AADE-05-NTCE-57

Development and Applications of Unique Fixed Cutter Bit Technologies to the Spraberry Field of West Texas

John Harris, James Cunningham, Pioneer Natural Resources
Bill Stark, Robert Gum, HES-SecurityDBS

Abstract

Roller cone bits have long dominated the drilling in the Spraberry field of West Texas. Experience and/or drilling log information have indicated that the formation is drillable with an insert type roller cone bit. A conical type insert bit is usually chosen because of the durability of its cutting structure. The interval from the 11-in. surface hole to 9000 ft was usually drilled with two to three insert bits. The formations drilled are from the bottom of the Spraberry, to the top of the Wolfcamp formations. The interbedded shale, and limestone, formations have typically been drilled with 527 and 537 type insert bits.

This paper discusses the development and applications of a new type of fixed cutter bit, able to drill very efficiently through interbedded formations. The durability of the fixed cutter bit is comparable with that of an insert type bit; but the rate of penetration is significantly improved. The new fixed bits incorporate new cutter technology with enhanced drillability, durability, and reduced vibration. The first fixed cutter bit run in the field drilled 8701 ft, to a depth of 9200 ft with an increase in rate of penetration from 44 to 53 ft/hr as compared to the roller cones run in the field. Since that first run, performance has been improved to a field record for a single run to TD of 8710 ft in 108.0 hours. The well reached TD in six days.

Introduction

The paper presents the results of a project to develop a PDC for specific application in the Spraberry field of West Texas. The inability of PDC bits to affectively drill hard rock because of the destructive force induced by drilling hard rock has been well identified in previous papers. Since the initial discovery well of the Spraberry Trend in the 1940's the standard drilling practice was to use roller cone bits, exclusively, to drill the 7-7/8" hole section. Despite PDC technology improvements over the last two decades, roller cone bits were still dominate in the Spraberry because of the impact damage leading to cutter breakage on the PDC bits. This impact damage was caused from drilling the intermittent soft and hard stringers.

Earlier advances into improving the PDC cutter/formation interaction, that lead to impact damage, were centered around two basic design principles. The anti-whirl design principle[1,2] incorporated a low friction gage pad to minimize the effect of the backward whirl phenomenon of PDC bits. According to this design principle, cutters were arranged on the face of the bit so that a net resultant radial force was directed towards a specific portion of the bit with less friction.

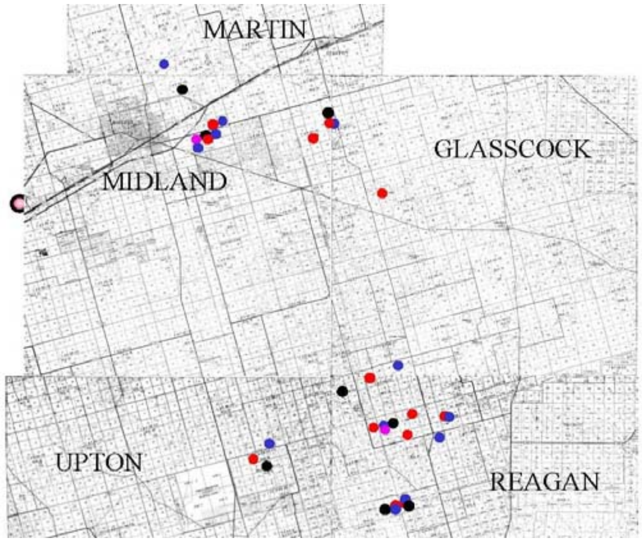
The force balanced PDC bit design principle[3] was developed based on an understanding of the PDC bit dynamics and the mechanism for cutter/rock interaction. Unlike an anti-whirl PDC bit, the cutters on a force balanced PDC bit were arranged so that a new resultant radial force was minimized or balanced. The design of a force balanced bit allows for a higher density of cutters on gage, which is more beneficial in harder rock drilling, than does the anti-whirl PDC bit. The use of additional force balancing tools, such as tracking cutters and asymmetrical spiraled blades improved bit performance significantly, further expanding the range of applications of PDC bits.

However, more recent advances in PDC bit design and cutter technology lead to the increased drilling efficiencies outlined in this paper.

