROP = \alpha_o + \alpha_1 WOB + \alpha_2 FR + \alpha_3 RPM + \alpha_4 TRQ + \alpha_5 Bd + \alpha_6 SPP + \alpha_7 MW \quad (14)$$

In the above equation another drilling parameter i.e. mud weight was introduced. The analysis was carried out using the same procedure as it was done initially in the B&Y linear regression analysis and a very desirable result was obtained.

Results & discussion

The table above shows the generated coefficient from Statistical Package for Social Sciences Software for both initial B&Y and new B&Y regression analysis. Comparison was made between the actual ROP and predicted ROP. The actual ROP was the ROP contained in the original well Data (Well A Data) while the predicted ROP was the ROP calculated using B&Y models (Table 1). The comparison was done between the well depths of 1000ft to 9000ft at 200ft depth interval. Percentage error at each depth interval was calculated and finally average percentage error was also calculated. A graph of ROP was plotted against well depth, depth on the horizontal axis in feet (ft.) and ROP on the vertical axis in feet per hour (ft./hr.) on the vertical axis. From the graph, the actual ROP was considered as the reference plot represented with blue dotted point (Table 2). The predicted ROP are represented with lines in difference colors (Table 3). B&Y line graph seem to correlate very well in many section of the well, this shows that this model performed very well (Figure 1).

Table 1 Output computed data from SPSS

Coefficients α_0		α1	α2	α3	α4	α5	α6	α7
Initial B&Y	309.5	0.036	-0.002	0.212	0.017	-4.891	-0.108	--
New B&Y	254.235	0.065	-0.002	0.292	0.017	-5.749	-0.121	8.776

Table 2 Predicted ROP using B&Y models

Depth	Actual	Predicted ROP (ft/hr)	%Error
1000	209	160	23%
1200	329	169	49%
1400	181	168	7%
1600	187	161	14%
1800	145	150	3%
2000	161	141	12%
2200	144	142	1%
2400	120	143	20%
2600	106	148	39%
2800	112	148	33%
3000	109	140	28%
3200	106	129	22%
3400	134	157	17%
3600	125	115	8%
3800	88	116	31%
4000	64	113	76%
4200	100	114	14%
4400	44	90	108%
4600	45	82	80%
4800	76	53	30%
5000	119	96	19%
5200	169	123	27%
5400	136	109	20%
5600	110	109	1%
5800	100	102	2%
6000	102	123	20%
6200	97	120	24%
6400	86	26	69%
6600	111	103	7%
6800	90	99	10%
7000	110	96	12%
7200	96	90	6%
7400	69	87	26%
7600	111	79	29%
7800	116	86	26%
8000	92	121	31%
8200	118	169	43%
8400	114	120	5%

Table 3 Predicted ROP for initial B&Y and new B&Y

Depth	Actual ROP (114-)	B&Y(TTRJ	New B&Y (tiALS)	% Error
1000	209	160	161	23%
1200	329	169	170	48%
1400	181	168	170	6%
1600	187	161	161	14%
1800	145	150	149	3%
2000	161	141	140	13%
2200	144	142	141	2%
2400	120	143	142	19%
2600	106	148	147	38%
2800	112	148	148	32%
3000	109	140	138	26%
3200	106	129	126	19%
3400	134	157	158	18%
3600	125	115	111	12%

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Table continued...

Depth	Actual ROP (114-)	B&Y(TTRJ	New B&Y (tiALS)	% Error
3800	88	116	111	26%
4000	64	113	108	69%
4200	100	114	111	11%
4400	44	90	83	92%
4600	45	82	76	67%
4800	76	53	44	42%
5000	119	96	83	30%
5200	169	123	129	24%
5400	136	109	116	15%
5600	110	109	115	5%
5800	1(H)	102	107	7%
6000	102	123	127	24%
6200	97	120	124	28%
6400	86	26	29	66%
6600	111	103	105	5%
6800	90	99	102	13%
7000	110	96	98	10%
7200	96	90	92	5%
7400	69	87	88	27%
7600	111	79	79	29%
7800	116	86	89	23%
8000	92	121	134	46%
8200	118	169	169	43%
8400	114	120	121	6%
8600	102	118	118	16%
8800	196	174	174	11%
9000	178	155	155	13%
	Sum	5007	4950	102700%
			Ave .% error	0%

