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Correlation of Penetration Rate with Drilling Parameters For an Iraqi Field Using Mud Logging Data

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Abstract

This paper provides an attempt for modeling rate of penetration (ROP) for an Iraqi oil field with aid of mud logging data. Data of Umm Radhuma formation was selected for this modeling. These data include weight on bit, rotary speed, flow rate and mud density. A statistical approach was applied on these data for improving rate of penetration modeling. As result, an empirical linear ROP model has been developed with good fitness when compared with actual data. Also, a nonlinear regression analysis of different forms was attempted, and the results showed that the power model has good predicting capability with respect to other forms.

Key Words: operation, Rate of Penetration (ROP),Modeling

Introduction

During the last decades, the drilling engineers have been concerned extensively on prediction of drilling rate. This step is necessary since it help in the process of selection of drilling parameters (drilling optimization), which is important to decrease drilling cost per foot [1, 2].

It is well known that penetration rate is affected by controllable and uncontrollable factors. The controllable factors included weight on bit, rotary speed, bit type, mud properties, and hydraulics. While the formation characteristics is one of the uncontrollable factors that had significant effect on penetration rate [3]. Unfortunately, there is no comprehensive mathematical drilling model that related the drilling rate and different drilling parameters. The primary reason for that is the large number of factors influencing the drilling rate, and due complexity and nonlinearity of relationship of these factors to each other and to drilling rate[4]. However, experts have put forward some suggestions to address this issue. They have succeeded to model the effects of different drilling parameters involving drilling rate as mathematical functions. Bourgoyne and Young is one of these model that is widely in practice [5].

Rate of penetration modeling is recognized as a tool which can be used to reduce drilling costs by assisting bit selection and drilling optimization. There are many rates of penetration models available in drilling operations. But these models have two major problems. Firstly, these models are derived under specific conditions, particularly from laboratory controlled experiments which are limited by the differences between the experimental and field data conditions. Secondly, the

models derived from field data have lacked a detailed and systematic analysis of bit run data tacking into account the particular conditions of the bit run. The lack of the availability of a comprehensive computerized data base has also slowed down progress in ROP modeling [6].

Today, a mud log provides foot-by-foot data base which assists in modeling of ROP accurately. These data includes, WOB, RPM, HIS etc., and electric wireline logs, such as Δt, Gamma ray, Resistivity and caliper logs. This data base provides an opportunity for ROP modeling taking into different parameters which permits the modeling process more accuracy [7].

Raw Logging Data

The raw mud logging data were recorded for Al Zubair oil field. This field is located in south Iraq, Basrah city. The sequence of formations in this field are Upper Faris,Tenoma, Sheransh, Umm Radhuma respectively. Umm Radhuma formation is predominantly limestone .Its considered the thickest formation in this sequence, about450 m, which made it a good selection for developing correlation. Figs. (1), (2), and (3) shows the measurements interval feet by feet for ROP, WOB, and RPM with depth for this formation. These figures illustrate the difficulties of evaluating the relationship between ROP and WOB, RPM due to high fluctuation in these dataset.

