Appendix A

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Paper Title: Real-Time Bit Wear Optimization Using the Intelligent Drilling Advisory System

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Abstract

Real-time tools and techniques have recently been used in drilling operations to minimize time and cost, thus improving drilling performance. The real-time drilling data transmission and analysis, from a remote server to an office location, plays an important role in the drilling optimization process. The drilling engineers can provide their expert opinions to the rig personnel, thus increasing drilling efficiency as well as reducing the associated risks. It has been shown that associated drill bit problems can greatly affect total drilling efficiency. Among them, bit wear while the bit is still in the hole can highly influence the operation if it is not properly analyzed. This paper describes the real-time application of a developed model for bit wear analysis. The model was developed based on the differences between rock energy models, Mechanical Specific Energy (MSE), and rock drillability from rate of penetration models. It has been modified and implemented as an engineering module in the newly developed software, Intelligent Drilling Advisory system (IDA's), and is used to estimate real-time bit wear for both rollercone and PDC bits. The drilling data is retrieved by the software from a remote server for the analysis. The data is subsequently quality controlled before calculating instantaneous bit wear while the bit is in the hole. In this study, bit runs for two offset wells in Alberta, Canada, will be analyzed in detail using the software module. Similarities between the recorded bit wear outs reported in the field and the simulation results indicate that the procedure can be used for bit wear estimation with good accuracy. This engineering software module could be used to identify unnecessary tripping which will result in time and cost reductions as well as an additional tool to aid in estimating bit wear status while drilling.

Introduction

Drilling penetration rate, or rate of penetration (ROP), is one of the key elements affecting drilling costs. One of the main factors that highly affect the rate of penetration is bit wear or the rate at which bit is worn while interacting with the formation rocks. Several models have been published to take the effect of bit wear in to account on ROP models. Galle and Woods (Galle and Wood, 1960) developed early mathematical models for use mostly in soft formations which has been modified by Young (Young, 1969) in a less complex form. Cunningham (Cunningham, 1960) proposed another model. The main problem with these models is that they can not be applied in real-time bit wear analysis. With the advent of MWD techniques, a few models have been published based on experimental results, i.e. Burgess and Lesso (Burgess and Lesso, 1985), which is suitable for argillaceous formations. Another method was introduced by Hurbert (Hurbert, 1993) for tracking bit tooth wear during drilling. The limitation of this method was that it could not be applied to rapid variation of weight on the bit (WOB) as well as different lithologies. In 1994, Hareland et al (Hareland, 1994) developed a wear function for both rollercone and PDC bits as a function of fractional bit wear. Fractional bit wear was also introduced as a function of WOB, rotary speed (RPM), formation abrasiveness, unconfined compressive strength and bit wear coefficient (which is a property of the bit cutters).

Furthermore, Mechanical Specific Energy (MSE) can be used as a tool that detects changes in drilling efficiency and can be applied as a real-time drilling tool to indicate drilling problems. The MSE model and the ROP models are being used competitively in the industry to analyze drilling performance. The MSE model does not properly take into account the effects of bit wear, bit design and hydraulics as opposed to the ROP models as shown below. Therefore, MSE can be used mainly to analyze the instantaneous drilling performance while ROP can be utilized for pre-planning, well design and post analysis.

$$MSE = WOB(\frac{1}{A_B} + \frac{13.33 \times \mu \times RPM}{D_B \times ROP}) \quad (1)$$

ROP=f (Operational parameters, hydraulic, Bit design, Bit Wear) .... (2)

Constantly assessing the drilling performance is crucial in maintaining drilling operation in an optimum mode. Real-time monitoring of the bit status and its performance can significantly affect the overall drilling efficiency. It can be achieved by continually pursuing the bit wear trend against depth using real-time tools and techniques. It has been shown that the combination of MSE and ROP models can be used for real-time bit wear estimation (Rashidi et al, 2008). The purpose of this study is to represent the application of this newly developed model in the form of a software module that can be utilized as a valuable tool in the field.

