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Improving Curve and Lateral Drilling Efficiencies: Case studies of bit and cutter designs that effectively utilizes the available WOB and reducing bit torque.

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Abstract

This paper outlines the success of bit designs with new geometry PCD cutters that enable drilling more efficiently in curve and long interval lateral applications where effective WOB transfer is crucial at the cutter rock interface. Another critical aspect in curve and laterals is the torque created by the bit cutting structure and how this technology manages it effectively at the bit level. Laboratory simulation tests demonstrated the benefits of this technology. The science of this technology will be presented in this paper. The first field validation was on a vertical drill out application which starts from soft clastic formations transitioning into highly interbedded lithologies and ending in a section of hard formations. Results reveal that the effectiveness evacuating the cuttings faster and engaging a new formation quicker and reducing the bit torque. The first lateral test consisted of trailing this new cutter technology on a 3-mile lateral against offsets with the identical bit designs. Drilling data revealed an improved efficiency and reduced MSE. This performance was observed on repeated occasions to validate the science in adopting the technology. In another application, there were torque limitations at the end of the lateral severely effecting ROP by control drilling. The test bit completed the section with higher efficiency at the end of the lateral section even though there were torque limitations from the rig. Overall, this paper discusses the benefits this technology brings to extended reach laterals by improved dull conditions, improving overall ROP and reducing days on well.

Introduction

Drilling technologies has undergone significant advancements in recent decades, with horizontal drilling becoming a standard practice in the exploration and extraction of oil and gas from unconventional reservoirs. A key component of horizontal drilling is the process of creating curves and laterals, which involve shifting the wellbore from a vertical orientation into a horizontal one and then drilling along the reservoir to access the hydrocarbons more efficiently. These techniques are essential for maximizing the productive potential of oil and gas fields, especially those with low permeability, such as shale formations. However, the complexity and precision required to drill curves and laterals pose several significant challenges that developing technologies and methods must continuously address.

While the benefits of drilling curves and laterals are undeniable, the process is far from simple. A range of technical and geological challenges must be overcome to ensure successful well construction. One key component is the fixed cutter drill bit also known as the PDC drill bit. The polycrystalline diamond compacts (PCD) commonly known as cutters which are typically cylindrical in shape are the components of the drill bit that impart force on the rock formation. The forces that are imparted on to the formation to fail them and be removed are complex. These forces must be borne by the cutters themselves which involve complex combinations of mechanical and thermal stresses, in the process can cause damage to the cutter itself. When drilling curves and laterals these forces become more challenging for the cutters. As a result, the PDC bits can encounter several issues that can affect drilling performance, efficiency, and cost-effectiveness.

Shape Cutter Technology

Polycrystalline Diamond Compacts (PCD), commonly known as "cutters" when used in drill bits were developed and manufacturable in the late 1970s. Since then, the cutters have been round in cross-section with a certain height. Much research resources were contributed towards non-planar interfaces (NPI) to better manage residual stress between the diamond and carbide substrate while providing greater resistance to impact. The introduction of leached cutter technology provided much greater thermal stability, taking the resistance from 700°C to almost 1,200°C.

Such advancements have been driven by the need for continuous improvements and that is how the drilling industry has evolved over the decades. Root cause failure analysis on each cutter from several runs from different applications has been a corner stone for continuous improvement.

Maintaining the cutter tip/edge sharp is of paramount requirement. A drill bit in which has cutters that become worn early can be the onset of drilling dysfunctions. SPE 206353 highlights how a worn cutter can potentially lead to HFTO and other bit related dysfunctions.

IPTC 24145 has highlighted how the cutter technology has evolved to provide significant gains in performance where ROP and footage drilled has doubled or trebled over the last decade and helping the industry reduce cost. It highlights the methods established to mimic complex thermal-mechanical failures and bring about solutions.

All these developments involved around the cutter diamond table being cylindrical in profile and the top of the diamond table being flat or single plane also termed planar in this paper.

