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A New Approach for the Prediction of Rate of Penetration (ROP) Values

H.I. Bilgesu, SPE, L.T. Tetrack, SPE, U. Altimis, SPE, S. Mohaghegh, SPE, S. Ameri, SPE, West Virginia U.

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Abstract

Today applications of drilling require proper identification of operations where a cost reduction is possible. Many indicators are present when one tries to optimize the drilling operations such as casing size and mud properties. On the other hand the selection of the optimum bit requires information from a variety of sources. The parameters affecting the bit performance are complex and their relationship is not easily recognized. The general trend is to evaluate the performance of the bit from an offset well.

A new methodology was developed to model the rate of penetration and bit wear under various formation types and operating parameters. This method introduces a new approach with improved bit wear prediction. A simulator was used to generate drilling data to eliminate errors coherent to field measurements. The data generated was used to establish the relationship between the complex patterns such as weight on bit, rotary speed, pump rates, formation hardness, and bit type.

The method was tested using data from runs conducted with a rig floor simulator. The validity of the proposed method was also demonstrated with data from an existing field.

Introduction

The success and hence the economics of a drilling operation depends on the condition of the bit. With bits performing at high penetration rates, the well drilling costs can be lowered. Thus, the selection of a proper bit type and the operating parameters are important challenges one faces during the drilling operations.^{1,2} Work performed by several investigators^{3,4,5} have shown that many bit and fluid components affect the penetration rates. Different methods can be utilized in the optimization of drilling. Researchers proposed the use of empirical correlations⁶ and predictive techniques.⁷ In these approaches either laboratory data were used to derive the empirical correlations or offset well data was used to

fine tune the predictive method.

Neural Networks. Neural networks have been successfully used in different fields due to their capability to identify complex relationships when sufficient data exist. Recently, they have been successfully applied to different areas of petroleum engineering such as multi-phase pipe flow,^{8,9} reservoir characterization,^{10,11} production,^{12,13} and drill bit diagnostics.¹⁴

The neural network developed to diagnose the drill bit used six parameters consisting of lithology (or formation type), torque, rate of penetration, weight on bit, rotational speed, and hydraulic horsepower per square inch of nozzle as input. The network was trained to predict the bit wear as output. The use of formation type or lithology introduces errors for conditions where the predicted formation types and depths differ from the predicted properties. Although the drill bit diagnosis network was successful it was based on laboratory data and did not cover all formation hardness and bit grade levels, thus limiting its applicability.

In this study, we introduce a new approach to predict a drilling parameter such as the rate of penetration by designing a new neural network.

Approach

A new methodology is introduced to predict the ROP values during drilling. This approach uses the measured data to determine the relationship between several parameters like bit type, weight on bit, depth, and rotary speed recorded during the drilling operations.

Two different data sets were used in this study. The first data set consisted of approximately 8,000 measurements taken at selected wellbore conditions. The rig floor simulator available in the departmental facilities were employed for this purpose. The use of simulated data provided additional insight in terms of parameters like formation abrasiveness, bit tooth wear, and bit bearing wear as a function of drilling time that are commonly not possible to measure in the field. The second data set consisted of approximately 500 measurements from several wells in the United States.

Simulated Data. Runs were conducted using a rig floor simulator and data were continuously recorded until bit fails either due to bearing wear or tooth wear. The data set contained approximately 8,000 measurements taken at predesigned wellbore conditions. The simulated data were chosen in this study to eliminate errors inherent to data acquired in the field.

Table I shows the recorded data types and their range. All other

parameters were kept constant throughout the measurements. The bit tooth wear and bit bearing wear values ranged between zero and one with one representing the completely worn out tooth or bearing wear. The formation drillability ranged between 30 and 75 in this study. The maximum possible value was 99 representing the highest drillability. The lowest possible drillability was one for hard formations such as hard shales and cemented sands. The formation abrasiveness values ranged between one and eight. The highest possible value was ten representing the most abrasive formation.

Several different neural networks were developed to predict the rate of penetration values. All networks were designed with a three-layer feed-forward back propagation, capable of identifying most relationships between parameters under investigation. In general, the three layers are termed as input, hidden, and output layers. The first network was developed with ten parameters in the input layer. These parameters were consisted of bit type, rotary speed, rotary torque, mud pump circulating rate, formation drillability and abrasiveness, weight on bit (WOB), bit tooth and bearing wears, and bit rotating time measured using the rig floor simulator. The rate of penetration was the only element in the output layer. The drilling parameters like mud density, bit size, and hole configurations were kept constant throughout this study for the purpose of completing the task in a given time and also eliminating their effect on the neural network predictions. However, a new network can be developed with additional parameters when they are available.

A second neural network similar to the first one was designed to predict the penetration rate using only six variables as input. This approach was selected to determine the effectiveness of the neural network approach where data from subsurface were not available and the bit tooth and bearing wear were both unknowns. The six input parameters used in this design were bit type, rotary speed, rotary torque, mud pump circulating rate, weight on bit (WOB), and bit rotating time.

Other drilling parameters and the wellbore configuration were kept same throughout this exercise.

