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New alternative MSE based ROP Modelling and Analysis with North Sea field Data

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Abstract

Oil companies employ different methods and techniques in order to achieve an optimized operation and cost reduction. Among others, accurate rate of penetration (ROP) prediction and optimization design improve drilling efficiency and reduce cost associated with the operation- and nonproductive time.

In this paper, the initial Pessier et al (1992) bit torque model was modified to couple the rotational effect on the sliding bit specific coefficient of friction. The proposed alternative ROP model is tested with North Sea field data and workflow for the application is presented.

Results showed that the alternative model prediction is quite as good as Pessier et al's (1992) model and the error deviation from the measured data was reduced.

1. INTRODUCTION

During the last decades, the oil and gas industry have developed drilling and well technologies to a higher level. However, Hovda et al's (2008) assessment of 5900 wells revealed that the technological development since the late 90's increased the drilling rate (m/day) while the nonproductive time was being held approximately 25% flat value. This cost the oil industry a lot. Optimization of drilling operations improves the drilling performance efficiency, as well as the cost reduction associated with nonproductive time and invisible nonproductive time.

Drill-bit optimization needs to be conducted during planning phase. Hareland et al, (2007) indicated that drill-bit performance design is aimed at achieving drilling with higher ROP, lower overall cost per foot, lower drilling time and lower wear rates.

ROP models documented in literature relates ROP with rock strength, bit torque, WOB and rotary speed, and bit characteristics. Warren's (1981, 1987) ROP model is the function of drilling parameters, bit type, formation strength, and jet impact and drilling fluid properties. Hareland and Hoberock modified (1993) modified Warren's model by coupling various effects such as differential pressure, bit wear rate and bit characteristics. Bourgoyne and Young (2003) have developed ROP model for tricon bit, which is the function of eight parameters. Several investigators analyzed specific energy in drilling (Pessier et al (1992) Dupriest et al, 2005, Guerrero, 2007). However, as well known, all models have their own advantages and shortcomings. Currently, there is no universal ROP model, which is API standardized and valid for all cases as well.

The background for this paper is the work of Pessier et al's (1992) that uses the bit sliding coefficient of friction. However, this paper will therefore look into the effect of rotation on the sliding coefficient of friction. The newly proposed model is analyzed using field-drilling data obtained from the North Sea.

Concept of Specific Energy in Rock Drilling:

Teale's (1965) laboratory tests result demonstrated that the energy spent to destroy a unit volume of rock is relatively constant, regardless of changes in ROP, WOB or RPM. When a bit performs at its peak efficiency, the ratio of energy to rock volume remains relatively constant. Teale defined minimum specific energy (MSE) as the energy required removing 1cm^3 of rock.

Pessier et al (1992) used the concept of specific energy to derive ROP model. According to Pessier and Fear, (1992), the MSE is roughly equal to the uniaxial compressive strength of the rock being drilled (C_o)

$$MSE = \frac{4WOB}{\pi d_{bit}^2} + \frac{480RPM * T}{d_{bit}^2 ROP} \approx C_o \qquad (1)$$

Where, D_{bit} is diameter of the bit (*inch*), RPM is rotary speed, WOB is weight on bit (lb), T is bit torque (ft-*lbf*)

Pessier et al's (1992) experimental data showed that bits are only 30-40% efficient at peak performance. To take into account the mechanical bit efficiency, Dupriest (2005) therefore modified MSE (MSE_{mod}) and given as:

$$MSE_{\mathrm{mod}} = EFF_M \left(\frac{4WOB}{\pi d_{bit}^2} + \frac{480RPM * T}{d_{bit}^2 ROP} \right) \qquad (2)$$

Where, EFF_M is mechanical bit efficiency.

Uniaxial compressive strength:

Unconfined compressive strength (UCS) is a fundamental property used for design purposes in civil, mining, and petroleum engineering. UCS is usually determined through a laboratory test. However, for field application, it is practically impossible to generate compressive strength profile using a rock extracting from the well, which is due to cost and the sample lose its in-situ stress states and fluid content as well. Lal (1999) reported that shales make up over 75% of the drilling oil and gas formation. Based on extensive shale extracted from the North Sea, Horsrud (2001) has derived empirical correlation equation for uniaxial compressive strength C_o (MPa) vs sonic slowness, dt(μs/ft) or compressional wave velocity, V_p (km/s). There are also many other sonic log based UCS models documented in literature for instance (Chang et al., 2006, Zhang, 2019). For practical purpose, one can estimate the UCS from the mechanical specific energy concept using drilling parameters as shown in Equation 1.