Shape cutter technology involves shaping the diamond table topology. The purpose is to leverage the science of geometries to enhance necessary cutter-rock interaction mechanics to result in a very defined benefit.

AADE -NTCE -041 introduces one such shape cutter that provides additional toughness over round conventional cutters.

This paper focuses on a newly shaped cutter that was designed to enhance performances and improve drilling efficiencies in curve and lateral applications.

New PDC Technology

With a continued focus on drilling efficiency and greater durability, a new shaped cutter has recently been introduced to the drilling industry, the effective center (EC) shaped cutter.

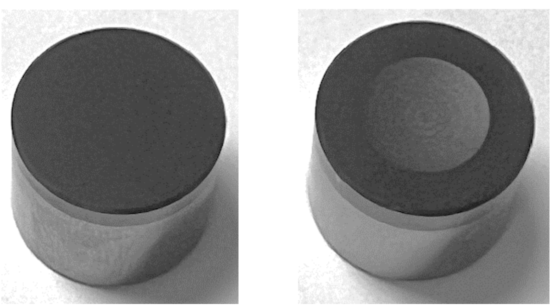

Fig. 1: Standard round cutter compared to the EC shape cutter

The approach was to build upon our findings through various laboratory testing and development of other shape cutters. This time the focus was on removing or pushing the cutting ribbon away from the diamond face, to allow for greater penetration, while lowering the reactive torque and finally allowing much better cooling to the cutter tip.

Fig.2: Cuttings flow from a conventional round cutter. 16mm size cutter interacting with sandstone under confining pressure.

Fig. 2 is a still image from a video recording as a round conventional cutter interacts with a sandstone under 3000psi confining pressure. The cutter is removing the rock formation at a constant rpm and depth of cut. As each round cutter interacts with the formation, it has been observed in the laboratory that the chip/cuttings flow along the whole surface of the cutter diamond table. The flow of the cuttings as a force component is proportional to the friction between the cuttings and the diamond table of the cutter.

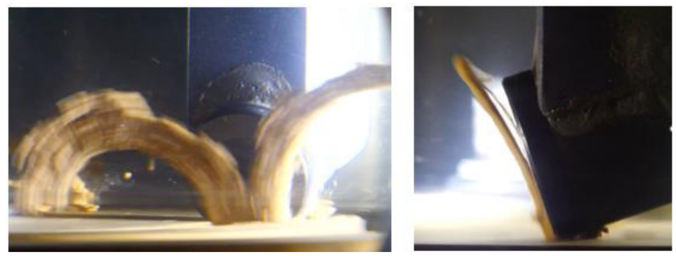

Fig. 3: Cuttings flow from a new technology EC shape cutter. 16mm size cutter interacting with sandstone under confining pressure

Friction matters and contributes to a significant magnitude toward the reactive forces experienced by each cutter. The EC shaped cutter concept stems from the approach to reduce the reactive frictional force on the face of the cutter. Laboratory testing demonstrated that the EC shaped cutter deflects the cuttings away effectively, much like a chip breaker on a machine tool insert. Fig. 3 shows a still image from a video recording captured during high-pressure single cutter tests on various formations, in this instance a Torreybuff sandstone. The cuttings ribbon is deflected from the face of the EC shaped cutter as it approaches the center of the cutter. Fig 4 shows the axial forces recorded in the laboratory. In comparing, it can be observed that the EC shape cutter requires lesser axial load significantly.

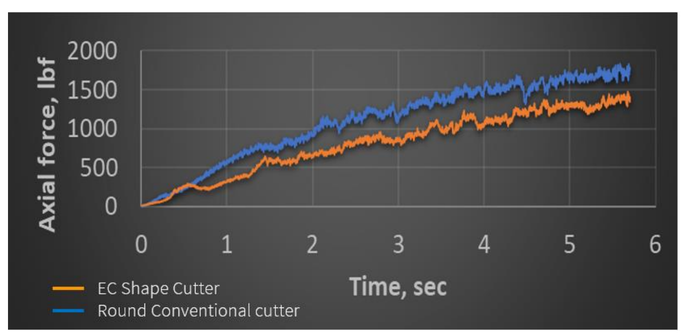

Fig. 4: Laboratory test data comparing the axial force required by cutters while removing identical volume of rock under confining pressure.

