Appendix H

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Paper Title: New Approach in Real-Time Bit Wear Prediction

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Abstract

Challenging wells have been drilled recently utilizing advanced real time tools and techniques to optimize drilling operation while reducing risk and increasing safety. Moreover, the real time tools and techniques help identify upcoming drilling problems using real time data before they occur. Real time drilling analysis begins when real time drilling data are available and transmitted to the office locations via a remote server. The data can then be interpreted and analyzed by the engineers implementing various models for appropriate decision making. Lately, real time bit wear estimation has been a challenge in drilling a well to reach to the highest drilling performance and avoid bringing serious problems to the bit.

It has been shown that the combination of Mechanical Specific Energy (MSE) and drilling rate models can be used for real time bit wear estimation while drilling. As MSE does not take the bit wear effect into account while drilling rate or rate of penetration (ROP) models do, their difference can be used to monitor and identify bit wear status while bit is in the hole. This paper demonstrates a new form of a developed model to predict bit wear status while drilling which is built by combining rock energy (MSE) model with a newly developed drilling rate model for roller cone bits as well as a previously developed model for PDC bits. Rock confined compressive strength (CCS) is obtained from ROP models and used in conjunction with MSE values to predict bit wear trend. Several bit run sections from offset wells in Alberta, Canada were tested utilizing the model and final results are compared with the reported bit wear outs from the field. Encouraging results show that this methodology can be applied to detect changes in drilling efficiency by monitoring bit wear trend in real time while drilling.

Introduction

Large portion of the drilling cost is related to non-productive time which is associated with drilling problems [(1)]. Although there has been a great attempt to address drilling problems in real-time while drilling using various tools and techniques, they are still challenging to be identified and hindered. Bit wear is one of the main causes that affect drilling performance. This work aims to employ more comprehensive ROP models combined with the MSE model through a developed methodology to predict bit wear especially in real time while drilling [(2)]. A previous methodology was established based on using Burgoyne and Young ROP model for both rollercone and PDC bits which shows uncertainties for the calculated results. In this study, more advanced ROP models were used which integrate the effect of all the associated drilling and bit design parameters to calculate rock confined compressive strength that can then be utilized in conjunction with MSE model for bit wear estimation. The ROP model for roller cone bits was developed in 2010 by Hareland et al. based on the rock bit interaction and takes the effect of different bit designs and cutting structures, drilling parameters and bit wear into account [3]. In 2008, Motahari et al. proposed a model for PDC bits to estimate drilling rate which also integrates bit wear effect [4]. Rock confined compressive strength (CCS) can be obtained by rearranging the aforementioned ROP models for a known bit wear status and a set of drilling parameters considering drilling operational and bit design parameters.

Application of New Drilling Rate Models for Bit Wear Prediction

A previously developed approach for bit wear estimation was based on combining MSE model and rock drillability obtained from a pre-developed ROP model. In this study, instead of rock drillability, rock confined compressive strength (CCS) is back calculated using newly inverted ROP models for both roller cone and PDC bits respectively as shown below.

$$ROP = K * \frac{80 n_t^{\,a} * m * RPM^b}{D_b^2 * \tan^2 \psi} \left(\frac{WOB}{100 * CCS} \right)^c * W_f \qquad (1)$$

$$ROP = W_f * \frac{R * WOB * RPM^b * Cos\,\alpha}{CCS * D_B * (\tan\theta + \mu)} \qquad (2)$$

D_b: Bit diameter
Ψ: Chip formation angle
a, b, c: Coefficients
K: Comprehensive coefficient
WOB: Weigh on the bit (lb)
RPM: Rotational speed (revelation/min)
CCS: Rock Compressive Strength (psi)
μ: Coefficient of friction between PDC cutter and the rock

For roller cone bits, m and n_t are speed ratio of cone to bit and number of inserts in contact with the formation per revolution of the bit which should be obtained separately for each bit IADC code. In eqn. (2), α and θ are PDC back rake and side rake angles. W_f is wear function and its purpose is to integrate the bit wear effect into the ROP models. CCS is rock confined compressive strength which can be calculated using inverted ROP models for each set of drilling data. It can also be converted to rock unconfined compressive strength utilizing eqn. (3) [5].

$$CCS = UCS(1 + a_s (BHP - P_p)^{b_s}) \qquad (3)$$

Where:

BHP: Bottom hole pressure (MPa)
P_p: Pore pressure (MPa)
a_s & b_s: Constants

Integrating rock mechanical energy (MSE) and Inverted Confined Rock Strength (CCS) to obtain real time bit wear

In real-time drilling applications, bit wear status can not be visually inspected and evaluated. A method to obtain real time bit wear is suggested using the ROP models and the cumulative effect of drilling data from every meter in a bit run. This will be done using a combination of the ROP models and rock Mechanical Specific Energy. By assuming no bit wear initially and calculating the CCS using the ROP models, it can then be used in conjunction with MSE to calculate the fractional bit wear while drilling [2] as shown below:

$$MSE = WOB\left(\frac{1}{A_B} + \frac{13.33 \times \mu \times RPM}{D_B \times ROP}\right) \qquad (4)$$

Where,

A_B : Bit area.
D_B : Bit diameter.
μ : Bit sliding friction factor (Constant).

MSE is calculated from eqn. (4) and the CCS is obtained from the ROP models.

$$MSE = K_1 \times CCS \quad \text{.......... (5)}$$

Constant K_1 can be obtained for each meter of the well using field drilling parameters to obtain the fractional bit wear contribution (*h*) as shown below.

$$Normalized\ (\frac{1}{K_1}) = 1 - h^B \quad \text{.......... (6)}$$

MSE, which incorporates the effect of bit wear, can then be used in combination with the CCS from the ROP models to back out real-time fractional bit wear (eqns. (5) and (6)). The calculated fractional bit wear (*h*) will then further be used to obtain the actual bit wear using the below equation where the standardized IADC fractional scale of bit grading from 0 to 8 is assumed.

$$\Delta BG = 8 \times h \quad \text{.......... (7)}$$

Applying eqn. (7), the wear function can be obtained using following equation for PDC and roller cone bits.

$$W_f = 1 - a(\frac{\Delta BG}{8})^b \quad \text{.......... (8)}$$

a, b: Constants

This approach will give us a new method and tool for predicting real –time bit wear which will help optimize drilling operation in real-time while drilling. It can also be integrated as a module in drilling optimization software after it has been developed, verified and tested. Some test analyses were done using offset well data of western Canada, Alberta. Tables (1) and (2) shows the data related to each bit run section as well as corresponding reported bit wear out values compared to the calculated ones. Acceptable match between final reported and calculated bit wear out values were obtained and shown graphically in Figures (1) to (5).

Conclusions

1) New comprehensively developed ROP models were used to generate rock confined compressive strength with taking the effect of various drilling and bit design parameters into account.
2) Calculated CCS values from inverted ROP models can be utilized combined with MSE model through a previously developed approached for real-time bit wear prediction.
3) Using CCS values instead of rock drillability helps calculate bit wear out while drilling with higher accuracy.
4) Good matches were obtained for different bit run sections between calculated and reported bit wear out values using offset well data.
5) This method can help the drilling operation in advance by predicting and optimizing the drilling performance to obtain the lowest cost per foot during drilling real time by being able to predict the CCS and instantaneous bit wear.
6) Utilizing this technique and possible integration into a simulator can be used as an excellent training tool to understand the integrated effects on bit performance especially bit wear effect.

References

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Table 1: Summary of drilling bit information and estimated bit wear grade for Alberta wells A and B.

Bit type	IADC Code	Bit Diameter (in)	Depth in (m)	Depth out (m)	Reported bit wear out	Calculated bit wear out
Rollercone (Well A)	547	8.75	2325	2490	1.0	1.8
Rollercone (Well B)	537	8.75	2220	2380	7.0	6.4

Table 2: Summary of drilling bits information and estimated bit wear grades for Alberta well C.