Bit Torque:

Torque at the bit can be measured by the downhole MWD tools. However, in most cases, bit torque measurements do not exist. Bit specific coefficient of sliding friction (μ) is introduced to express torque as a function of the WOB, making MSE to be calculated in the absence of reliable torque measurement (Pessier & Fear, 1992):

$$T_{bit} = \frac{\mu D_b WOB}{36} \qquad (3)$$

Substituting Eq. 3 in Eq. 2, the ROP model yields (Pessier & Fear, 1992):

$$ROP = \frac{13.33\mu RPM}{D_{bit}\left(\frac{MSE_{\mathrm{mod}}}{WOB} - \frac{1}{A_{bit}}\right)} \qquad (4)$$

It is important to realize that the presence of cutters, and the bit characteristics, the rate of penetration can varies (Hareland and Hoberock, 1993). However, let us assume a simple case that the total work done by the applied external load is the same as the total energy that is used to excavate a volume of rock sample.

2. THIS WORK ROP MODEL DEVELOPMENT

Let us consider the rock ahead of the bit is loaded with axial load (i.e. WOB) and applied rotational force that is supplied by the torque. As can be seen in Eq. 3, the sliding friction presented by Pessier & Fear, 1992 does not consider the rotation effect. Therefore, this work will look into it by coupling the effect of rotation on the sliding friction. The modified sliding of friction, which is a function of axial velocity, angular speed and bit radius (Aadnøy et al, 2009). The modified torque can thus be written as:

$$T_{bit} = \frac{\mu \cos\left(\tan^{-1}\left(\frac{v_a}{r_{bit} RPM}\right)\right) D_b WOB}{36} \qquad (5)$$

Where, V_a is the axial velocity during tripping, which is the same as ROP during drilling operation. Inserting Eq. 5 into Eq. 2 and solving for ROP, one can get:

$$ROP = \frac{5\sqrt{2}\pi D_{bit} RPM}{2}\left(\sqrt{\sqrt{1 + \frac{16\mu^2 WOB^2}{9(MSE_{mod}A - WOB)^2}} - 1}\right) \qquad (6)$$

Where, D_{bit} is in inch

3. MODEL TESTING

Example #1 North Sea Field data #1 (Pessier and Fear, (1992)

Pessier et al's (1992) field drilling data was used for the assessment of the ROP models (i.e. Eq. 4 and Eq. 6). In this example, the specific bit coefficient inverted from Equation 3 was used as input for used for the two models. **Figure 1a** is the comparisons of measured ROP and **Pessier** & Fear, 1992 model (Eq. 4) prediction. Similarly, **Figure 1b** shows comparison of the measured ROP with the proposed model **(Eq. 6**). Both shows quite good prediction.