In soft to medium rock strength formations, it was observed that the reduction of the net force on the cutter could be as much as 20% in both the axial and drag components. Similar benefits were observed in limestone formations, but the magnitude was different. Also, the visual observations reveal that better hydraulic cooling to the diamond face of the cutter could be another significant benefit. Fig.5 shows the data from a drilling simulation conducted in the laboratory. A 8.75 size drill bit was employed for this test. The baseline bit was fitted with round conventional cutters and drilled sandstone at different WOB and constant RPM. An identical bit was then fitted with the new technology EC shape cutter and tested under identical conditions. The data clearly demonstrates the torque at bit with EC shape cutter to be lower.

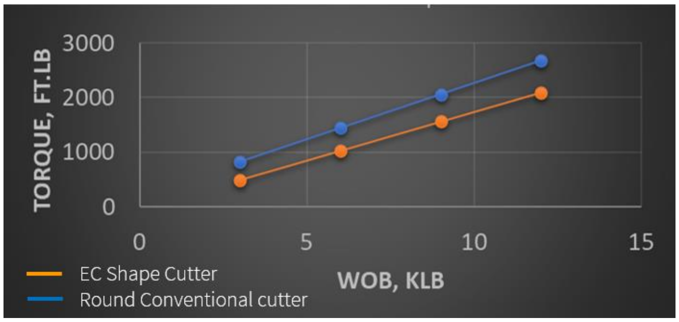

Fig. 5: Laboratory full scale bit test data demonstrating the new technology EC shape cutter reduces torque at bit.

In summary, the new technology EC shape cutter allows for higher DOC, reduced sliding distance, and better cooling to withstand thermal cutter failure. Both single cutter test data and drill bit drilling simulation tests demonstrated such benefits.

Field Validations

Case Study 1

The first field validation was taken up in Williston Basin in North Dakota, see Fig.6. This application was selected because of the number of offsets run data available. Also, it was critical to test in an application where the bit design of choice was established. It became a good test to just swap out cutters on the bit frame of choice. Fig 7 shows the bit design that was widely used in the application. The test bit frame was of 8.75" in size and was a six bladed design with 16mm cutters in the primary locations. In the first round of validation the new technology EC cutters were placed along the shoulder region of the test bit, Bit A. The baseline bit, Bit B has conventional round cutters in the shoulder region. The nose and cone regions on both Bit A and Bit B had identical cutters. A total of xxx cutters on the bit of which YYY qty were the total shoulder cutters

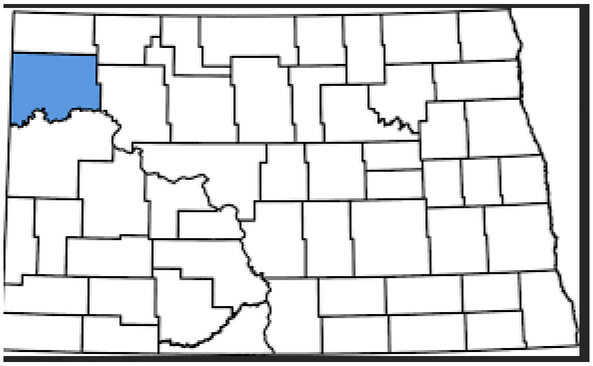

Fig 6: Test region in Williston Basin, North Dakota

Both bits were tested on the same pad so as to minimize the variables between the 2 bits and provide a fair comparison in drilling efficiencies.