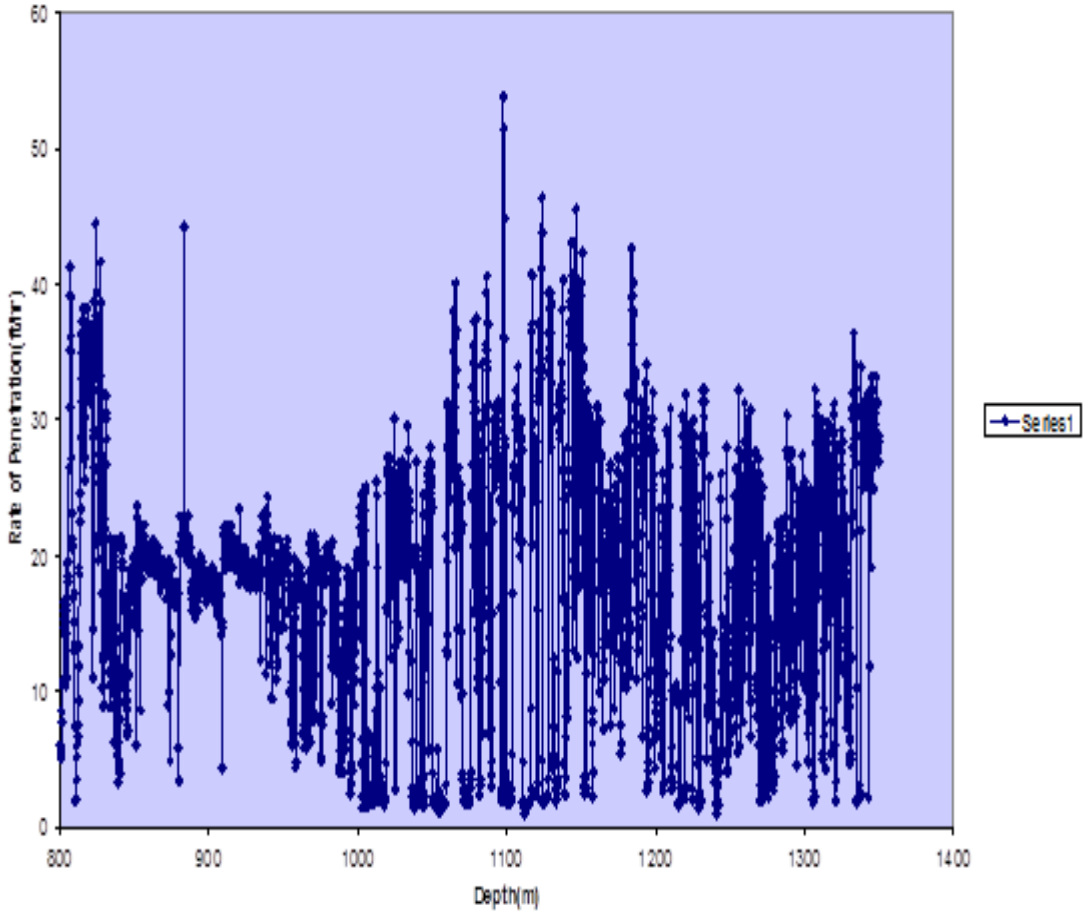

Fig.1, Raw ROP versus Depth Data

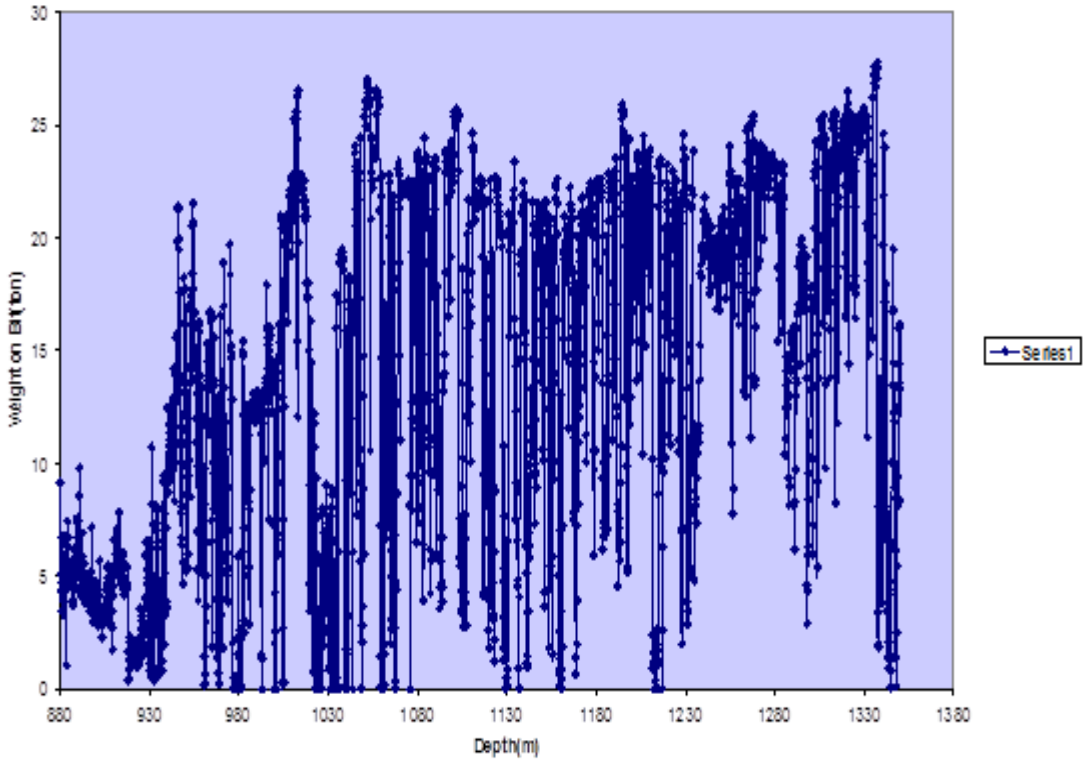

Fig.2, Raw WOB versus Depth Data

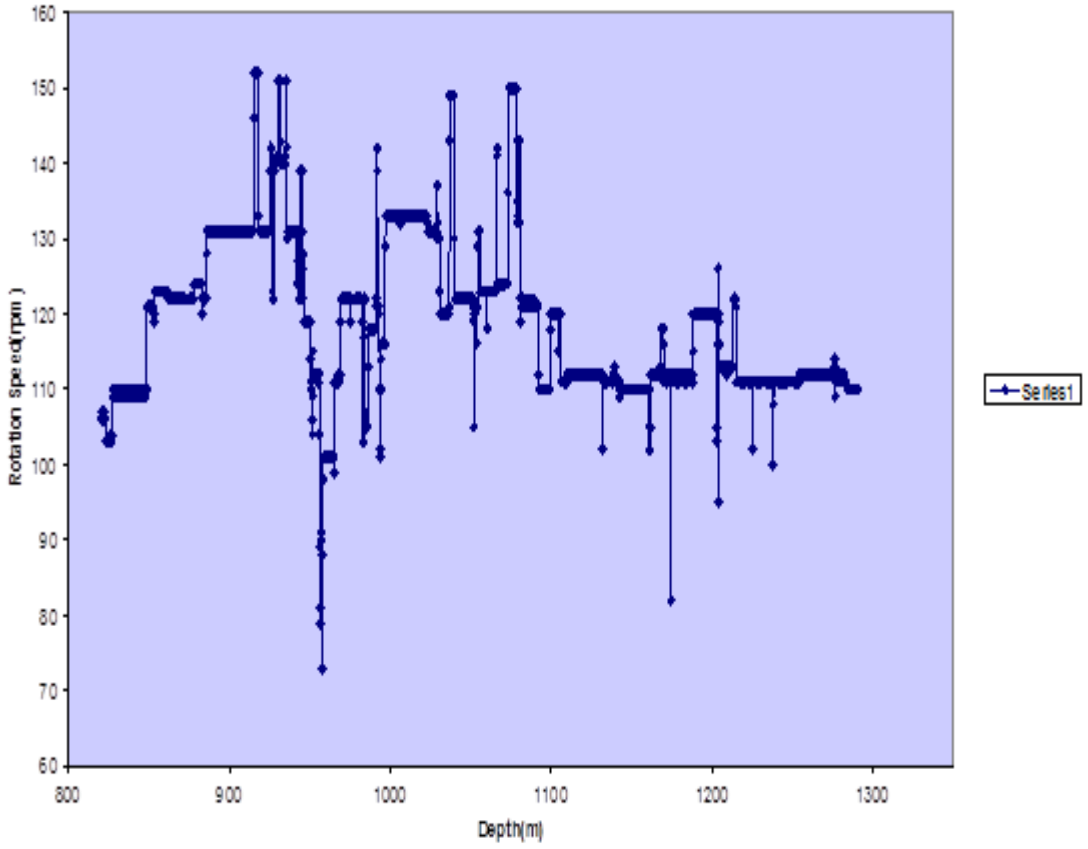

Fig.3, Raw RPM versus Depth Data

Penetration Rate Modeling

Statistical software called "SPSS" was used to perform various statistical analysis for modeling penetration rate with other drilling parameters. The raw data for Umm Radhuma formation was extracted from mud log data of well ZB-232.As first step, a linear regression model was attempted for the modeling. Table (1) shows the main drilling parameters that used in regression analysis and some statistical analysis for each parameter entered in the modeling. The ROP is dependent variable, while the WOB, RPM, MW, and Q are the independent variables.