Bit type	Bit Diameter (in)	Depth in (m)	Depth out (m)	Reported bit wear out	Calculated bit wear out
PDC	8.75	750	2350	4.5	4.2
PDC	8.75	2540	2690	2.0	1.4
PDC	6.15	2900	3710	2.0	1.74

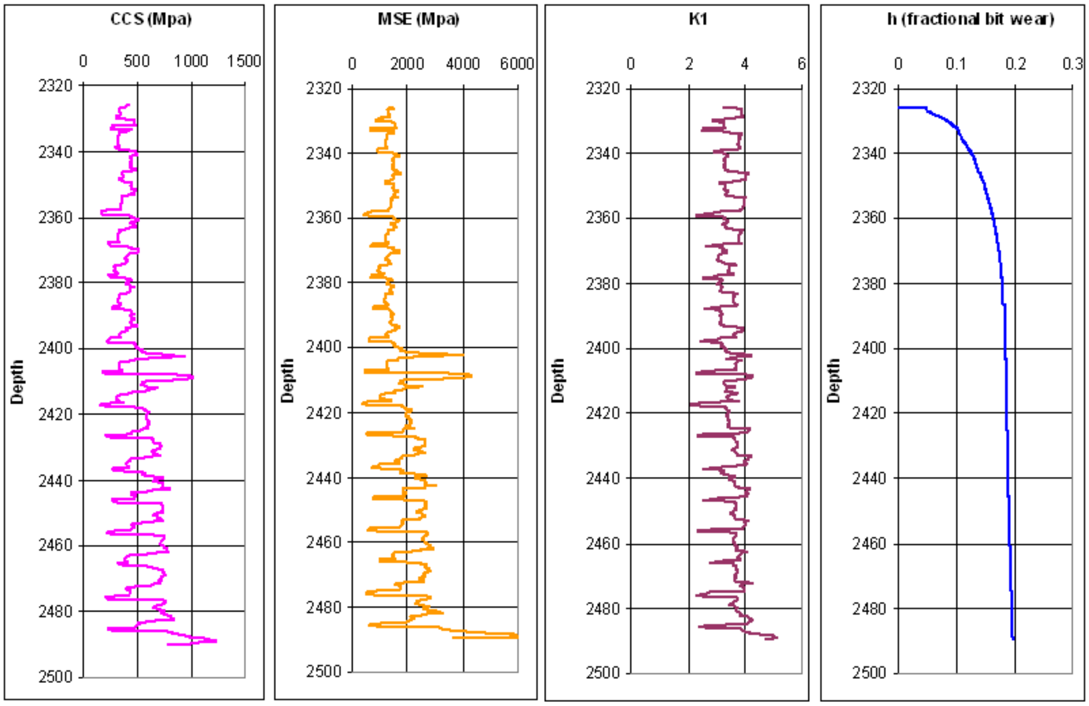

Figure 1: Graphical representation of MSE and UCS and corresponding calculated fractional bit wear out of well A.

