# MONITORING DRILLING BIT PARAMETERS ALLOWS OPTIMIZATION OF DRILLING RATES

**Assoc. Prof. V.C. Kelessidis**[1], **P. Dalamarinis**[1]

[1] Mineral Resources Engineering Dept. Technical University of Crete, **Greece**
kelesidi@mred.tuc.gr

Paper to be presented at the INTERNATIONAL MULTIDISCIPLINARY SCIENTIFIC GEO-CONFERENCE & EXPO, Modern Management of Mine Producing, Geology and Environmental Protection SGEM 2009, Albena, Bulgaria, June 14-19.

## ABSTRACT

Drilling for mineral resources can be one of the most expensive processes in the exploration and production. Hence, drilling industry has been striving since its inception for developing drilling techniques which allow for fast drilling rates but ensuring the safety of the well and of the workers. Parameters affecting the drilling process can be cast in two major categories, rig and bit related parameters and formation parameters. The first category includes weight on bit, torque, rotational speed, and hydraulic parameters like flow rate, density and rheology of the drilling fluid. The second category includes local stresses, rock compaction, mineralogy, abrasivity of formation, formation fluids. The drilling parameters can be controlled while formation parameters have to be dealt with. To achieve faster drilling rates, drilling industry has developed and uses a multitude of sensors which monitor the above parameters while at the same time allow for estimation of formation parameters. This information must then be analyzed, either in-situ or post-drilling for the design of new wells and appropriate software packages have been developed which perform these tasks to a certain extend but has been accepted widely, maybe because of the great complexity of the drilling process. In this paper we review such available packages and address the issues of the capability of a particular software package, Payzone, to be used and tuned, with monitored drilling data, so that one can design future wells using information provided from an existing well. Bibliographic drilling data are used from various drilling wells, the data monitoring is analyzed with the view of having the best available data and future designs are proposed which would allow for faster drilling rates.

**Keywords:** drilling optimization, drilling rates, data monitoring, drillability

## INTRODUCTION

Drilling may be the most expensive process during the exploration campaign and the ability to predict penetration rates under given subsurface conditions with the various drilling rigs is very essential for the safe design and the accurate cost prediction before the start of the drilling campaign. Prior experimental and field evidence has already demonstrated that penetration rate depends on two groups of parameters, formation properties and drilling parameters. In the first group, these involve local stresses, rock compaction, mineralogical content, and fluid pore pressure. The most significant drilling parameters are applied weight on bit and torque, rotary speed and hydraulic parameters (flow rate, density and rheology of drilling fluid). Bit condition is equally important because there is blunting while drilling progresses, which depends on the formation being drilled. Drilling tools have evolved significantly over the years but modelling of the drilling process and the interaction of bit – formation rock has yet to be modelled adequately, which would allow for better penetration rate prediction.

Improvements in bit design and on operating procedures could offer, especially in deep wells, improvements in rate of penetration (ROP), with numbers indicated in the range of +25% which could translate to significant savings [1]. While drill bit design is at the hands of capable drill bit companies, operating procedures can only be applied by the operator and availability of such models or simulators could allow for better operating procedures, especially in a long drilling campaign in the same field. For e.g. when using PDC bits, one is never sure whether to increase weight on bit (WOB) or revolutions per minute (RPM). In a field study [2] it was shown through testing that doubling the bit RPM in 6,000-psi rock while keeping WOB constant resulted in 70% increase in ROP, however, doubling WOB, with RPM constant, resulted in 300% increase in ROP. Availability of a good rock-bit interaction model via a well tuned simulator, such as the one that will be analyzed below, could alleviate necessity for such lengthy and expensive experiments. Of course, besides the simulator, one needs the real data from previous similar wells, hence the monitoring of almost everything that is moving is more than essential for such successful application of the simulator. Drilling data are then essential, gathered from the sensors installed on the rig, for running the simulator and as such the following data is needed, surface weight-on-bit, torque, rotary speed, pump pressure, flow rate, nozzle configuration, detailed bit grading.