Field Data. The drilling records from several wells in the United States were used as data to develop new neural networks. Several networks were developed, however, only the results with good final correlation coefficients are presented in this paper.

The ranges of data available from field measurements are shown in Table 2. The field data consisted of approximately 500 data sets recorded at different wells with different drilling rigs. This value represents a smaller domain when compared to the simulated data set. Although fewer number of data points were available, there were sixty different bit types covering a wide range. In this data set, the formation types range between one and nine representing an increase in depth and hardness with increase in value. The bit wear values also ranged between zero and nine where zero is used for a new bit without any wear. The ROP values differ significantly in field data and they represent averages based on the total footage drilled during the life of the bit. In the case of data from the rig floor simulator, it was possible to record several penetration rates

for the same bit during its life.

The first network with field data was developed using bit type and diameter, formation type, bit tooth and bearing wear, mud circulation rate, gross hours drilled, footage, weight on bit, and rotary speed as the input parameters. In the design of the second network, the bit tooth and bearing wear parameters were excluded from the input.

A third network design was used to predict the bit life based on gross hours of rotation. The parameters for input layer were consisted of bit type and diameter, formation type, mud circulation rate, footage, weight on bit, rate of penetration, and rotary speed.

Due to different nature of parameters no attempt was made to design a neural network with the combination of field and simulated data.

Discussion of Results

In all networks designed in this study, the data sets were divided into two groups by randomly selecting 10 percent of the total data and setting as the test set. The remaining 90% of the data, termed as training set, were used to train the network and determine the relationship between input and output parameters. Once the network reached a stable state satisfactory to the investigators, the training was terminated and the design was applied to the test set that was set aside. It is interesting to note that the networks were subject to test sets for the first time. Although several networks were designed, the following discussion presents only the results from the final networks.

The rate of penetration values predicted by the first neural network for the simulated data are shown in Figure 1. For a perfect match, all points should lie on the straight line. The measured ROP values in this network range from 51.3 ft/sec to 0 ft/sec and a very good agreement was observed between measured and neural network predicted values. A correlation coefficient of 0.982 was obtained with the predicted ROP values. This network was developed using 100 neurons in the hidden layer and 0.1 was used as the momentum and learning rates.

Figure 2 shows the values predicted by the second network using simulated data. The network consisted of six input neurons, 110 hidden neurons in the middle layer, and one output neuron. The measured ROP values ranged between zero feet per second and 51.3 ft/sec. This second network was developed after excluding four input parameters used in the first network, namely, bit tooth and bearing wear, and formation abrasiveness and drillability. These four parameters were excluded to determine the effectiveness of the neural network in predicting the penetration rates when data from subsurface are not available. The correlation coefficient obtained was 0.955. This correlation coefficient value is less than the 0.982 obtained for the first neural network, however, it represents a good value. An interesting feature here is the capability of neural network to predict the ROP values even in the absence of several parameters used in the first design.

The results from neural network developed in this study using the field data are shown in Figure 3. Even with few and widely distributed data points at ROP values above ten feet per hour, a close agreement was observed between the neural network

predicted values and the values measured in the field. The design for this network involves 27 hidden neurons and a correlation coefficient of 0.965 was obtained.

Figure 4 compares the neural network predicted ROP values with field measured values when data for the bit condition was eliminated from the input layer. A correlation coefficient of 0.980 was obtained for the test set using this design with 24 hidden neurons. The field data included the bit wear values measured after the bit was pulled contrary to the laboratory data where the bit tooth and bearing wear values were available during the measurements.

The final network was designed for the prediction of bit life based on field data. As shown in Figure 5, the agreement between the neural network predicted times and the measured times were very good. There were two data points where the predictions deviated completely from the straight line. Further investigation revealed that these two points represent the times for bits pulled due to well problems and should be either discarded or other parameter used to identify the cause of removal. The deviations from the straight line resulted in a correlation coefficient value of 0.902 which was the lowest correlation among the networks developed in this study.

Conclusions

1. A new methodology was introduced to predict the penetration rates at a drill site using the recorded data. The applicability of this neural network approach was successfully demonstrated.

2. The neural networks developed in this study are valid within the bounds of data used in the development. For systems with data values beyond the range of this study, new networks need to be developed.

3. The new neural network provides an integral approach for predicting the rate of penetration values. When the drilling rate falls below the expected value, a new bit can be selected based on the network predictions.

4. More parameters are needed to identify the field cases where the bit was pulled due to reasons other than wear.

5. Although fewer data were available from field measurements the neural networks developed for ROP prediction in the field yielded good correlation coefficients. Thus, it is important to have a data set covering as wide range as possible to have an effective neural network design.

6. The correlation coefficients ranged between 0.902 and 0.982 for networks developed in this study. The high correlation coefficients are attributed to the capability of the neural networks to identify the contribution of input parameters used in this study.