Application of Real-Time Bit Wear Estimation Model

The model used in this study for the real-time bit wear estimation, is based on the approach developed by Rashidi et al [7]. General form of the equation is shown below.

$$Normalized\left(\frac{1}{K_1}\right) = f(h) \quad (3)$$

$$f(h) = 1 - h^B \quad (4)$$

In the above equations, “h” is the fractional bit wear out and “B” is a constant. The coefficient K_1 is determined by the ratio of mechanical specific energy to the inverse of rock drillability for each meter of the drilled wells. The rock drillability is obtained from the ROP model using the corresponding drilling parameters. The normalized values of the inverse of K_1 will be used to indicate instantaneous fractional bit wear.

Real-time Field Data Collection

In general, the real-time drilling data is transferred to a server from the rig site through a service company and the clients retrieve the required data from the server to the office locations by e-mail, FTP file transfer or application software.

The application software (Tahmeen et al, 2008), IDAs, has been developed for the real-time drilling data analysis and drilling optimization. IDAs is capable of working with any WITSML server compatible with versions 1.2.0 and 1.3.1. In this study, the software retrieves real-time drilling data from a WITSML version 1.2.0 server, by implementing XML-based Web Services using Simple Object Access Protocol (SOAP). After successful server authentication, the client needs to select a particular well from the list of available wells, either completed or active. Required drilling parameters, of that specified well, are then selected and the corresponding real-time data, either depth based or time based, are retrieved from the server for the analysis. Figure 1 shows the selection of drilling parameters required for bit wear analysis, such as, WOB, ROP, RPM, mud density, pump flow rate corresponding to a selected well. The graphical and digital representations of the depth-based drilling data are shown in Figures 2 and 3.

The real-time bit wear estimation model has been slightly modified and implemented in this software as an engineering module. In this study, different bit run sections from two offset wells located in Alberta, Canada, have been analyzed.

Data Quality Control

Quality controlling the data referrers to the procedures for eliminating and correcting the data acquired from the server based on the set boundaries. Table 1 shows the practical range for drilling parameters for checking the quality of the data. Some data points collected which are located outside the normal operational range, have to be either removed or averaged. This averaging process creates useable data for all formation intervals. As an example, Figure 4 shows the ROP values versus measured depth before and after quality controlling, to generate the smoother and more accurate bit wear trend.
RPM data points obtained from the server only reflects the surface recorded values. Rotary speed generated by the mud motor

needs to be added to the surface RPM before being used by the software. To do this, the mud motor capacity factor should be multiplied by the flow rate to give the motor rotary speed. These factors can be seen in Table 2 for one of the analyzed wells.

Bit Wear Analysis

To calculate the instantaneous bit wear while drilling using equation (4), constant "B" has to be defined separately in a new equation. The two equations can be solved simultaneously to obtain fractional bit wear, "h", in each meter of the hole. In most of the bit runs, it has been observed that the fractional bit wear in the initial ten meters is almost double of the wear observed in the first five meters as below:

$$h_{10th} = 2 \times h_{5th} \qquad (5)$$

Fractional and final cumulative bit wear trends are calculated using equations (4) and (5) for two Albertan wells, "A" and "B", using the "Engineering Module" in IDA's. Schematic representation of this interface and related options are represented in Figures 5 to 7. On the "Parameter Selection" page, all the drilling parameters can be set manually to correspond to the units provided by the server. The "Spreadsheet" and "Graphical Analysis" pages show the calculated values and graphical view of the bit wear along with the input parameters, in one plot. In the "Other Parameters" section, it is possible to specify a depth interval using related bit parameters as well as selecting proper value for depth of normalization of constant K_1 to be used in equation (3). Calculated fractional bit is shown to be fluctuating as the bit penetrates the rock. The cumulative sum of the cumulative average of fractional bit wear is used as the fractional bit wear out in all the bit run sections. Total bit wear out, ΔBG, can also be obtained using the following equation:

$$\Delta BG = 8 \times h \qquad (6)$$

Results and Discussions

Different bit run sections from two wells in Alberta, Canada, were tested with the Intelligent Drilling Advisory System (IDA's). The data was retrieved from a datahub server and each bit run was separately analyzed. In all the cases, the simulated final bit wear outs were matched to the values from the field. It can be seen that the final simulated results are reasonably matched with the field values. Hence, it can be applied in real-time drilling operations to detect bit wear changes, thus providing a method of improving drilling efficiency and bring a possible cost savings potential to the drilling industry. Tables 3 and 4 represent the summary of the simulated bit wear out results for different bit run sections of the two analyzed wells. The corresponding graphical views are also shown in Figures 8 to 14.