Use of a software program in combination with real time monitoring of drilling parameters together with the availability of a drillability model allows one to calculate optimum weight-on-bit, pump pressures and rotary speeds [3]. Use of simulators to predict effects of changing parameters has been attempted in the past [4,5,6] but requirements are such that in order to model the process with fair degree of accuracy, a large number of parameters is needed, making them fairly complex, expensive and not very flexible in terms of simulating various encountered conditions, thus, they have not been accepted widely. Another approach is to produce a simple simulator but based on phenomenological modeling; having thus the basic parameters in place and the proper model, using then real data from previously run conditions, to tune the simulator, one can produce similar results to the real world. Then, the simulator can be used to predict conditions for the operating parameters in a new drilling campaign in the same field. Such a drilling simulator, under the name of Payzone, has been developed in recent years [7,8,9]. Recent developments allow for a slightly different approach to drilling simulator allowing the prediction of rock mechanical strength, based on the input of the monitoring parameters, giving input to the formation change and alarming the operator of any changes [10,11,12].

The Payzone simulator allows for defining different lithologies along the wellbore, in terms the rock type, strength, and abrasivity. Rock-type data are usually available in a typical LAS file, strength data are sometimes given, sometimes not, and in these cases, estimation is made, either from databases for similar rocks or they are estimated from sonic data, although these are fairly crude estimates. This parameter will be further explored later. When all the data is loaded, the simulator is adjusted to reproduce the drilling performance observed in the offset or reference well. Then any well can be re-drilled to see if a better set of operating conditions can be specified. In the same way, a new well can be "drilled" and its drilling performance optimized [7-9].

## MAIN FEATURES OF SIMULATOR

The Payzone drilling is developed for teaching and research purposes [7,8] and it is fairly flexible and simple to use. Besides the capabilities, although not so advanced, which give a picture of the well drilled and present also the Lithology and drill time log, the main feature is the prediction of drilling rate, using Eqn. (1),

$$ROP = (flow\_factor)(C)(aggressivity)(RPM)(tooth\_length)(G) \quad (1)$$

where

$$G = 1 - \exp\left[-\left(\frac{WOB}{UCS}\right)^{curv}\left(\frac{12}{D^{2.5}\left(0.4 * tooth\_length\right)}\right)\right] \quad (2)$$

where, RPM is rotary speed, tooth_length is the average length of the bit teeth, UCS is unconfined compressed stress of the rock, D is bit diameter, WOB is applied weight on bit; the following modifiable by the user constants are used: C is a constant; (aggressivity) is a formation and bit characteristic constant ranging between 20% and 100% and normally is given the value of 35%; (curv) is a formation – WOB interaction constant and it is usually given the value of 1.5; (flow_factor) is a constant, ranging between 50% and 100% and defines the capability of the system to adequately clean the bit front by the cuttings [9].

A similar rock-bit interaction model, with adjustable parameters, is the one that has been presented by Teale [13] who introduced the concept of specific energy, the energy required by the rig to drill a unit volume of rock. The model has been used by many researchers and practitioners in the years that followed [14,15] and is given as,

$$ROP = \frac{(8)(RPM)(\mu D)(WOB / Abit)}{\frac{UCS}{eff} - \frac{WOB}{Abit}} \quad (3)$$

where, (Abit) is the bit diameter, (μ) is the coefficient of friction between drill string and formation, converting applied WOB to torque, and (eff) is the efficiency of transmitting the rock destruction power of the drilling rig to the rock.

One can show that the two models could give similar results when simulating experimental data. For e.g., using the above equations and experimental data used by

Abouzeid and Cooper [9], the results of Fig. 1 were derived, which show that both models, when properly adjusting the constants, could reflect reality. In this simulation, the Payzone model was used with the following parameters (aggressivity=25, curv=1.5, Tlen=0.5667), while for Teale's model the parameter values used were (eff=0.20) and for the coefficient of friction (μ=0.25). Of course, Payzone has full capabilities for simulating a real drilling process, as it is presented below.

