

# Leveraging the Continuous Improvement Cycle to Deliver Improved Drilling Performance in Tertiary and Cretaceous Lithology

Jibreel Hussain & Franklin Valbuena, Baker Hughes Incorporated

Copyright 20209, AADE

This paper was prepared for presentation at the 2020 AADE Fluids Technical Conference and Exhibition held at the Marriott Marquis, Houston, Texas, April 14-15, 2020. This conference is sponsored by the American Association of Drilling Engineers. The information presented in this paper does not reflect any position, claim or endorsement made or implied by the American Association of Drilling Engineers, their officers or members. Questions concerning the content of this paper should be directed to the individual(s) listed as author(s) of this work.

## Abstract

The Oil and Gas industry is under extreme pressure, and operators rely on optimization to reduce drilling time and shorten time to production. Driving efficiency through reduced well time requires a thorough understanding of the drilling environment that recognizes geological and drilling process hazards. Studying individual components of the drilling system and environment in isolation restricts the proper identification of the root causes of the problem, leading to less than optimal solutions and performance. To overcome performance barriers, one must first have an in-depth understanding of the root causes by taking a holistic approach to the analysis of the drilling environment.

## Introduction

The top hole 16-in. applications are drilled through Tertiary and Cretaceous lithologies where severe vibrations and bit damage may lead to inefficient drilling. Vibrations have been observed and recorded in these vertical sections, and performance improvements have been made through identification of drilling limiters. Challenges in this section include low penetration rates due to vibration damage to the drill bit, low penetration rates due to harder layers, and difficulty in controlling vibrations.

This service company organization has developed and used an innovative process within a dedicated drilling optimization group that enables a structured approach for understanding the complete drilling environment. This successful process, founded on the continuous improvement cycle—plan, execute, analyze, and capture—delivered practices and technology recommendations to realize performance gains and significant well-time reduction. Taking lessons learned from one well and implementing these on subsequent wells delivered further performance improvements.

## Results, Observations, Conclusions

The authors will describe in the following sections how the drilling optimization process was applied to two different field case studies. The first case study details how the optimization

engineers helped the operator with an extensive pre-well study. The sections were then drilled from shoe to shoe with one bit at a record drilling rate of penetration (ROP), overcoming challenges where the section was drilled with 110% faster penetration rates and a dramatic savings on drilling time.

## Application & Formation Details

The hole size of 16-in. starting from Dammam till Sulaiy. The lithology is predominantly carbonates interbedded with sandstone and anhydrite. The unconfined compressive strength (UCS) ranged from 2 to 35 ksi.

- 16-in. hole size started from 100 to 900 ft.
- 16-in. section starts at 1300 ft and goes till 3800 ft.

### The Drilling issues

Hole Size (in.)	Issues
16.0	Bit Bouncing & Top Drive Damage, Vibration, Twist Off, Stick Slip

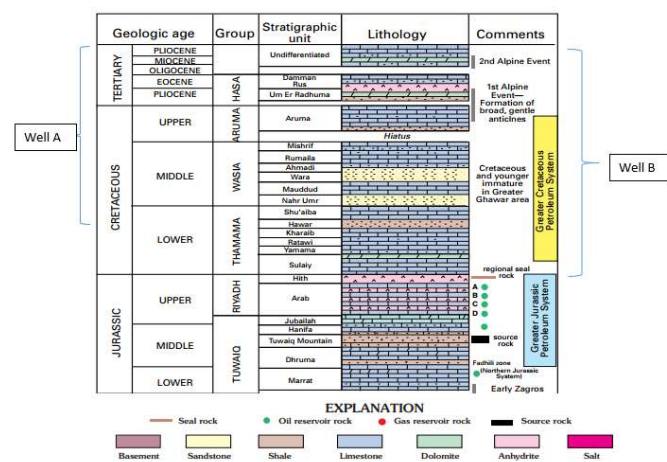


Figure 1 – Lithology Column

## Well Objectives

The main identified objectives for drilling the 16-in. section were:

- Reduce drilling days
- Mitigate drilling vibrations
- Optimize borehole quality

This urged for the optimized selection of a drilling solution to upscale performance.

Well 1 and 2 shall be the reference names given to the wells where hybrid technology is successfully deployed, for reference purposes.