Table 1, Statistical Analysis of Drilling Parameters

	N	Range	Minimum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
ROP	2251	395.41	1.00	17.3373	.27307	12.95550	167.845
WOB	2251	27.03	.01	14.0190	.16803	7.97226	63.557
RPM	2251	79	73	119.33	.226	10.721	114.948
MW	2251	.05	1.10	1.1239	.00052	.02458	.001
Q	2251	1696	1508	3023.55	1.945	92.267	8513.115
Valid N (listwise)	2251						

Table(2) provides the analysis of variance for the data of the model. Each items of this analysis can be defined by the following equations:

SSR= $\sum(\hat{y} - \bar{y})$ … (1)

SSE = $\sum(y_i - \hat{y}_i)$ … (2)

MSR=SSR/K … (3)

MSE=SSE/N-K-1 … (4)

F=MSR/MSE … (5)

Where:

SSR=sum of square regression

SSE=sum of square error(residual)

MSE= mean of sum error

MSR=mean of sum regression

K=No.of parameters

N= no. of points

Yi=actual value

$\bar{Y}$=mean value

$\tilde{Y}$=predictive value

Df=degree of freedom

Table 2, Analysis of Variance of the Liner Model

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	74872.621	4	18718.155	138.851	.000[b]
	Residual	302778.652	2246	134.808		
	Total	377651.273	2250			

Table 3, Values of Coefficients of Linear Model

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-105.346-	17.467		-6.031-	.000
	WOB	-.799-	.034	-.491-	-23.471-	.000
	RPM	.049	.025	.040	1.939	.053
	MW	125.132	11.939	.237	10.481	.000
	Q	-.004-	.003	-.030-	-1.512-	.131

Table 4, Model Summery

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.445[a]	.198	.197	11.61068	.198	138.851	4	2246	.000