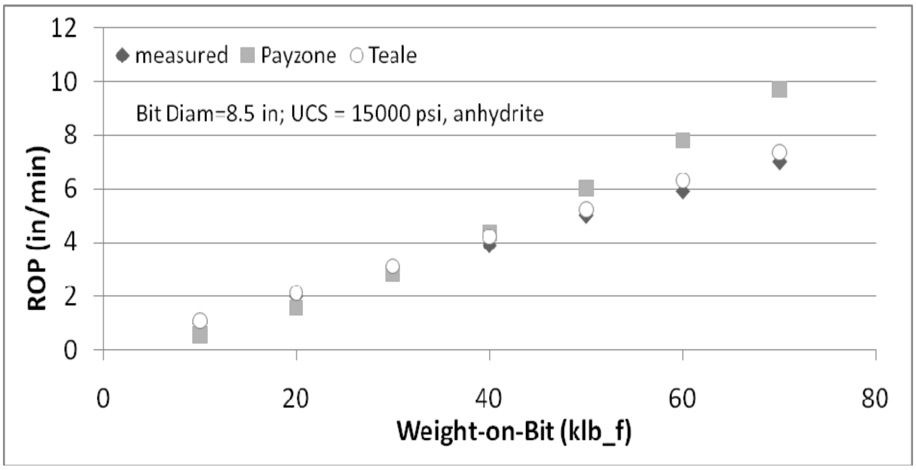


Fig. 1. Simulation of experimental data for anhydrite, with Payzone and Teale's equation.

## ANALYSIS OF CASE STUDIES

Several case studies have been analyzed and experience so far has indicated that Payzone simulator could be used effectively to predict new well designs and parameters, after tuning it to the real experimental data. We have used available publicly data, primarily from North sea in last decades. For this presentation we will be presenting one such case, well 31/3-3 for which a well completion report was available [16]. As indicated above, the first steps were to input all available data, especially lithologies and drill bit records. Estimation of UCS was made from external sources, based on the information of Lithology. We have then tried to re-construct the drill time log, i.e. re-drill the well, by adjusting the main bit parameters, using the options available on the simulator window. We have focused on one depth interval, between 1917 and 2414 m, which was simulated with 18 formation intervals with four main lithologies, soft sand, hard sand, coal and shale. Drilling base case was by applying 85 to 190 kN, 50 to 180 RPM and approximately 2400 lpm flow rate. The actual drilling process was simulated well as the data in Fig. 2 indicate where the reported real drilling time is given versus the re-drilled time given by Payzone.

Having simulated the data well, we wanted to see what would be the effect if operating parameters were changed, for e.g the weight-on-bit, the rotary speed and the flow rate, each one individually and all at the same time. In Fig. 3, we show the results of the simulations with all other parameters constant, applying extra weight on bit of 44.5 kN

(4.5 tons) which represents an increase between 25 and 50%, and extra 50 RPM, which represents an increase of 50 to 63%.

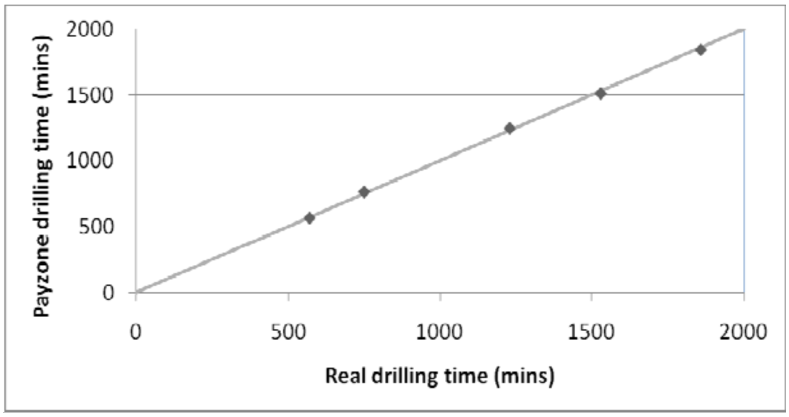


Fig. 2. Simulation of real drilling data, well 31/3-3, from 1917-2414 m.