The overall goal of the project was to drill the complete 7-7/8" section of hole, from surface to TD, with one PDC bit. The project involved the joint development effort between the operator and bit manufacturer. The direct benefit of the joint development effort was that significant savings could be realized because of reduced trips and increased ROP. In addition, further developmental efforts were geared towards increasing bit reparability to achieve additional runs in a rental market and further reduce overall drilling costs. Further drilling and performance improvement was achieved by the optimization of drilling parameters.

Target Area

The target area for this project encompassed four (4) major counties in the Spraberry field. These are Midland, Glasscock, Upton, and Reagan.



Lithology

Logs were collected to perform a Rock Strength analysis to investigate the lithology and rock hardness. It was also helpful in identifying possible trouble spots that may be detrimental to the PDC cutters. Historically, PDC cutters have been susceptible to cutter degradation due to impact and to heat damage due to abrasion.

The lithology in the top hole is a shale and intermittent dolomite interval with unconfined compressive strengths (UCS) of between 5 and 10 Kpsi. From 1000 ft to 5000 ft the intermittent dolomite increases in density and hardness. The rest of the interval can be divided into 3 major intervals:

- from 5000' to 7650' heterogeneous interval from medium hard, 10 Kpsi to hard, 35 Kpsi limestone, dolomite, and shale.

- from 7650' to 9000' shaly carbonates, of medium hard to hard.

- From 9000' to TD hard to very hard carbonates, primarily limestone to 40Kpsi.

The major formations encountered are the:

Rustler
Yates
Graybill
San Andreas
Upper Spraberry
Lower Spraberry
Wolfcamp

(Figure 2)

Benchmark Performance

Since their introduction in 1951, roller cone insert bits have been used exclusively to drill the hard and abrasive limestone formations of west Texas[1].

To benchmark past Spraberry wells to develop a new PDC bit, a total of twenty-one (21) wells using roller cone bits, from surface to TD, in the 7-7/8" section of hole, were analyzed in the target area. It generally took two to three bits to drill the interval. The bit types used were 527 and 537 insert bits. Bits were analyzed for footage, hours, and cost-per-foot for the 7-7/8" section. The wells analyzed showed that a typical well averaged 38.3 ft/hr and took 9.7 days at an interval cost of $104,361. (Figure 3)

Well Plan

The 7-7/8" interval starts at an approximate depth of 450 ft to a TD of 9,300 ft. All wells are vertical. Water based drilling fluid is used with relatively high solids. The bottom hole assembly used was chosen in order to provide rigidity and stability in the well bore as well as optimum Rate of Penetration.

The BHA consisted of (1) Tri-Drill Collar, (1) Square Drill Collar, and (30) 6" Drill Collars. The Tri-collar and Square collar provided the rigidity to keep the bit engaged and the wellbore straight without an increase in torque and drag, such as a packed hole, which could lead to a reduction in ROP and an increase in cost per foot.

Development

For initial trials a standard 7-blade, ½" cutter (FM2745) bit was chosen. Previous experience in other developmental areas has proven this bit platform to have sufficient durability to achieve maximum footage and eliminate one or more roller cones bits and trips. These bits utilized the force balanced features previously mentioned, asymmetrical spiraled blades with a heavier set gage cutter configuration.

The damage observed on the first runs included chipped and broken diamond layers, and fractures in the cutters carbide substrate. This damage was attributed to shock loading of the cutting structure, primarily related to the nose, and thermal degradation of the diamond layer, primarily related to the shoulder cutters. In addition, there was heavy erosion to the matrix bodies.

In order to control the axial shock loading leading to cutter breakage, Impact arrestors were added. Impact arrestors are protrusions from the bit body which are aligned directly behind a preceding PDC cutter and slightly under-exposed from the cutter tip so that the impact arrestor rides in the track of the cutter. Because arrestors are the same matrix material as the bit body, they tend to wear at a higher rate than the cutter. The impact arrestor dampens the vibrating pattern of the bit by limiting the cutter's over-engagement.

While the impact arrestors initially were helpful in reducing the shock loading to the cutters, the matrix erosion limited the affects to the first run of the bit. Additional runs, on repaired bits, would have similar shock loading and erosion as seen on the first trials.