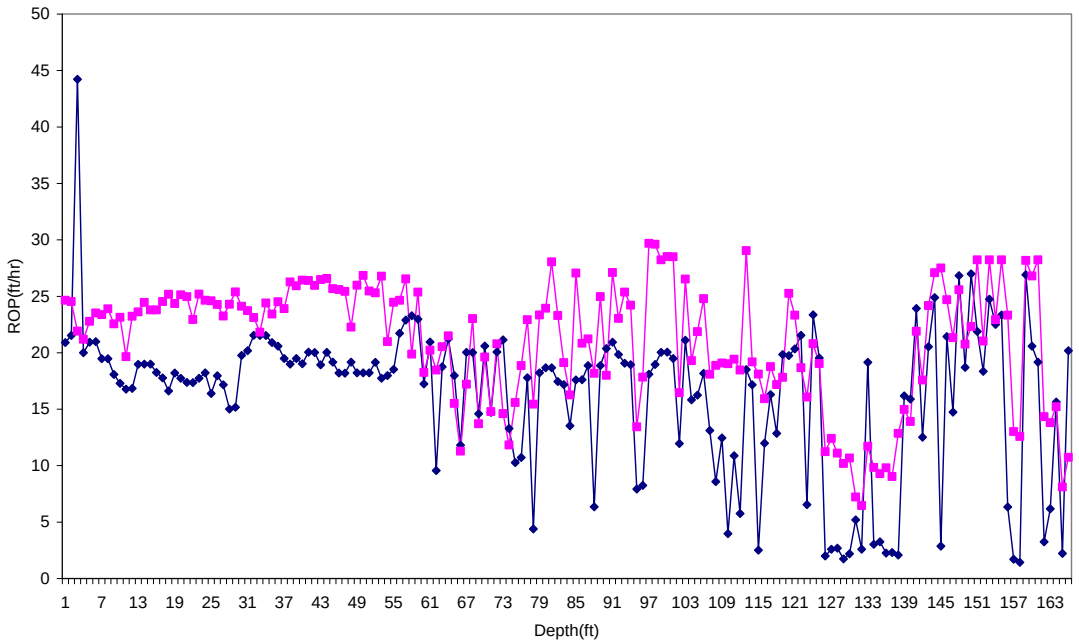

Fig.4, Fitted and Actual ROP with Depth before Improving

According to these statistical analysis of the interest data , the values of coefficients of this linear model are shown in the table(3).Table (4) shows a weak strength of this relationship between ROP and the other parameters since the value of square correlation coefficient is 0.197. Fig. (4) displays the actual and fitted rate of penetration values as functions of depth for this data set.

Improving Data Quality

In order to obtain more representative relationship between ROP and its related variables, the quality of logging data for ROP modeling must be improved by the following means:

A. Exclusion of Outliers

Outlier may defined as the value that are far from the middle of distribution. In statistics language, any points that are beyond the outer fences are considered as outliers. Thus, the statics software SPSS performs this exclusion process for logging data and detected the outliers for each parameter included in the modeling(ROP,WOB,RPM,Q ,MW) as shown in Figs.(5),(6),(7),(8),and(9).

As result of this process,32.5% of the variation in the data was obtained by the model(R^2=0.325) as shown by the Fig.(10).