The results show the beneficial effect of increasing the WOB, giving increased performance by 28-35%, of RPM, giving an increase of 14 to 28%, for the given conditions, with WOB of course having more significant effect. An increase of the flow rate has given a slightly smalle effect than the increase in RPM. Applying all increases at the same time, i.e. plus 4.5 tons, plus 50 RPM and plus 200 lpm, the results of Fig. 4 are obtained, which show reductions of the order of 35 to 50%, depending on the particular section.

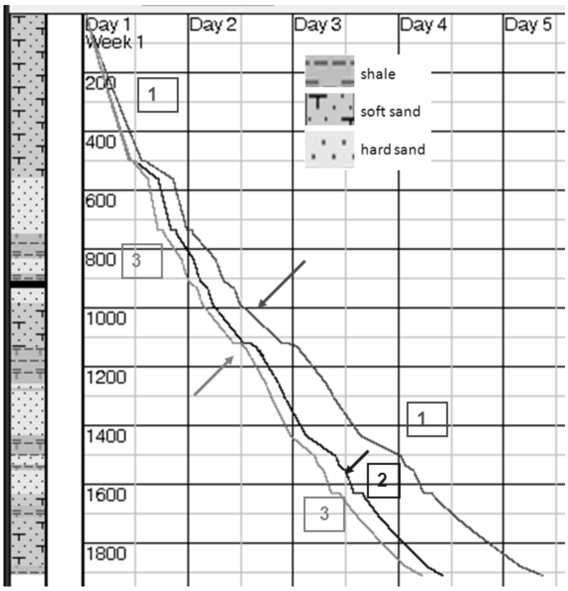


Fig. 3. Normall drilling curve [1], drilling curve with RPM+50 rpm [2] and drilling curve with WOB+45 kN [3].

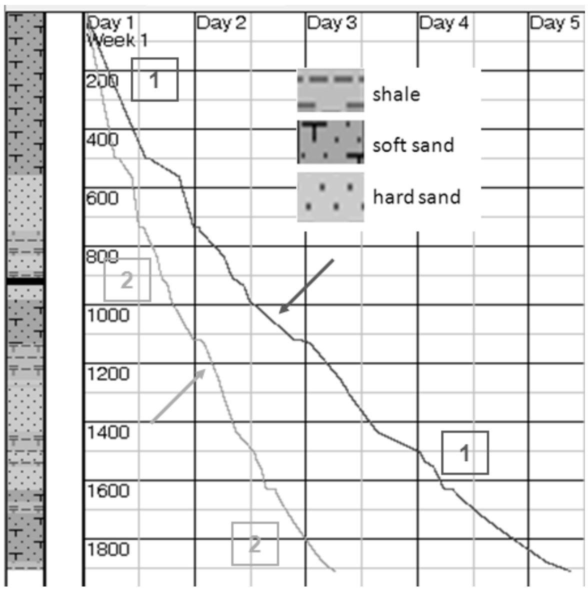


Fig. 4. Base drilling time plot [1] and simulated drilling time plot [2] by having extra 4.5 tons, extra 50 RPM and extra 200 lpm.

One of the main parameters affecting the drillability of any formation and of course dictating drilling efficiency is the compressive strength of the rock, as it is also evident from equations (2) and (3) above. It is a parameter that still intrigues researchers and practitioners because it is not definite how should it be used in order to predict rock drillability [17,18]. Furthermore, the accuracy of the values of this parameter is still questionable [19]. The simulator can thus be used to determine the effect of the errors made in estimating UCS for the various rocks encountered in the drilling of a well on the prediction of rate of penetration. In Fig. 5, we present the results for such a simulation, for the same sections as above, by increasing UCS by 50% for the different rocks encountered, as this type of error is not uncommon [19]. The results show that an error in UCS by 50% could have significant effect on the prediction of drilling time for given formation which, depending on the conditions, may range between 58 and 96%, giving an overall increase in total drilling time for the sections chosen for the simulation of 82%.