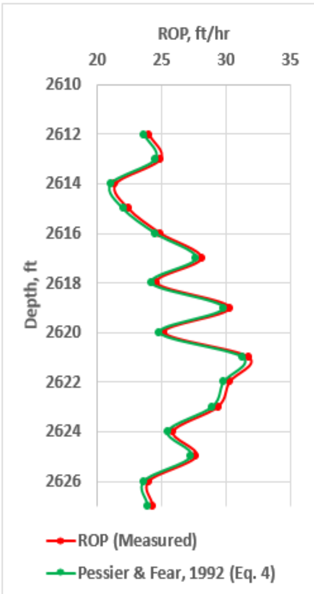

Figure 1a: ROP measured vs. Calculated

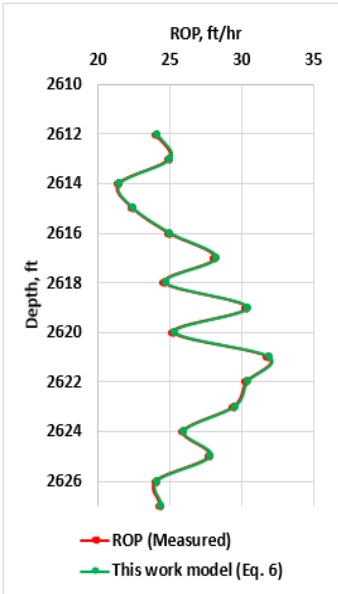

Figure 1b: ROP measured vs. Calculated

For better visualization, the plots displayed in figure 1a and b are plotted as measured versus model calculated (**see Figure 2**). As shown in the figure, the proposed model predicted ''better'' than Pessier & Fear, 1992) model (Eq. 4). Pessier & Fear, 1992 shows about 2% discrepancy. The proposed model shows about 0.5% discrepancy.

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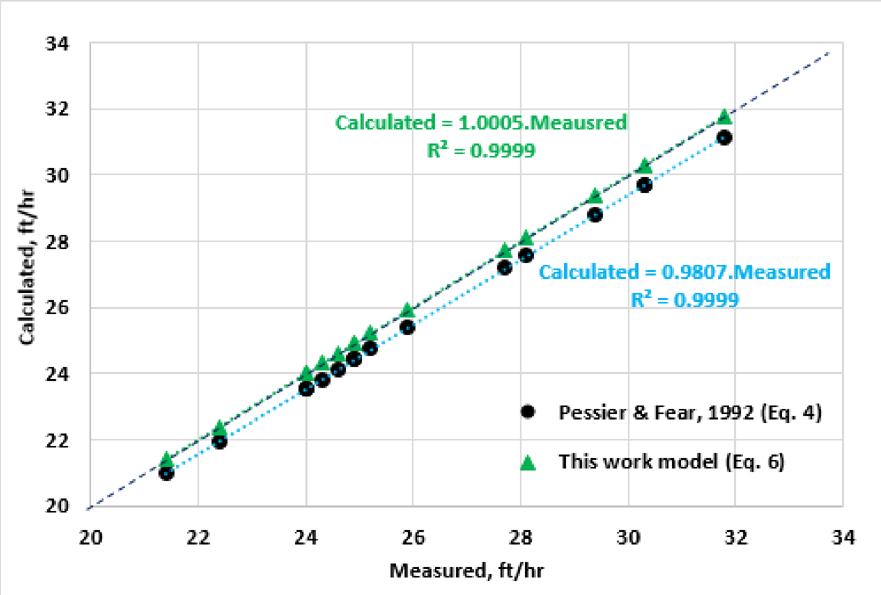

Figure 2: Measured vs model calculated

Example #2: North Sea Field data #2 (Pessier and Fear, (1992)

Similarly, the second set of Pessier et al's data were also used for the analysis. **Figure 3a** shows the drilling parameters used to compute the ROP. **Figure 3b** displays the predicted ROP compared with the measured data. For comparisons, the absolute percentile deviation is calculated and plotted in **Figure 3c**. As shown, the proposed model reduced the percentile deviation nearly by half as compared with **Pessier** & Fear, 1992 model.