## What is Drilling Optimization, and why is it important?

Drilling optimization can be defined as the provision of real-time data to expedite decision making based on information transmitted from downhole. Trends in data need to be examined to derive accurate conclusions about bit status, weight transfer, and drilling progress.

The optimization of the drilling performance in a field development context requires:

1. Data acquisition: Surface and/or downhole drilling data with sufficiently high sampling rate that include tracks such as, (weight on bit (WOB), revolutions per minute (RPM), torque (TQ), ROP, flow rate, stand pipe pressure (SPP), etc.
2. Data processing based upon relevant drilling data inclusive of drill bit response follow up (MSE, HMSE logs, E/S Diagram), events identification (steady drilling, vibrations, cleaning issue, wear development), and drilling response optimization (drilling parameters adaptation).

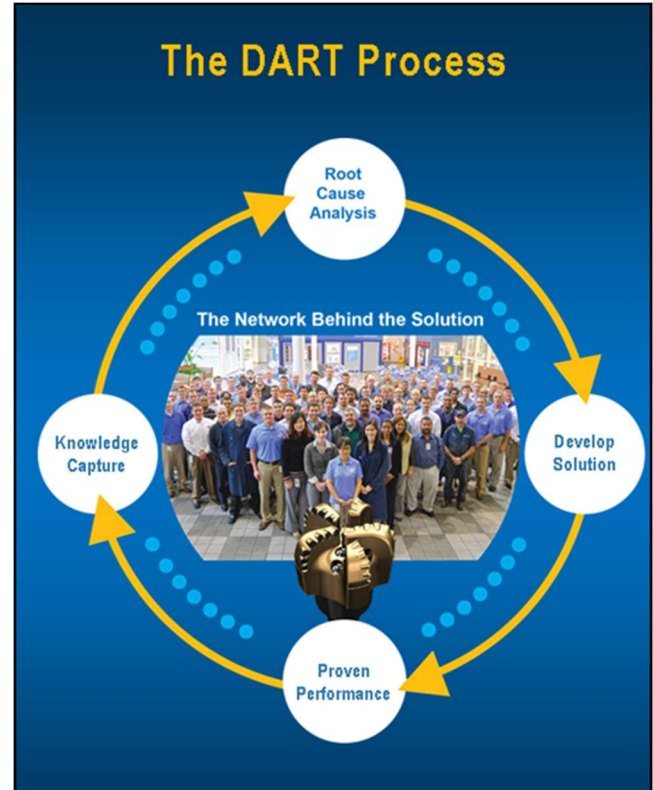
Using analytical and physics based models, tied to real time data acquisition, further drilling optimization decisions can be made.

## Methods Utilized

### *Design Application Review Team (DART) Process*

There are different methods to analyze the loss in drilling performance. In this case, multiple approaches were utilized to identify the problem zones.

1. Surface data along with offset well analysis
2. Formation unconfined compressive strength (UCS)
3. Geological studies in a 5-mile radius
4. Statistical data analysis tools
5. Drillstring dynamics analysis tools
6. Hydraulics analysis tools
7. Computational fluid dynamics (CFD) Analysis
8. Lab testing



## STEP : 1

### *Gathering Data*

The topics below are a sampling of the information necessary for DART meetings. The more information that is gathered, the better the DART team will be able to help:

### *Area Information*

- Location / geography
- Lithology
- Well information
- Type of well
- Casing program
- Day curves (foot-based data)
- Drilling practices /system – bottom hole assembly (BHA), motors, directional info