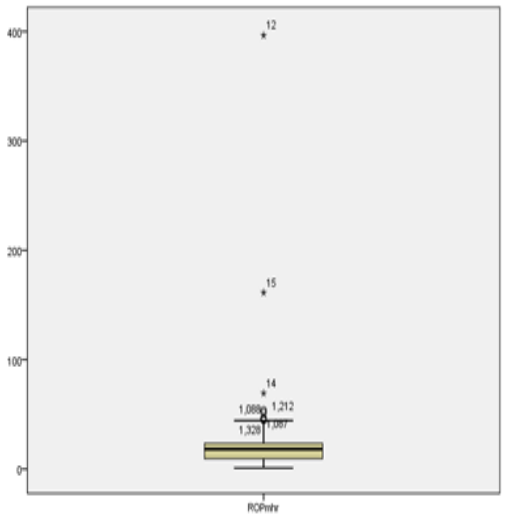

Fig.5, Outliers of ROP Data

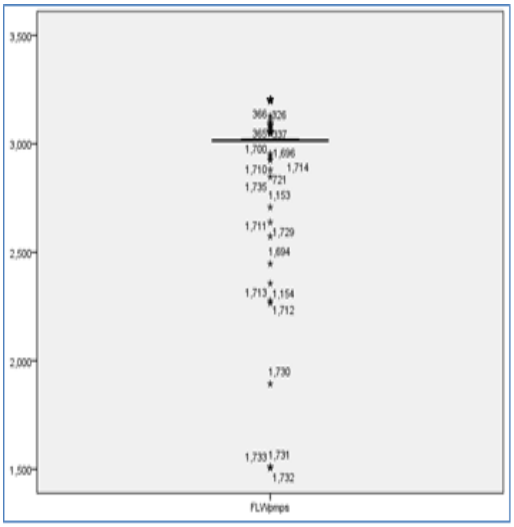

Fig.8, Outliers of Flow Rate Data

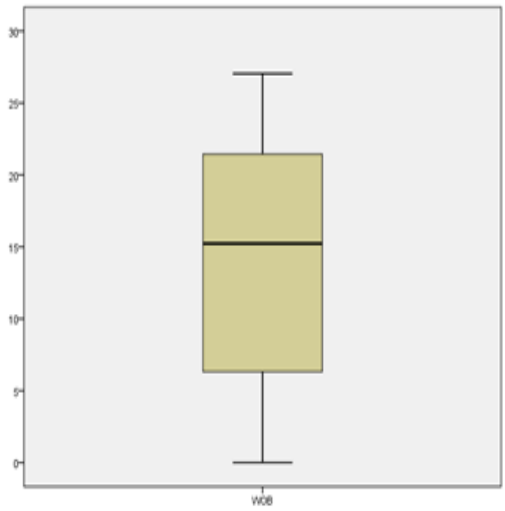

Fig.6, Outliers of WOB Data

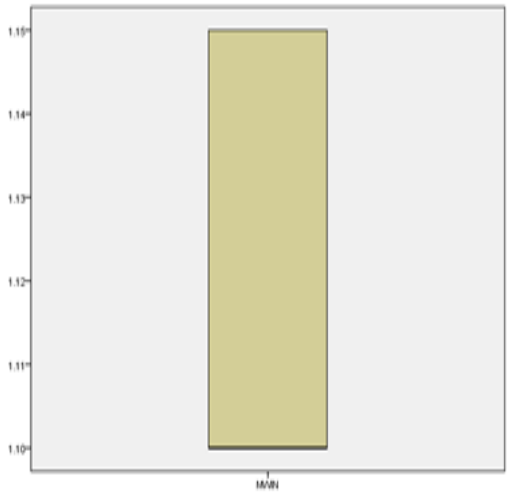

Fig.9, Outliers of Mud Weight Data

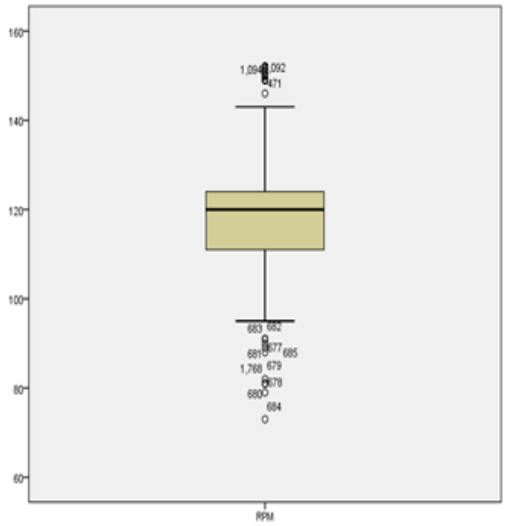

Fig.7, Outliers of RPM Data

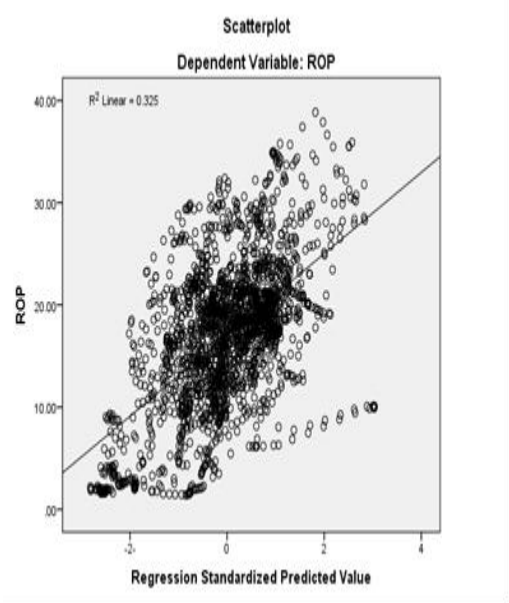

Fig.10, Predicted ROP after Removing Outliers

Table 5, Groups of Modeling Data

t	data size	depth	ROP	WOB	RPM	Density	flow rate
1	8	1042.03	21.80	2.50	107.55	1.11	3015.21
2	42	1047.97	23.20	3.57	116.89	1.11	3015.05
3	17	1037.22	23.55	4.44	117.64	1.10	3015.01
4	28	1049.39	23.50	5.50	117.00	1.11	3015.18
5	29	1000.40	26.02	6.60	121.46	1.11	3015.34
6	33	1090.08	25.87	7.51	123.40	1.12	3015.29
7	23	1091.06	25.41	8.53	121.69	1.12	3015.39
8	48	1100.38	23.63	9.52	124.00	1.12	3015.68
9	42	1114.43	24.75	10.46	120.91	1.13	3015.25
10	45	1104.07	22.91	11.56	121.38	1.13	3015.40
11	49	1088.77	23.02	12.52	125.16	1.12	3015.68
12	66	1110.39	23.17	13.50	121.36	1.13	3015.45
13	47	1104.31	18.85	14.46	120.19	1.12	3015.26
14	117	1128.27	19.62	16.12	120.20	1.13	3015.26
15	73	1117.76	17.33	17.59	121.26	1.13	3015.30
16	76	1145.35	17.29	18.53	120.55	1.14	3015.20
17	45	1114.25	13.22	19.46	121.11	1.13	3015.30
18	53	1104.27	10.85	20.54	120.62	1.12	3015.40
19	57	1089.62	7.60	21.57	122.90	1.12	3015.50
20	64	1068.00	5.63	22.39	122.01	1.11	3015.69
21	17	1073.22	2.40	24.49	121.97	1.10	3015.37
22	9	1076.98	1.83	25.26	125.03	1.10	3015.91
23	4	1051.90	2.01	26.04	122.81	1.10	3015.00

Table 6, Descriptive Statistics for Grouped Data

	N	Range	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
depth	23	144.95	1000.40	1145.35	1084.7885	7.15576	34.31784
ROP	23	24.19	1.83	26.02	17.5411	1.73989	8.34421