To retard this erosion, less expensive diamond cubes (TSP), were added to the impact arrestors. The added TSP reduced the matrix wear and added two to three additional runs per bit. (Figure 4)

Stabilization of the Cutting Structure

PDC bit profile layouts generally have an overlapping of cutters to ensure no uncut formation. This type of cutter layout is more efficient as no more than 90° of a cutter tip is used to drill it's particular area of bottom hole before adjacent cutters come into play. Various designs with individual cutter layout were tested. They provided excellent ROP in the shale, but shortened runs due to cutter breakage from drilling the intermittent hard limestone stringers.

Weaver had introduced a cutting structure that was self-stabilizing[3]. This type of cutter layout, called Trac-set, eliminated the cutter overlap causing deep kerfs to be cut into the formation. Without the cutter overlap, the formation is allowed to extend up between the cutters and form concentric rings on the bottom hole and increase cutter contact with the formation. The extended ridges cause the bit to lock into place and resist the lateral forces leading to cutter breakage. It is also beneficial in the fact that two or more blades can have cutters that are cutting the same path of formation.

This type of cutter redundancy added durability to the bit, further reducing bit whirl and allowed for longer runs. The ROP lost by the less efficient drilling in the shale was made up in the harder limestone sections. (Figure 5)

Cutter Technology

Initial trials with the industry standard cutter produced shorter runs with reduced ROP below 5000 ft. The standard thin diamond table cutters would hold up better to the shock loading of the transitional drilling but would lose ROP due to cutter wear from the abrasive limestone. Trials with thick diamond table cutters held up to the abrasive wear but would suffer catastrophic breakage due to the high residual stresses inherent to such cutter types.

Development of an improved cutter ran parallel to PDC bit development in the Spraberry. Clayton discussed an improved cutter better suited for hard rock drilling applications[5]. Development of the new cutter was a result of a better understanding of cutter failure mechanisms. As mentioned previously, abrasion and impact have been the two characteristics observed and studied in the past.

Abrasion refers to the mechanically generated wear that occurs due to failure of the individual diamond crystals or the diamond to diamond bond between those crystals. The diamond failure can be a result of mechanical loading or thermal degradation.

Impact wear is a mechanical failure that occurs when forces are applied that overcome the strength of the bond between the crystals and\or to the carbide of the PDC.

As a result of the extensive cutter research and development, a third dimension of PDC cutter failure was identified, Thermal Mechanical Integrity (TMI). TMI failure is defined as a loss of diamond that occurs due to a combination of thermal degradation and force, and is a measurement of toughness and wear as thermal degradation occur. New testing capabilities were implemented that enabled cutter optimization of durability in both abrasive and hard inter-bedded formations, and led to development a new cutter more suitable to the tougher environments of hard rock drilling.

The resultant new cutter was shown to be 13.5 times more abrasion-resistant than the industry standard and 3.9 times that of the industry premium standard cutter, with no loss of impact resistance. The new highly abrasion resistant cutter was designated as Z3™. (Figure 6)

Field Applications

In addition to the bit development aspect described in this paper significant improvements have been seen by the optimization of drilling parameters to the formation types drilled. All testing was done on rotary assembly. The rotary application allows for more abrupt weight on bit and RPM changes required for transitional drilling through inter-bedded formations. It was found that higher RPM's, 75-80, could be run in the top of the hole down to around 5000 ft with less than 20K WOB. As rock hardness increased below 5000 ft the RPM's were reduced to 60-70 and WOB increased to 25K to optimize ROP and prolong bit life.

A few of the significant results of the field testing of the features and innovations outlined in this paper are listed in the following case studies.

Midland County

An FM2745, with 1st generation Z3 cutters and trac-set design, drilled 7686' in 84.0 hours for an overall ROP of 91.4 ft/hr. The run did not TD the well but the resultant cost-per-foot of $5.76 was well below the average $11.75 cost-per-foot of the 7-7/8" roller cone runs in the area. The dull graded a 3-3-CT-A-In gage.

Reagan County

Equipped with the new Z3 cutters an FM2745, trac-set design with full Impact Arrestors, was able to drill 8272' in 106.0 hours to TD at 78.0 ft/hr. The dull graded a 3-2-CT-N-In gage. As a result of the outstanding ROP performance, the customer realized approximate savings of $44,000.

