Determination of Optimum Mechanical Drilling Parameters for an Iraqi Field with Regression Model

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Abstract

An optimization analysis of drilling process constitutes a powerful tool for operating under desired pressure levels and simultaneously maximizing the penetration rate, which reduces costs and time thus increases the profit.

In this study, a composite drilling model (Young-Bourgyen model) of eight functions was used to determine the optimum drilling mechanical parameters (Weight on bit and rotary speed) for an Iraqi oil field. These functions model the effect of most drilling parameters such as formation strength, mud density, formation compaction, weight on bit, rotary speed, tooth dullness, and bit hydraulic on drilling rate. Data are extracted from bit record and drilling report of well BUZ-20 for calculation of eight exponents of the model with regression analysis method. For each formation within the geologic section of drilled well, the drillability constant was calculated .The rate of penetration for the field had been predicted based on constants for every data against depth, and noticeable differences between them were observed . Also, an optimized weight on bit and rotary speed had been calculated for several data point.

Keywords: Drilling, Optimization, Rate of Penetration

تحديد امثل قيم لعوامل الحفر الميكانيكية لحقل عراقي باستعمال موديل تراجعي

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الخلاصة:

يعتبر استخدام تحليلات الامثلية في عملية حفر الابار اداة فعالة لتحقيق امثل سرعة حفر باقل التكاليف في هذا البحث تم تطبيق موديل يونغ –بوركين ذي الثمانية دوال على احد الحقول العراقية لغرض حساب امثل تركيبة من العوامل الميكانيكية(الوزن المسلط على الحافرة والسرعة الدورانية).تم استعمال البيانات المتوفرة من سجل الحافرة لبئر بزركان–20 لحساب قوى الاسس الثمانية الخاصة بهذا الموديل بواسطة طريقة الانحدار، وبعدها تم حساب سرعة الحفر النظرية بواسطة الموديل وامثل القيم الميكانيكية عند اعماق مختلفة. وقد لوحظ بان هنالك تباعد وتقارب بين قيم سرع الحفر النظرية والواقعية عند اعماق مختلفة.

Introduction

Drilling optimization is very important during drilling operation. This is because it could save time and cost of operation thus increase the profit. Drilling optimization aims to optimize controllable variables during drilling operation such as weight on bit and bit rotation speed for obtaining maximum drilling rate [1]. In oil well drilling, drillability of rock is noticed to decrease with increasing depth of

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the hole. The increase in complexity for drilling operation has increase many problems thus results in critical cost consideration [2].

Major drilling variables considered to have an effect on drilling rate of penetration are not fully comprehend and complex to model. There are many proposed mathematical models which attempted to combine known relations of drilling parameters. The proposed models worked to optimize drilling operation by mean of selecting the best but weight and rotary speed to achieve minimum cost [3].

In this paper, final drilling reports and bit records for well of an iraqi field were selected to determine the constants a_1 to a_8 of regression drilling model. These constants represent several drilling parameters for the field which are formation strength, normal compaction, pressure differential, weight on bit, rotary speed, bit tooth wear, and hydraulics. Also , prediction of drilling rate of the field based on these constants and determination of optimum values for weight on bit and rotary speed for certain depth were conducted to obtain an optimum drilling operation.

Bourgoyne and Youg's Model:

The most complete mathematical drilling model that has been used for rolling bits is the model proposed by Bourgoyne and Young [5]. They proposed using eight functions to model the effect of most of drilling variables.They defined their model as follows:

$R=f_1.f_2.f_3.f_4.f_5.f_6.f_7.f_8$ -------- (1)

Formation Strength Function (f_1)

This function represents the effects of formation strength and bit type on penetration rate .It also includes the effect of drilling variables such as mud type, solid content. It has the same units of penetration rate and commonly is called the drillability of the formation.