### *Market Information*

- Bit size and type
- Operator

### *Field Benchmarking Analysis*

- Day curves
- Bit records
- Historical Bit Performance

- Bit Type
- Area
- Foot-based ROP
- Vibration analysis
- Dull analysis

**Lab Benchmarking Information**  
**Identify Problems and Opportunities**  
**Strategy going forward**

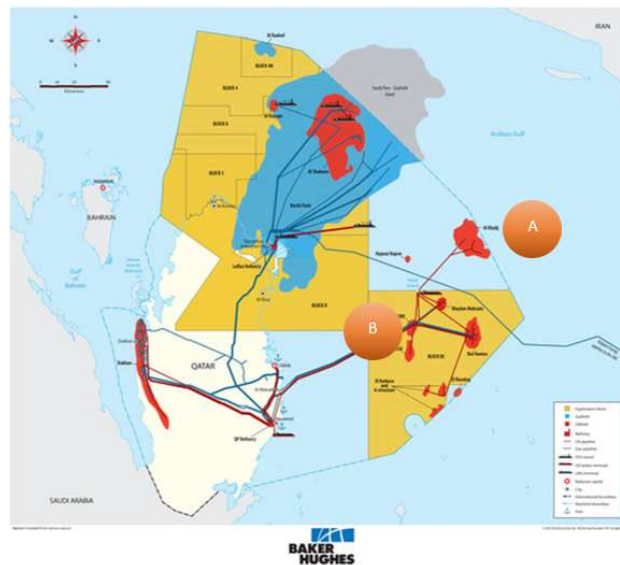
- Bit design
- Systemic issues

**STEP : 2**



- Completing application analysis.
- Identification of primary issues related to target applications.
- Implementing product development concepts in specific applications.

**Application Analysis & Recommendation**



**Figure 2 – Map Showing the Location of Wells**

As part of the proposal, the service provider's optimization team conducted a complete and detailed analysis of the offset wells data to identify and diagnose the barriers to improve drilling performance. Data consisted of daily drilling reports, BHA details, mud reports, bit records, and dull bit photographs.

Well A was analyzed by formation breakdown as illustrated in Figure 1. Dammam, Mishrif, Ahmadi, Wara and Mauddud formations tend to have the best drilling efficiency using polycrystalline diamond compact (PDC) bits. In contrast to Kharaiab and Latawi formations that tend to induce high torsional vibrations using PDC bits. This conclusion is correlated to the lithological properties of each formation.

In the Wara sandstone layer, PDC bits experience high drilling torque fluctuations due to the instability of the BHA in inter-bedded streaks, thus ROP decreases. The stabilizers have a high tendency of balling up in Ahmadi and the bottom layers of NahrUmer formation due to presence of shale layers. When stabilizers ball up, the BHA loses stability and drilling vibrations noticeably increase.

Drilling parameters have been thoroughly studied to conclude the recommended parameters for drilling the 16-in. section of both the wells.

WOB, RPM and mud weight (MW) are directly linked to lithological characteristics of each formation. Taking NahrUmer formation as an example, the inter-bedded nature of the formation allows for a wide range of WOB to be applied depending if the bit is drilling in sandstone, limestone, or shale. Higher weight is applied in limestone and less in sandstone layers.

Large hybrid ( PDC & tricone combination) bits tend to drill more efficiently with higher flow rates in comparison to other steel tooth (ST) & PDC types. This is due to the design dimensions of the hybrid bit and the urgency of keeping the bit

cleaned efficiently between the cones and the blades. Thus, it was recommended to maximize rig gallons per minute (GPM) throughout the hybrid run.

Bottom hole assemblies for offset wells using roller cone bits were studied relative to ROP performance and drilling vibrations, to conduct an optimized selection.

In reference to Well A, the benchmark ROP performance, the BHA was recommended to be packed with three points of stabilization. This configuration provides stability along the length of the BHA in vertical applications, and it does not allow angle build tendencies.

#### Offsets Section BHA:

Bit, Near Bit Stabilizer, 1 x 8.25" drill collar, Stabilizer, 1x 8.25" Drill Collar, Stabilizer, 12x 8.25" Drill Collar, Jar, 2x 8.25" Drill Collar, 15x Heavy Weight Drill Pipes

#### Recommendation:

- Increase two 10-in. drill collars, to transition more weight to the drill bit

- Use of three-point BHA stabilization

- Meet weight below jar requirement, 90 klb., thus WOB applied can reach up to 70 klb., with consideration to the jar's safety margin.

Bit hydraulic recommendations were a primary factor in the pre-well plan and optimization process, since balling tendencies are expected in Ahmadi and bottom Burgan formations. The following points cover the hydraulics plan:

- Hydraulic horsepower to be optimized at 0.9 -1.0 hydraulic horsepower per square inch (HSI) throughout the run

- The active mud system shall be converted to polymer inhibitive mud prior to entering Ahmadi shale to avoid formation swelling and maintain hole integrity

- High viscosity additives should be pumped as hole dictates to ensure maximum hole cleaning. The frequency of pumping the pills should be modified at the discretion of the drilling fluids engineer and operator rig representative. Fluid viscosity is based on instantaneous rates of penetration, trends and results of the most recent cleaning pill pumped

- Monitor the trip in to bottom on wiper trips to evaluate hole condition

- Shale shakers should be highly monitored while drilling Ahmadi formation – record cutting shape, integrity and percentage of formation carvings if any in the daily mud report