Midland County

Another FM2745, trac-set design with Z3 cutters, run in Midland County, drilled 8540' in 127.75 hours for an overall ROP of 66.8 ft/hr. The dull graded a 2-1-CT-A-In gage. The PDC run replaced three roller cone runs and 2 trips for a combined saving of over $39,000.

Conclusions

A total of twenty-one (21) wells using roller cones, and thirty-nine (39) wells with PDC bit runs, have been analyzed. The PDC bit runs incorporated a new type PDC cutter extending the life of the bits in the hard transition drilling of the Spraberry field of West Texas.

The features incorporated into this new series of bits included:

- Impact Arrestors, with TSP diamond reinforcement, to dampen axial vibrations leading to cutter breakage.
- A Trac-set cutting structure to reduce lateral vibrations and add cutting structure durability through redundant cutter placement.
- A new PDC cutter, Z3, with significantly increased abrasion-resistance with no loss of impact-resistance, effectively drilling harder rock and hard transitions.

The result of this PDC development in the Spraberry is a PDC bit capable of drilling from surface to TD with one bit at an average ROP above 60 ft/hr which results in savings of up to $40,000 per well to the customer.

Acknowledgments

The authors would like to thank Halliburton, SecurityDBS, and Pioneer Natural Resources for permission to present this paper. Collective thanks to the field personnel and contractors who collaborated to make these runs possible. Special thanks to Robert Clayton, Rob Arfele, and Jim Dahlem for their assistance on the information collected in this paper.

References

1. T.M. Warren, J.F. Brett, and L.A. Sinor, "Development of a Whirl – Resistant Bit", SPE Drilling Engineering, 5 (1990) 267-274.
2. T.M. Warren and L.A. Sinor, "PDC bits: what's Needed to Meet Tomorrow's Challenge", paper SPE 27298, presented 1994.
3. Weaver, G.E., Clayton, R.I.: "A New PDC Cutting Structure Improves Bit Stabilization and Extends Application into Harder Rock Types" SPE 25734, SPE/IADC Drilling Conference, Amsterdam, Feb. 23-25, 1993.
4. Isbell, M.R., Besson, Alain, Torgerson T.A..: "Unique Roller Cone Bit Design Improves Economics of Soft Formation Drilling" SPE 27469, IADC/SPE Drilling Conference , Dallas, Texas, Deb. 15-16, 1994.
5. Clayton, R.I., Chen, S., Lefort, G. : "New Bit Design, Cutter Technology Extend PDC Applications to Hard Rock Drilling", SPE/IADC 91840, Amsterdam, Feb. 23-25, 2005.

Compressive Strength Analysis

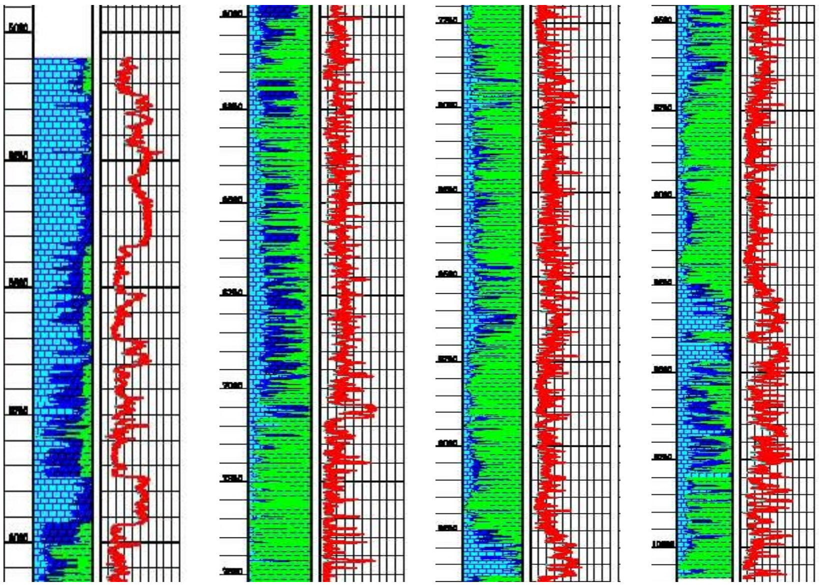


Fig. 2 - Typical Spraberry Interval from 5000' to 10,000'