Fig 7: Test bit of 8.75" in size that was used for the field validation

Details of Application

Fig.8 shows the formation details of the application being drilled. The top section consists of extremely soft clastic formation up to 6,000 feet. Typically, in drilling the first 4,000 feet, it is considered easy drilling and drill bits are expected to perform at the minimum expectations of high ROP ranges and maintain their effectiveness. It can be noticed that the second section i.e. below 6,000 feet there is a formation change which consist of highly interbedded lithologies. From 6,600 feet to 8,100 feet, compressive strength values are both high and variable.

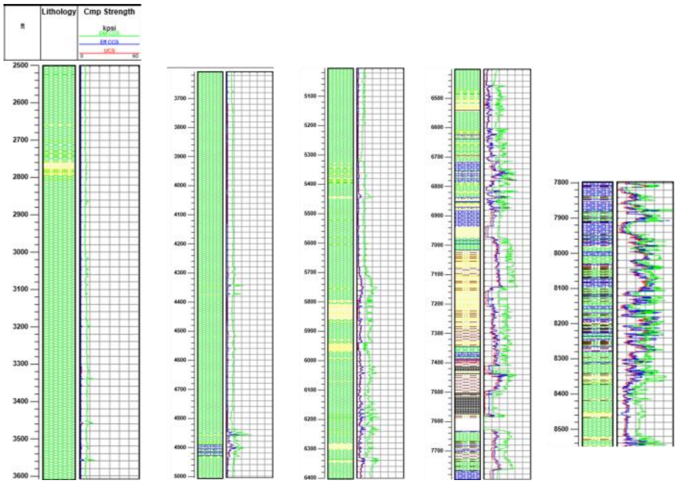

Figure 8: Formation details for the bit test runs.

Both bits were run in this application. Fig.9 shows the big picture performances between Bit A and Bit B. Based on the on-bottom data, it is very clear and evident that Bit B with round conventional cutters outperformed Bit A. The footage drilled were almost identical. The ROP of Bit B was reported as 347.7 ft/hr. in comparison to Bit A's 311.4 ft/hr.

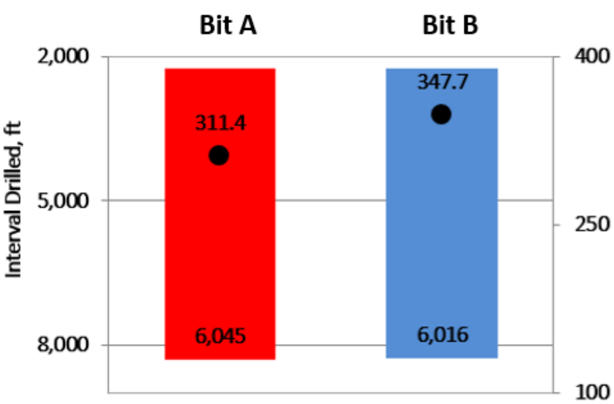

Fig 9: on-bottom performance comparison between the test bit A and test bit B

Drilling data for both the runs were gathered and further analyzed in detail. Figure 10 shows that the bit A had a higher inclination well to drill. Test bit A drilled a well which had an average inclination of 11 deg in while test B drilled a near vertical well. Hence test bit A had to encounter directional requirements.

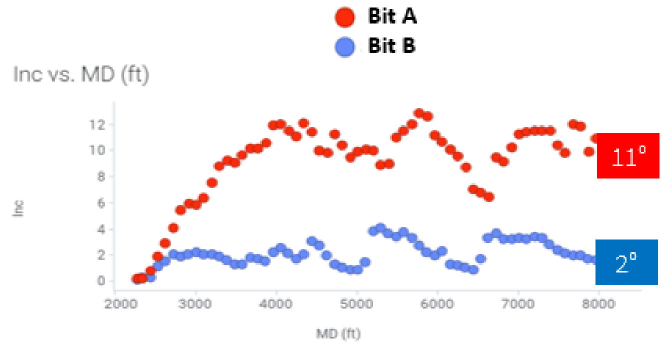

Figure 10: Well profiles between the two test bits

Having noted the difference in the well inclinations between the two runs, the rotary parameters were then compared for benchmarking.