- Maintain the pH at the high side if potential gas exists. If corrosion rings are available, it needs to be utilized to determine the corrosion rate. The concentration of corrosion inhibitor to be used in fluid system to be varied based on rate of corrosion in consultation with operator engineering team

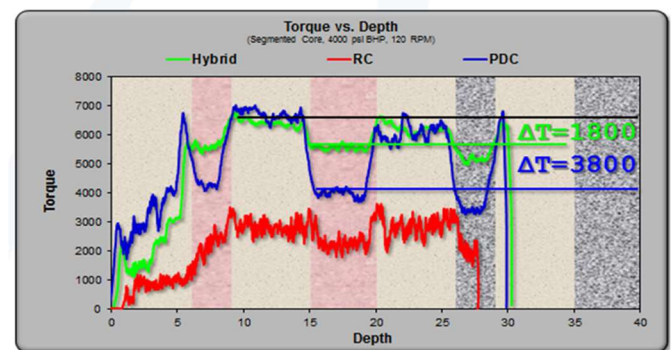
At this stage, the main contributors to the drilling system have been reviewed and analyzed to propose an optimized solution for Well A&B where hybrid drill bit technology was applied.

### Selection

The three drill bit types (PDC, roller cone and hybrid) along with different drives were considered for the application.

The criteria for bit selection were confined to three main key performance indicators (KPI), drilling efficiency, borehole quality, and section delivery time. The following section shall provide a brief technical comparison between the three different type drill bit technologies.

Drill bit durability determines the probability of having an additional trip while drilling any given section.



**Figure 3 - Lab test results for Torque Ranges and Fluctuations – by Bit Type**

Durability, bit type, and formation are directly linked factors. PDC and tungsten carbide insert (TCI) wear is relative to formation UCS and grains' friction angle. Commonly, TCI are more durable in abrasive formations, yet the durability of TCI and PDC is dependent on their material grades, cobalt inclusion, and diamond table designs. The major difference in between PDC and roller cone is the presence of bearings on roller cone bits. This is the main limiter for durability, since bearings have a finite bearing life. Whereas PDC bit fixed cutter design does not have this limitation.

In both wells, PDC bits are a durable solution to drill the entire section using one bit. However, high vibrations are expected by drilling with a PDC, either on rotary drive or mud motor. The torque range required to drill with a PDC is higher than that for a roller cone bit. Large diameter PDC bits tend to generate high drilling vibrations and stabilizing the BHA becomes increasingly challenging. Figure 3 shows plotted results for torque ranges and fluctuations in a drilling laboratory tests of full size bit. The experiment conducted illustrates that when drilling through interbedded formations, at constant WOB and RPM, torque fluctuations are a function of bit type. Roller cone bits tend to provide the least torque fluctuations in comparison to PDC and hybrid bits, but at a much lower overall ROP. The hybrid bit torque fluctuations through the different formations were approximately one-half that of the PDC bit

fluctuations in these laboratory drilling tests.

High torsional vibrations may be a limiter to PDC durability in the subject 16-in. hole sections. High torque fluctuations may cause the BHA to stall and eventually may lead to a more serious consequence, such as BHA twist off. Along with the higher cost of PDC bits, in comparison to roller cone bits, the requirement of a mud motor may raise the cost per foot to undesirable figures, therefore, PDC is not the most feasible solution to the challenges faced.

The hybrid bit combines features of both PDC and roller cone bits. The innovative design combines the performance enhancement of both bit designs to provide a hybrid solution. The blades and cones drill simultaneously providing crushing action followed by shearing force to the formation. The PDC elements provide higher cutting efficiency while the roller cone inserts reduce torsional vibrations.

Hybrid bits tend to provide higher ROP than roller cone bits. In this specific case, 16-in. hybrid design would achieve higher ROP than a PDC by mitigating the vibrations experienced with a PDC.

Given that Mechanical Specific Energy (MSE) is exerted on both formation penetration and drilling vibrations. If by using hybrid drilling efficiency is improved, ROP will increase.

The proposal to use a hybrid design on well A & B was based on the theory that hybrid bits drill more efficiently than roller cone bits and more smoothly than PDC bits. As a result, only one hybrid bit was proposed to drill the entire 16-in. section.