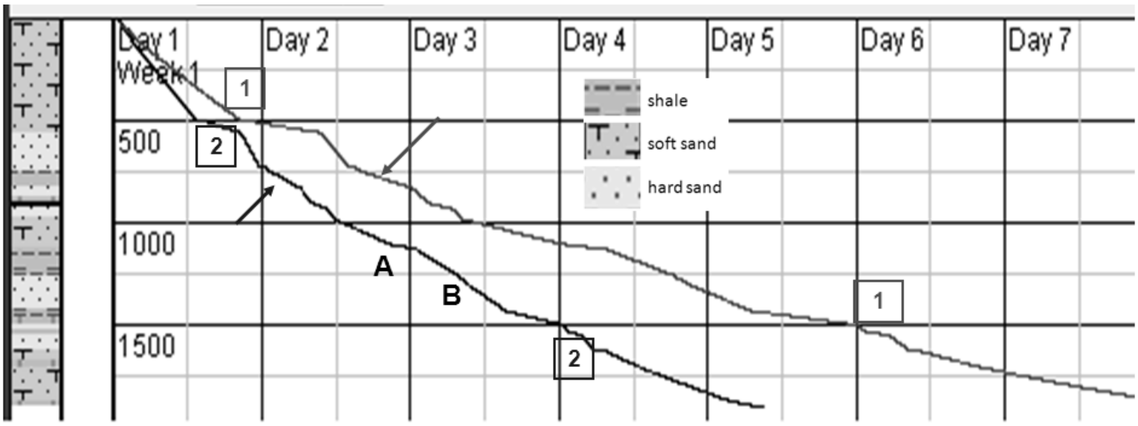


Fig. 5. Normal drilling time plot [2] and simulated drilling time plot [1] when UCS for all formations encountered is estimated as increased by 50%.

## CONCLUSIONS

Prediction of rate of penetration is among the most sought after parameters in a drilling campaign for oil and gas exploration as it allows for optimization of drilling parameters to decrease drilling costs and enhance drilling process safety. There have been attempts to have available such simulators but none has been widely accepted because of the severe requirements for running them.

Recent advances made available simulators which could be used onsite having been adjusted with real time drilling data so that they can be used in future campaigns in similar fields. In order for this to be successful, real time drilling monitoring is essential with the main parameters at hand such as weight on bit, torque, rotary speed, flow rate. We have been testing one such simulator, Payzone, to verify its capabilities and determine how different drilling parameters affect drilling process, using publicly reported data. For the case on hand, data from the North Sea were used.

The simulator uses a drilling advance model with a few adjustable parameters that can be fine-tuned with available drilling monitoring data. Our analysis has shown that the drilling rate model is similar to the equation proposed by Teale, in terms of specific energy, which contains two adjustable parameters. Fine tuning this model as well use of the Payzone simulator, similar results can be obtained. However, the latter allows for simulation of full drilling activity with several enhancements.

Re-engineering the well and re-drilling it is possible with no major difficulties. The key-parameters to fine tune the simulator are overall drilling time and rate of penetration, for the sections to be analyzed. For the case on hand, an almost perfect 1:1 correspondence between simulated and real drilling time has been achieved. Increasing WOB, RPM and flow rate had all beneficial effect, i.e. a god reduction in drilling time, for the situation analyzed, with WOB having the most significant effect. Application of all enhancements at the same time shows that overall decrease in the drilling time can be of the order of 30 to 50% on the average, thus bringing significant savings for drilling new wells.

An assessment was also made on the effect of errors on estimation of rock strength, one of the main parameters affecting rate of penetration, because recent analysis shows that significant errors occur currently. Full simulation showed that increasing UCS by 50%, can have a dramatic effect on reduction of rate of penetration, giving overall increases in drilling time by up to 82%, thus sending the message for better techniques and methodologies to estimate rock strength.