Conclusions

1) A previously developed model was used to build a software module for real-time bit wear estimation.
2) The software was built to receive the input data from an online server which is sent directly from the rig site.
3) Quality control of the drilling input data and unit conversions can be done automatically by the software.
4) Cumulative sum of cumulative average values for fractional bit wear are used to show as bit status.
5) Depth for normalization of constant K_1 and multiplication factor are set manually for each bit run section to get a smother bit wear trend. The automatic calibration and setting of these factors will be integrated into the future development of the software.
6) Calculated final bit wear out values show good matches compared to the field data.
7) Using a bit wear estimation module can save drilling cost by reducing tripping time.

Acknowledgement

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Nomenclatures:

h: Fractional bit wear

IDA's: Intelligent drilling advisory system

MSE: Mechanical Specific Energy

MWD: Measurement while drilling

ROP: Rate of Penetration

RPM: Rotary speed

ΔBG: Total bit wear out

WOB: Weight on the bit

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7) Rashidi, B., Hareland, G. and Nygaard, R., "Real-Time Drill Bit Wear Prediction by Combining Rock Energy and Drilling Strength Concepts", paper SPE 117109 presented at the 2008 Abu Dhabi International Petroleum Exhibition and Conference, UAE, November 3-6, 2008.
8) Tahmeen, M., Hareland, G. and Nygaard, R., "Software Development for Real-time Drilling Data Analysis by Retrieving Data from a Remote Server", paper presented at the International Conference Energy, Informatics and Cybernetics: EIC-2008, Orlando, Florida, June 29 to July 2, 2008.

Table 1: Acceptable range for quality control of drilling parameters

No.	Drilling parameter	Acceptable Range
1	Rate of penetration, m/hr	1-150
2	Weight on the bit, 1000 kg	1-30
3	Rotary speed, rpm	Less Than 300
4	Flow rate, m^3/min	0.8 -2.7
5	Plastic viscosity, litre/sec	Less Than 20
6	Mud weight, kg/m^3	Greater Than 900
7	Mud type	Oil based or Water based

Table 2: Specification for different hole sizes of well A

No.	Hole section/Hole Size	Reveloution/m^3
1	Surface / 349 mm	44.88
2	Intermediate / 222mm	73.92
3	Main / 156mm	147.84

Table 3: Simulated results versus actual field values for well A

Bit Section	Bit Type	IADC Code	Bit Diameter	Actual Bit Wear	Calculated Bit Wear
1	Tricone	115	13.75	3	2
2	Tricone	115	13.75	1	0.95
3	PDC	999	8.75	2	1.7
4	PDC	999	8.75	4.5	4.6

Table 4: Simulated results versus actual field values for well B

Bit Section	Bit Type	IADC Code	Bit Diameter	Actual Bit Wear	Calculated Bit Wear
3	PDC	999	8.75	1.5	1.8
5	PDC	999	8.75	3.5	2.9
6	PDC	999	6.15	2	3