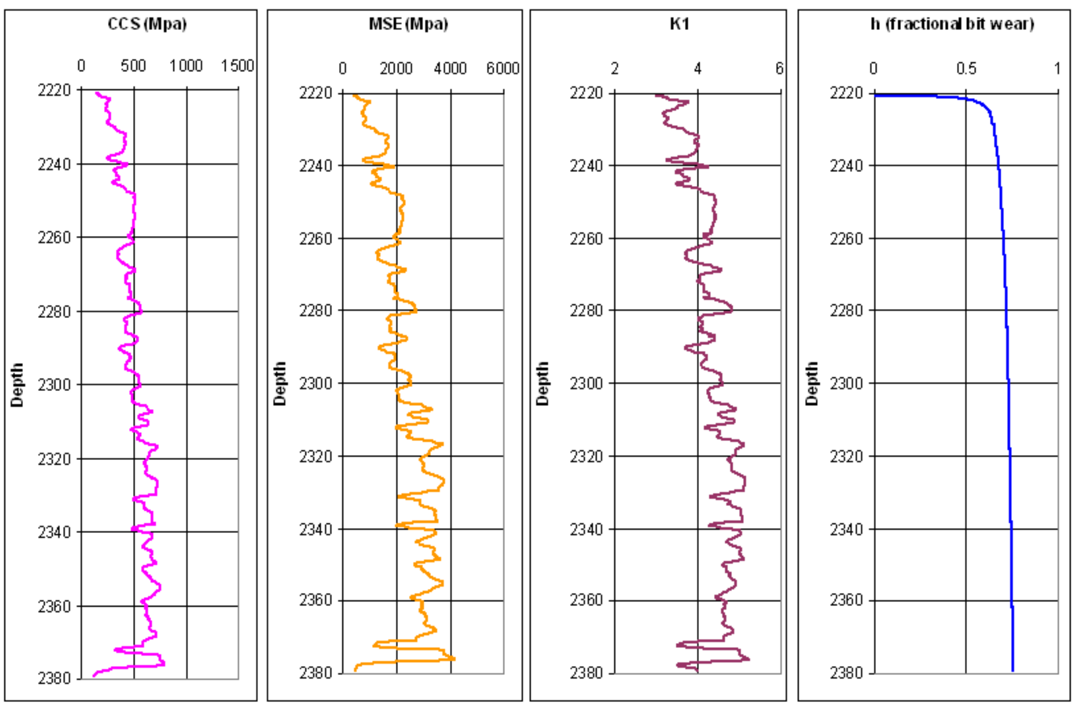

Figure 2: Graphical representation of MSE and UCS and corresponding calculated fractional bit wear out of well B.

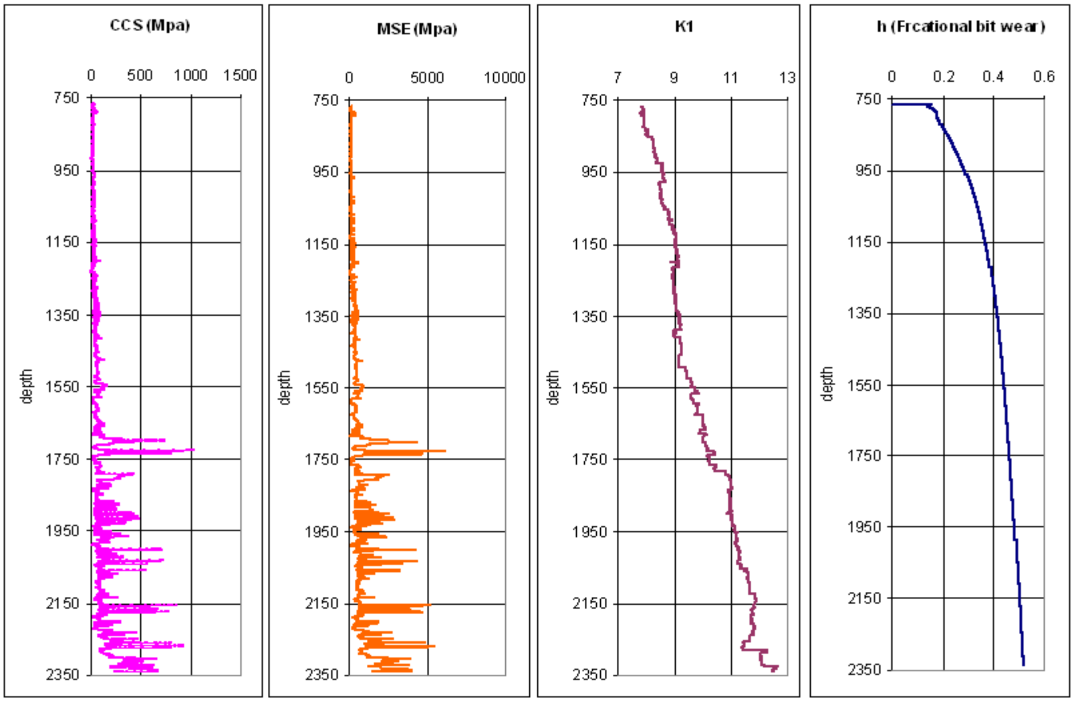

Figure 3: Graphical representation of MSE and UCS and corresponding calculated fractional bit wear out for bit run 1 of well C.