$F_1=e^{2.303a1}=K$ ------------ (2)

Formation Compaction functions (f_2,f_3)

The function f_2 accounts for the rock strength increase due to the normal compaction with depth. The primary effect of normal compaction consider an exponential decrease in penetration rate with increasing depth in normally compacted formations as given by the following equation:

$F_2=e^{2.303a2x2}=e^{a2}$ (10000-D) --------- (3)

While the function f_3 models the effect of under compaction experienced in abnormally pressured formations. In other means within over pressured formation the rate of penetration is going to show an increased behavior as following:

$F_3=e^{a3x3}=e^{2.303a3D0.69(gp-9)}$ ---------(4)

Overbalance function(f_4)

The function f_4 models the effect of overbalance on penetration rate(differential pressure between the bottom hole and formation). It can be expressed as follows:

$F_4= e^{a4x4}=e^{2.303a4D(gp-\rho c)}$ -------(5)

Weight on bit Function (f_5)

This function models the effect of weight on bit and bit diameter on penetration rate. This assumes penetration rate is directly proportional to weight per bit diameter. The given function is normalized for 4000 lbf per bit diameter as follows:

$F_5=e^{a5x5}=((W/d_b)-(W/d_b)_t/4-(W/d_b)_t)^{a5}$ -----(6)

Rotary Speed Function (f_6)

This function models the effect of rotary speed on penetration rate, and its assumes that penetration rate is directly proportional to rotary speed as follows:

$F_6=e^{a6x6}=(N/60)^{a6}$ ---------(7)

Tooth wear Function (f_7)

The tooth wear function is calculated by means of determining the fractional tooth height, the more the tooth wear, the less the penetration rate as follows:

$F_7=e^{a7x7}=e^{-a7(h)}$ -----------(8)

Hydraulic Function(f_8)

The hydraulic function represents the effects of the bit hydraulic on penetration rate. Jet impact force was chosen as the hydraulic parameter of interest with normalized value of 1 for f_8 at 1000 lbf as follows(4):

$F_8=e^{a8x8}=(F_j/1000)^{a8}$ --------(9)

Table 1- Field data from Well Buz-20[4]

Data No	Depth ft	Drilling Rate ft/hr	Bit Weight lb	Rotary Speed RPM	Tooth Wear	Jet Impact Force lbf	ECD ppg	Pore Gradient ppg
1	516	23.78	220416	100	0.5	773	8.96	8.38
2	3021	57.32	44092	100	0.75	782	9.95	8.38
3	4101	26.65	68342	115	0.75	784	9.99	8.38
4	4848	18.37	79365	125	0.75	793	10.15	8.39
5	5338	11.9	72752	120	0.625	687	9.96	8.38
6	5833	12.15	77161	120	0.625	687	10.17	8.38
7	6359	13.3	77161	120	0.625	687	10.21	8.38
8	6744	8.65	70547	120	0.625	755	10.28	8.38
9	7001	10.1	70547	120	0.7	767	10.42	8.38
10	7014	10.5	70547	120	0.7	767	10.42	8.38
11	7080	7.29	39683	120	0.7	696	10.35	8.38
12	9127	12.27	33069	180	0.65	645	18.75	8.38
13	9212	9.22	39683	90	0.75	612	18.75	8.38
14	10492	18.27	33069	60	0.75	612	9.92	8.38
15	11100	7.43	35273	47	0.625	612	9.98	8.34
16	11410	11.9	33096	70	0.75	612	9.92	8.34
17	11755	12.3	33096	80	0.5	612	10.17	8.38
18	12404	7.7	37478	60	0.5	612	10.25	8.38
19	13021	10.4	39683	55	0.625	612	10.25	8.38

Optimum Weight on Bit and Rotary Speed

Bourgoyne and Young derived the following equations for best constant bit weight and rotary speed for the case in which tooth wear limits bit lifeas follows [5]:

$(w/d_b)_{opt}=(a_5H_1(W/d_b)_{max}+a_6(W/d_b)_t)/(a_5H_1+a_6)$---(10)

$N_{opt}=60(\tau H(W/d_b)_{max}(W/d_b)_{opt}/(W/d_b)_{max}-4)^{1/H1}$-----(11)

Table 2- Values of regression constants

Variable	constant	value
Formation strength	a_1	4.22
Normal compaction	a_2	0.000086
Under compaction	a_3	0.0000076
Pressure Differential	a_4	0.000045
Weight on Bit	a_5	0.77
Rotary Speed	a_6	0.96
Tooth Wear	a_7	0.5
Jet Impact Force	a_8	0.64

Case Study

A field data taken from well Buz-20 are shown in table-1. A regression analysis of above drilling data (bit record) was performed in order to determine values of constants a_1 through a_8. The primary drilling variables required for regression analysis are depth, penetration rate, bit weight per inch of bit diameter, rotary speed, fractional toothwear, jet impact force, mud density, and pore pressure gradient. Also, the drillability constant for each formation in the lithological column of well is calculated. Table-2 provides these parameters values.