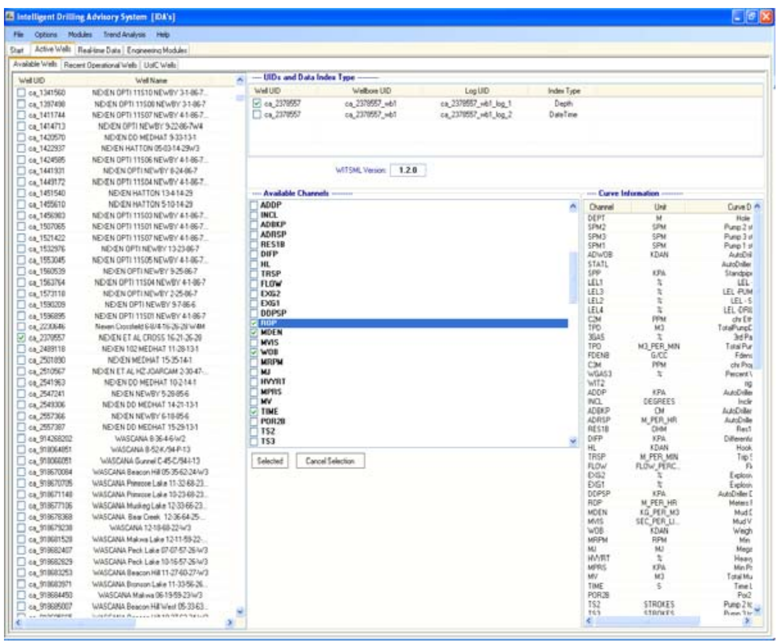

Figure 1: Schematic representation of the "Active Well" page required for parameter selection.

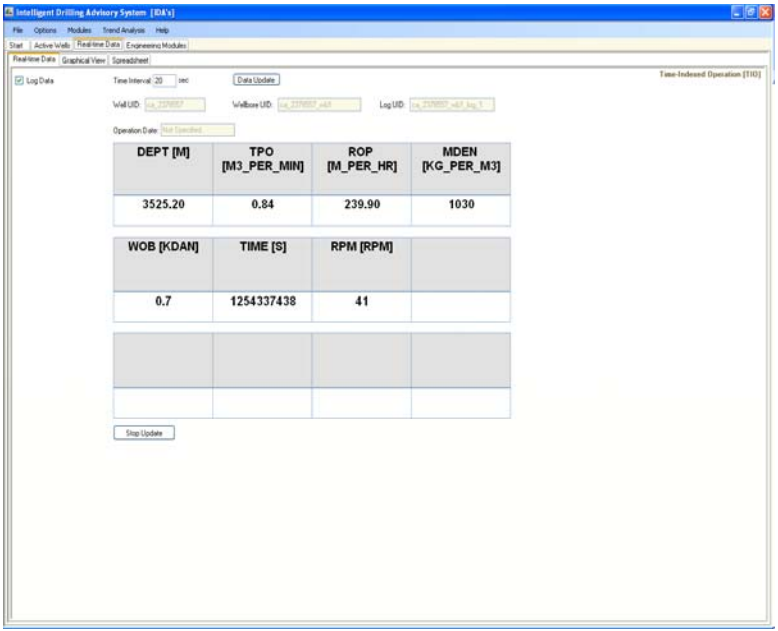

Figure 2: Schematic representation of the "Real-time Data" page being updated with a user-defined time.