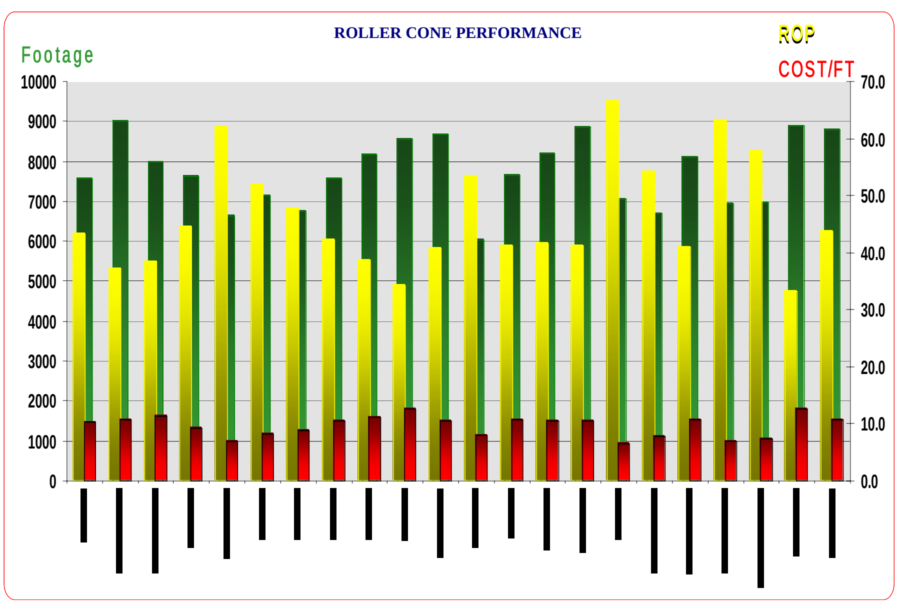


Fig. 3 - Roller Cone Performance

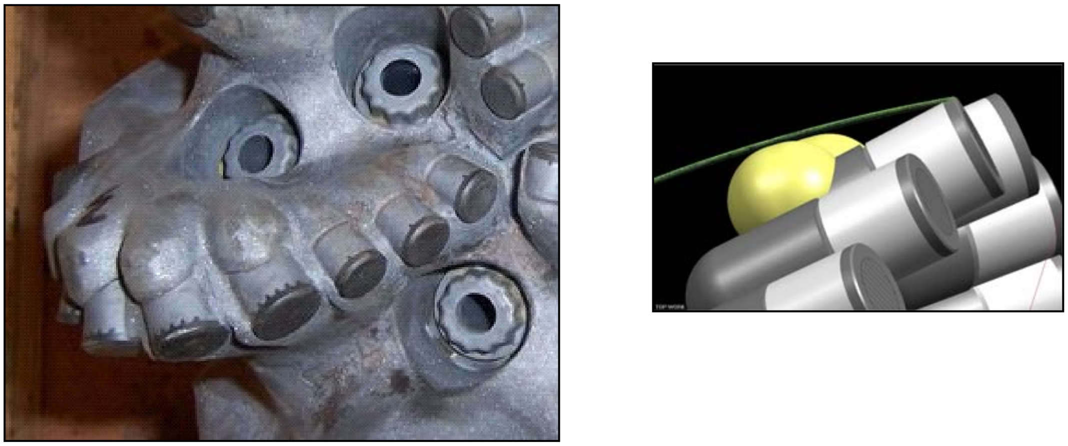


Fig. 4 - Impact Arrestors to Dampen Axial Vibrations

Single Set vs. Track Set

Standard Cutter Bottom Hole Pattern **Tracking Cutter Bottom Hole Pattern**

Little resistance to lateral forces with the standard cutter layout