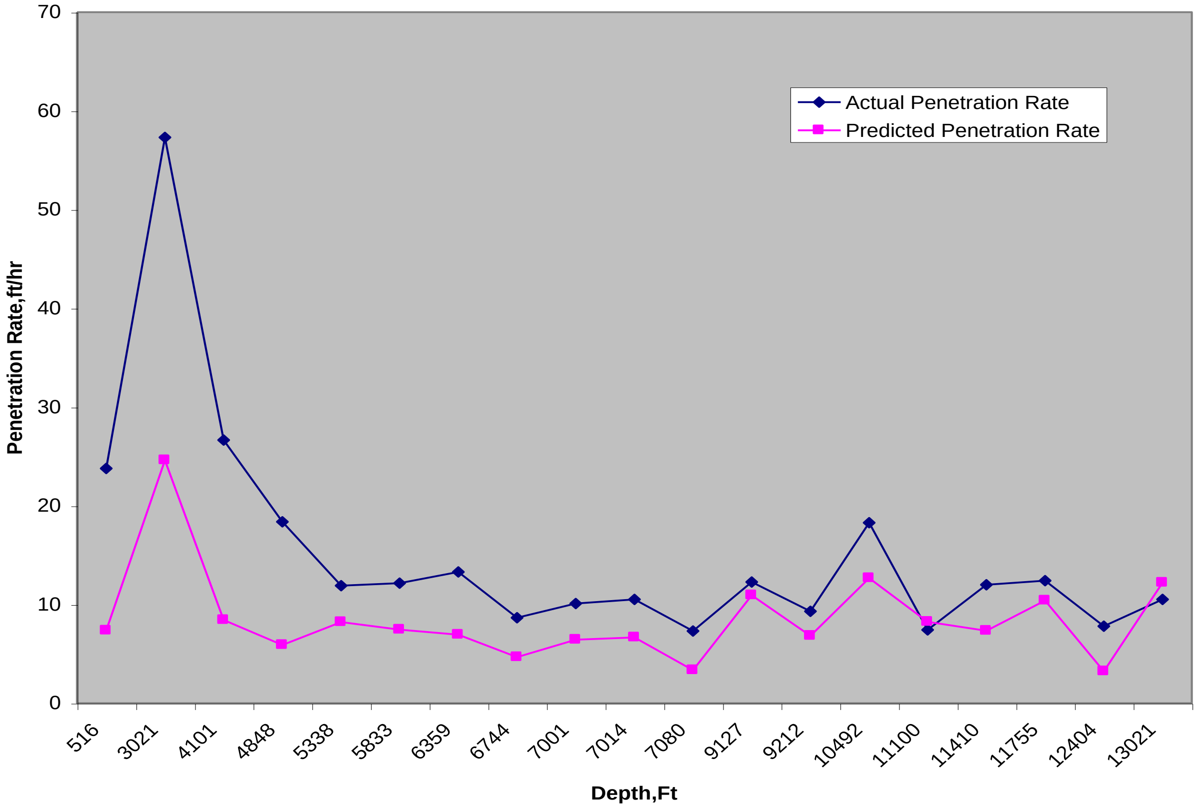

Figure 1- Actual vs.Predicted ROP for Well Buz-20

Estimation of Penetration Rate

The drilling model of Bourgoyne Young then is used to calculate the penetration rate for each formation in the field. Figure-1 shows the predication of rate of penetration with drilling model and the actual rate of penetration from bit record. A noticeable differences between these two values for certain depths (points 1 through 5). These differences may be attributed to unexact values of data that are used in regression analysis. While a good approximation between these two values was obtained at certain depths such as, (points 12, 15 ,17,and19).