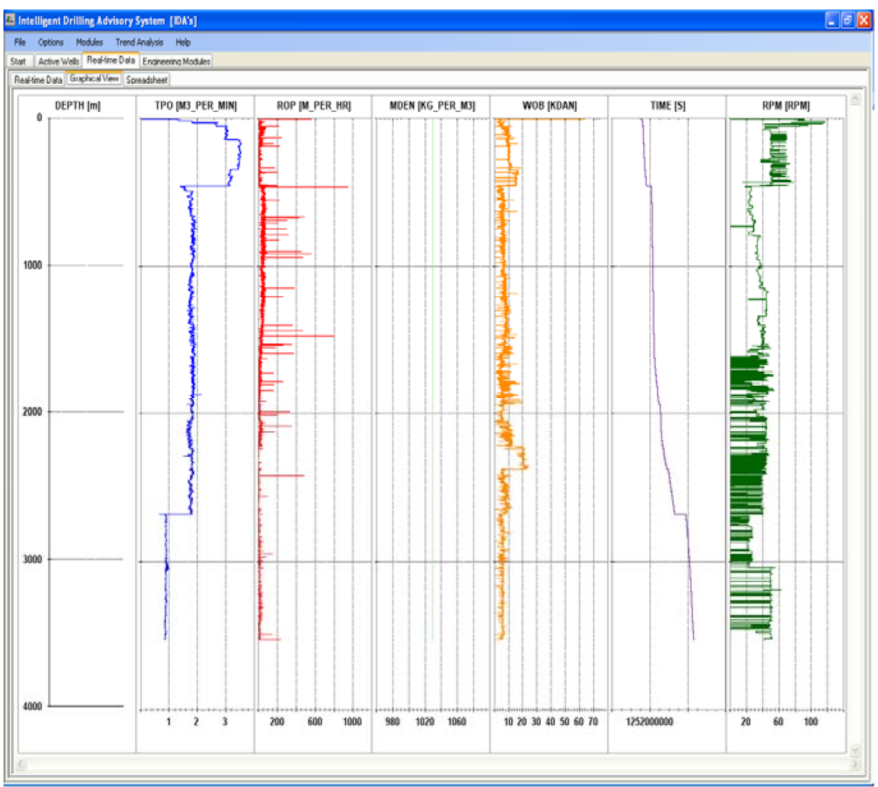

Figure 3: Graphical representation of the input parameters.

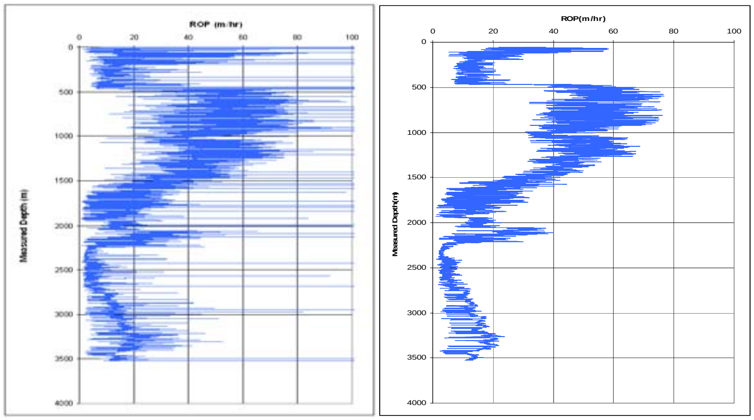

Figure 4: Quality Control on ROP Data (Left: Before QC, Right: After QC).

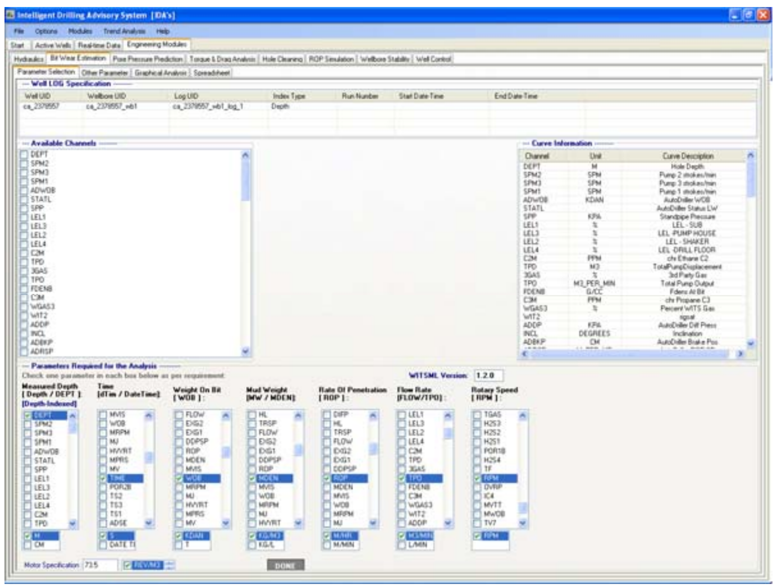

Figure 5: Schematic representation of selecting input data and corresponding units.