WOB	23	23.54	2.50	26.04	14.0278	1.53514	7.36229
RPM	23	17.61	107.55	125.16	120.7425	.74842	3.58928
MW	23	.04	1.10	1.14	1.1166	.00227	.01089
Q	23	.91	3015.00	3015.91	3015.3529	.04700	.22538
Valid N (listwise)	23						

B. Grouping the Data

After removing the outliers, the logging data that were used for rate of penetration modeling will divided into number of groups. This approach for increasing the size of grouped data was proved statistically. With the aid of SPSS software, the

Logging data were grouped into 23 groups for each variable as shown in table(5). Other statistics analysis of grouped data is shown in table (6).

C. Regression of Grouping Data

As a final step, a linear regression analysis of logging grouped data was conducted to establish general model that relating drilling rate with drilling variables. Table (7) summarizes the values of coefficients, while tables (8) and (9) provide other statistical analysis of this regression modeling. The final form of this model will be:

ROP=20902.003-1.059WOB+
1.11RPM+315.9MW+
2.419Q… (6)

Table 7, Coefficients values of Linear Model

Model	95% Confidence Interval
	Upper Bound
1- Constant	20290.003
WOB	-1.059
RPM	1.11
MW	315.902
Q	2.419

As it was noticed from the above tables, a better relationship was obtained after processing logging data(R^2=0.978) compared to the relationship before improving the interested log data. Figure(10) also shows clearly very good correspondence between the measured and the calculated values of ROP from Eq. (6).

Table 8, Linear Model Summery

Model	R	R Square	Adjusted R Square	Std.Error of the Estimate
1	0.989	0.978	0.972	1.3592

Table 9, Analysis of Variance of the Linear Model

Model	Sum of Square	df	Mean Square	F
1 Regression	1173.423	4	293.356	158.782
Residual	25.866	14	1.848	
Total	1199.288	18		