Scalloped bottom hole pattern is created by tracking cutters

Fig. 5 – Trac-Set Bottom Hole for Lateral Stabilization

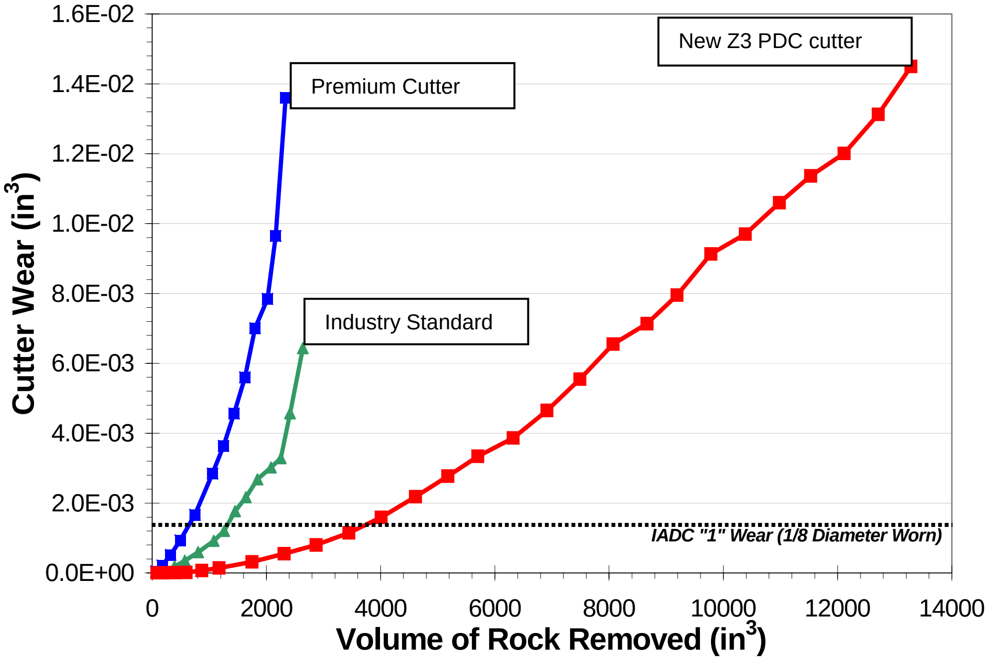


Fig. 6 – New cutter offers 13.5 times the abrasion resistance of industry standard cutters.

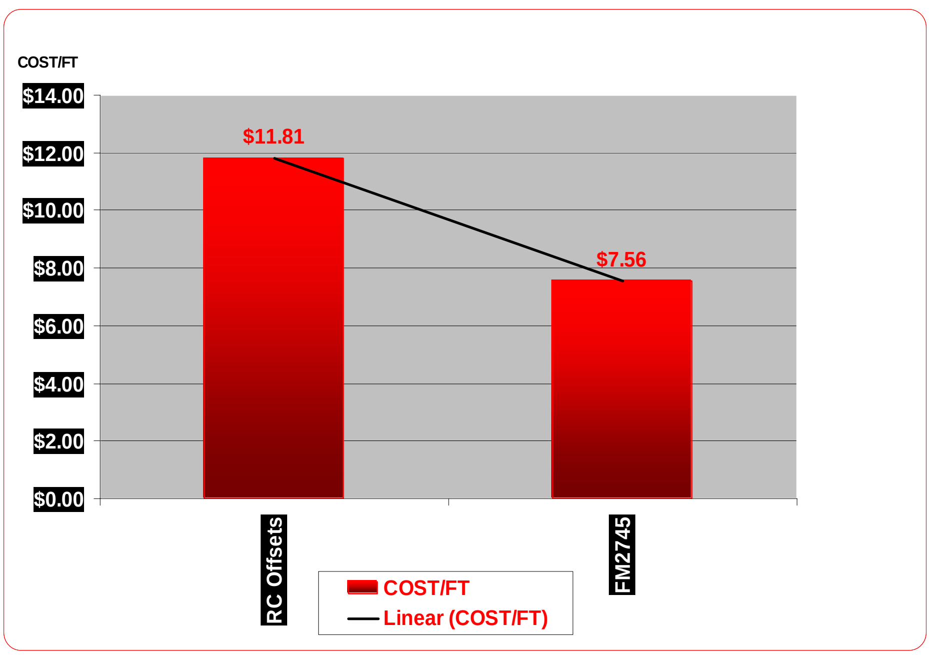


Fig 7 - Cost-per-Foot Comparison Roller Cone vs PDC