Multiple factors were considered in the selection of the most applicable hybrid design, shown on Figure 3. The following were the main considerations made:

- Fixed cutter size, blades and cones count are the major frame selection criteria. In the section in both the hybrid bit selected had three major outer blades, three cones and 19-mm size PDC cutters.
- Fixed cutters selected had to match the lithological challenge. The cutters on the 16-in. hybrid design for well 2 had to have high abrasion and impact resistivity to withstand the limestone and sandstone layers of the studied section. Additionally, high focus was illustrated on the cutter chamfer size, diamond table thickness and interface design along with the back rakes and overall cutters layout.
- Cone design selection was based on the bearing life capacity, insert shape and configuration and finally the carbide grade used. The application engineering team focused on matching the features to the requirements of the project.

Other verifications included revision of selected design's total flow area (TFA), drilling parameters limits, pin connection size and gauge specifications.

## Design Advancements from Region Offset

While considering the design, offset analysis from other countries were reviewed. The design philosophy for roller cones in hybrid designs began to change to utilize a higher density of inserts and increased sharpness of heel rows. An improvement in carbide grade resistance to fracturing and abrasion was a leading attribute in the shift to heel rows with higher projection and sharpness as dulling characteristics are mitigated with the enhanced properties.

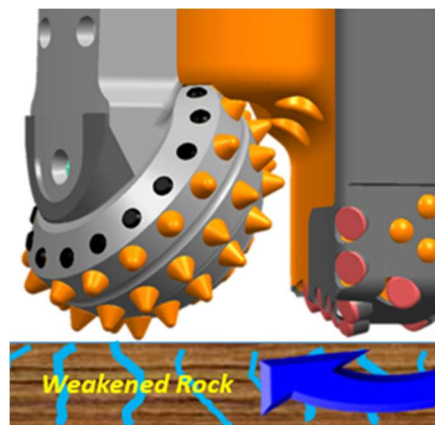


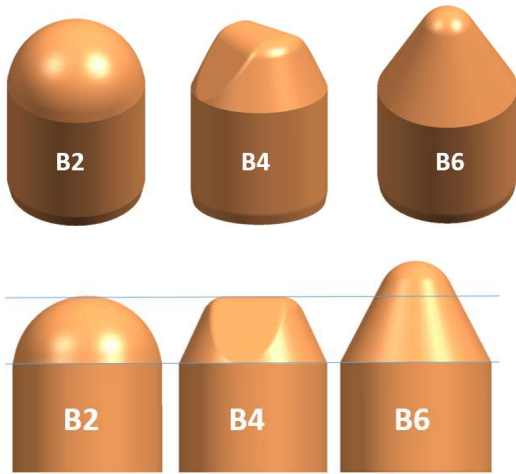
Figure 4 - Concept of High Density – Sharp inserts fracturing formation whilst PDC's shear across formation

The roller cone design comparing three iterations over time are displayed in Figure 5, where a clear contrast in volume of sharp conical insert is apparent from design 1 and 2 to 3. In compounding the cone insert coverage with the use of 3 roller cones, a high density of sharp inserts was envisioned to fracture the rock more efficiently whilst also being more durable through compact count.



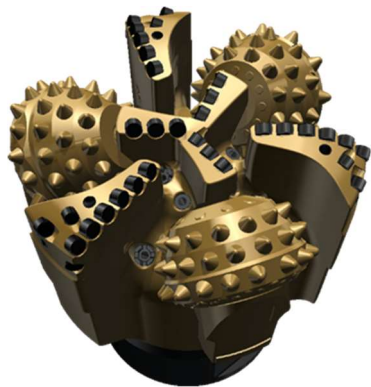
Figure 5: Comparative view of the roller cone insert layouts used in 2014 and 2017

As a perspective of individual heel row compact geometry used in the three iterations, Figure 4 displays the significant difference in the new approach for hybrid cone designs.



**Figure 6 - Geometry perspective of the heel row inserts as applied in the Barossa Field.**

The new cutting structure concept of high density and sharp conics was applied in 16 in. bit designs in the same application where the two others were. The resultant drilling performance was highly contrasting between the 2014 and 2017 drilling campaigns.