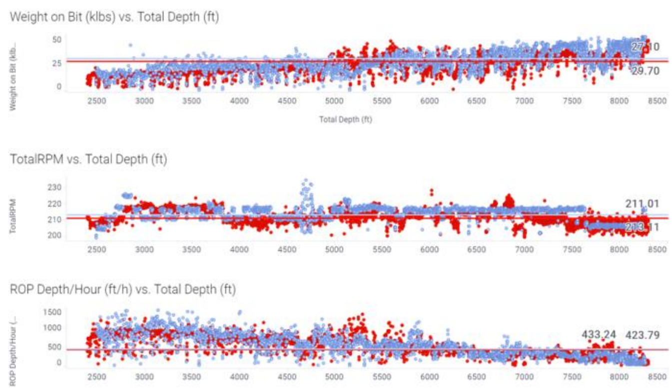

Figure 11: Rotary parameters comparison between Bit A and Bit B runs

From the data shown in Fig 11, it is obvious that both bits A and B had more or less similar WOB and RPM ranges and safe to say that the averages were identical.
Next the drilling slope vs well profile was investigated to see the differences, if any, between the 2 runs. See Fig 12. We will review two parts of the plot in Fig 12. The first top section up to 6000 ft hole depth, both bits had identical slope. However, when you compare the inclination for the two bits, Bit A had higher inclination than that for Bit B. See the Fig. 10

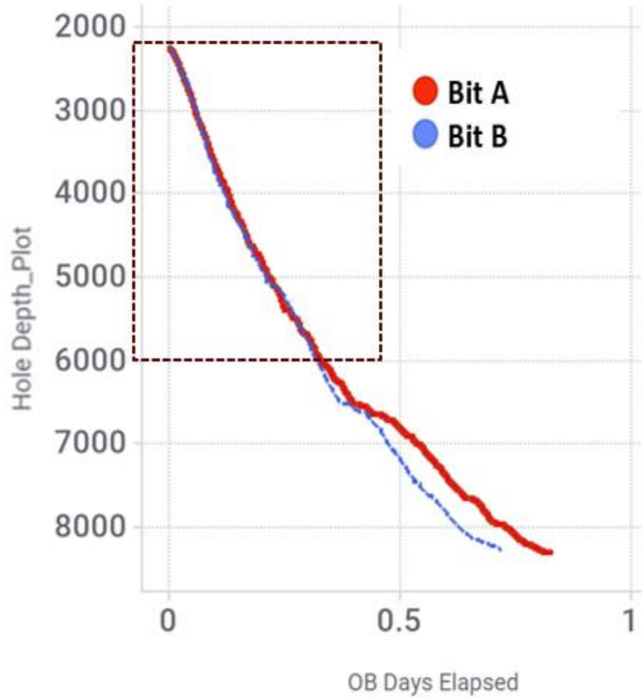

Figure 12: Days vs Depth Plot (On bottom difference is 2.1 hours)

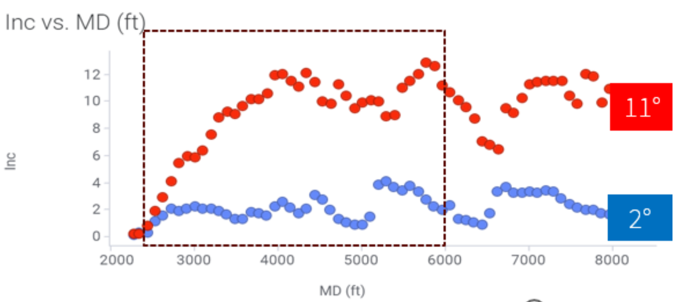

Fig 13: Inclination vs Measured depth Plot- comparing Bit A and Bit B

It is obvious from Fig.12 that Bit A has performed on par to Bit B despite the directional requirements. Hence Bit A has outperformed Bit B up to the 6,000 ft mark, with equal run parameters but with higher inclination. This clearly validates what was observed in the laboratory where the new technology shape cutter handle cutting ribbons and minimizing friction across the diamond table.