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TABLE 1 - LABORATORY DATA

Parameter	Range
Formation drillability	30 - 75
Formation abrasiveness	1 - 8
Bearing wear	0 - 1
Tooth wear	0 - 1
Pump rate, str/min	50 - 105
Rotating time, sec	0 - 42,220
Rotary torque, ft/bif	176.3 - 6,748
Weight on bit, lbf	0 - 93,900
Rotary speed, rpm	40.4 - 139.2
Rate of penetration, ft/sec	0 - 51.3

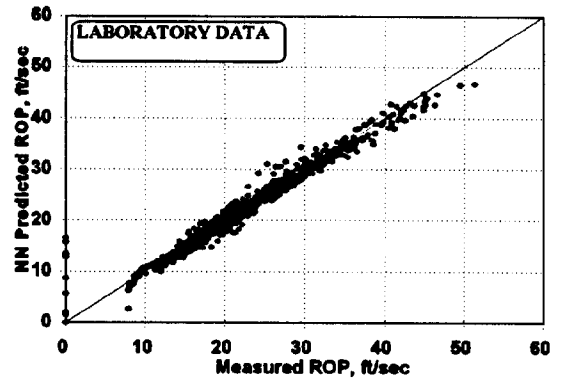


Fig. 1 - Comparison of neural network predicted ROP values with measured values using simulated data.

TABLE 2 - FIELD DATA

Parameter	Range
Bit type	1 - 60
Bit size, in.	5 1/8 - 20
Formation type	1 - 9
Bearing wear	0 - 9
Tooth wear	0 - 9
Pump rate, gpm.	0 - 2,448
Rotating time, hrs.	0 - 206
Interval drilled, ft.	0 - 4,044
Weight on bit, 1,000 lbf	0 - 75
Rotary speed, rpm	0 - 350
Rate of penetration, ft/hr.	0 - 116.3

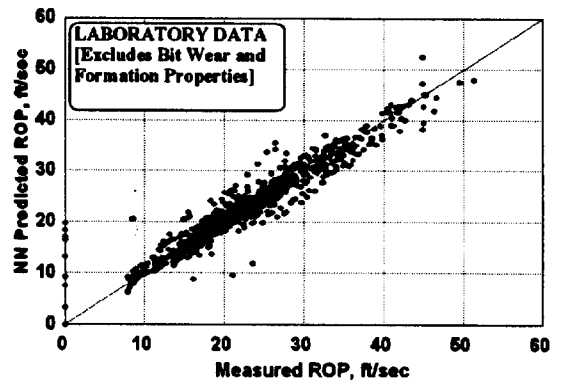


Fig. 2 - Comparison of neural network predicted ROP values with measured values using simulated data(excludes bit wear and formation properties).

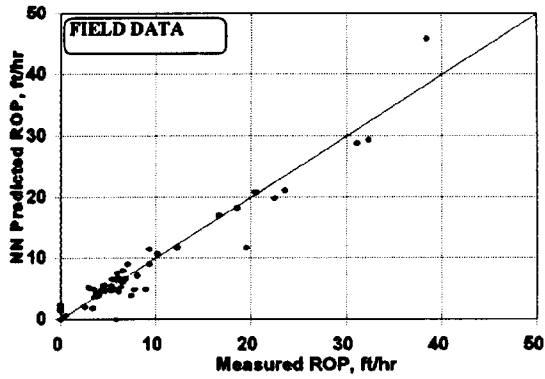


Fig. 3 - Comparison of neural network predicted ROP values with measured values using field data.

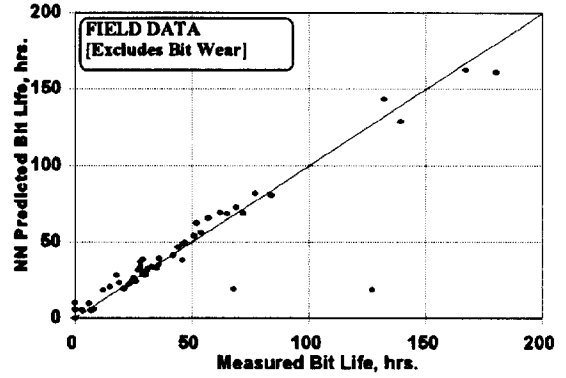


Fig. 5 - Comparison of neural network predicted ROP values with measured values using field data (excluding bit tooth and bearing wear).

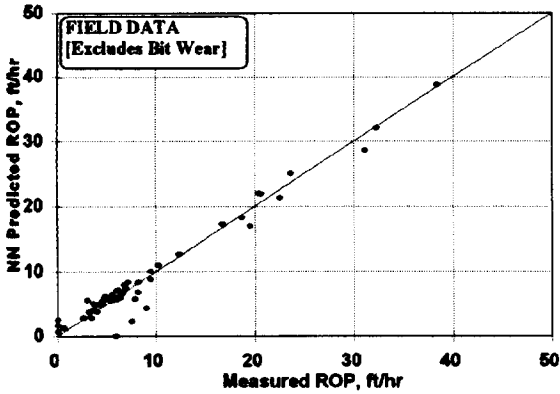


Fig. 4 - Comparison of neural network predicted ROP values with measured values using field data (excluding bit tooth and bearing wear).