**Figure 7 – 16 in. Hybrid Bit Design Selected for Well A**

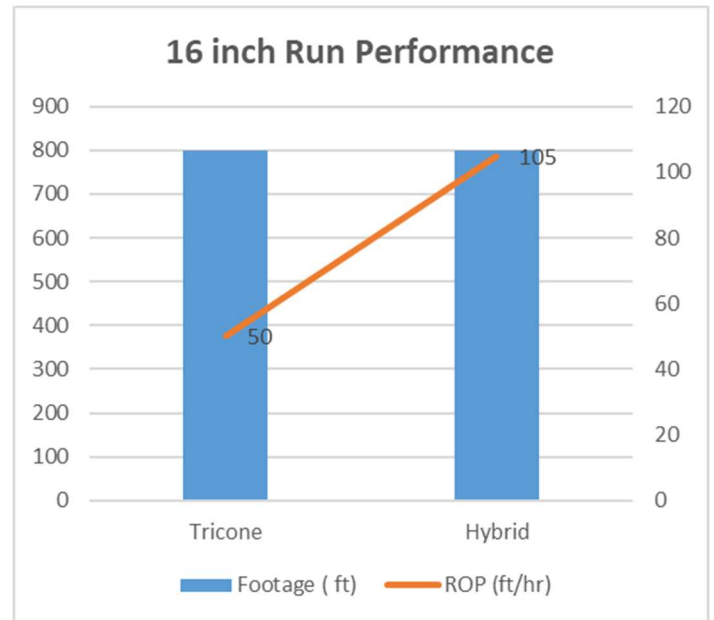


**Figure 8 – 16 in. Hybrid Bit Design Selected for Well B**

**Performance Overview**

The hybrid drill bit deployment with the optimized system achieved a breakthrough in ROP performance and rig days saved through two consecutive deployments on well 1 and 2 for two different applications.

**Well: A**



**Figure 9 – Well A Best Tricone Run vs Hybrid Run**

7.6 hours were required on the 16-in. section of well A compared to 16 hours with the offset rolling cone bit with an estimated saving of \$95,000, and the hybrid bit came out in green condition. Refer to the dull images below.





Figure 10 – Dull images



Figure 12 – Dull images

**Well : B**

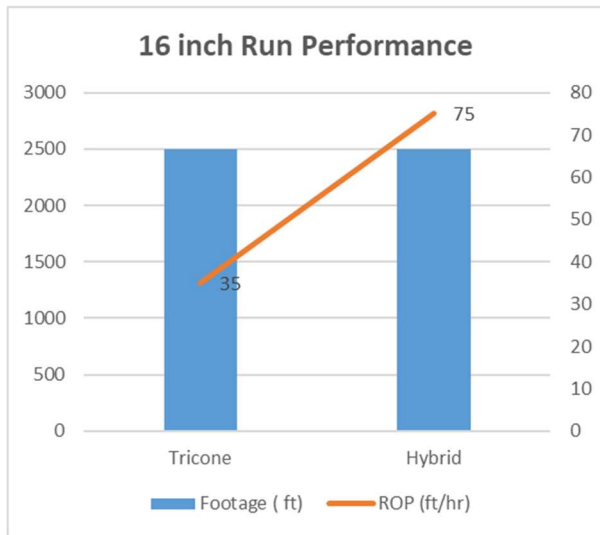


Figure 11 – Well B Best Tricone Run vs Hybrid Run

16 in. section was drilled in 34.6 hours compared to 80 hours for the offset roller cone bit, saving 45.4 hours or 1.89 days, with an estimated hole section cost savings of \$175,000. Refer to the dull images below.



Table 1 – Optimization between Well 1 and Well 2

	DEPTH IN FT	DEPTH OUT FT	DISTANCE FT	ROP (TC) FT/HR	ROP (KYMERA) FT/HR	% INCREASE IN ROP
WELL -A	100	900	800	50	105	110
WELL-B	1300	3800	2500	35	75	113

Three main points have been optimized and developed to enhance performance between well A and well B.

- Bit design- use of single edge cutters instead of double edge to increase cutting efficiency
- Hydraulics - mud additives and increase flow
- BHA – add 10” DC after third 10” DC Use 3 x 1/8” Under-gauge stabilizers for 3-stabilizations points.

**Conclusions**

The project is recognized by the operator as a multifunctional team-driven collaboration leading to the first successful deployment of hybrid technology in Qatar.

The deployment of the 16-in. hybrid drill bit with system optimization resulted in a 75% decrease in cost per foot with 46 and 8 hour savings in the two wells. Customized data log analysis revealed that the hybrid bit drilled more efficiently than roller cone bits in this application. The three major key performance indicators have been achieved: reduced drilling days and increased drilling efficiency.