## REFERENCES


1. MR Isbell and Berzas, S.K. Re-engineered Drilling Laboratory is a Premium Tool Advancing Drilling Technology by Simulating Downhole Environments. Paper ASME ETCE99-6653 presented at the ASME Energy Sources Technology Conference and Exhibition, Houston, 1–3 Feb. 1999.
2. P Langille, J Hildebrand and K Massie, Aggressive Drilling Parameters, PDC-Bit Innovations Cut Run Times in Abrasive Oklahoma Granite Wash, J Petrol. Tech. March, 36-41, 2008.
3. DC Mannon, Reducing well cost by increassing drilling efficiency, paper AADE-01-NC-HO-35 presented at the AADE 2001 National Drilling Conference, Houston, Texas, March 27 - 29, 2001.
4. KK Millheim, and Huggins R. L., An engineering simulator for drilling, Parts I & II. papers SPE 12075 & 12210, presented at the 58th Annual Technical Conference and Exhibition, San Francisco, CA, 5-8 October 1983.
5. JF Brett, and Yoder, D. L., Use of an engineering simulator for drilling rigs, paper SPE/IADC 13480 presented at the 1985 SPE/IADC Drilling Conference, New Orleans, LA, 5-8 March 1985.
6. AS Bamford, Z Wang, Well control simulation integrated with real rig equipment to improve training and skills validation, paper SPE 27269 presented at the Inernational Conf., Jakarta, 25-27 Jan. 1994.
7. GA Cooper, AG Cooper, G Bihn, An interactive drilling simulator for teaching and research, paper SPE 30213 presented at the Petroleum Computer Conference, Houston, TX, 11-14 June, 1995.
8. GA Cooper, JF Mota, AG Cooper, Integrated petroleum engineering simulation and decision making teaching program, paper SPE 36660 presented at the SPE Annual Technical Conf, Denver CO, 6-9 Oct. 1996.
9. A.A. Abouzeid and G.A. Cooper, Experimental verification of a drilling simulator, paper presented at the 8th International Conference on Mining, Petroleum and Metallurgical Engineering, Suez Canal University, Egypt, 17 – 19 March 2003.

10. RK Bratli, Hareland, G., Stene, G.W., Dunsaed, G.W., and Gjelstad, G., Drilling Optimization Software Verified in the North Sea," paper SPE 39007 presented at the SPE LACPEC Conference, Rio de Janeiro, 30 August-2 Sept. 1997.
11. RP Rampersad, Hareland, G., and Boonyapaluk, P.: "Drilling Optimization Using Drilling Data and Available Technology," paper SPE 27034 presented at the SPE LAPEC Conference, Buenos Aires, 27-29 April, 1994.
12. G Hareland, PR. Rampersad and S Hellvik, OM. Skår, Simulation can help optimize drilling and cut costs, Drilling Contractor, 42-47, Jul/Aug 2000.
13. R Teale R. The concept of specific energy in rock drilling, Int. J. Rock Mechanics and Mining, 2, 57-73, 1965.
14. Bilgin N., The cuttability of evaporates, Bull. IAEG, 25, 85-90, 1982.
15. E Detournay, CP Tan, Dependence of drilling specific energy on bottom hole pressure in shales, paper SPE/ISRM 78221 presented at the SPE/ISRM Rock Mechanics Conference, Irving TX 2-23 Oct. 2002.
16. Saga Petroleum, 31/3-3 Well Completion Report, http://www.npd.no/engelsk/cwi/pbl/en/well/all/447.htm, accessed Febr. 2009.
17. W Calhoun, R Ewy, New Confined Compressive Strength Calculation Improves Bit Selection and Bit Performance, paper AADE-05-NTCE-61 presented at the AADE National Technical Conference and Exhibition, Houston, Texas, April 5-7, 2005.
18. H Rabia. Specific energy as a criterion for bit selection, JPT, July, paper SPE 12355, 1225-1229, 1986.
19. VC Kelessidis, Need for better knowledge of in-situ unconfined compressive strength of rock (UCS) to improve rock drillability prediction, paper to be presented at the 3rd AMIREG Conference, Athens, 7-9 Sept. 2009.