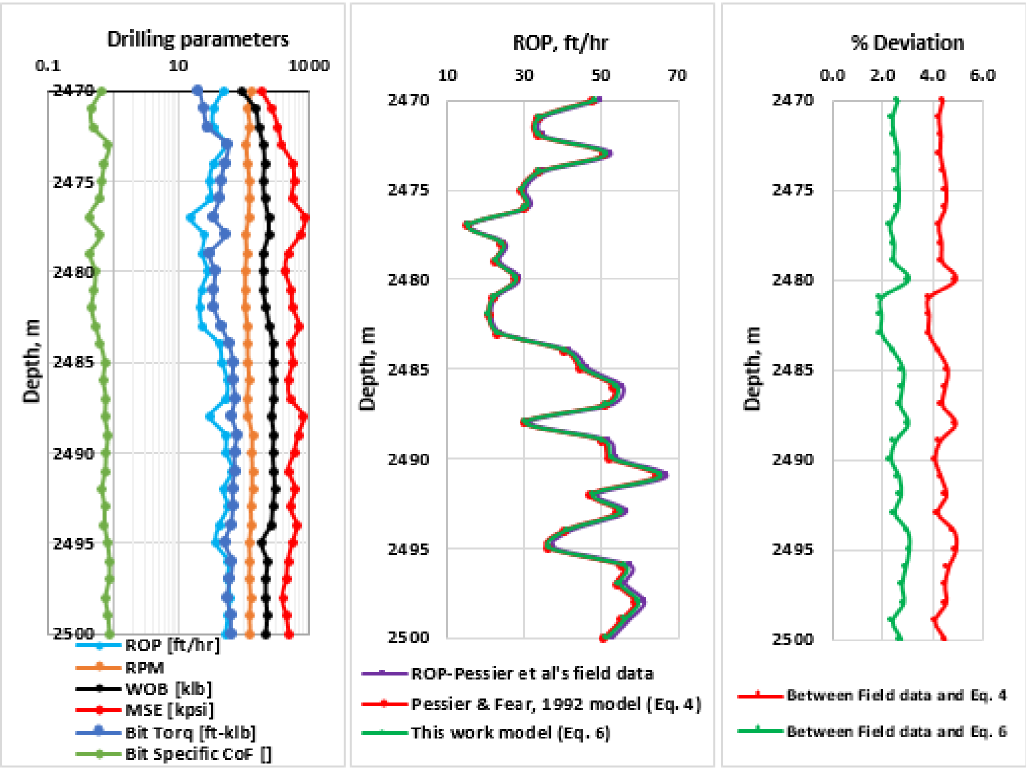

Figure 3a: Drilling data [Pessier and Fear, 1992] **Figure 3b: Measured vs Calculated ROP** **Figure 3c: % Deviation between model and measured data**

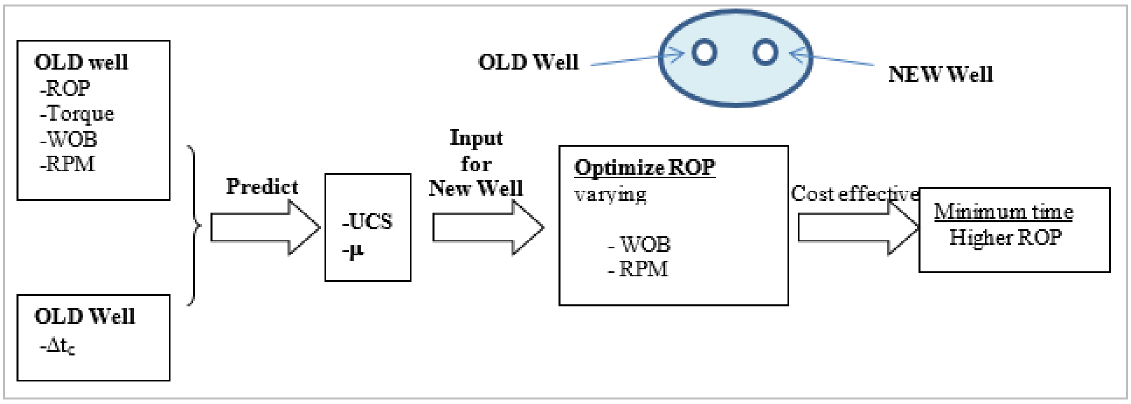

Figure 4: Proposed workflow for field application

4. WORKFLOW FOR FIELD APPLICATION

Figure 4 outlines the workflow for the application of the model. As displayed in the chart, the UCS and bit coefficient of friction profiles are to be estimated from the drilling and log data of an old drilled wellbore. Assuming that the lateral geological features are quite the similar, the parameters estimated from the old well will be used as input for the model to simulate an optimized ROP for the new well. During the simulation study, the combination of drilling parameter, which results in a higher ROP is the key for the cost effective drilling operation. However, it also important to consider bit wear. The higher ROP along with the minimum bit wear is selected as the best-optimized parameters, which reduces drilling time -and undesired tripping operation.

5. SUMMARY

The paper presents an alternative ROP model along with workflow for the application. Evaluation of the alternative proposed -and the Pessier, et al.'s (1992) ROP models through the measured field data showed quite good predictions. However, the proposed model reduced the error. It is important to note that more testing is required to judge the models more.

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