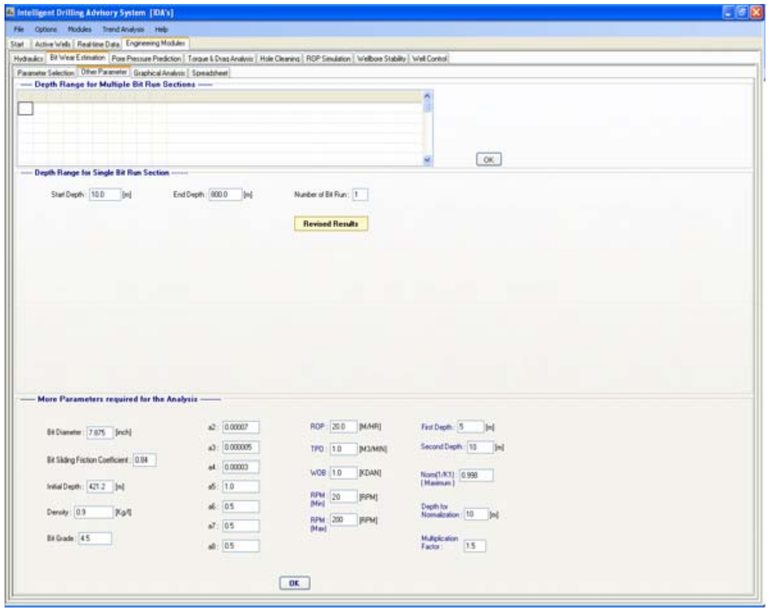

Figure 6: Schematic representation of selecting bit run depth and related options.

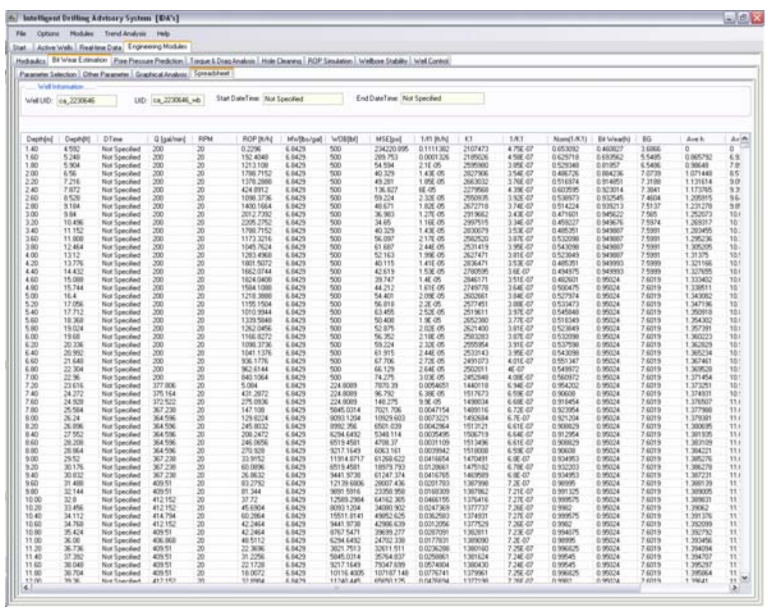

Figure 7: Schematic representation of input and calculated data.