Table 3- Actual and Optimum Values of WOB and N

Formation	Act.WOB,lb	Opt.WOB,lb	Act.N,rpm	Opt.N,rpm
Upper Fars	71000	45000	110	90
Loewr Fars	40000	33000	120	100
Asmari	33000	29000	60	50
Jaddla	35000	30000	50	40
L.Shirinish	33000	28000	75	60
Tanuma	33000	28000	80	65
Khasib	37000	34000	60	50

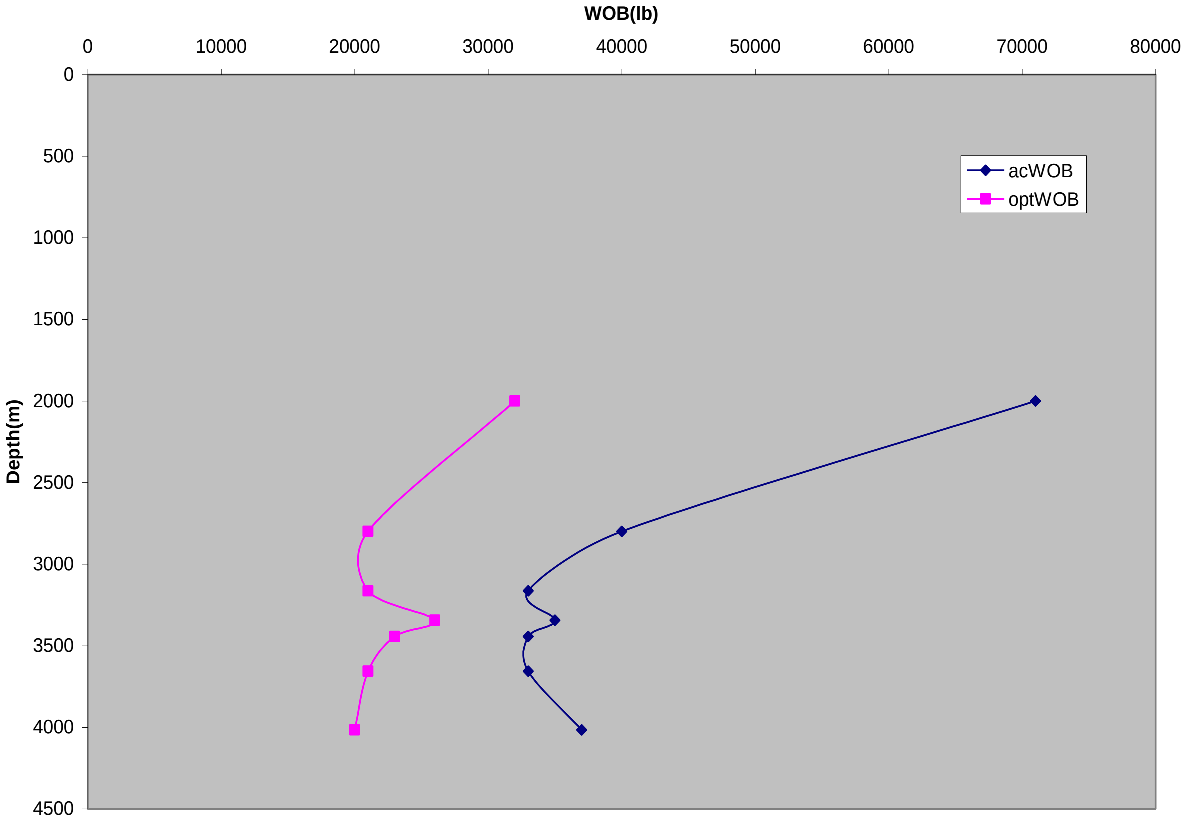

Figure 2- Actual vs optimal values of WOB for certain depths.