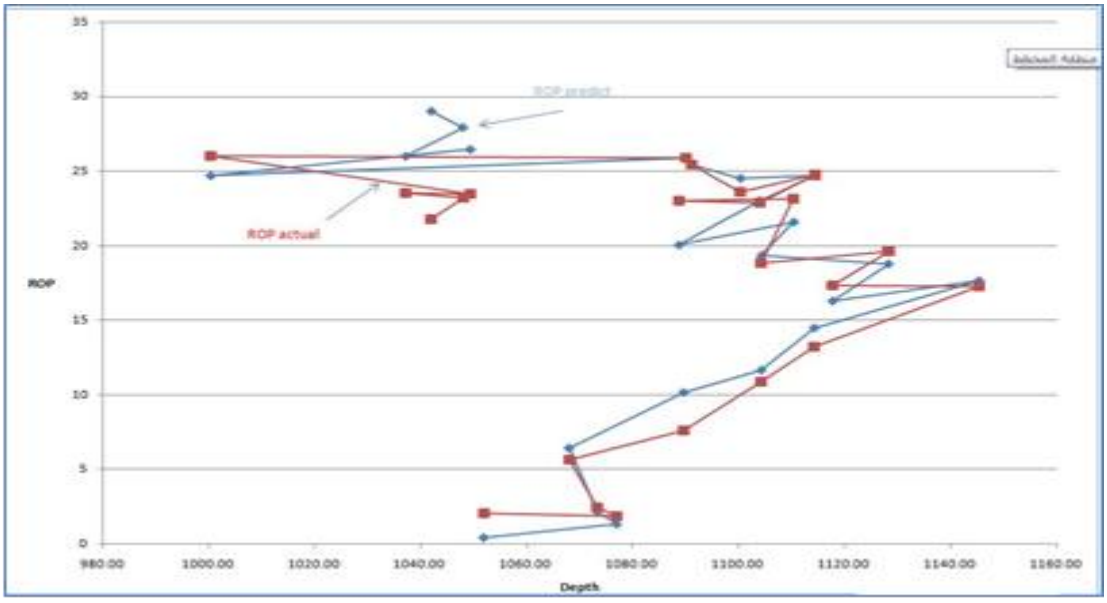

Fig.10, Actual and Fitted ROP

Table 10, Nonlinear Parameters Estimation (Case1)

Parameter	Estimate	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
a	3.841	5.928	-8.795-	16.477
b	.436	.543	-.722-	1.594
c	.001	.000	.001	.001
d	-3.694-	.000	-3.694-	-3.694-
e	.001	.000	.001	.001
f	.892	.000	.892	.892
g	.542	.000	.542	.542
h	-2.668-	213062466.597	-454131900.271-	454131894.935

Table 11, Nonlinear Parameters Estimation (Case2)

Parameter	Estimate	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
a	-10.792-	2.576	-16.183-	-5.401-
b	18.614	55.137	-96.789-	134.017
c	17.298	127.173	-248.879-	283.474
d	-5.863-	32.434	-73.748-	62.021

D. Non Linear Regression

A nonlinear regression analysis was also conducted on the logging grouping data for comparison purpose. In the first case a power model was attempted, and good fitness model was obtained (R^2=0.91).Table (10) provided the values of coefficients of this power model which has the following equation.

$ROP=3.841WOB^{0.436}+0.001RPM^{-3.67}+0.001MW^{0.892}+0.542Q^{-2.668}$… (7)

In the second case a natural log form was conducted on logging grouped data. The results of regression analysis showed moderate strength of the model (R^2=0.597).Table (11) showed the values of coefficients for this model which has the following equation:

$LnROP=-10.8\ln(WOB)+18.6\ln(RPM)+17.3\ln(MW)-59\ln(Q)$… (8)

Conclusions

1- An empirical linear model that relating rate of penetration with drilling parameters was developed for Umm Radhuma formation in ZUBAIR field , using mud logging data.
2- The accuracy of the linear developed model could be enhanced by statistical processing which including removing of outliers, and grouping the logging data.
3- A power modeling of logging data would also provide good estimation of rate of penetration, while the natural log model provided moderated estimation of rate of penetration.

Nomenclature

Df: degree of freedom
K: No.of parameters
MW: Mud Weight,ppg
MSE: mean of sum error
MSR: mean of sum residual
N: No.of point data
Q: flow rate,l/m
R: Correletion coefficient.
RPM: Bit revolution per minute
ROP: Rate of Pentration,ft/hr
SSR: sum of square regression
SSE: sum of square error(residual)
WOB: Weight on Bit,ton
Yi: actual value
$\bar{Y}$: mean value
$\tilde{Y}$: predictive value

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