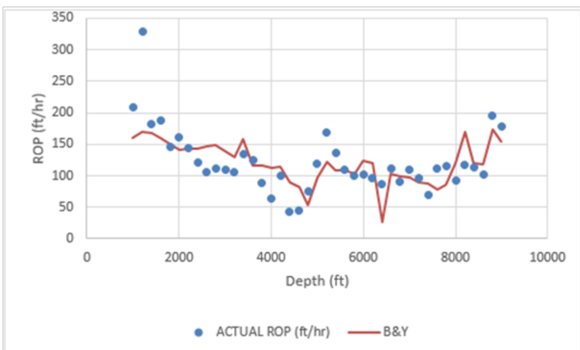

Figure 1 Actual & predicted ROP vs. well depth.

Predicted B&Y model was further modeled by including additional drilling parameter (i.e. mud weight) into the initial regression equation and analyzed. The result shows that the error was minimized from 0.03% to 0.0003%. Actual ROP, Predicted ROP of initial B&Y and modified B&Y in feet per hour was plotted against well depth measured in feet. From the fig, the actual ROP was considered as the reference plot represented with dotted point. The initial and modified B&Y predicted ROP are represented with lines (Figure 2). Initial and modified B&Y line graph seem to correlate very well in many section of the well, this shows that the modified B&Y model performed very well even more than the initial B&Y Model. The error difference between initial & and new predicted ROP using B&Y model can be can be clearly illustrated from the chart in Figure 3.

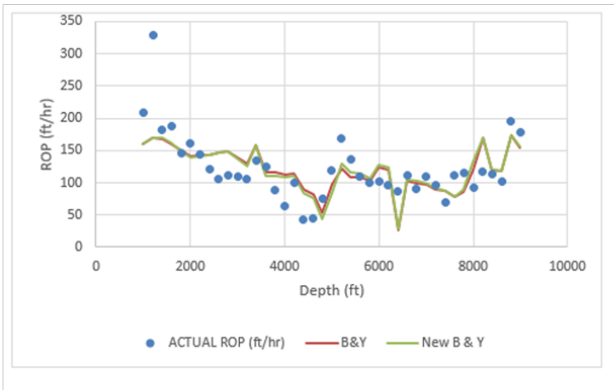

Figure 2 Actual, initial B&Y and new B&Y ROP vs. well depth.

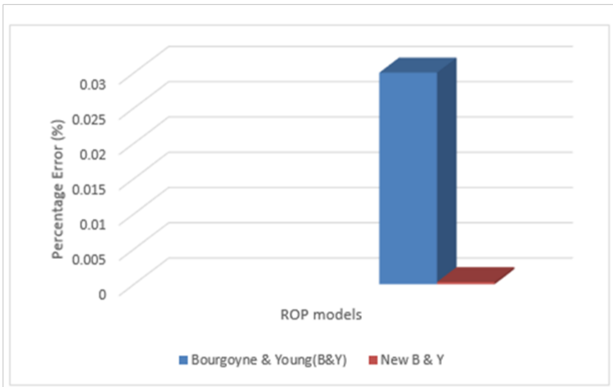

Figure 3 Average percentage error vs. Initial B&Y and new B&Y.

Conclusion

B&Y model has been tested with Niger Delta well data for ROP prediction, the result shows that the model performed very well by producing a little amount of error of about 0.03% and the error was further minimized to 0.0003% after inclusion of additional drilling parameter. The model can estimate ROP as function of several drilling parameters such as WOB, RPM, Mud weight, Standpipe Pressure, Torque, flow rate, mud weight etc. with a reasonable accuracy.

The result can also provide a guide for next drilling operation near the drilled well within the Niger Delta basin and the predicted values can be used as a reference to obtain optimum drilling performance and therefore reduce cost and time of drilling operation.

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Conflicts of interest

There are no conflicts of interest.

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