Now zooming in on to the second section of the application that is past the 6000 feet depth, Fig. 14 and 15 clearly shows that the Bit A received lower WOB throughout the remaining run.

Fig. 16 shows the bit toque vs drilled depth for both the bits. It is interesting to note that bit torque were almost identical in the top section. But during the later section past the 6000 feet depth, where the formation is expected to be harder, the bit A torque was higher. This demonstrates that the Bit A was sharper and maintained it edge from drilling the top section.

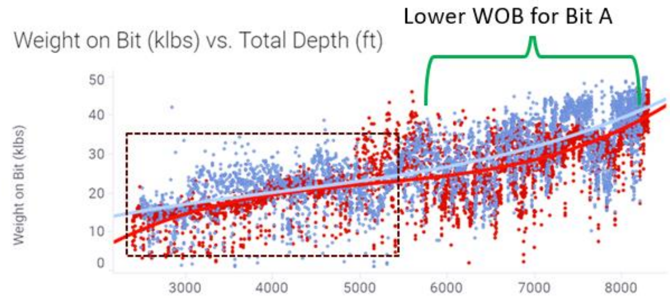

Fig 14: Comparing WOB for Bit A and Bit

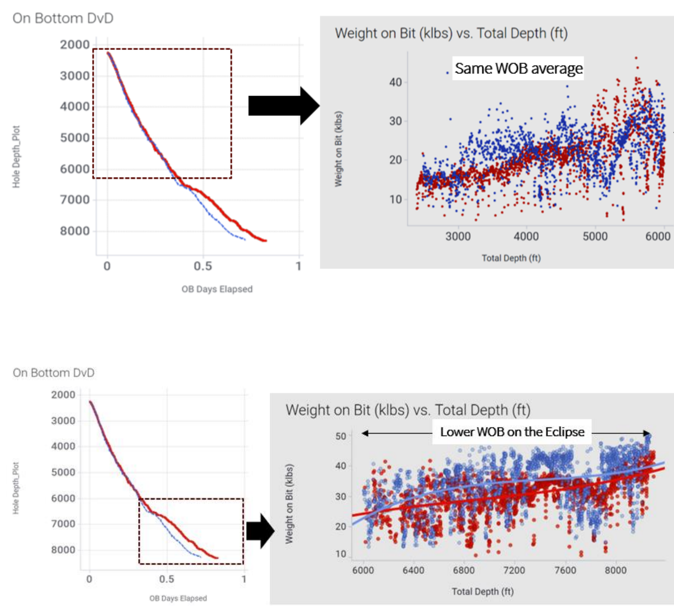

Fig 15: Comparing WOB for Bit A and Bit at the 2 sections

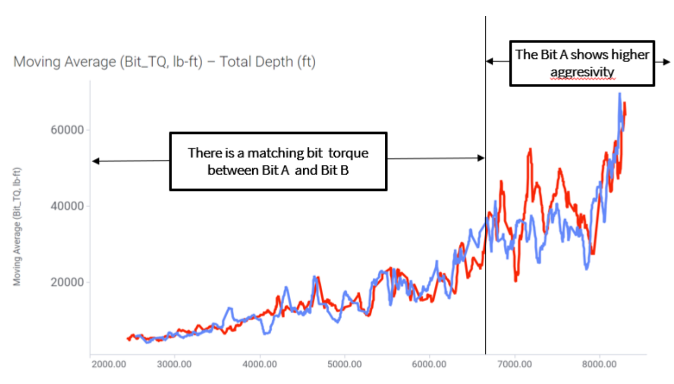

Fig 16: Comparing Torque at Bits A & B vs drilled depth.