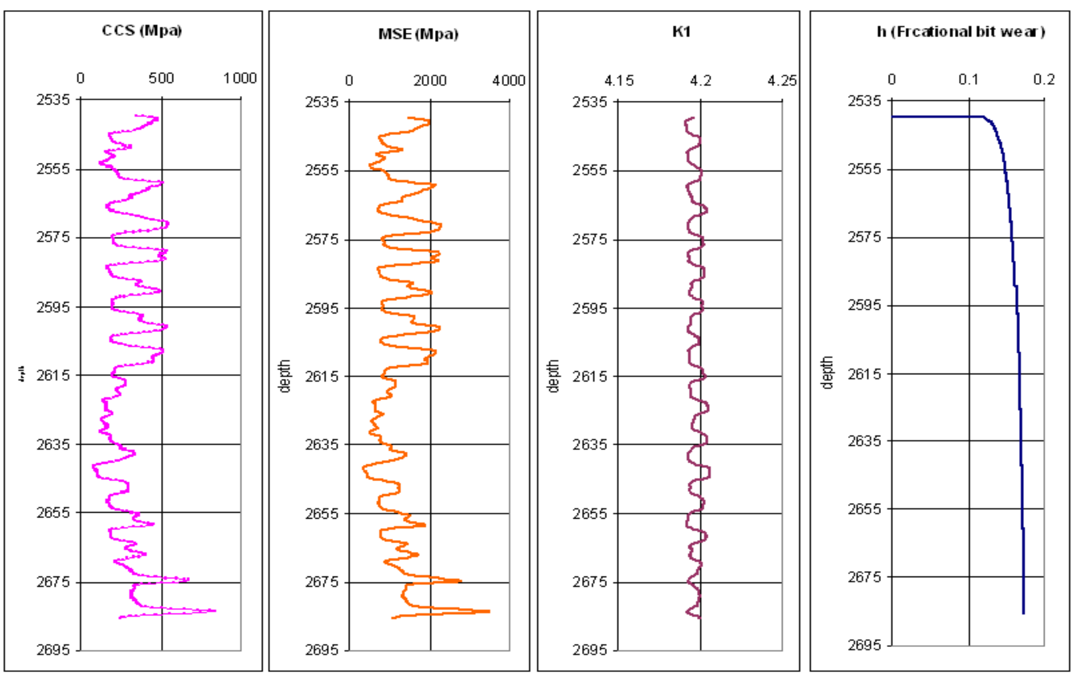

Figure 4: Graphical representation of MSE and UCS and corresponding calculated fractional bit wear out for bit run 2 of well C.

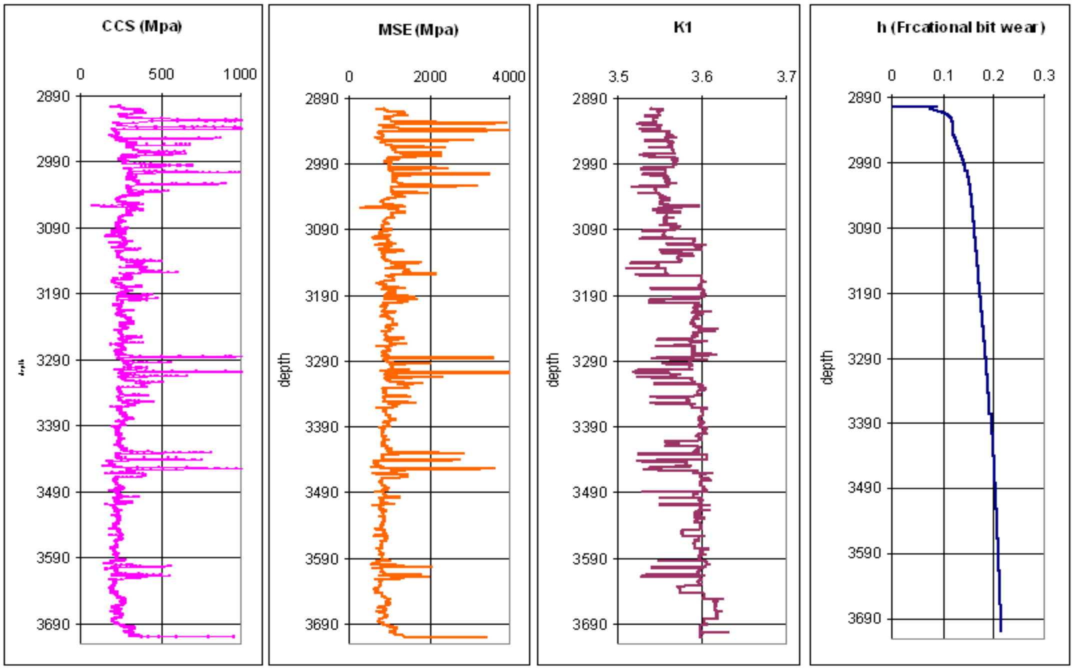

Figure 5: Graphical representation of MSE and UCS and corresponding calculated fractional bit wear out for bit run 3 of well C.