The significant economical savings and technical optimization proved that hybrid bit technology is a viable solution for drilling these 16-in. hole sections in Qatar.

**Acknowledgments**

The authors would like to thank the management of Baker Hughes for their permission to publish the data presented and other information in this paper.

## Nomenclature

<i>BHA</i>	= <i>Bottomhole assembly</i>
<i>WOB</i>	= <i>Weight on Bit</i>
<i>RPM</i>	= <i>Rotation Per Minute</i>
<i>TQ</i>	= <i>Torque</i>
<i>ROP</i>	= <i>Rate of Penetration</i>
<i>SPP</i>	= <i>Standpipe Pressure</i>
<i>MSE</i>	= <i>Mechanical Specific Energy</i>
<i>E/S Diagram</i>	= <i>Drilling Specific Energy/ Drilling Strength</i>

## References

1. Curry D., Christensen H., Fear M., Govzitch A., Aghazada L. 2005, Technical Limit Specific Energy - An Index to Facilitate Drilling Performance Evaluation, Proc. of SPE/IADC Drilling Conference, Amsterdam, Netherlands.
2. Waughman R.J., Kenner J.V., Moore R.A., 2002, Real time specific energy monitoring reveals drilling inefficiency and enhances the understanding of when to pull worn PDC bits, in IADC/SPE conference, SPE: Dallas, Texas.
3. Ismail A., Mustafa W., 2014, New Hybrid Drill Bit with Innovative Technology Improves Drilling Efficiency in Challenging Jordanian Drilling Project, in SPE Saudi Arabia Section Technical Symposium and Exhibition, Al-Khobar, Saudi Arabia
4. Krueger R. E., Mock P. W., Moore N. B., 2012, Mechanical specific energy drilling system, US Patent US 20120261190, SPE
5. Lee R., Felderhoff F., Zeng J., Richards A., 2010, Collaboration and Communication Lead to Continuous Improvement of 8 ½-in. Bit Design and Improved Drilling Efficiencies in Changbei Horizontal Application, in SPE International Oil and Gas Conference and Exhibition, Beijing, China
6. Rashidi B, 2010, G.Hareland, R. Nygaard, 2008, University of Calgary, Real-Time Drill Bit Wear Prediction by Combining Rock Energy and Drilling Strength Concepts, in SPE Abu Dhabi International Petroleum Exhibition and Conference, Abu Dhabi, UAE
7. Bevilacqua M., Ciarapica F., Marchetti B., 2013, Acquisition, Processing and Evaluation of Down Hole Data for Monitoring Efficiency of Drilling Processes, in SPE DIISM-Università Politecnica delle Marche, , Ancona, Italy
8. Rolf Pessier, Michael Damschen 2010. Hybrid Bits Offer Distinct Advantages in Selected Roller Cone and PDC Bit Applications. Paper IADC/SPE 128741 presented at the SPE/IADC Drilling Conference, New Orleans, 2-4 February, 2011. DOI Number: 10.2118/128741-PA
9. Lee, R., Chang, G., Li, B., Zhang, W., Xu, J., Zhu, C.Q., Xia, J. X., 2010. Comprehensive Pre-Well Preparation and Collaboration Leads to Record Drilling Performance in Challenging Exploration Well in Sichuan. Paper SPE 131302 presented at the CPS/SPE International Oil & Gas Conference and Exhibition, Beijing, 8–10 June, 2010. DOI Number: 10.2118/131302-MS
10. Wei, G.Q., Du, J.H., Xu, C.C., Zou, C.N., Yang, W., Shen, P., Xie, Z.Y., Zhang, J., 2015. Characteristics and accumulation modes of large gas reservoirs in Sinian-Cambrian of Gaoshiti-Moxi region, Sichuan Basin. Published on ACTA Petrolei Sinica.
11. Sheng, S.M., Valbuena, F., Zeng, J., Wan, J., Lan, Z.X., Guo, H.Y., Gao, C.L., 2015. New Generation Cutters Boost Hybrid Bit Performance in Volcanic Basement in Northeast China. SPE-176146-MS presented at the SPE Asia Pacific Oil & Gas Conference and Exhibition, Bali, Indonesia, 20–22 October, 2015. DOI Number: 0.2118/176146-MS