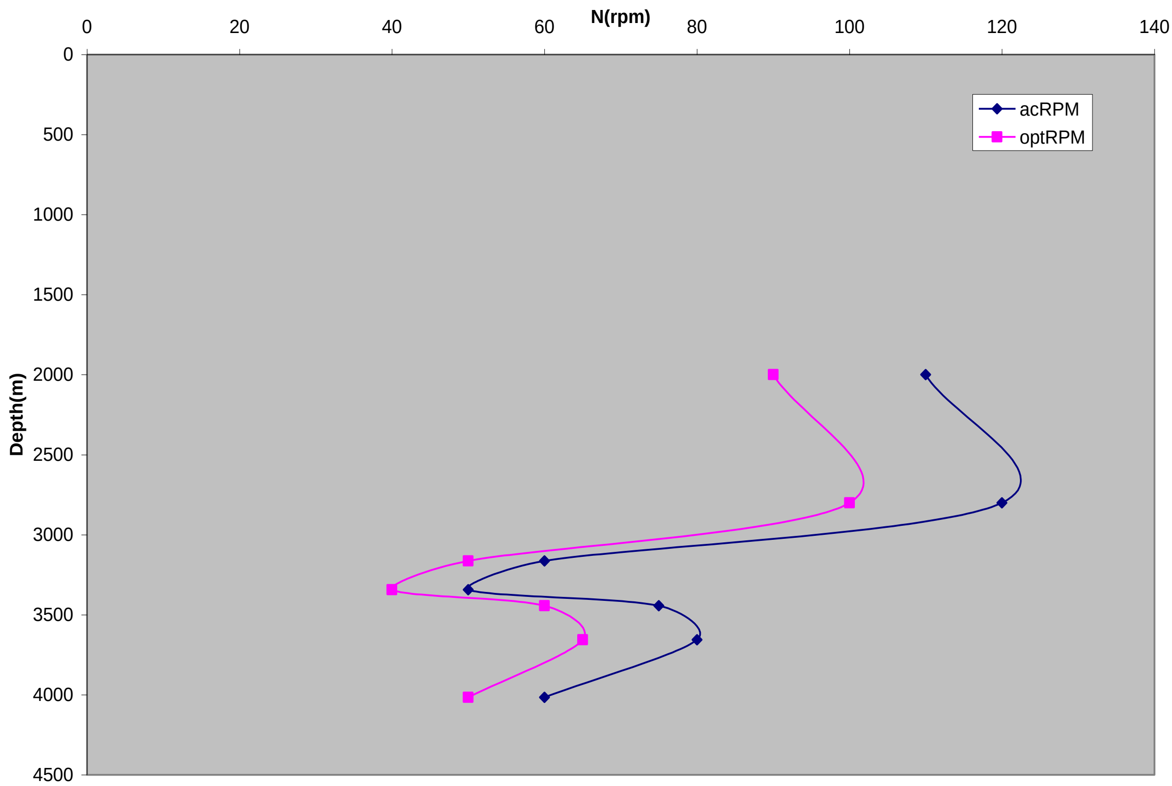

Figure 3- Actual vs optimal values of N for certain depths.

Optimum Weight on Bit and Rotary Speed

The second step in this paper is to estimate the optimum values for mechanical parameters (weight on bit and rotary speed) for each formation within the lithological column. Equations 10 and 11 are used for these calculations. Table-3 and figure-2 and figure-3 shows the values of these mechanical parameters for certain formations within the lithological column of the Buz-20 well. Again noticeable differences between the actual values of these mechanical parameters obtained from the bit record, and the predicated values from equations 10 and 11.

Conclusion

A composite drilling model (Bourgoyne and Young model) of eight functions was constructed for an Iraqi field. Past drilling data of certain well were used to evaluate parameters of this model.Based on the obtained results from this model, the following conclusions can be drawn:

1- A regression analysis could be used for estimating constants of the drilling model, For each formation within the geological column of the well.
2- Agood agreement between the predicted rate of penetration with model, and the actual penetration rate obtained from bit record at certain depths. While noticeable difference between them at other depths. An corrected field data may constitute the main cause.
3- Also, the optimum weight on bit and rotary speed derived from the drilling model were closely to the actual field values at certain depths.

Nomenculature

A_1=Formation strength constant
A_2=Normal compaction constant
A_3=Under compaction constant
A_5=Bit weight constant
A_6=Rotary speed constant
A_7=Tooth wear constant
A_8=Hydrulic constant
d=Bit diameter,in
d_n=Bit nozzle diameter,in
D=well depth,ft
G_p=pore pressure gradient lb/gal
H=Fractional tooth wear
H_1=Constants that depend on bit type
K=constant
N=rotary speed,rpm
Q=flow rate,gpm
w/d=Weight on bit per inch of bit diameter,1000 lb/in
$(w/d)_{opt}$=Optimum weight on bit per inch
X_2=Normal compaction parameter
X_3=Under compaction parameter
X_4=pressure differential parameter
X_5=Bit weight parameter
X_6=Rotary speed parameter
X_7=Tooth wear parameter
X_8=Hydraulic parameter
ρ=Mud density,ppg
ρ_c=Equivalent circulating density,ppg

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