Case Study 2

The second case study was a lateral application where test bits were 6” in size. This time Bit A (red legend) was fitted with the new technology EC shape cutter across the complete bit profile. Bit B (blue legend) was fitted with standard round conventional cutters across the complete bit profile. Fig. 17 shows the dip profile to be comparable. Fig 18 shows the Gamma vs hole depth and also comparable and consistent. Fig. 17: Data on the dip profile between the two wells drilled by Bit A and Bit B. Fig 18. Is the Gamma vs hole depth which indicates that the two bits drilled very similar formation tops. Fig 19. Is the run parameters experienced by the Bit A and Bit B for up to 16000 feet. Both bit had near identical WOB and RPM. Bit A with the new technology cutter generated an ROP of over 11 percent higher.

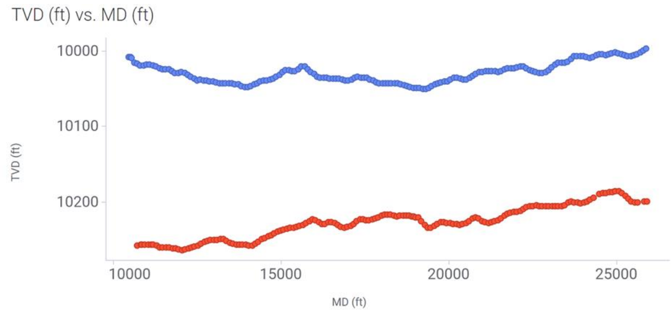

Fig 17: Similar dip profiles for Bit A and Bit B wells

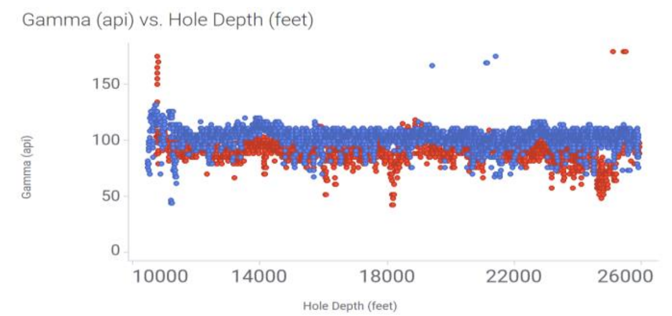

Fig 18.:Formation Gamma vs hole depth for the two wells drilled

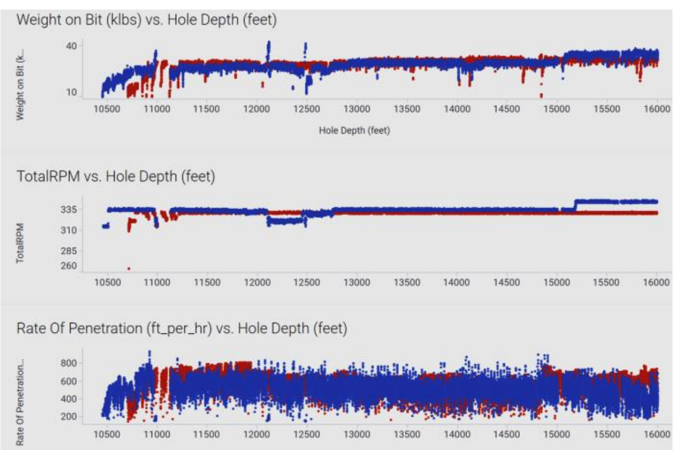

Fig. 19.: Run parameters comparison between the 2 bit runs

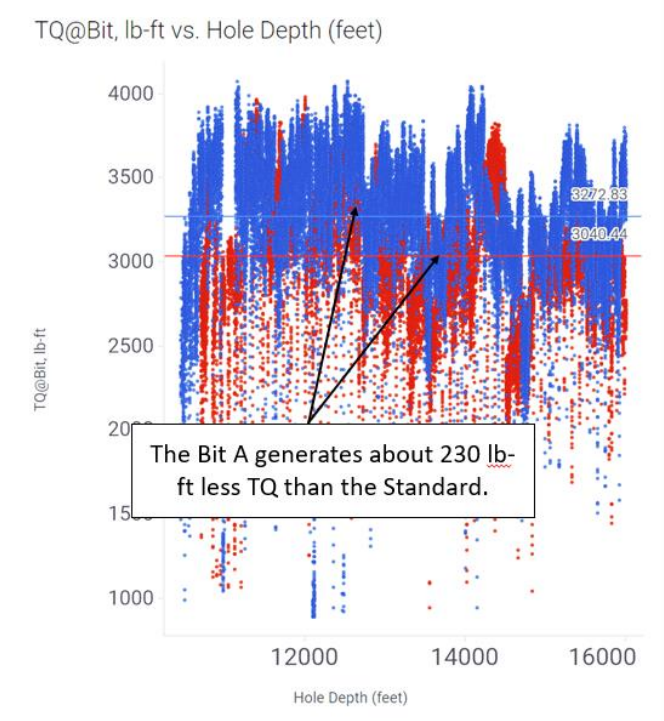

Fig.20:Plot of Torque vs hole depth comparison

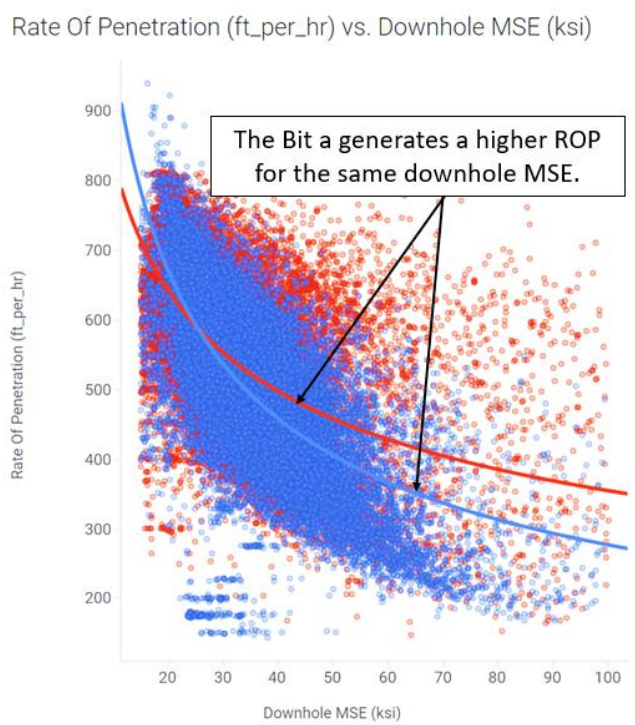

Fig.21: Plot of ROP vs MSE comparison between Bits

Fig 20 shows that Bit A experienced lower level of torque. Fig 21 demonstrated that Bit A delivered better ROP for the same given MSE. It was evident from the drilling data that the Bit A with the new technology EC shape cutters demonstrated the benefits observed in the laboratory.

In case study 2, the drill bits were drilling shale in lateral application. The advantages of using this new technology EC shape cutter was very clearly evident by the performance gain observed.

Conclusions

1. Poly crystalline compact also known as cutters on a drill bit are evolving rapidly in technology.
2. Shaping the diamond table to be complex is a recent deviation from conventional round with flat or planar top surface.
3. New technology EC shape cutter is introduced in this paper.
4. As drilling progresses, particularly in the curve and lateral sections where the bit is subject to higher friction and heat, PDC drill bits can experience thermal damage.
5. The high temperatures generated at the cutting surface can cause the PDC cutters to degrade or lose their effectiveness. New technology EC shape has brought about a step change to keep the cutter more durable and effective while drilling vertical, curve and lateral applications.
6. The shape technology presented in this paper demonstrates through a field case study data as to how the cuttings are effectively generated and minimizing the frictional component on the cutter diamond table.

Acknowledgments

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Nomenclature

PCD	Polycrystalline diamond
RPM	Revolutions per minute
WOB	Weight on bit
HFTO	High frequency torsional oscillation
MSE	Mechanical specific energy
ROP	Rate of penetration

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