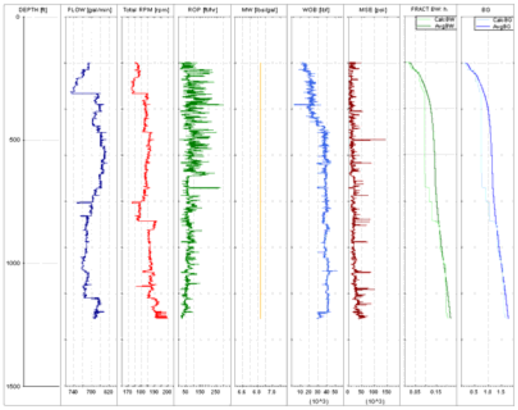

Figure 8: Simulated bit wear trend for the first bit run of well A

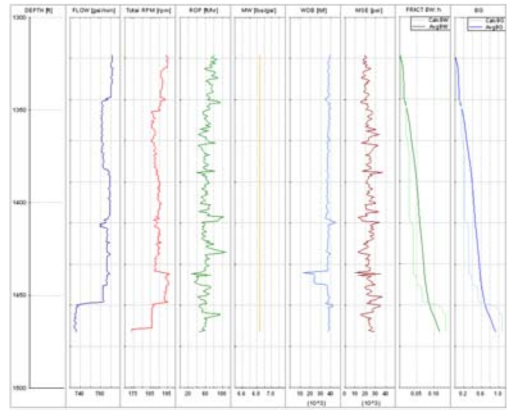

Figure 9: Simulated bit wear trend for the second bit run of well A

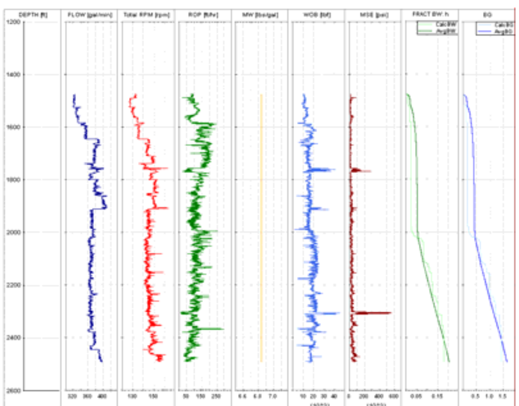

Figure 10: Simulated bit wear trend for the third bit run of well A

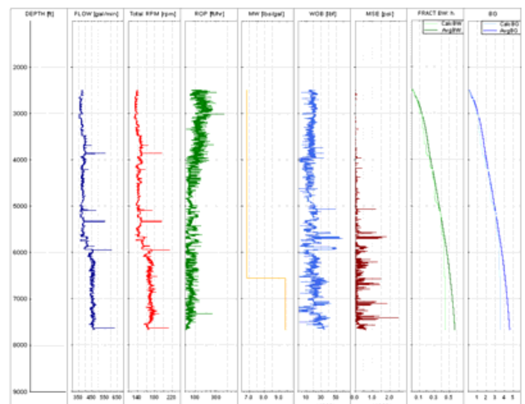

Figure 11: Simulated bit wear trend for the fourth bit run of well A

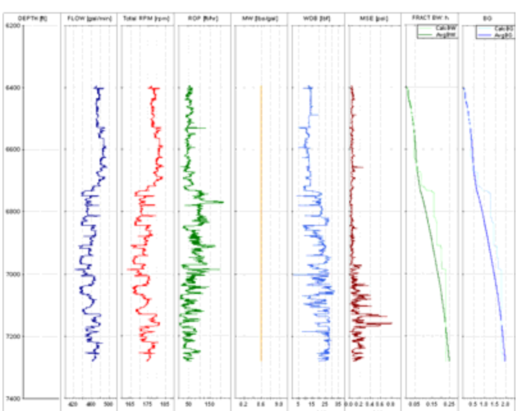

Figure 12: Simulated bit wear trend for the third bit run of well B

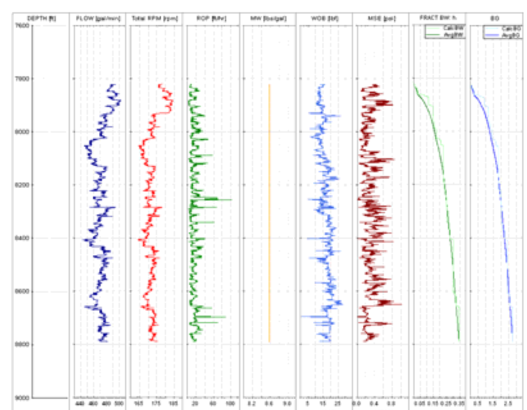

Figure 13: Simulated bit wear trend for the fifth bit run of well B

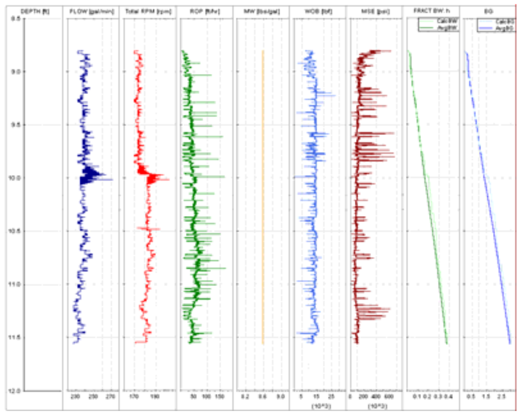

Figure 14: Simulated bit wear trend for the sixth bit run of well B based on depth ($x10^3$) in ft